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Article

Risk Identification in Cogeneration (Combined Heat and Power) Projects: A Polish Case Study

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Abstract: The purpose of the article is to define the risk factors in cogeneration projects and to demonstrate that a lack of sufficient identification of risks in different phases affects project implementation. A theoretical study is conducted, which aims to identify risk factors in cogeneration projects, based on case studies of such projects in Poland. The study offers a view at CHP (combined heat and power) projects as extremely dependent on the external environment of the organisation. These projects are subject to many external regulations due to their environmental impact and dynamically changing technical aspects. The biggest technical errors occur at the planning and construction stages. The biggest economic and financial risks occur at the execution stage after 2% and 3% of additional design costs occur, respectively. The authors estimated the risks at different stages of the project and concluded that the total cost of failure in correct identification of the risks at the planning stage exceeded PLN 1.5 billion, which amounted to almost 60% of the total additional costs of materialised project risk. Consequently, the biggest challenges in the area of CHP project management at the planning stage are a thorough identification of risks, and the pricing and planning reactions to risk.

Keywords: project management; management project risk; cogeneration projects; risk factors

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1. Introduction

CHP (combined heat and power) construction is a difficult and complex project that requires proper planning and execution, together with a systematic control process culminating in project results' analysis. Combined heat and power or cogeneration can play a strategic role in addressing environmental and climate change issues. CHP systems require less fuel than separate heating and power systems to produce the same amount of energy, saving primary energy and improving the security of supply [1].

The process of a proper risk identification is essential for the correct implementation of a project [2], as making a mistake in this area generates huge costs, which in the case of the analysed projects exceeded the value of PLN 2 billion. There are alarming deficiencies in a proper management of projects in the planning, implementation, controlling and closure stages, and in particular when identifying, estimating and planning reactions to risk occurrence. Evaluation at the stage of project definition is limited to examining the profitability of the company responsible for the project, without verifying the results generated during the exploitation of its products. Failure to define such a need may result in the dilution of the evaluation to fluid, vague or biased criteria, without which we will not be able to draw conclusions for the future to improve project management mechanisms.

There have been research articles on risk management in CHP investments published in the past. The 2008 study by Zafra-Cabeza [3] presents risk management methods for operating cogeneration units. In 2008, there was also a study by Fleten and Maribu [4] on the investment risks of CHP installations in commercial buildings. Moreover, in 2015, a study by Maurovich-Horvat [5] was published, indicating ways to minimise risks in CHP investments in the sector of distributed energy.

While the articles mentioned above quite aptly fill the niche of individual aspects of CHP investments, there is no study in the literature that offers a holistic view of the CHP project risk management process. Therefore, we address this research gap and set forth to fill it with the goal of defining risk factors and to indicate which phases of project implementation related to the initiation, implementation and operation of investments in cogeneration units (CHP) are most affected by those factors. Chapter 2 presents a literature review on CHP projects and an explanation of the legal and economic environment of these projects. The aim of the study is to systematically classify the project environment and the resulting risk factors. Then, the major CHP projects implemented in Poland are analysed and the risks encountered are presented. Accordingly, this study makes two contributions. First, it distinguishes determinants of project risk in CHP projects. Second, the study of CHP project implementation in Poland provides information on the impact of individual risk determinants in different project phases and sets the agenda for future research. The article is structured as follows: the next 3rd section presents the terminology of project risk; Chapter 4 provides a description of the CHP project market in Poland; further Sections describe the research methods, and present the analysis and description of the results; and the last Section presents the conclusions.

2. Environmental Analysis of Ongoing Investments in Cogeneration Units

The new requirements of the European Union's climate and energy policy are forcing Poland into an energy transition period, which creates enormous challenges for:

- The professional power industry and local authorities, which supervise several hundred heating companies (of which ca. 300 already operate cogeneration units);
- Energy-consuming industrial customers who, due to high consumption and rising energy prices, are facing the challenge of building their own generation units (EGUs).

Energy transformation will require involving many entities and making substantial investments, the scale of which in 2021–2040 may reach approximately PLN 1.6 bn. Part of this amount is to be covered by the EU (European Union) and national funds of about PLN 0.26 bn [6] by the year 2030.

The European Commission has estimated the annual cost of energy transition across the EU, by the year 2050, at a level between EUR 175 bn and EUR 290 bn. It is worth noting that these costs are not spread evenly across all EU countries. For example, in 2016, EUR 57 billion was spent on developing and supporting renewable energy sources (RES), which on average resulted in an increase in energy costs by 17.60 EUR/MWh within the EU. In this overview, Poland invested almost the lowest amount (3.52 EUR/MWh), while the country that spent the most on RES was Germany (37.67 EUR/MWh) [7], identified in a 2017 Russian study [8] as one of the leaders of the transition, due to the successive reduction of fossil fuels in the energy mix and investing in RES. The scale of the challenges that Poland will face is therefore much bigger, due to its relatively early stage in the energy transition period. The problems that Poland will have to solve also lie ahead for many other Central and Eastern Europe (CEE) countries, especially the ones within the Visegrad Group, which remain highly dependent on gas imports from Russia and continue to support the coal industry—in particular the Czech Republic, whose energy mix is mostly based on lignite and hard coal (44% and 5.4%, respectively; 2017 data) [9,10].

Poland's dependency on a net import of energy is growing and may increase due to the elimination of generation units (2.6 GW net in the period 2021–2025 and 26.5 GW net in the period 2016–2040), resulting from stringent emission reduction requirements (among others, BAT (Best Available Techniques) conclusions applicable) and other assumptions to achieve climate neutrality by 2050, which increases the exposure of domestic economy and consumers, including industrial ones, to the risk of ensuring stability of energy (electricity and heat) supply at competitive prices.

According to Eurostat, in the period between 2000 and 2019, Poland's dependency on energy imports increased by about 36 percentage points, while on average it increased by only about 4 percentage points across the European Union. This increase is one of the largest in the entire European Union [11].

The Polish economy consumes about 170 TWh of electricity using its own production (installed capacity is about 47 GW gross, of which more than 75% is commercial power plants, mostly based on hard coal and lignite; RES—more than 15%; and industrial power plants—more than 5%). Co-generation units (CHP) using coal/gas/biomass account for a key share of heat generation in Poland and a significant share of electricity generation. At the end of 2018, the electrical capacity with thermal capacity available was 5.8 GW and the thermal capacity with electrical capacity available was 14.5 GW (see Table 1) [12].

Table 1. Thermal and electrical capacities in combined heat and power plants.

Capacities in Combined Heat and Power Plants		2008
Electric power with thermal output	[MW]	5875
Thermal power with electrical power output	[MW]	14,561

Source: Bujalski, W. "Report on cogeneration in heating-industry". Polish Society of Professional Heat and Power Plants, Warsaw, 2019 [12].

It is worth noting that, between 1990 and 2018, the European Union Member States that joined in 2004 or later experienced a trend of decrease in energy demand, by as much as 18% across the group. The two countries that broke out of this trend were Slovenia (whose demand increased) and Poland (which experienced no significant change). In contrast, the pre-2004 Member States noted an increase in energy demand, which ultimately resulted in an overall increase across the European Union [13,14].

According to data provided by the Energy Regulatory Office Department of Electricity and Heat Markets of the Energy Regulatory Office [15] and the Polish Association of Combined Heat and Power Plants [12], the total net heat generated in CHP plants at the end of 2018 was 170.9 PJ, including heat production from power boilers, recovery boilers, gas turbines or internal combustion engines in CHP plants (152.8 PJ), while 18 PJ of heat was produced in district heating boilers. The amount of heat produced in district heating boilers accounted for 10.5% of the total heat produced in CHP plants [12]. In 2018, CHP plants produced 28.1 TWh of gross electricity, of which 19.7 TWh (about 70% of the total electricity production in CHP plants) was produced in cogeneration (the amount of energy was determined according to the PN-93/M-35,500 standard), 4.2 TWh was produced in gas turbines and internal combustion engines, and 1.7 TWh was produced from RES sources (see Tables 2 and 3) [12].

Table 2. Electricity production in combined heat and power plants.

Electricity Production in Combined Heat and Power Plants		2018
Gross electricity production, of which:	[MWh]	28,106,612
In cogeneration	[MWh]	19,673,479
Gas turbines and internal combustion engines	[MWh]	4,155,540

Source: Bujalski, W. "Report on cogeneration in heating-industry". Polish Society of Professional Heat and Power Plants, Warsaw, 2019, p. 9 [12].

Table 3. Percentage share of gross electricity production and gross cogeneration in Poland's electricity production.

	2018
Share of electricity production from cogeneration	11.6%
Share of electricity generation in CHP plants	16.5%

Source: Bujalski, W. "Report on cogeneration in heating-industry". Polish Society of Professional Heat and Power Plants, Warsaw, 2019, p. 9 [12].

The graph below (Figure 1) presents a decrease in heat production in heating plants, but also an increase in heat production in CHP plants, which is an extremely desired trend towards improving energy efficiency.

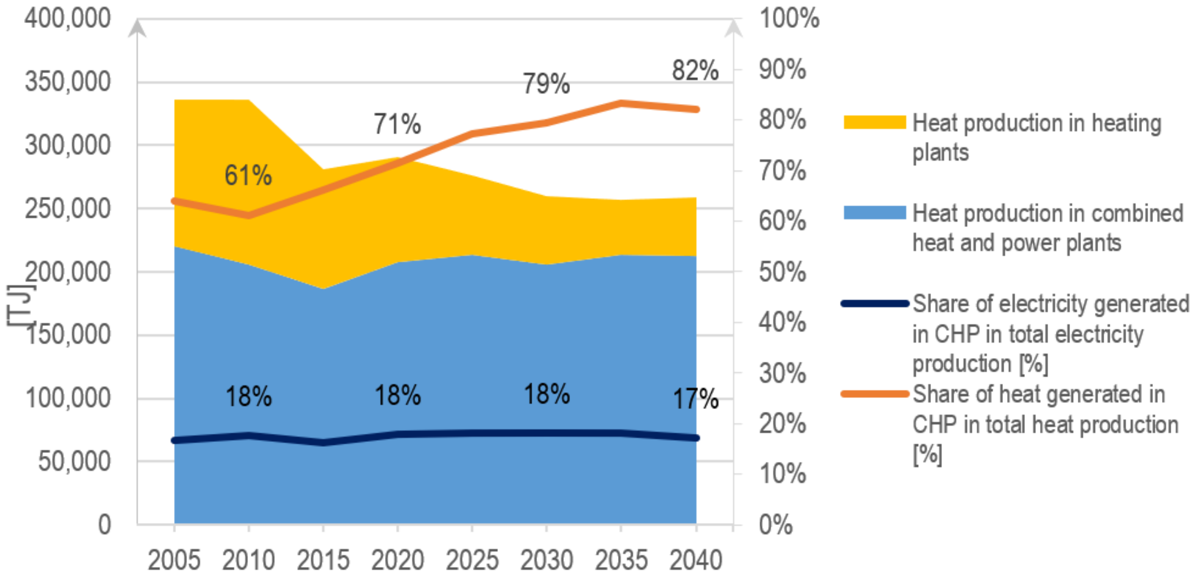

Figure 1. Forecast of heat production [TJ] and share of electricity and heat produced in cogeneration [%]. Source: PEP2040 [16].

The scale of operation of CHP generation units illustrates the significant challenges that lie ahead of the commercial power industry, local authorities and industrial energy, as well as consuming customers, who have started the process of investing in the modernisation of existing CHP or the replacement of heat generating units with CHP. The first investments were initiated by a professional power industry with industrial energy-consuming customers, followed by local government district heating plants.

The key issues are evoked by EU climate and energy regulations and policies, in relation to which it is crucial to properly define the assumptions of the transition and identify risks in energy investments, which is the main challenge for Poland. Managing cogeneration investment projects is very difficult due to technical, economic, financial, legal, regulatory and environmental challenges. Without a proper identification of risks, the entities that manage projects are exposed to costs increase and project delays.

3. Definition of Project Risk and Risk Factors

Risk is defined as a potential event or circumstance that, if it occurs, can affect one or more project objectives (scope, time, cost and quality) in a favourable or unfavourable way. The source of risk is uncertainty, the essence of which is lack of or incomplete information.

The risk that, to some extent, is put on the implemented project is defined as the probability [17] of the occurrence of an action or phenomenon that may have a negative or positive impact on the course of the entire project. One of the most important characteristics of risk is not only the possibility of estimating its probability, but also its impact on the entire project. This allows the project manager to actively influence it (i.e., manage the risk) [18].

In short, it turns out that most of implemented investments do not develop as expected during the planning stage. Many of them fail only because of improper risk assessment. Disregarding risks, for example by planning with overly optimistic assumptions, leads to investments that are already vulnerable to failure. On the other hand, being very conservative and not taking risks may result in the regression of activities or even the fall of the organisation, which is the planning of the considered investment [19].

Risk management is associated with assessing the achievement of project success, taking into account a number of factors [20], including the extent to which a project fits with other ongoing projects within the parent organisation. It is therefore a process of finding potential risks and defining methods to eliminate or minimise them [21].

The approach to project risk identification and analysis is presented in the leading methodologies [22]: PMBOK (Project Management Body of Knowledge), IPMA ICB (IPMA Individual Competence Baseline) and PRINCE2 (PRojects IN Controlled Environments), the IPMA ICB (International Project Management Association Individual Competence Baseline) global competency model, and more recent approaches, such as PRISM (PRojects Integrating Sustainable Methods). One of the more common definitions of risk can be found in ISO standards. ISO 73:2009—Risk Management Vocabulary defines risk as "the impact of uncertainty on goals" [23].

PMBOK distinguishes six phases of risk management [24]:

1. Risk Management Planning—this phase involves creating a plan and deciding how risk management activities will be carried out;
2. Risk Identification—this is where risks that may affect the project are identified and characterised;
3. Qualitative Risk Analysis—is aimed at risk evaluation on the basis of numerical analyses;
4. Quantitative Risk Analysis—is the numerical assessment of the likelihood of a risk occurrence and its consequences;
5. Risk Response Planning—the strategies developed at this stage are designed to reduce risks;
6. Risk Monitoring and Control—aims to track detected risks, identifying new risks and implementing risk response plans and maintaining them throughout the project.

Risk identification is the identification of potential threats or opportunities (risk factors) that can positively or negatively affect the project. The PMI (Project Management Institute) methodology presents many methods for collecting and using information in the area of risk identification (brainstorming, Delphi method, root cause analysis, checklist analysis, SWOT analysis and expert opinion), where the final result of risk factor identification is the risk register.

The identification of project risk factors requires analysing their sources both in the complexity and specificity of the project, but also in the project environment [25]. These sources can be divided into several basic groups:

- Project features—complexity and specificity of the project;
- Project staff and employment issues;
- The organic Project Management Institute station of the project provider, e.g., the maturity of such organisation to manage projects;
- Resources and their availability in the project;
- Project environment.

4. Investment Projects in Cogeneration Units (CHP)

The cogeneration investment planning phase is a major challenge for the preparation of CHP investments in Poland—primarily in the technical, economic, financial and environmental areas. The lack of proper identification of project risks causes delays, increases costs and worsens the investor's economic performance. Due to inadequate risk identification at the phase of project definition and planning, wrong technical assumptions are made, which interfere with the proper project implementation or reduce their profitability. Figure 2 shows potential locations for new natural gas-fired generating units in the period up to 2040.

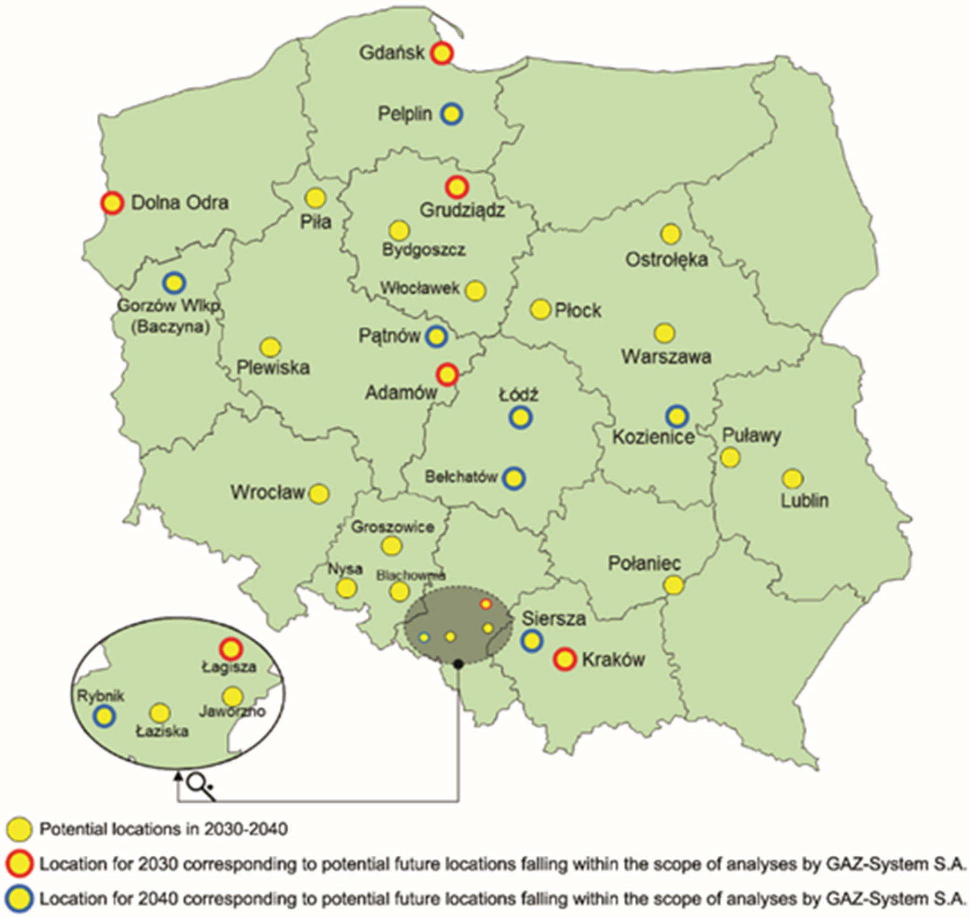

Figure 2. Potential locations for new natural gas-fired generating units in the period up to 2040. Source: PSE SA, 6/2020 r., Development plan for meeting current and future electricity demand for period 2021–2030 [26].

5. Survey Sample and Methodology

The aim of the study is to systematically classify the project environment and the resulting risk factors. Then, the major CHP projects implemented in Poland are analysed and the risks occurred are presented. The methodology of the study is shown in Figure 3.

The research sample includes six large cogeneration projects implemented in Poland over the last 6 years. The data for the analysis of the situation of the projects and the value of risk were estimated on the basis of publicly available materials published in the trade press. The authors distinguished the most frequent risk areas of cogeneration projects on the basis of several recent cogeneration projects in Poland. The value of the risk was presented as a percentage of the deviation of the total project costs from the assumed initial budget amounts. For the sake of information protection, they were described under the names A/B/C/D/E/F. Four projects were completed and the rest is in the execution phase (Table 4).

Table 4. Cogeneration projects under discussion.

Project	Type of Cogeneration Used in Project
A	Coal-fired CHP construction
B	Coal-fired CHP construction
C	Construction of gas-fired CHP
D	Construction of coal- and gas-fired CHP
E	Construction of gas-fired CHP
F	Construction of gas-fired CHP

Source: our own study.

The research includes the identification of risk factors for cogeneration projects, followed by an attempt to assess the value of risk according to the distinguished categories. In addition, an analysis was conducted of the occurrence and value of risks at different stages of project implementation and at the stage of project operation. Complementing the research with the exploitation phase of the project is justified due to:

- The long planning period for the sustainability of projects;
- Planning and the need to evaluate long-term results;
- The changing legal, regulatory and technical environment for this type of project.

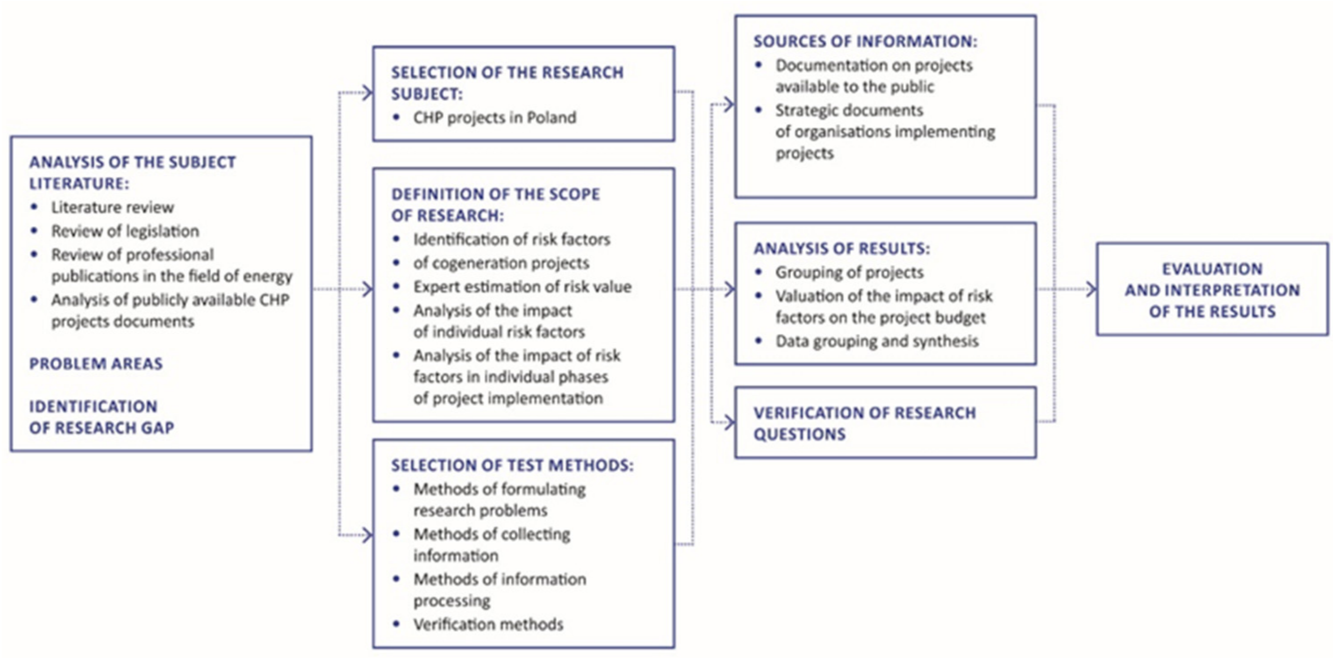

Figure 3. Research concept. Source: our own study.

6. Methodological Assumptions for the Assessment of the Risk Value

On the basis of publicly available information, the performance of individual projects under the names A/B/C/D/E/F was assessed. On the basis of the analysis of the source materials concerning the exemplary CHP projects mentioned above, the basic risk factors that particularly affect this type of projects were distinguished. Due to the specificity of this type of projects, the greatest threat to CHP projects are factors of an external nature and these were accepted for detailed analysis. These include:

- Technical risk;
- Economic risk;
- Financial risk;
- Legal risk;
- Regulatory risk;
- Environmental risk.

The valuation of risk was carried out on the basis of a comparison of the change in the value of project implementation over time, comparing the initial value of the investment cost (CAPEX) and its change due to emerging project risks. In addition, the change in operating costs (OPEX) due to emerging risks was verified. Based on expert knowledge, the allocation of risks was assessed:

- Broken down into technical, economic, financial, legal, regulatory and environmental risks;
- Broken down into different phases of project implementation: planning, execution (implementation), control and closure (see description below), as risk is present in all phases of project implementation [27].

The authors also identified risks for the different phases of CHP projects. The results of the analysis are presented in Table 5.

For confidentiality reasons, we do not provide sources of public information or specific data on risk values in individual projects from which it is possible to determine which projects are involved.

Table 5. Risks of CHP investment projects at the planning phase.

Phase of the Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk
Planning	−/+	−	−	+	+	+
Execution	+	−	−	+	−	−
Control	−	+	−	+	+	+
Closure	−/+	−/+	+	+	+	+

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started to function. Source: our own study.

6.1. Technical Risks in Cogeneration Projects

Technical risk identification is a major challenge for the project, especially when technical knowledge is marginalised by political pressures, incorrect business or regulatory assumptions [28]. The failure to properly assess the facts and forecast future operating conditions of CHP units leads to poor technical decisions. In this way, the technical conditions of new CHP units make them unsuitable or only partially meet user and market expectations [29]. Most technical errors occur in the planning (corresponding to 20% of additional project costs), control (almost 5% of additional project costs) and execution (almost 3% of additional project costs) phases. In total, the additional technical costs amount to about 28% of the share of total additional project costs (Table 6).

Table 6. Technical risk assessment at different phases of CHP projects.

Phase of the Project	Technical Risk
Planning	20%
Execution	3%
Control	5%
Closure	0%
Total	28%

Source: our own study.

6.2. Economic and Financial Risks

Economic and financial risks relate, in particular, to errors in business and financial assumptions. The business case for projects is often dominated by political and social expectations. The lack of a reliable assessment of the actual state and the forecast of future operating conditions for CHP units leads to inaccurate economic calculations and, consequently, to unforeseen financial costs. Thus, economic effects and financial resources are estimated on the basis of unreliable, often over-optimistic assumptions or without taking into account all market conditions (e.g., change in price forecasts or misjudgement of supply) and cost conditions (e.g., increase in emission allowances—EUA (European Union Allowance) or gas costs).

- The greatest economic and financial risks occur at the execution phase, at 2% and 3% of additional project costs, respectively. The way of controlling the disbursement of financial costs is insufficient, which leads to increase in disbursement and consequently burdens the economic result of the operation of CHP units, about 3% of additional project costs. In the case of the indicated projects, the budgets are exceeded or additional costs appear at the controlling phase, with 3% of additional financial project costs;

- Overall, the additional economic costs represent up to 2% of the total additional project costs, while the additional financial costs reached 6% of the total additional project costs (Table 7).

Table 7. Evaluation of economic and financial risks in the different phases of CHP projects.

Phase of the Project	Economic Risk	Financial Risk
Planning	0%	0%
Execution	2%	3%
Control	0%	3%
Closure	0%	0%

Source: our own study.

6.3. Legal, Regulatory and Environmental Risks

Global emission allowances (CO_2 or EUA) reduction objectives focus on the importance of decarbonising the heating and cooling sector, which consumes half of the residual energy in the European Union (EU). Consequently, district heating network operators need to adapt to the increasing carbon neutrality requirements [30]. Legal, regulatory and environmental conditions are the most important factors determining the success of CHP projects. The external environment in this regard is extremely dynamic and complex. The implementation of this type of project and, consequently, the exploitation of the project's products after its completion is conditioned by environmental strictures, and at the same time must comply with both national and European legislation. Therefore, failure to identify possible risks associated with this area may lead not only to serious hindrances to the implementation and exploitation of the project, but even make it impossible to implement the project or exploit the products. It should be noted that these factors are dynamic and complex. Legal and regulatory provisions may change during the project implementation; hence, they should be permanently monitored. The analysis of the exemplary projects shows that such actual changes resulted in preventing the implementation of the investment (in the case of one project), forced a major change in business assumptions (in the case of one project), changed budget and economic assumptions (in two projects) or worsened financial and economic conditions (in two projects). Additionally, in the period of energy transition, Polish weather conditions (lower temperatures and higher heat consumption), location (logistics and access to raw materials) and industrial conditions (very high share of fossil fuels, especially coal) are different from those of Western European countries, which have different switching costs and higher competitiveness and efficiency of processing and manufacturing products without a carbon footprint. Against the background of Central and Eastern Europe, Poland also has more difficult industrial conditions that, unfortunately, in the absence of an alternative possibility of ensuring secure and stable sources of electricity and heat supply, constitutes a serious challenge that burdens the economy and reduces its competitiveness. Another element is the lack of a proper perception of environmental regulations and conditions in the European Union, which have so far been ignored in Poland, and which have begun to be implemented with delay and without due verification. The regulatory and political competencies that have been built up, are only just beginning to grapple with the challenges of transformation and need to be strengthened with analytical and expert support. The lack of a proper assessment of the actual state of affairs and forecasting of future conditions of CHP operation leads to the risk of inaccurate economic calculations and the consequent creation of unforeseen costs [31]. Thus, economic and financial conditions are calculated with wrong assumptions or without taking into account all regulatory and environmental conditions, which affects the emergence of additional costs that burden projects from the technical, economic, financial, legal, regulatory and environmental side, which affects the delay.

The highest risks were recorded in the area of environmental risks at the cost planning stage, as they generate as much as 45% of additional project costs. Regulatory risk increases the construction costs of CHP units by about 10%. Materialisation of legal risk was valued at 1% of additional project costs (Table 8).

Table 8. Assessment of legal, regulatory and environmental risks in the different phases of CHP projects.

Phase of the Project	Legal Risk	Regulatory Risk	Environmental Risk
Planning	0%	10%	45%
Execution	1%	0%	0%
Control	0%	0%	0%
Closure	0%	0%	0%

Source: our own study.

7. Overview of Risks in Cogeneration Projects in the Individual Project Phases

In this section, the authors present the conclusions of the project analysis on the basis of several recent CHP projects described under the names A/B/C/D/E/F in different stages of project implementation and in the operation phase of the investment and project results. The methodological approach for risk analysis includes the identification of risks at the planning phase of the investment and, at this stage, both the risk register, the impact of risks on individual project variables and the planned response to risks are prepared, while in subsequent phases of the project it is necessary to verify individual factors. Part of the risk may have already materialised and is no longer a threat to the project, but at the same time new risk factors emerge that make it necessary to update the register. It should be noted that the so-called secondary risks may appear, which are the result of the undertaken reaction to the previously existing risks. The authors have analysed and evaluated the risks for the different phases of the project life cycle.

7.1. Project Planning Phase

Table 9 indicates the individual risks and their valuation. The minus sign (-) represents projects in which risks appeared in the planning phase. It was estimated that the total cost of not correctly identifying a given risk in the planning phase exceeded PLN 1.5 billion, which amounts to almost 60% of the total additional cost of materialised project risk. Consequently, reliable risk identification, pricing and response planning are the biggest challenges in the area of CHP project management in the planning phase.

In the area of risk identification, the planning phase saw the most risks, which accounted for almost 75% of the additional project costs. In the control phase, risks occurred that accounted for almost 10% of additional project costs, and, in the execution phase, about 15% of additional design costs.

Table 9. Project risks of CHP investments in the planning phase.

Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk
A	−/+	−	−	+	+	−
B	−	−	−	+	−	−
C	−	−	−	+	+	+
D	−	+	−	+	+	−
E	−/+	−/+	+	+	−	+
F	+	+	+	+	+	+

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started operation. Source: our own study.

7.2. Implementation Phase—Project Execution

The biggest problems with updating project risks occur in the execution phase of cogeneration investments. Unfortunately, they also appear in the area of technical, economic and financial risks and, consequently, delays in project completion. Polish construction and environmental regulations are not friendly to investors; however, the biggest problem arises in the identification of economic and financial risks and related delays. Technical risks related to execution errors also appear in the investment implementation phase.

The results of the survey are presented in Table 10.

In line with the methodology described above, the table illustrates the biggest problem in identifying and managing the risk of delays in the construction of CHP units, which unfortunately involves technical, economic and financial risks. It was estimated that the total cost of not properly updating the risk in the investment phase amounted to PLN 0.2 billion.

Table 10. Risks of CHP investment projects during the execution phase.

Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk
A	−/+	−	−	+	+	+
B	+	−	−	+	−	−
C	−	−	−	+	+	+
D	−	+	−	+	+	+
E	−/+	−/+	+	+	+	+
F	+	+	+	+	+	+

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started operation. Source: our own study.

7.3. Project Monitoring and Control Phase

The results of the survey on the occurrence and value of risks in the monitoring and control phase of projects are presented in Table 11. From the analysis, it can be concluded that many projects did not have sufficiently structured risk management processes for project monitoring and control. The reason for this may be the lack of a sufficiently established culture of verification of the construction plan and the correctness of the CHP projects, which indicates ignored or inadequate control, based on neutral criteria (the so-called evaluation according to political or corporate expectations) by non-independent entities (the so-called dependency, cover-up pressures or lack of competence).

It was estimated that the total cost of the failure to correctly identify risks in the control phase amounted to PLN 0.3 billion, which primarily indicates the need to introduce control mechanisms by an independent body, according to recognised control methodologies.

Table 11. Risks of CHP investment projects during the control phase.

Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk
A	+/−	−	+	+	+	+
B	+	−	−	+	−	−
C	−	−	−	−	+	+
D	−/+	−	−	+	+	−
E	-	−/+	+	+	−/+	+
F	+	+	+	+	+	+

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started operation. Source: our own study.

7.4. Project Closure

Reduced carbon emissions, reduced electricity costs and independence from the grid are some of the advantages of fuel cell CHP systems. Despite these advantages, the high initial capital cost is a key factor hindering commercialisation [32]. In addition, it is worth noting that the long payback period of these investments makes it difficult to prepare a full project profitability analysis.

In the Polish context, the analysis and evaluation of projects tend to be neglected after the cogeneration system is commissioned, which results in a lack of information as to whether the project settled and whether the client received the products of the project. In the investment phase, mistakes or irregularities are often underestimated, and what is more, in the closure phase it is not verified whether the investment meets the customer's requirements or whether the project was implemented within the budget and planned timeframe. Table 12 shows the results of the study of this phenomenon on the research sample.

Table 12. Risks of CHP investment projects in the closure phase.

Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk	Implementation Phase
A	−	−	+	+	+	+	Project completed
B	n/a	n/a	n/a	n/a	n/a	n/a	Project in progress
C	−	−	−	+	+	+	Project completed
D	n/a	n/a	n/a	n/a	n/a	n/a	Project in progress
E	−	−/+	+	+	+	+	Project completed
F	+	+	+	+	+	+	Project completed

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started operation. Source: our own study.

Not all projects have reached the stage of completion (four projects have been built and two are under construction), therefore only part of the projects can be settled. In the study, we draw attention to the negligence of the verification of projects in the phase of completion, because the assessment of project implementation is often limited to the accounting mechanism of costs settlement (although even this phase is sometimes omitted), which enables drawing conclusions for the future.

8. Evaluation of the Project Results and the Risk of Achieving Those Results in the Operational Period

Table 13 below shows the risk evaluation in the exploitation phase, based on four projects. The analysis shows that mainly economic and financial risks and, to a lesser extent, technical risks occurred in the exploitation phase of the investment. Two of the analysed projects (B and D) were not completed and products were not commissioned.

Table 13. Assessment of risks during the operation phase of CHP projects.

Project	Technical Risk	Economic Risk	Financial Risk	Legal Risk	Regulatory Risk	Environmental Risk
A	−/+	−	−	+	+	+
B	n/a	n/a	n/a	n/a	n/a	n/a
C	-	−	−	−	+	+
D	n/a	n/a	n/a	n/a	n/a	n/a
E	−/+	−/+	+	+	+	+
F	+	+	+	+	+	+

Symbols: + no risk, − risk present, −/+ risk partially present, n/a—does not apply to the project in question as it has not yet started operation. Source: our own study

Identifying risks in the operation phase is a major challenge for CHP units due to the volatility of the market and weather conditions, which are described below under economic and financial risks.

First of all, the increase in EUA prices has reduced the CDS (clean dark spread) and CSS (clean spark spread) in Poland, as shown in the Figure 4.

First of all, the increase in EUA prices has affected the decrease in the CDS (clean dark spread) and CSS (clean spark spread) in Poland: the CDS has been negative since 2019 and the CSS has been negative since May 2021. Given the experience of developed countries, the trend of negative CDS and CSS poses a serious challenge to profitability and requires a change in trading strategies and trade risk management mechanisms.

Identifying technical risks is a major project challenge, especially when technical knowledge is marginalised by political pressure. Technical risks during the lifetime of projects are mainly due to wrong assumptions about the future operating conditions of CHP units, leading to wrong technical decisions. In this way, the technical conditions of new CHP units cause them to fail to meet user and market expectations and thus to fail to deliver the expected economic results. Few technical errors occur in the phase of improper operation of cogeneration units.

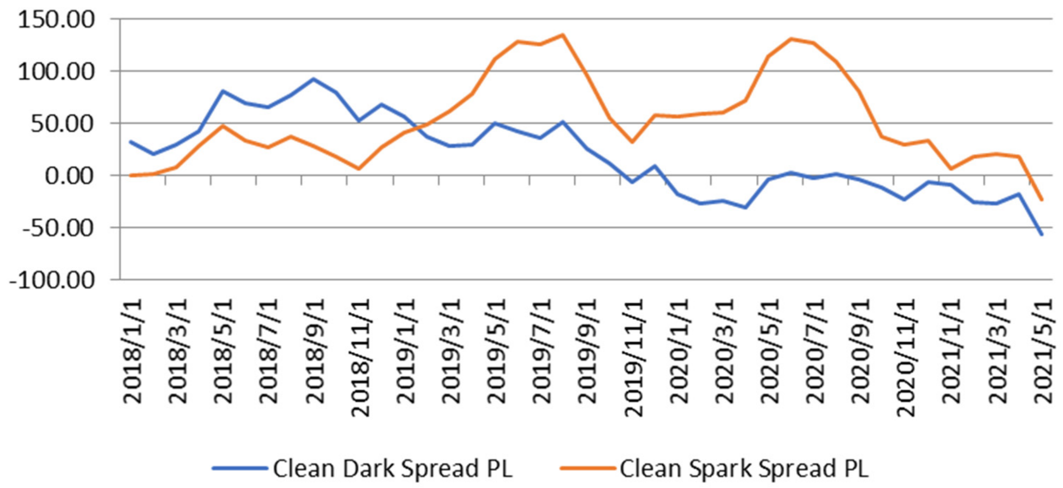

Figure 4. CDS and CSS in Poland, 2018–2021. Source: Society for Energy Trading, Electricity And Gas Market In Poland—state as of 31 March 2021, SET Report, p. 363 [33].

Economic and financial risks are mainly caused by the incomplete assessment of the facts and the forecast of future operating conditions of CHP units, which leads to incorrect economic calculations and consequently to the emergence of unexpected financial costs. Thus, economic and financial conditions are calculated with incorrect assumptions or regardless of all market conditions (changes in price forecasts or misjudged supply) and cost conditions (increased costs of, e.g., EUA or gas). The investor's awareness of the possibility and importance of risks during the project lifetime is a major challenge for CHP units due to the volatility of the market and atmospheric conditions. We have estimated that the cumulative costs of not correctly identifying these risks have increased, or may increase in the future, OPEX by up to PLN 0.2 billion per year. Poland is one of the largest emitters of CO_2, one of the largest CO_2 emitters by indicator (743 kg/MWh) and the most exposed to the cost of EUA (322 million tonnes of CO2 in 2019, of which 298 million tonnes of CO_2 come from the energy sector [34] in proportion to the cost of electricity generation in the European Union). This applies primarily to coal, but also affects gas. In addition, there are market risks associated with price volatility and the need to manage exchange rate risk. This area will be particularly challenging in the future, as we have already seen problems with the profitability of cogeneration units for many years, in particular the negative clean dark spread (CDS) for coal-fired generation and big fluctuations in the clean spark spread (CSS) for gas-fired generation, which have been on a negative note since May 2021, following the huge increase in gas prices. Unfortunately, the trend of rising emission allowance (EUA) prices further exacerbates the economics, in particular CDS and, to a lesser extent, CSS. The OPEX cost will burden the Polish economy each year, worsening its economic efficiency in relation to its competitors.

In addition, it is worth noting that, during the life of an investment, and this period due to the specificity of this type of investment that lasts for several decades, regulatory and legal assumptions may change, which then may affect the lack of economic viability of cogeneration units. Such cases have already taken place in Poland and can be expected due to the experiences of other highly developed countries. They will be affecting the limitation of volumes generated by individual units, which will worsen the economic viability of cogeneration units (e.g., shutdowns or restrictions on the operation of generation units). As a consequence, it requires changes in legal conditions, related to the costs of project implementation. According to the mentioned period of energy transition, Polish conditions are different from those of Western European countries, which negatively affects the competitiveness and efficiency of energy generation. When compared to Central and Eastern Europe, Poland has worse industrial conditions, which, in the absence of an alternative possibility to ensure safe and stable sources of electricity and heat supply, is unfortunately a serious challenge that burdens the economy and reduces its competitiveness. What is more, changing regulations and environmental conditions in the European Union are worsening the conditions for the competitiveness of Polish cogeneration units. The lack of proper assessment of the actual situation and forecasts of future operating conditions for cogeneration units leads to inaccurate economic and financial calculations and, consequently, to the occurrence of unexpected financial costs or economic losses. Thus, economic and financial conditions are calculated with wrong assumptions or without taking into account all regulatory and environmental conditions. Most economic errors occur in the management of commercial risks, which are at a low level of application by domestic companies. The lack of correct methodological and analytical assumptions further deteriorates the competitiveness of the Polish energy sector.

9. Summary and Conclusions

Managing risk in a conscious and structured way reduces uncertainty in a project and increases the likelihood of its final success. There are many standards in management practice that can provide support for project risk managers. CHP projects are projects of considerable complexity. This complexity results from the high technical innovation of these projects, on the one hand, and from the turbulent regulatory, legal and environmental environment, on the other hand. Additionally, it is worth noting that these projects have a high implementation budget. The analysis conducted on the basis of cogeneration projects implemented in Poland over the last six years shows that project risks have a major impact in all phases of project implementation. Most technical errors occur at the planning stage (corresponding to 20% of additional project costs), the inspection stage (almost 5% of additional project costs) and the construction stage (almost 3% of additional project costs). The greatest economic and financial risks occur at the execution stage, at 2% and 3% of the additional costs of the project, respectively. The way of controlling the disbursement of financial costs is insufficient, which leads to an increase in disbursement and consequently burdens the economic result of the operation of CHP units, at about 3% of additional project costs. In the indicated projects, the budgets exceeded or additional costs appeared at the controlling stage, at 3% of the additional financial costs of the project.

Legal and regulatory factors have the greatest impact on the investment planning phase. It is worth noting that, in projects of this type, one should analyse the risk of achieving results during the project's operation, when monitoring the project's results. The authors estimated the risks in the different phases of the project, and the conclusions indicate that the total costs of failure to correctly identify the risks at the planning stage exceeded the value of PLN 1.5 billion, which amounted to almost 60% of the total additional costs of materialized project risks. Consequently, the biggest challenge in the area of CHP project management at the planning stage is a thorough identification, valuation and planning reaction to risks. In the implementation phase, the biggest challenge is to update the project risks, especially in the area of technical, economic and financial risks. It is also worth noting that the analysis and evaluation of projects after the commissioning of the CHP system is neglected, which results in a lack of information as to whether the project settled and whether the customer received the products of the project. In the investment stage, mistakes or irregularities are often underestimated, and, additionally, in the project completion stage, it is not verified whether the investment meets the customer's requirements or whether the project was executed within the budget and planned time.

The research was based on data obtained from published reports on the status of CHP projects. Undoubtedly, it would be an important and valuable perspective if there was a detailed analysis conducted from the perspective of other project stakeholders, such as project teams, implementing organisations and governmental institutions that co-finance projects. The authors attempted to develop the study to include a broader spectrum of stakeholders. Attempts were made to contact other stakeholders to verify the presented conclusions. It was agreed to use the interview method with other stakeholders.

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Nomenclature

CAPEX	Capital expenditures
CDS	Clean dark spread
CEE	Central and Eastern Europe
CHP	Combined heat and power
CSS	Clean spark spread
EGU	Electric generating unit
EUA	European Union Allowance
ICB	Individual Competence Base-line
IPMA ICB	International Project Management Association Individual Competence Baseline
OPEX	Operating Expenditures
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PRINCE2	PRojects IN Controlled Environments
PRISM	PRojects Integrating Sustainable Methods
RES	Renewable energy sources

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