WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2026.158593
ARCHIVES OF CIVIL ENGINEERING
Vol. LXXII ISSUE 2 2026

pp. 47 – 65

Review paper

Development of a risk map, a risk allocation matrix, and a risk assessment matrix for the energy construction sector

Lidia Więcław-Bator[1], Ryszard Chmielewski[2], Leopold Kruszka[3]

Abstract: This article presents an integrated framework for developing risk management tools tailored to energy construction projects. It advocates for a transition from traditional reactive methods toward a proactive, engineering-led approach. The study examines the systematic development and synergistic application of three distinct tools: risk maps, risk allocation matrices, and risk assessment matrices, evaluating their collective impact on key project parameters such as cost, schedule, scope, and quality.

Central to the research is a multi-dimensional analysis of sector-specific risk determinants, ranging from macroeconomic volatility and regulatory shifts to the complex technical interdependencies inherent in high-voltage infrastructure. Grounded in the contractual frameworks of the “Code of Good Practices for the Energy Industry” (PZPB) and “Standards for Investment Execution” (SIDiR), and bolstered by empirical research conducted between 2022-2025 regarding contractor claims in 35 national electric power projects, the article develops practical, validated tools for comprehensive risk management.

Keywords: risk allocation, electrical works, project management, cost optimization, energy infrastructure

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[1] MSc., Eng., Doctoral School, Military University of Technology in Warsaw, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, Poland, e-mail: lidia.wieclaw-bator@wat.edu.pl, ORCID: 0009-0008-8389-6186

[2] DSc., PhD., Eng., Prof. Military University of Technology in Warsaw, Faculty of Civil Engineering and Geodesy, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, Poland, e-mail: ryszard.chmielewski@wat.edu.pl, ORCID: 0000-0001-5662-9180

[3] PhD., Eng., Military University of Technology in Warsaw, Faculty of Civil Engineering and Geodesy, ul. gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, Poland, e-mail: leopold.kruszka@wat.edu.pl, ORCID: 0000-0001-5129-2531

1. Introduction

Energy infrastructure projects, specifically the construction and modernization of electrical substations and transmission lines, represent a vital pillar of economic stability and national development [1]. These investments are characterized by extreme complexity, resulting from the rigorous intersection of technical, regulatory, environmental, and operational requirements. Executed within a volatile macroeconomic environment and under the pressure of the global energy transition, these projects face significant risks. Their materialization leads to severe consequences: significant budget overruns, schedule slippages, and threats to the continuity of the power supply.

Research indicates that 30 to 40% of large-scale energy infrastructure projects exceed their initial budgets or milestones. The primary cause is typically not an isolated "black swan" event, but rather systemic deficiencies in the processes of risk identification, assessment, allocation, and mitigation. A proactive, structural approach is needed, based on an engineering-led analysis of threat sources and their cascading effects [2–4].

This article addresses these challenges by presenting a suite of integrated decision-support tools designed for contractual risk management. These instruments (Table 1) are grounded in international standards (ISO 31000:2018 [5], PMBOK® Guide [6]) and national sectoral guidelines (PZPB [7], SIDiR [8]).

Table 1. Contract risk analysis and management tools

Tool	**Components**	**Purpose**
1	2	3
Risk map	Taxonomy of risks; modeling of correlations and cascade effects.	Systematic identification and ontological classification of risks. Prioritization of impact on cost, time, scope, and quality.
Risk allocation matrix	Risk-sharing mechanisms; compensation models; formal delineation of liability.	Formal assignment of responsibility to the party best equipped to control the risk.
Risk assessment matrix	Final decision-support output; semi-quantitative assessment (probability vs. impact).	Determination of the final risk level for project success and calculation of the required financial/resource buffer for the bid.

The proposed model follows a logical analytical sequence. The process begins with the development of a risk map to identify and classify threats. This is followed by the creation of a risk allocation matrix, which delineates the responsibilities of the parties according to the selected contract model (e.g., Build-Only, Design-Build, or EPC). The final output of this decision- support process, conducted by an entity bidding for electrical power works during the tendering phase, is the risk matrix. Serving as the definitive result of the entire analysis, this matrix determines the composite risk level for the investment by applying a unified five-level assessment scale. Through this mechanism, the bidder can make informed strategic decisions, precisely define the required management response, and estimate the necessary risk contingency to be included in the contract price.

A key element providing this work with practical value is its empirical grounding in the analysis of 35 national electrical power projects executed between 2022–2025. The structure of the article reflects this logic:

- Chapter 2 is dedicated to the risk map, providing an exhaustive ontological description of risk determinants and their classification within the specific context of energy infrastructure.
- Chapter 3 delineates the structural development and practical application of the risk allocation matrix, analyzing the distribution of liability across diverse contractual models.
- Chapter 4 presents the methodology for constructing the risk matrix, serving as a semi-quantitative instrument for risk quantification and strategic decision support during the tendering phase.
- Chapter 5 offers a comprehensive summary and discussion of findings, correlating the theoretical framework with empirical data derived from the analyzed energy projects.
- Chapter 6 synthesizes the research to provide final conclusions, emphasizing the impact of the integrated tools on the stability and predictability of investment delivery.

2. The risk map

The risk map constitutes the fundamental instrument for the systematic identification and ontological classification of potential threats inherent to energy infrastructure projects. Its primary objective is the deconstruction of the multidimensional risk landscape into a structured taxonomy, facilitating a transition from reactive management to a proactive, engineering-led methodology [9]. Beyond its role as a classificatory repository, the risk map enables the analytical modelling of correlations and cascade effects, which is critical for maintaining the stability of high-voltage substation and linear asset investments.

Based on an exhaustive analysis of investment processes within the power sector, the following five-group classification of risk determinants has been established, with a focus on their impact on project constraints:

1. Macroeconomic and regulatory risks: These constitute the external boundary conditions affecting the project's financial and legal integrity [10, 11]. The high volatility of commodity markets-specifically for strategic raw materials such as copper, aluminum, and structural steel- directly impacts the cost of cabling systems, busbars, and support structures. Heavy reliance on imported high-technology components (e.g., Gas Insulated Switchgear – GIS) introduces significant currency exposure. Regulatory shifts, including updates to grid codes or environmental standards regarding SF6 gas management, may force a re-evaluation of the project scope and necessitate costly re-engineering of secondary circuits during the execution phase.
2. Technical and technological risks: These represent core engineering challenges, particularly acute in the "brownfield" modernization of energized facilities. Discrepancies between historical "as-built" documentation and the actual physical state of infrastructure (undocumented underground utilities, non-standard earthing systems) pose a direct threat to the quality and safety of works [12–14]. Furthermore, the integration of

Substation Automation Systems (SAS) and Supervisory Control And Data Acquisition (SCADA) based on the IEC 61850 standard introduces systemic risks; interoperability failures between Intelligent Electronic Devices (IEDs) from different vendors can lead to significant delays in the time to commissioning and energization.

3. Location and environmental risks: These are inherent to the site-specific nature of energy infrastructure. Unfavorable geotechnical conditions often necessitate unforeseen soil stabilization or piling for tower and gantry foundations, escalating the cost and potentially altering the technical scope. For linear projects, terrain heterogeneity and collisions with uninventoried underground infrastructure may require a shift to expensive Horizontal Directional Drilling (HDD) technologies. Environmental constraints (e.g., Natura 2000 areas) impose strict seasonal windows; non- compliance with bird nesting periods or water protection zones can lead to administrative suspension of the construction logbook, severely impacting the time parameter.
4. Organizational risks: Derived from the multi-party and hierarchical structure of energy contracts. The primary threat lies in interface management between execution teams, where a lack of synchronization between civil works and primary technology delivery (e.g., lack of foundation readiness for long-lead transformer items) disrupts the time schedule [15]. Decision inertia within the investor's structure regarding the approval of detailed executive designs or material variances often blocks the manufacturing of control cabinets and steel structures, jeopardizing both the time and quality parameters.
5. Time-period and seasonal risks (timing-operational): This unique category encompasses risks strictly dictated by the operational stability of the National Power System and the specific season of execution. The time parameter is entirely dependent on pre-approved, inflexible grid outage windows; missing a confirmed window due to minor preparatory delays results in a disproportionate delay of several months until the next window meets the N-1 grid security criterion. Furthermore, the technological regime of HV works prohibits assembly during adverse seasonal conditions (high humidity or precipitation) due to dielectric safety standards. Consequently, schedule slippages pushing electrical works into the autumn-winter season significantly increase the probability of quality degradation and project failure.

3. The risk allocation matrix

The risk allocation matrix serves as a formal instrument for operationalizing the identified risk taxonomy into a structured contractual governance framework. Its primary objective is the unambiguous assignment of managerial responsibility and financial liability for each categorized risk to the contracting party possessing the superior technical competencies and specialized resources necessary to control, monitor, or absorb the associated consequences at the lowest aggregate project cost [16].

This principle, fundamentally defined in economic theory as allocative efficiency, is a prerequisite for the long-term stability and economic viability of energy infrastructure contracts. In the specific context of electrical power investments, such as high-voltage substations or linear transmission assets, risk allocation must account for the high capital intensity and the stringent operational regimes of the National Power System.

As detailed in Table 2, the matrix provides a granular delineation of responsibilities, specifically tailored to the nuances of the selected project delivery models:

- Build-Only (BO): Wherein the employer retains the majority of locational, environmental, and design-related risks, specifically those arising from latent defects in the functional-utility program or uninventoried underground utility collisions. The contractor's liability is limited to execution quality and schedule discipline based on provided documentation.
- Design and Build (D&B): Which entails a significant translation of technical and technological risks toward the contractor. As the party responsible for the integrity of both the design and execution phases, the contractor assumes the burden of design errors, interoperability failures in the IEC 61850 standard, and the optimization of technical solutions.
- Engineering, Procurement, and Construction (EPC): Representing the most rigorous allocation variant, in which the contractor serves as the guarantor of the final investment outcome, absorbing nearly the full spectrum of market risks, including commodity price volatility and logistical delays in the delivery of long-lead technology items.

Table 2. Risk allocation matrix

Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
CONTRACTUAL DOCUMENTATION							
Unambiguity, consistency, and transparency of contract provisions		×		×		×	
Completeness, detail, unambiguity and consistency of the description of the subject of the contract – enabling:	making a fair estimate by the contractor	×		×		×	
	development of a construction project and detailed designs	–	–	×		×	
	precise definition of the contractor's obligations	×		×		×	
	proper and timely execution of the subject matter of the contract	×		×		×	
Correctness of the selection of solutions in the description of the subject of the contract, in particular:	functional-utility solutions	×		×		×	
	technological solutions	×		×		×	
	material solutions	×		×		×	

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Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
The correctness of the selection of target design solutions – in the project documentation, in terms of	functional-utility solutions	×		×		×	
	technological solutions	×			×		×
	material solutions	×			×		×
Electricity infrastructure shutdown plans	development and updating of exemption plans	×		×		×	
	notification of necessary exclusions and possible cancellations in accordance with the required deadlines	×		×		×	
Detailed schedule for the implementation of the contract	presentation of a schedule for approval by the contracting authority		×		×		×
	timely approval by the ordering party or submission of comments	×		×		×	
Guaranteed data	presentation of guaranteed data for approval		×		×		×
	timely approval or objection by the ordering party	×		×		×	
CONSTRUCTION SITE AND ACCESS							
Availability of the construction site for purposes:	organization of the construction site, including the location of construction facilities and temporary storage of materials and excavated material		×		×		×
	implementation of technological transport and delivery of materials and equipment	× (concerning investor supplies)	×	× (concerning investor supplies)	×	× (concerning investor supplies)	×
	conduct survey work and ground investigations	×		×		×	
	execution of construction works	×		×		×	
	construction and maintenance of temporary access roads and technological transport routes		×		×		×
	movement of construction machinery and equipment		×		×		×

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Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
	maintain traffic safety and environmental protection around the construction site		×		×		
	possible repair of damages and restoration of the site to its original condition after completion of the project	×		×		×	
Provide access to temporary technical infrastructure and connection points			×		×		×
Discernment of geotechnical, geological-engineering, hydrogeological, archaeolo- gical, sapper, natural-environ- mental conditions for the purposes:	making a valuation	×		×		×	
	performance of the subject of the contract	×			×		×
COST RESOURCES/INPUTS AND MATERIAL/PHYSICAL RESOURCES							
Direct construction costs in:	original completion date		×		×		×
	extended completion date due to circumstances dependent on the contracting authority	×		×		×	
	extended completion date due to circumstances beyond the control of both parties	×	×	×	×	×	×
	extended completion date due to circumstances beyond the contractor's control		×		×		×
Construction overhead in:	original completion date		×		×		×
	extended completion date due to circumstances dependent on the contracting authority	×		×		×	
	extended completion date due to circumstances beyond the control of both parties	×	×	×	×	×	×
	extended completion date due to circumstances beyond the contractor's control		×		×		×

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Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
Management overhead in:	original completion date		×		×		×
	extended completion date due to circumstances dependent on the contracting authority	×		×		×	
	extended completion date due to circumstances beyond the control of both parties	×	×	×	×	×	×
	extended completion date due to circumstances beyond the contractor's control		×		×		×
Price indexation of factors/components of construction and assembly production		×	×	×	×	×	×
Human resources:	technical staff and construction management		×		×		×
	production staff		×		×		×
Hardware resources			×		×		×
SITE SUPERVISION							
Activities beyond the contractual delegation:	investor supervision	×		×		×	
	project author supervision	×			×		×
	construction manager and work managers		×		×		×
Implementation of instructions in accordance with the contract:	investor supervision		×		×		×
	project author supervision		×		×		×
	construction manager and managers		×		×		×
IMPLEMENTATION OF CONSTRUCTION WORKS, WORKS AND SUPPLIES							
Construction site and accesses:	ensuring safety and security at work		×		×		×
	development of the construction site		×		×		×
	environmental protection and maintenance of order at the construction site		×		×		×

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Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
	protection of property and protection of construction works from third party access and external influences		×		×		×
	coordination of construction works		×		×		×
	responding to threats and emergency situations	×	×	×	×	×	×
Equipment and materials:	investor	×		×		×	
	provided by the contractor		×		×		×
	provided by the contractor without the possibility of offering equivalent solutions recommended by the contracting authority	×	×	×	×	×	×
Subcontractors for construction work:	selection of subcontractors		×		×		×
	subcontractors appointed by the contracting authority	×		×		×	
	delay in approval of the draft subcontract	×		×		×	
	joint and several liability for the wages of subcontractors	×	×	×	×	×	×
Implementation of construction works in accordance with the contract, legal regulations, current state of technical knowledge, standards and principles of engineering art			×		×		×
Correctness of implementation of target functional-utility, material and technological solutions (in accordance with approved design documentation)			×		×		×
Changes in legislation		×	×	×	×	×	×
Price indexation of factors/components of construction and assembly production		×	×	×	×	×	×
Schedule disruptions resulting from:	failure to make the construction site or work front available within the agreed timeframe	×		×		×	

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Table 2 – *Continued from previous page*

Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
	deficiencies or errors in the description of the subject matter of the contract, preventing the proper execution of construction work	×		×		×	
	unpredictable geotechnical, geological-engineering, hydrogeological, archaeological, sapper, natural-environmental conditions	×		×		×	
	collision of the designed facility with unlisted technical infrastructure	×		×		×	
	lack or error in the technical documentation prepared by the contractor	–	–		×		×
	delays in obtaining administrative decisions, permits, arrangements or approvals	×		×		×	
	weather conditions that exceed predictable seasonal and local norms	×		×		×	
	failure of equipment belonging to the contractor		×		×		×
	improper organization of construction work or logistics at the construction site		×		×		×
	social protest, strike, blockade or other disruption of a social or local nature	×		×		×	
	omission or error on the part of the contractor, subcontractor or supplier		×		×		×
	failure to coordinate the delivery of materials or equipment		×		×		×
	unavailability of resources due to force majeure or global market disruptions	×	×	×	×	×	×

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Table 2 – *Continued from previous page*

Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
	changes to the design solution initiated by the ordering party or the investor's supervisor	×		×		×	
	lack of decisions or delays in the contracting authority's actions	×		×		×	
	other force majeure events	×		×		×	
Electricity infrastructure outages:	planning optimal infrastructure shutdowns necessary for the execution of the work	×		×		×	
	notification of shutdowns well in advance, as agreed with the contracting authority and the owners of the equipment		×		×		×
	the effects of demobilization, downtime, re-mobilization and reorganization of work in the event of cancellation by the contracting authority of a previously approved shutdown	×		×		×	
	the consequences of abandoning the exemption or not using it for reasons attributable to the contractor		×		×		×
Contractor's interference with infrastructure covered by another contractor's quality guarantee (guarantor)	organizing and conducting arrangements with the guarantor regarding the technical, organizational and formal conditions for interference with the elements covered by its guarantee	×		×		×	
	preparation to the guarantor of the required execution documentation for the planned intervening works		×		×		×
	provide the guarantor with the required execution documentation for the planned intervening work	×		×		×	

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Table 2 – *Continued from previous page*

Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
	obtaining the guarantor's consent to the interference and ensuring that the warranty provided is maintained after the interfering work is carried out	×		×		×	
	implementation of interfering works in accordance with the documentation approved by the ordering party, applicable laws and principles of technical knowledge – excluding liability for defects, damage or failure of elements made by the guarantor		×		×		×
	immediately notify the purchaser in writing of the circumstances preventing the performance of interfering work or the need for additional arrangements with the guarantor		×		×		×
	covering the costs of supervision by the guarantor during the interfering works – if such supervision proves necessary	×		×		×	
TAKEOVER OF CONSTRUCTION WORKS, QUALITY GUARANTEE PERIODAND DEFECT WARRANTY PERIOD							
Effects of use of construction works by ordering party before acceptance		×		×		×	
Losses and lost benefits:	on the part of the ordering party – as a result of the contractor's delay in implementing the subject of the contract, including the removal of a significant defect		×		×		×
	on the part of the contractor – as a result of the ordering party's delay in accepting the subject of the contract or its groundless refusal to do so	×		×		×	

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Table 2 – *Continued from previous page*

Risk factors and determinants		**Allocation of risk effects**					
		Formula BO		**Formula D&B**		**Formula EPC**	
		Contracting authority	**Contractor**	**Contracting authority**	**Contractor**	**Contracting authority**	**Contractor**
1		2	3	4	5	6	7
Removal of defects in the completed construction works during the quality guarantee period or the defect warranty period			×		×		×
Third-party claims for:	indirect immissions		×		×		×
	material damage to movable or immovable property		×		×		×
	violations of cultural heritage protection regulations	×	×	×	×	×	×
	restriction of ownership or use rights, including easements, lending, temporary occupation or other rights necessary for the construction of infrastructure	×		×		×	
	violations of environmental regulations		×		×		×
	labor, concerning employees employed by the contractor, including wage claims, violations of health and safety regulations and other obligations of the employer		×		×		×

This formalization, synthesized from the PZPB [7] and SIDiR [8] standards, effectively eliminates interpretive ambiguities and implements the “fair risk allocation” paradigm. By establishing a transparent and objective foundation for cooperation, the matrix serves as the primary mechanism for minimizing the frequency of contractual claims and protracted legal disputes arising from conflicting interpretations of obligations. Consequently, it secures the project’s critical path and ensures the preservation of the four cardinal parameters: cost, time, scope, and quality.

4. The risk allocation matrix

The risk assessment matrix constitutes the analytical core of the integrated framework, providing a structured, semi-quantitative methodology for evaluating the severity of contractual threats. Its primary objective is the objectification of hazard assessment through systematic quantification, enabling a decisive transition from intuitive estimation toward rigorous risk exposure management prior to the formal assumption of contractual obligations [17–20].

The mechanics of the matrix are predicated on a dual-factor assessment protocol that evaluates each identified risk determinant across two distinct, interrelated dimensions:

- Estimated probability of occurrence – defined on an ordinal scale of 1–5 (from "rare" to "almost certain"), this parameter is derived from expert judgment, historical data from similar electrical infrastructure projects, and an exhaustive analysis of the investment's boundary conditions.
- Projected magnitude of impact on core project objectives – evaluated on a scale of 1–5 (from "very low" to "very high"), this dimension requires discrete analyses of potential consequences across the four cardinal project parameters: budgetary (cost), temporal (schedule), qualitative, and substantive (scope).

The interaction between these two parameters is codified in Table 3, which serves as the fundamental evaluative framework of the model. By mapping the intersection of probability and impact, the matrix determines the composite risk level.

Table 3. Decision matrix for determining composite risk levels

Probability ↓ Impact →	1 Very low	2 Low	3 Medium	4 High	5 Very high
1	2	3	4	5	6
5 Almost certain	M	H	H	C	C
4 Probable	M	M	H	H	C
3 Possible	L	M	M	H	H
2 Unlikely	L	L	M	M	H
1 Rare	VL	L	L	M	M

This methodology facilitates strategic prioritization; rather than diluting managerial focus across all potential hazards, project leadership is empowered to concentrate resources on risks designated as critical (C) and high (H). According to the risk scale (Table 4), these levels necessitate the mandatory formulation of formal response protocols and the quantification of specific risk buffers within the tender price.

Table 4. Five-level risk scale

Risk Level	**Description**	**Required response**
1	2	3
Very low (VL)	Negligible impact; no noticeable consequences	No countermeasures required; monitoring is optional
Low (L)	Minor disruption; easily managed without major adjustments	Periodic monitoring; implement countermeasures based on cost-benefit analysis
Medium (M)	Noticeable impact; may require reorganization or corrective actions	Regular monitoring; mitigation can be deferred but requires consistent re-evaluation
High (H)	Significant impact on cost, schedule, or quality; jeopardizes objectives	Active mitigation required; continuous supervision is mandatory
Critical (C)	Critical consequences; threatens overall project success or safety	Immediate strategic intervention; project viability is at stake

4.1. Practical application: modernization of a 110/15 kV substation

The operational utility of this decision-support tool is demonstrated in Table 5, which presents a pre-project risk assessment matrix for a typical substation modernization.

Table 5. Model risk assessment matrix

Risk category	**Specific key risk factor**	**The impact of the risk factor on the project parameter**				**Probability (1–5)**	**Impact (1–5)**	**Risk level**
		Cost	**Time**	**Scope**	**Quality**			
1	2	3	4	5	6	7	8	9
Macroeconomic and regulatory	Concurrent inflation, currency volatility, and regulatory amendments impacting material costs and design compliance.	H/C	H	L	M	4	5	C
Technical, technological, systems	System integration complexity and interoperability failures during the commissioning of new SAS/SCADA with legacy protection devices.	M	H	M	H	3	4	H

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Table 5 – *Continued from previous page*

Risk category	**Specific key risk factor**	**The impact of the risk factor on the project parameter**				**Probability (1–5)**	**Impact (1–5)**	**Risk level**
		Cost	**Time**	**Scope**	**Quality**			
1	2	3	4	5	6	7	8	9
Locational and environmental	Discovery of undocumented subsurface utilities and delays in securing final environmental permits for construction.	M	H	M	M	3	4	H
Operational and organizational	Supply chain disruptions for critical components and coordination failures between civil and electrical works contractors.	H	H	M	M	3	3	M
Timely	Extended manufacturing lead times for power transformers and conflicts with the pre-approved, inflexible grid outage schedule.	M	H	M	H	4	4	H

While the example serves a model function, the input parameters-such as grid outage constraints and commodity price volatility-are entirely realistic and representative of the current conditions within the Polish energy sector.

By correlating the probability and impact factors through the logic established in Table 4, stakeholders can identify critical areas, such as macroeconomic volatility or inflexible grid outage schedules, that generate high (H) or critical (C) risk exposures. This systematic identification provides a substantively justified basis for the allocation of a financial contingency or the implementation of technical mitigation strategies, ensuring the preservation of project viability during the execution phase (Table 5).

5. Summary and discussion of findings

The primary value proposition of the presented decision-support framework lies in its capacity to preempt regressive project developments through systematic engineering and contractual analysis during the investment preparation phase. The research demonstrates that the transition from qualitative to semi-quantitative assessment facilitates the objectification of risks that are often underestimated in the energy sector, such as secondary circuit interoperability or the impact of seasonal dielectric rigors.

The ability to identify a critical (C) or high (H) risk level during the bidding phase provides the contractor with a defensible, analytically-grounded basis for determining a precise financial and resource buffer. Furthermore, it enables a proactive approach to the negotiation of disproportionately unfavorable contractual clauses, particularly those related to liquidated damages and inflexible grid outage schedules. This methodology not only enhances the predictability of financial outcomes but also fosters a higher degree of transparency between the employer and the contractor, which is of paramount importance in a market characterized by volatile commodity prices and dynamic regulatory instability.

6. Final conclusions

Based on the research conducted, the literature review, and the verification of empirical data, the following final conclusions have been formulated:

- It has been demonstrated that effective risk management in energy construction cannot rely on isolated, reactive actions. Instead, it requires the integrated, sequential application of three core tools: the risk map (for ontological identification), the risk allocation matrix (for delineating contractual responsibility), and the risk matrix (for probabilistic quantification). Only their combined, synergistic use ensures comprehensive control over strategic project parameters, namely: cost, schedule, scope, and quality.
- The implementation of transparent, clause-based risk allocation (as detailed in chapter 3) provides contracting parties with a consistent technical-legal language. This standardized communication significantly reduces the frequency of contractual claims and protracted legal disputes, as it eliminates egzegetical discrepancies regarding the boundary of liability [19, 20].
- The application of the proposed framework directly contributes to the stability of the National Power System. By ensuring that substation and linear investments are executed within their planned temporal and budgetary frameworks, the model supports the continuity of energy supply and the successful realization of the energy transition, regardless of external macroeconomic perturbations.

Acknowledgements

The research results presented in this article constitute an integral part of Lidia Więcław-Bator's doctoral dissertation concerning the determination of the contractor's resource buffer for the materialization of risks in construction contracts.

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Opracowanie mapy ryzyka, macierzy alokacji ryzyka oraz macierzy oceny ryzyka kontraktowego w sektorze budownictwa energetycznego

Słowa kluczowe: alokacja ryzyka, roboty elektroenergetyczne, zarządzanie projektem, optymalizacja kosztów

Streszczenie:

Niniejszy artykuł prezentuje zintegrowane ramy metodologiczne tworzenia narzędzi zarządzania ryzykiem, zaprojektowanych specjalnie na potrzeby sektora budownictwa energetycznego. Publikacja kładzie nacisk na paradygmatyczne przejście od tradycyjnych metod reaktywnych w stronę proaktywnego podejścia opartego na analizie inżynierskiej. W pracy poddano analizie proces systematycznego opracowywania oraz synergicznego zastosowania trzech narzędzi: mapy ryzyka, macierzy alokacji odpowiedzialności oraz macierzy ryzyka, oceniając ich łączny wpływ na kluczowe parametry projektu, takie jak koszt, czas realizacji, zakres oraz jakość. Kluczowym elementem badań jest wielowymiarowa analiza determinant ryzyka specyficznych dla sektora elektroenergetycznego – od zmienności makroekonomicznej i zmian regulacyjnych, po złożone współzależności techniczne nierozerwalnie związane z infrastrukturą wysokiego napięcia. Treść artykułu, osadzona w ramach kontraktowych „Kodeksu Dobrych Praktyk dla Branży Energetycznej” (PZPB) [1] oraz „Standardów Realizacji Inwestycji” (SIDiR) [2], została wsparta badaniami empirycznymi przeprowadzonymi w latach 2022–2025 w obszarze roszczeń wykonawczych w 35 krajowych projektach elektroenergetycznych. Wynikiem pracy jest opracowanie praktycznych, zweryfikowanych narzędzi służących do kompleksowego zarządzania ryzykiem.

Received: 2025-07-28, Revised: 2025-12-27