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MODEL OF MANAGERIAL DECISION-MAKING
IN MINING OPERATIONS WITHIN
THE FRAMEWORK OF SUSTAINABILITY
REPORTING OBLIGATIONS AND THE METHANE
EMISSION REDUCTION REGULATION

MODEL PODEJMOWANIA DECYZJI ZARZĄDCZYCH
W ZAKŁADACH GÓRNICZYCH W RAMACH
OBOWIĄZKU SPRAWOZDAWCZOŚCI
ZRÓWNOWAŻONEGO ROZWOJU
I ROZPORZĄDZENIA O REDUKCJI EMISJI METANU

Abstract: Regulation (EU) 2024/1787 of the European Parliament and of the Council on methane emission reduction, together with the CSRD and CSDDD directives, imposes reporting and environmental obligations on coal mines that structurally conflict with the logic of mining law, creating new requirements for managerial staff. This article examines how this conflict transforms *mining middle management* from a methane hazard control role into *operational ESG management*. The study employs two methods: bibliometric analysis of Scopus and WoS databases using VOSviewer, and cross-analysis of legal acts across five thematic clusters. The results indicate that the existing *regulatory uncertainty* – stemming from incomplete transposition of EU regulations into Polish mining law – generates four-sided pressure: production, safety, environment and reporting, which no existing management model adequately resolves. The identified *safety-environment trade-off* is structurally embedded in legislation, while the *double materiality* concept under CSRD cascades environmental accountability from board level to operational roles. Analysis through the lens of *institutional logics* and real options theory reveals that technical leaders operate simultaneously within competing institutional fields without adequate governance tools. The article proposes a *methane governance* architecture based on the RACI matrix as an instrument for operationalising the new leadership role under *EU methane regulation 2024/1787* and Industry 5.0 conditions. The article is conceptual in nature and based on deductive modelling. The proposed framework requires empirical validation in real-world mining organisations.

Keywords: Operational ESG management, mining middle management, double materiality, safety-environment trade-off, methane governance

Streszczenie: Rozporządzenie Parlamentu Europejskiego i Rady (UE) nr 2024/1787 w sprawie redukcji emisji metanu oraz dyrektywy CSRD i CSDDD nakładają na zakłady górnicze obowiązki raportowe i środowiskowe, które strukturalnie kolidują z logiką prawa górniczego, tworząc nowe wymagania wobec kadry kierowniczej. Artykuł analizuje, w jaki sposób ta kolizja przekształca *mining middle management* z roli zarządzającego zagrożeniem metanowym w rolę *operational ESG management*. Badanie opiera się na dwóch metodach: analizie bibliometrycznej w bazach Scopus i WoS z wykorzystaniem VOSviewer oraz analizie krzyżowej aktów prawnych w pięciu klastrach tematycznych. Wyniki wskazują na to, że istniejące *regulatory uncertainty*, wynikające z niepełnej implementacji regulacji UE w polskim prawie górniczym, generują czterostronną presję, którymi są produkcja, bezpieczeństwo, środowisko, raportowanie, której nie rozwiązuje żaden istniejący model zarządczy. Zidentyfikowany *safety-environment trade-off* jest strukturalnie wbudowany w przepisy, a koncepcja *double materiality*, przewidziana w CSRD, przenosi odpowiedzialność środowiskową z poziomu zarządu na poziom operacyjny. Analiza z perspektywy *institutional logics* oraz teorii opcji realnych ujawnia, że lider techniczny działa w konkurujących polach instytucjonalnych bez adekwatnych narzędzi governance. Artykuł proponuje architekturę *methane governance*, opartą na matrycy RACI, jako narzędzie operacjonalizacji nowej roli lidera w warunkach *EU methane regulation 2024/1787* i Przemysłu 5.0. Artykuł ma charakter konceptualny, oparty na modelowaniu dedukcyjnym. Proponowany model wymaga empirycznej walidacji w warunkach rzeczywistych przedsiębiorstw górniczych.

Słowa kluczowe: operacyjny menedżer ESG, menedżer średniego szczebla w górnictwie, podwójna istotność, kompromis bezpieczeństwo–środowisko, zarządzanie metanem

INTRODUCTION

The historical approach to methane, from the perspective of the broader public, is primarily associated with mining tragedies caused by the ignition or explosion of this gas in hard coal mines. Paradoxically, even in everyday life, methane is not associated with the infrastructure closest to human beings, as the collective consciousness is dominated by the concept of natural gas. Meanwhile, methane is a gas that accompanies humanity on a daily basis, serving simultaneously as a natural hazard, a valuable energy resource, and a significant greenhouse gas. In a world moving away from energy production from solid fossil fuels, methane is becoming a transitional stage on the path to renewable energy sources, owing to its lower environmental impact upon combustion compared to hard coal or lignite¹. Unfortunately, the added value of methane can easily be negated if its uncontrolled and unprocessed release into the Earth's atmosphere is allowed to occur. The global warming potential of methane over a 100-year horizon is 28–36 times greater than that of carbon dioxide². Moreover, in the 20-year perspective that is key for policymakers, its contribution to the greenhouse effect is as much as 82.5 times stronger than that of carbon dioxide³.

The problem of methane emissions into the atmosphere has been recognised by the European legislator, and the existing legal solutions applied by member states have been expanded and tightened by a dedicated European act⁴. Pursuant to Article 33 of that regulation, EU member states had until 5 August 2025 to establish national provisions and notify the European Commission accordingly. The Polish legislator did not manage to introduce the appropriate legal act in time, satisfying the condition only partially by designating the President of the Higher Mining Authority (*Wyższy Urząd Górniczy*, WUG) as the authority responsible for monitoring and enforcing the application of the so-called methane regulation⁵. The act extended the remit of the institution previously responsible for technical supervision of mining operations to include the role of environmental guardian and an authority responsible not only for ensuring compliance with the Regulation of the European Parliament and of the Council, but above all for implementing this legal act within the Polish legal system. In the role of an environmental authority, the

¹ KOBiZE, Calorific values (CV) and CO₂ emission factors (EF) in 2023 for reporting under the Emissions Trading System for 2026, Warsaw 2025.

² M. Borowski, K. Zwolińska-Gładyś, J. Cheng, *Methane emissions from coal mines: Quantification, capture and utilization strategies for atmospheric impact mitigation – A case study from Poland*, "Atmosphere" 2025, No. 16(2), Article 174, p. 1.

³ IPCC, Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report, Cambridge University Press, Cambridge 2021.

⁴ Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on methane emission reduction in the energy sector, Art. 33.

⁵ Act of 25 June 2025 amending the Act – Geological and Mining Law (Journal of Laws of 2025, item 1023), Art. 165(1a).

WUG does not merely become a supervisory body, but also an institution setting compliance standards regarding the manner in which operators are to act, report, and modernise their infrastructure. The new law directly affects the models of managing a mining operation, and its implementation will require modifications to the current decision-making practices of managerial staff.

The primary objective of this article is to develop an original model of managerial decision-making for members of the management and supervisory staff of mining operations referred to hereinafter as *technical leaders* – under conditions characterised by the simultaneous convergence of several equally significant pressures. These pressures arise from the risk of potential legal consequences and the necessity to fulfil reporting obligations resulting from the chosen course of action. This article addresses the identified research gap by seeking answers to the following research questions:

- What impact does the methane regulation have on the managerial staff of a mining operation?
- Are methane hazard management methods structurally at odds with the environmental objectives of Regulation 2024/1787?
- In what manner does the concept of double materiality influence the relationships between mining operations and their surroundings, in particular local government units (*jednostki samorządu terytorialnego*, JST)?
- How does regulatory uncertainty affect the investment decisions of mining companies' boards in the area of emission reduction?

LITERATURE REVIEW

In the classic neo-institutional framework, organisations do not function in a market vacuum but within a specific institutional field in which “appropriate” practices are co-shaped by regulatory, professional, and societal pressures. DiMaggio and Powell (1983) defined the mechanism of institutional isomorphism, indicating that organisations come to resemble one another under the influence of three types of pressure:

- coercive (resulting from law and sanctions),
- normative (associated with professional standards),
- mimetic (consisting of imitation of solutions regarded as effective)⁶.

The introduction of the methane regulation simultaneously reinforces all three of these pressures: it establishes hard obligations in the area of measurement, monitoring, reporting, and verification (MRV) – constituting a form of coercion – elevates

⁶ P.J. DiMaggio, W.W. Powell, *The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields*, “American Sociological Review” 1983, 48(2), pp. 147–160.

the standing of methodological verification standards (normativity), and, through data benchmarking, encourages entities to copy the best available technological and organisational solutions (mimicry)⁷. Within this field thus defined, institutional legitimacy becomes the central concept, understood as the generalised perception that an organisation's actions are desirable and consistent with the prevailing system of norms and values⁸. Under the new regulatory conditions, a mine's legitimacy ceases to rest solely on its historic economic role in the region and increasingly depends on its capacity to demonstrate control over emissions and the credibility of the data it presents. Three dimensions of this legitimacy can be distinguished:

- regulatory – directly dependent on compliance with MRV requirements and reporting obligations⁹,
- normative – arising from the demonstrated real capacity for reduction that goes beyond the formal minimum,
- cognitive – associated with the perception of the mine as a natural element of the local order, which is being eroded in the face of an expanding climate logic and the media exposure of emissions data within a given social order¹⁰.

The stakeholder theory perspective allows for a more precise characterisation of these relationships. R.E. Freeman defines an organisation as a node in a network of relationships with actors who can influence the enterprise or are affected by its actions¹¹. The methane regulation significantly strengthens the role of local government units (JST) as data stakeholders, replacing formerly soft declarations with a discourse based on indicators and trends. Drawing on the concept of stakeholder salience, JST in this context becomes a dominant stakeholder, combining democratic legitimacy, the urgency of claims related to environmental risks, and power based on planning and informational instruments¹². The new provisions reduce information asymmetry, enabling local governments to formulate expectations on the basis of verifiable data (MRV) rather than solely on corporate narratives¹³.

The tensions inherent in methane management are best illustrated by the perspective of institutional logics¹⁴, according to which organisations operate within competing systems of values that determine the concept of rationality. A mine, as an organisation operating at the intersection of multiple institutional logics,

⁷ Regulation (EU) 2024/1787, Art. 10, Art. 20(4), Art. 30.

⁸ M.C. Suchman, *Managing legitimacy: Strategic and institutional approaches*, "Academy of Management Review" 1995, 20(3), pp. 571–610.

⁹ Regulation (EU) 2024/1787, Art. 20(7).

¹⁰ M.C. Suchman, *Managing legitimacy...*, pp. 571–610.

¹¹ R.E. Freeman, *Strategic management: A stakeholder approach*, Pitman, Boston 1984, p. 46.

¹² R.K. Mitchell, B.R. Agle, D.J. Wood, *Toward a theory of stakeholder identification and salience*, "Academy of Management Review" 1997, 22(4), pp. 853–886.

¹³ Regulation (EU) 2024/1787, Art. 8(1) and (4).

¹⁴ P.H. Thornton, W. Ocasio, M. Lounsbury, *The Institutional Logics Perspective*, Oxford University Press 2012, pp. 78–83.

must integrate the production-economic logic with the safety logic and the newly reinforced climate-regulatory logic. Empirical analyses indicate that in the Polish context, methane emissions are not a straightforward function of output¹⁵, and the crucial distinction lies between emission streams from ventilation and degasification systems¹⁶. The integration of the impact reduction logic with the value creation logic becomes a test of the maturity of a mine's governance model¹⁷.

Transparency and data quality form the foundation that either enables or undermines an organisation's institutional legitimacy. Regulation 2024/1787 establishes an MRV system, transforming emissions data from an "internal mine resource" into a component of public institutional infrastructure serving state authorities, local governments, and a broad range of stakeholders. This system introduces a regime of public accountability based on verification requirements and defined standards for information disclosure. The literature indicates a risk of discrepancies in environmental performance assessments when they are based on methodologically non-transparent indicators¹⁸. In the case of hard coal mining, the transparency of methane data is particularly reputation-sensitive due to its high socio-political salience. The key instrument reinforcing the strategic standing of methane is the concept of double materiality (*podwójna istotność*), developed within the framework of the CSRD directive and ESRS standards. In this approach, methane is analysed along two dimensions:

- impact materiality – the actual impact on climate and environment,
- financial materiality – as a carrier of regulatory, cost-related, and reputational risks affecting the company's financial condition¹⁹.

MRV data thus becomes the "common currency" of institutional dialogue, enabling local governments to make substantive assessments of the effectiveness of a mine's reduction efforts. In the Polish context, the significance of transparency is amplified by disputes over reporting methodology, and analyses point to controversies surrounding emissions verification, generating a risk of trust erosion²⁰. At the same time, atmospheric studies identifying the Upper Silesian Coal Ba-

¹⁵ M. Dreger, *Changes in the methane emissions and hard coal output in the Brzeszcze mine (the Upper Silesian Coal Basin, Poland)*, "Geology, Geophysics & Environment" 2020, No. 46(2), pp. 159–174.

¹⁶ R. Patyńska, *Methane emissions from ventilation and degasification systems of hard coal mines in Poland in the years 2001–2010*, "Gospodarka Surowcami Mineralnymi – Mineral Resources Management" 2013, No. 29(1), pp. 17–33.

¹⁷ M. Borowski, K. Zwolińska-Gładyś, J. Cheng, *Methane emissions...*, Article 174, p. 3.

¹⁸ M. Delmas, V. Doctore Blass, *Measuring corporate environmental performance: The trade-offs of sustainability ratings*, "Business Strategy and the Environment" 2010, No. 19(4), pp. 245–260.

¹⁹ Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023, Art. 1; Directive (EU) 2022/2464 (CSRD); Commission Delegated Regulation (EU) 2023/2772 (ESRS), Preamble recital 29. ²⁰ Directive (EU) 2022/2464 (CSRD); Commission Delegated Regulation (EU) 2023/2772 (ESRS), Preamble recital 29.

²⁰ Instrat, *Methane from coal mines – will Poland clarify doubts regarding emissions and their verification?*, Instrat, Warsaw 2025.

sin as a point source of significant emissions increase the pressure for consistency between reported data and external observations²¹. In the relationship between a mine and JST, transparency should be understood as a complete data quality chain encompassing: the measurement method, validation procedures, independent verification, and communication enabling an assessment of the effectiveness of actions taken. In such a model, MRV ceases to be merely a reporting obligation and becomes an infrastructure for dialogue, enabling the development of “hard” relationships based on verifiable trends rather than public relations messaging²².

The described mechanism is consistent with real options theory as applied in environmental economics: a costly and irreversible investment (e.g. installation of gas engines) is deferred by a rational decision-maker until the key regulatory uncertainty is resolved, even if its expected value is positive²³. The regulatory delay on the part of the Polish legislator is therefore not solely a compliance problem for decision-makers within mining companies and firms, but a generator of their optimal investment decisions with direct climatic consequences. At the same time, investment constraints subsequently influence the decisions of technical leaders who, lacking adequate infrastructure for methane utilisation and facing decisions that increase emissions, expose their companies to potential penalties and themselves to the necessity of preparing reliable reports.

From the perspective of management and quality sciences, however, the question is not the shape of European regulations per se, but their direct impact on the operational activities of mining operations. This concerns in particular the technical leaders of mining operations that is, senior supervisory personnel and management of ventilation departments responsible for methane safety and the degasification process – who are the actual generators of emissions and reporting data. Existing literature dedicated to sustainable development in the extractive sector focuses to a greater degree on governance systems and processes and on ESG policy implementation at the organisational and corporate reporting level, while the impact of these regulations on the social and organisational dimension – including operational roles and organisational culture – remains less well captured²⁴. At the same time, the literature describes the decision-making conflict along the production-safety axis, with still limited insight into how the reporting and envi-

²¹ J. Swolkień, *Polish underground coal mines as point sources of methane emission to the atmosphere*, “International Journal of Greenhouse Gas Control” 2020, No. 94.

²² Regulation (EU) 2024/1787, Art. 20; M. Delmas, V. Doctori Blass, *Measuring corporate...*, pp. 246–252.

²³ R.S. Pindyck, *Irreversibility, uncertainty, and investment*, “Journal of Economic Literature” 1991, No. 29(3), pp. 1110–1148.

²⁴ M.U. Podobińska-Staniec, M. Sukiennik, M. Kęsek, K. Oleksak, *Organisational culture based on ESG standards and knowledge management – premises for implementation for the mining industry*, “Gospodarka Surowcami Mineralnymi – Mineral Resources Management” 2024, No. 40(4), pp. 183–205.

ronmental pressure arising from ESG regulations changes everyday operational decisions in mining²⁵. This competence remains embedded in the operator's (entrepreneur's) responsibility and in the reporting and organisational obligations set out in the regulation, including in Article 2(1)–(3) and Article 20²⁶.

The requirement for precise double-materiality reporting means that environmental data becomes a new plane of institutional dialogue. In this context, the generational diversity of employees takes on particular significance. As research indicates, younger generations display a higher orientation towards environmental and social standards and proficiency in the use of modern information technologies²⁷. Conversely, more experienced employees (including technical leaders) possess invaluable tacit knowledge developed through years of practice, which is crucial for safety and the operational functioning of a mine in crisis situations^{28 29}. The collision of these two worlds may lead to the introduction of modern management mechanisms in which both classical and reverse mentoring are applied, enabling the development of reporting and administrative systems, including those utilising artificial intelligence. At the same time, such trilateral collaboration, between a senior employee, a junior employee, and artificial intelligence may become an indispensable bridge for preserving an organisation's tacit knowledge and integrating it with ESG reporting requirements.

METHODS

BIBLIOMETRIC ANALYSIS

Mapping of the existing literature began with a deductive identification of clusters, inferred indirectly from one author's practical and operational experience and from the introduced legal act, Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on methane emission reduction in the energy sector (OJ EU L of 15.07.2024). The bibliometric analysis serves a verifying function: it establishes the extent to which the introduced legal act and its components are reflected in the scientific literature of the discipline of management and quality sciences, and whether the existing literature allows the research questions defined in Section 1 of this article to be answered.

²⁵ G. Gowrisankaran, C. He, E.A. Lutz, J.L. Burgess, *Productivity, safety, and regulation in underground coal mining: Evidence from disasters and fatalities*, NBER Working Paper 21129, 2015, pp. 1–12; S.M. Hashemian, K. Triantis, *Production pressure and its relationship to safety: A systematic review and future directions*, "Safety Science" 2023, No. 159, pp. 1–14.

²⁶ Regulation (EU) 2024/1787, Art. 2(1), (3), Art. 20.

²⁷ Deloitte, *2023 Gen Z and Millennial Survey*, London 2023.

²⁸ I. Nonaka, H. Takeuchi, *The knowledge-creating company*, Oxford University Press, New York 1995, pp. 59–73.

²⁹ R. Ribeiro, *Tacit knowledge management*, „Phenomenology and the Cognitive Sciences" 2013, Vol. 12, No. 2, p. 337–366.

The sequence adopted, in which clusters were defined prior to the database search and the VOSviewer visualisation, is a deliberate methodological choice rather than a departure from standard bibliometric procedure. The classic exploratory approach, in which VOSviewer derives clusters from keyword co-occurrence across the entire retrieved corpus, answers the question of what thematic structure emerges from the literature. The present study poses a different question: to what extent the literature addresses five predetermined, legally and practically anchored problem areas arising from a specific regulatory act. Answering a question framed in this way requires clusters defined a priori, irrespective of whether and how densely the literature populates them, since the degree of population, or its absence, is itself the object of inference regarding the research gap. Exploratory clustering would not permit such a test, as it would group publications according to natural clusters within the data, which could merge or separate categories of theoretical and legal significance, obscuring the very gap under verification. VOSviewer was applied subsequently, within the already defined clusters, to visualise keyword co-occurrence and confirm the degree of thematic isolation between clusters (Figures 1 and 2), not to derive them.

The selection of individual terms within each cluster was neither arbitrary nor purely exploratory but resulted directly from the mapping of elements of the legal act, established constructs from the literature, and the authors' practical operational experience. The rationale is presented in Table 1.

Table 1. Rationale for keyword selection by research cluster

Tabela 1. Uzasadnienie wyboru słów kluczowych według klastrów badawczych

Cluster	Term	Rationale
K1	“safety culture”	the core of the cluster is safety culture as a determinant of the technical leader’s decision-making behaviour under conditions of methane hazard, anchored in the author’s practical operational experience
	“coal mine*” / “underground mine*” / “high-risk industry”	sectoral scope; the extension beyond coal mining to include “high-risk industry” was justified by the need to capture sectors analogous in risk structure (oil and gas, construction, energy), in order to verify the transferability of the construct
	“middle manager*” / “supervisor*” / “leadership*”	definition of the unit of analysis, the technical leader (senior shift supervisor, department head, shift supervisor), consistent with the article’s focus on middle and lower management, not the board
K2	“methane regulation*” / “EU 2024/1787” / “methane emission*”	direct mapping of the legal act constituting the starting point of the study
	“coal mine*”	sectoral narrowing consistent with the substantive scope of the regulation and of the study itself
	“compliance” / “management” / “reporting”	operationalisation of the MRV obligations (measurement, monitoring, reporting, verification) arising from the regulation
K3	“production pressure” / “safety-production trade-off”	a construct describing the competing decision-making logics faced by the technical leader, anchored in the author’s practical experience (production-output pressure versus safety)
	“mining” / “coal*”	sectoral scope
	“decision making” / “manager*” / “supervisor*”	level of analysis, operational decisions of managerial staff, not the board

Cluster	Term	Rationale
K4	“real options” / “real option theory”	theoretical framework chosen to analyse board investment decisions under conditions of irreversibility (e.g. construction of gas engines) and uncertainty regarding sanctions
	“regulatory uncertainty” / “environmental investment” / “irreversible investment”	operationalisation of the regulatory uncertainty arising from the Polish legislator’s delay in transposing the regulation
	“mining” / “coal*”	sectoral scope
K5	“Industry 5.0” / “Leadership 5.0”	paradigmatic frameworks placing the human being at the centre of processes, invoked as the context for the transformation of the technical leader’s role towards that of an operational ESG manager
	“resilience” / “human-centric” / “operational manager*” / “sustainability”	four alternative, mutually overlapping access paths to literature addressing the operational dimension of Industry 5.0, corresponding to different strands of this interdisciplinary field
	“mining”	the broadest sectoral scope among all clusters, deliberately not restricted to “coal mine*”, owing to the novelty of the Industry 5.0 paradigm in the extractive sector; this choice, however, carried an elevated risk of semantic drift (the term “mining” denoting a data-mining technique), which was identified and addressed through the manual verification procedure

Source: own elaboration.

Searches were conducted with all queries entered in Advanced Search mode using Boolean logic fields: the TITLE-ABS-KEY field in Scopus and the Topic field in Fielded Search mode in WoS. The publication-year filter (2015–2026) was applied at the query stage using the database’s built-in date-range tool, rather than by selecting individual years in the results-narrowing panel. Boolean operators were grouped with explicit parenthesis around each OR clause to avoid ambiguity in operator precedence.

No separate language filter or document-type filter was applied in any cluster or in either database. The language criterion was implemented indirectly through the construction of all queries exclusively in English, which in both databases in

practice restricts results to English-language literature or literature with an English-language abstract indexed in the searched field.

For each cluster, the raw result set was subjected to manual review of titles and abstracts. Records were retained if:

- the content concerned mining (coal, underground, or, in cluster K5, the extractive sector more broadly understood) as the main empirical or analytical context, rather than as one of several example sectors listed in a general review,
- the substantive theme corresponded to the analytical area of the cluster, rather than representing an incidental match arising from terminological ambiguity (in particular, in cluster K5 records were excluded where the term “mining” referred to data-mining techniques rather than to resource extraction).

Retraction notices were excluded regardless of content. Data were collected by grouping queries into the clusters listed below and using the following keyword strings:

K1 – Safety culture and mining:

(Scopus): TITLE-ABS-KEY(“safety culture” AND (“coal mine*” OR “underground mine*” OR “high-risk industry”) AND (“middle manager*” OR “supervisor*” OR “leadership*”)) AND PUBYEAR > 2014

(WoS, pole Topic / Topic field): (“safety culture” AND (“coal mine*” OR “underground mine*” OR “high-risk industry”) AND (“middle manager*” OR “supervisor*” OR “leadership*”)).

K2 – Methane regulations and emissions reporting:

(Scopus): TITLE-ABS-KEY((“methane regulation*” OR “EU 2024/1787” OR “methane emission*”) AND “coal mine*” AND (“compliance” OR “management” OR “reporting”)) AND PUBYEAR > 2014

(WoS, pole Topic / Topic field): ((“methane regulation*” OR “EU 2024/1787” OR “methane emission*”) AND “coal mine*” AND (“compliance” OR “management” OR “reporting”)).

K3 – Production–safety trade-off:

(Scopus): TITLE-ABS-KEY((“production pressure” OR “safety-production trade-off” OR “safety-production tradeoff”) AND (“mining” OR “coal*”) AND (“decision making” OR “manager*” OR “supervisor*”)) AND PUBYEAR > 2014

(WoS, pole Topic / Topic field): ((“production pressure” OR “safety-production trade-off” OR “safety-production tradeoff”) AND (“mining” OR “coal*”) AND (“decision making” OR “manager*” OR “supervisor*”)).

K4 – Real options theory and regulatory uncertainty:

(Scopus): TITLE-ABS-KEY((“real options” OR “real option theory”) AND (“regulatory uncertainty” OR “environmental investment” OR “irreversible investment”) AND (“mining” OR “coal*”)) AND PUBYEAR > 2014

(WoS, pole Topic / Topic field): ((“real options” OR “real option theory”) AND (“regulatory uncertainty” OR “environmental investment” OR “irreversible investment”) AND (“mining” OR “coal*”)).

K5 – Industry 5.0 and Leadership 5.0:

(Scopus): TITLE-ABS-KEY(("Industry 5.0" OR "Leadership 5.0") AND ("resilience" OR "human-centric" OR "operational manager*" OR "sustainability") AND "mining") AND PUBYEAR > 2014

(WoS, pole Topic / Topic field): (("Industry 5.0" OR "Leadership 5.0") AND ("resilience" OR "human-centric" OR "operational manager*" OR "sustainability") AND "mining").

Table 2. Results of publication filtering in WoS and Scopus databases for the period 2015–2026 by research cluster, with the number and reasons for exclusions

Tabela 2. Wyniki filtrowania publikacji w bazach danych WoS i Scopus za lata 2015–2026 w podziale na klastry badawcze wraz z liczbą wykluczeń i przyczynami ich wykluczenia

Cluster	Data-base	Raw records	Excluded records	Reason for exclusion	Final records
K1	Scopus	33	0	-	33
K1	WoS	9	0	-	9
K2	Scopus	57	1	article retraction	56
K2	WoS	43	0	-	43
K3	Scopus	4	4	thematic mismatch at abstract level	0
K3	WoS	1	1	thematic mismatch at abstract level	0
K4	Scopus	3	3	CCS / coal-fired power plant literature, not mining	0
K4	WoS	2	1	CCS / coal-fired power plant literature, not mining	1
K5	Scopus	58	48	semantic drift of "mining"; mining as one of several example sectors; no reference to mining in content; conference proceedings volumes of dispersed scope	10
K5	WoS	31	22	as above	9
Total	Scopus	155	56	-	99
Total	WoS	86	24	-	62

Source: own elaboration.

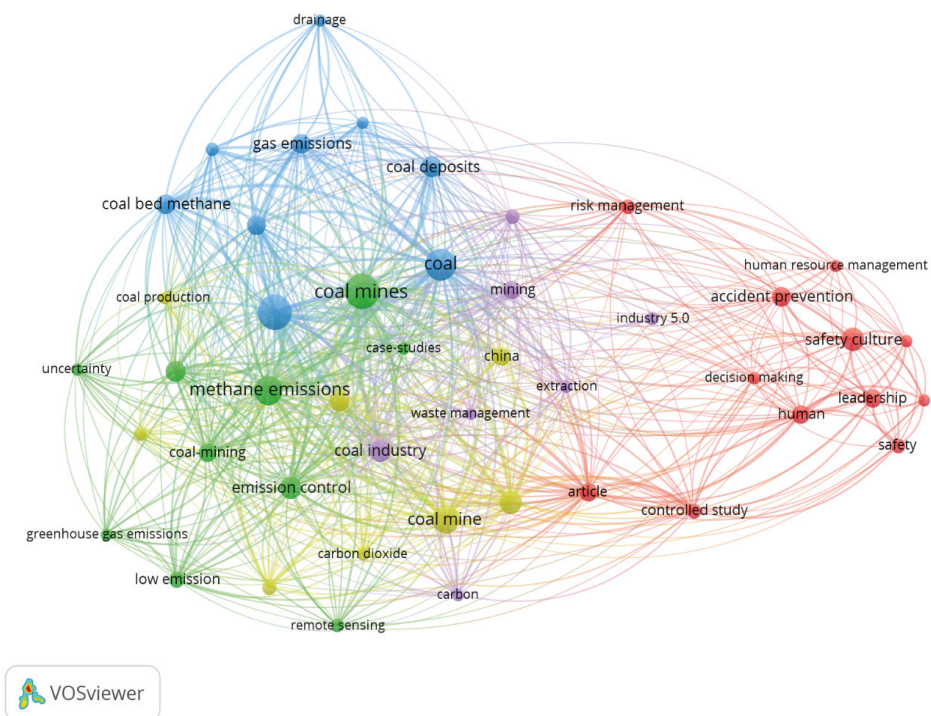
Of the 241 raw records obtained from both databases, 161 items were retained for further analysis (Table 2). The main reasons for exclusion included: thematic mismatch identified at the abstract level (K3, K4), semantic drift of the term “mining” denoting a data-mining technique rather than resource extraction (K5), the presence of mining merely as one of several example sectors in publications of broader scope (K5), and one instance of an article retraction (K2, Scopus), excluded regardless of content in accordance with the adopted protocol.

In cluster K4, one item met the formal search criteria (Foo, N., Bloch, H. & Salim, R. Assessing the timing of mining investment under tax policy uncertainty: the case of the Asia-Pacific region. *Miner Econ* 30, 117–139 (2017). <https://doi.org/10.1007/s13563-017-0106-y>), the scope of which is however limited to the economics of mining investment under tax-policy uncertainty, with no reference to sustainability reporting, ESG, or double materiality, confirming the existence of a research gap in the area addressed by this article.

Similarly, in cluster K5, of the ten identified items, the majority adopt an engineering-technological perspective (digital twins, ore-sorting, Mining 5.0 conceptualised as cyber-physical-social systems), not a managerial one. The exception is the work of Mohammadian B, Pishdar M, Zarei Matin H (2026), “Transition of mining industry toward sustainable value creation in developing countries”. *International Journal of Quality & Reliability Management*, Vol. 43 No. 1 pp. 277–294, doi: <https://doi.org/10.1108/IJQRM-04-2024-0127>, which addresses the sustainability of productivity and value in the extractive sector from a managerial perspective. This publication, however, does so at the level of a macro model, not of the operational leader responsible for generating and ensuring the credibility of S-dimension data. The presence of this single item thus confirms not an absence of scholarly interest in the intersection of mining and Industry 5.0 as such, but rather the absence of an operational and managerial perspective in the existing body of work, which constitutes direct justification for the problem addressed in this article.

Figure 1. Analysis of the most significant keywords from publications in the Scopus database within the defined clusters

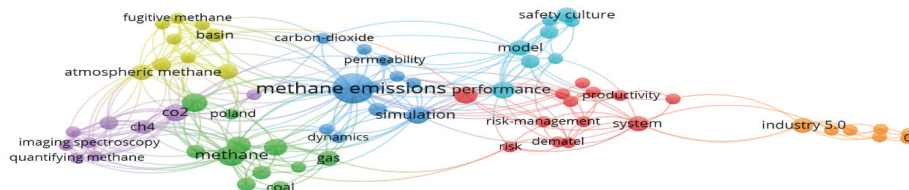
Rysunek 1. Analiza najistotniejszych słów kluczowych z publikacji w bazie Scopus w zdefiniowanych klastrach



Source: own elaboration in VOSviewer.

Figure 2. Analysis of the most significant keywords from publications in the Web of Science (WoS) database within the defined clusters.

Rysunek 2. Analiza najistotniejszych słów kluczowych z publikacji w bazie Web of Science (WoS) w zdefiniowanych klastrach



Source: own elaboration in VOSviewer.

Both figures visualise the isolation of the keyword cluster related to safety from the clusters related to ESG and sustainable development. At the same time, an analogous separateness is visible between mining and methane terminology and keywords related to Industry 5.0 and Leadership 5.0.

CROSS-ANALYSIS

The bibliometric analysis served to establish whether the scholarly literature addresses the intersection of mining safety law and EU sustainability regulation. The cross-analysis of legal acts, by contrast, was intended to establish whether that intersection exists at the level of binding legal norms, providing independent confirmation of the four-sided pressure construct identified through the research clusters (K1–K5). Both analyses jointly serve to demonstrate that this pressure is not an interpretive artefact of the authors but arises directly from the construction of the binding provisions to which middle and lower-level managers, who generate and report sustainability data, are subject.

The selection of legal acts was deductive and anchored in the research clusters, following the same procedure as the selection of keywords in the bibliometric analysis (Table 1). For each cluster (K1–K5), the source provision was identified within Polish mining law (the Act of 9 June 2011 – Geological and Mining Law, together with its executive regulations) governing the corresponding operational decision, and subsequently juxtaposed with the provision of EU and national sustainability-reporting law most closely related to that same decision. The selection

was not exhaustive with respect to either body of law. It was bounded by the operational scope of the technical leader, as defined by the article's research questions, and informed by the first author's practical experience regarding which provisions actually govern day-to-day decisions at the level of a mining establishment. Provisions falling outside this operational scope, for example disclosure requirements addressed to financial-market participants rather than to operational staff, were deliberately excluded as lying outside the unit of analysis.

Each pair of provisions was coded against two predefined categories:

- **contradiction** – a situation in which compliance with the requirement of mining law and compliance with the requirement of EU sustainability regulation cannot be achieved through the same operational action (for example, a provision requiring the controlled release of methane to eliminate a hazard, juxtaposed with a provision prohibiting the routine venting of methane into the atmosphere);
- **synergy** – a situation in which the two provisions, although arising from different regulatory logics, converge on the same underlying data or decision-making infrastructure (for example, emissions data generated within the MRV system simultaneously serving a safety-reporting function under mining law and a verification function under the methane regulation).

The coding was performed by the first author, drawing on operational experience in the sector, and the result was reviewed by the co-authors for consistency with the literal wording of the provisions. The analysis was intended to identify specific managerial problems arising from the juxtaposition of differing legal logics, the resolution of which conditions the coherence of organisational action across all three dimensions of sustainable development: proper conduct in the area of environmental protection (E), working conditions enabling employees to report data credibly (S), and the corporate governance mechanisms overseeing this process (G). The analysis does not claim to provide an exhaustive treatment of the entire body of Polish mining law and EU sustainability law, nor is its purpose a systematic doctrinal review in the sense practised within legal scholarship. Its purpose is to demonstrate that the four-sided pressure bearing on the operational ESG leader, in particular on the generation and reporting of S-dimension data, arises directly from the construction of the binding legal norms, rather than solely from organisational practice or researchers' interpretation. This scope limitation is stated explicitly in order to avoid conflating the applied method with a comprehensive legal review.

Table 3. Overview of mining and sustainability legal acts by research cluster

Tabela 3. Zestawienie aktów prawnych górniczych i zrównoważonego rozwoju wg klastrów badawczych

Cluster / Area	Regulations under Polish mining law (Safety and production logic)	EU law regulations (Climate and ESG logic)	Identified contradictions and conflicts (Four-sided pressure)
K1: Safety culture	Order to withdraw crew upon exceeding 3% methane concentration; shutdown of degasification station upon concentration falling below 30% ³⁰	Prohibition on routine venting of methane into the atmosphere. Despite safety also being a priority under the EU regulation, the operator must prove that the release of gas was necessary to eliminate the hazard ³¹	(S vs E): Conflict between safety and the prohibition on emissions. A technical leader acting in accordance with Polish law exposes the company to EU sanctions for an environmental incident, while simultaneously incurring the obligation to report the reasons.
K2: Reporting and Compliance	Supervision of the Higher Mining Authority (WUG) over public safety in the operation of a mining establishment ³²	Obligation to quantify and rigorously verify emissions by an auditor ³³ . The act directly serves the application of Regulation 2024/1787, and the President of WUG is designated as supervisor ³⁴	(G) Supervisor paradox: The President of WUG, traditionally appointed to maximise the level of safety (including methane-related safety), simultaneously becomes the authority imposing penalties on those same establishments for releasing greenhouse gases into the atmosphere.

³⁰ Regulation of the Minister of Energy of 23 November 2016 on the detailed requirements for the operation of underground mining plants (Journal of Laws of 2016, item 1118, as amended) Art. 275 and 349.

³¹ Regulation (EU) 2024/1787, Art. 15, 22 and 23.

³² Act of 9 June 2011 – Geological and Mining Law (Journal of Laws of 2023, item 633, as amended), Art. 164 and 165.

³³ Regulation (EU) 2024/1787, Art. 8 and 12.

³⁴ Act of 9 June 2011 – Geological and Mining Law, Art. 165.

K3: Production-OSH trade-off	Mine operation plan based on rational management of the deposit and protection against hazards. Technical designs specifying ventilation methods and protection against hazards ^{35 36}	Systematic identification and assessment of potential adverse environmental effects in own activities. Assessment of preventive and mitigating measures every 12 months ³⁷	Production vs ESG: A mine's operation plan could theoretically be suspended by due diligence requirements; however, given the complexity of maintaining and securing a mining establishment without its full closure, this is practically impossible.
K4: Real options theory and regulatory uncertainty	Requirement to demonstrate financial and technical capacity prior to obtaining a licence, and establishment of security arrangements in case of claims and potential mining damages ³⁸	System of financial penalties imposed on companies for methane incidents ³⁹ . (Absence of Polish implementing provisions.) Changes to thresholds obligating ESG reporting ⁴⁰ .	(G) vs (E): Boards must plan extraction with multi-year lead times. Meanwhile, uncertainty regarding penalties under Art. 33 (Regulation 2024/1787) and the deregulation policy for reporting thresholds (Omnibus) generates regulatory uncertainty.
K5: Industry 5.0 and Leadership	Personal professional liability of the leader for decisions taken under pressure of risk ⁴¹	Obligation of double materiality analysis and collective board responsibility for sustainability reporting ⁴²	(G) vs (S): The board bears collective responsibility for ESG results vis-à-vis the market ⁴³ , while this risk is cascaded downward, falling directly on technical leaders who bear personal professional responsibility for decisions made underground ⁴⁴

Source: own elaboration based on legal acts.

³⁵ Act of 9 June 2011 – Geological and Mining Law, Art. 108.

³⁶ Regulation of the Minister of Energy of 23 November 2016, Art. 36.

³⁷ Directive (EU) 2024/1760 (CSDDD), Art. 8 and 15.

³⁸ Act of 9 June 2011 – Geological and Mining Law, Art. 24, 26–28a.

³⁹ Regulation (EU) 2024/1787, Art. 33.

⁴⁰ Directive (EU) 2026/470, Art. 2(1)(a).

⁴¹ Act of 9 June 2011 – Geological and Mining Law, Chapters 2 and 3.

⁴² Directive (EU) 2022/2464, Preamble recitals 29 and 59.

⁴³ Ibidem, Art. 33.

⁴⁴ Act of 9 June 2011 – Geological and Mining Law, Chapter 5.

The cross-analysis of legal acts constitutes empirical confirmation of the structural information gap identified previously through bibliometric analysis. The separation of the defined thematic clusters and the visible isolation of mining safety issues from modern concepts of sustainable development and Industry 5.0 represents a significant research gap. EU regulations do not replace the existing mining law but are superimposed upon it and alongside it, creating multi-sided pressure and decision-making dissonance among technical leaders accustomed primarily to balancing production performance with safety. The technical leader must now supplement their decision-making and management paradigm with the understanding that the routine release of gas into the atmosphere constitutes a prohibited environmental incident sanctioned by severe financial penalties for the company, while emergency releases require thorough documentation of the causes.

The most important EU directives related to sustainable development (CSRD 2022/2464 and CSDDD 2024/1760), by introducing the concept of double materiality and the rigour of due diligence, transform methane from a purely technical problem into a key parameter of the company's financial and reputational risk. Responsibility for this area is placed at the management level; however, the execution and the burden of generating reliable evidence within the MRV system falls on the engineering staff – the technical leaders — who are personally accountable for it, despite lacking real ESG training. The research gap highlighted at this point indicates that the main challenge is not the absence of technology (the safety-oriented gas metering systems of mines are accurate and extensive), but rather the lack of an adequate management model (*governance*) capable of integrating this data and making it a platform for dialogue with external auditors and stakeholders (JST). At the same time, filling the identified gap in management and quality sciences requires a transition from diagnosing overlapping pressures to constructing tools that optimise decision-making processes. The application of the RACI matrix will serve to operationalise the new role of the technical leader, transforming a set of conflicting regulations into a structured architecture of responsibility (*methane governance*) under Industry 5.0 conditions.

RESULTS OF THE ANALYSIS AND CONCEPTUAL PROPOSALS

The management culture in high-risk industries, which had been based on balancing production performance pressure against the imperative to maintain the safety of the employed workforce, has – with the introduction of sustainable development regulations, and in particular the methane regulation – added further elements of pressure on decision-makers. The need arises to improve the quality of monitored and reported data, but above all the confrontation with the pressure to limit methane emissions into the environment, which is becoming one of the key sustainability issues⁴⁵.

⁴⁵ Regulation (EU) 2019/2088 (SFDR), Art. 2(24).

An unprepared technical leader is faced with the task of considering, within their standard scope of duties, an additional range of obligations related to compliance with sustainable development requirements. What had previously formed the essence of such decision-making – that is, balancing production results with safety requirements – has gained an additional burden associated with taking into account regulatory matters, including responsibility for methane emissions into the environment. Managerial staff responsible for methane emissions will in every case first consider the safety of employees, and only secondarily the impact on the environment. The methods of eliminating the methane hazard are, for the most part, opposed to the environmental objectives of sustainable development and involve the release of gas into the atmosphere, which under EU law is clearly restricted and in many respects prohibited.

The lack of legal transparency – and above all of defined sanctions – also does not facilitate managerial decisions with a direct impact on the surroundings of the mining operation. Company boards do not know what the sanctions for methane emissions will be, and at the same time they are not encouraged to seek and introduce innovations (often very costly), as no mechanism has been – and it remains unclear whether it will be – defined for reinvesting penalties into systems and processes that reduce methane emissions. Emitters undertaking investment management activities draw on the double materiality of methane in the operations of a mining establishment and, beyond the impact on the immediate surroundings, weigh the impact of those surroundings on their finances. Not being aware of the benefits of investing in environmental protection, or of the financial impact this would have on their companies, they refrain from making investment decisions and adopt a wait-and-see stance. An example of such behaviour is the construction of gas engines for electricity generation from methane. A company must weigh whether investing millions of zlotys in equipment assemblies that will operate for a very short period (during the so-called peak of emissions) is cost-effective, and whether maintenance and servicing costs will not exceed potential revenues from electricity or heat production. Legal transparency that defines for entrepreneurs the potential reduction in penalties for emissions or the possibility of reinvesting paid penalties through special investment funds could significantly facilitate managerial decisions regarding new investments and thereby facilitate technical leaders' decisions regarding increased emissions caused by raising the level of safety while maintaining a defined level of production.

Contemporary methane emission management in the extractive sector extends beyond the framework of narrowly understood technical safety or pure compliance. Methane governance constitutes an architecture of accountability in which data generated within the MRV system (measurement, monitoring, reporting, verification) must be permanently integrated with decision-making processes, in-

vestment planning, and management responsibility. It is precisely the governance structure that determines whether an organisation builds substantive legitimacy (based on real actions) or merely symbolic (façade) legitimacy⁴⁶.

Regulation 2024/1787 compels a transition from reactive reporting to an active operational cycle: *detect – repair – document – explain – prevent*. The effectiveness of this cycle depends on a precise allocation of roles, which is particularly important in the Polish context, given that a significant proportion of methane – despite investment in degasification processes and its commercial utilisation – still enters the atmosphere⁴⁷. The instrument for ordering these relationships and stabilising dialogue with the surroundings, including JST, is the RACI model:

- **Accountable (Managerial Accountability):** Full, non-transferable responsibility for achieving reduction targets, allocating resources to degasification investments, and ensuring the integrity of ESG reports and MRV systems rests with the company's board⁴⁸. The absence of a genuine link between reporting and decision-making mechanisms reduces ESG to a "facade" role, which in conditions of public data verifiability leads to erosion of institutional trust⁴⁹.

- **Responsible (Executive Responsibility):** Execution of operational tasks is assigned to technical services, including ventilation, degasification, and maintenance departments. Practical experience indicates that production levels and atmospheric conditions (in particular atmospheric pressure trends) have a decisive influence on the level of methane release. The systemic optimisation of these processes – for example, by increasing the efficiency of degasification, drilling, and closure operations – allows for an increase in the rate of gas capture and a reduction of its emissions from closed areas into the atmosphere.

- **Consulted / Informed (Support and Integration):** Compliance functions and ESG managers play an integrating role, ensuring methodological coherence and preparing the organisation for external audits. Combining engineering competence with a business perspective (MBA) enables the effective implementation of EU standards while maintaining operational continuity.

In a mature governance model, JST ceases to be a passive recipient of PR messages and becomes a stakeholder who must be systematically informed and – in areas of high conflict potential – consulted⁵⁰. This need arises from the fact that local government is responsible for environmental safety and spatial planning, and the methane regulation extends the mine's institutional accountability to include inactive and post-operational facilities over a multi-year horizon. The implemen-

⁴⁶ J. Bebbington, J. Unerman, B. O'Dwyer (eds.), *Sustainability accounting and accountability*, 2nd ed., Routledge, London 2014, pp. 248–272.

⁴⁷ M. Borowski, K. Zwolińska-Gładyś, J. Cheng, *Methane emissions...*, Article 174, p. 10.

⁴⁸ Regulation (EU) 2024/1787 Art. 33

⁴⁹ J. Bebbington, J. Unerman, B. O'Dwyer, *Sustainability Accounting...*, pp. 287–305.

⁵⁰ R.K. Mitchell, B.R. Agle, D.J. Wood, *Toward a theory...*, pp. 853–886.

tation of the RACI model in the methane area thus becomes an operational test of a mine's governance maturity. An organisation that is able to demonstrate the effectiveness of its reduction activities through credible data and clearly assigned responsibility builds a lasting *social licence to operate* in its relationships with the institutional environment.

THE TECHNICAL LEADER AS OPERATIONAL ESG MANAGER IN THE DEDUCTIVE RACI MODEL UNDER INDUSTRY 5.0 AND LEADERSHIPS 5.0 CONDITIONS

The challenges discussed in the preceding sections place new roles and tasks before the managerial staff of mining operations. The evolution of the path of technical leaders towards operational ESG managers and their participation in the decision-making process are presented in Table 3. The deductive RACI model developed by the authors constitutes an operational solution to the identified phenomenon of four-sided pressure and evidences a fundamental change in the competence profile of mine management personnel. This method allows for a precise separation of the board's accountability for ESG results from the technical leader's personal professional responsibility for operational safety arising from geological and mining law. A clearly structured decision-making framework enables the technical leader to focus their actions on hazard elimination. An analysis of the individual decision clusters reveals the mechanism of cascading regulatory risk and the evolution of the technical leader's role.

Table 4. RACI Model of decision-making processes by research cluster

Tabela 4. Model RACI procesów decyzyjnych wg klastrów badawczych

Decision-making process by research cluster	Operational process/decision arising from legal provisions	Company Board	Technical Leader: Mine Operations Manager, Senior Management and Supervisory Staff of Ventilation Department	ESG Manager / Independent Verifier	Dominant Stakeholder (JST, President of WUG)
K1: Safety culture (S vs E)	Physical safety management: Decision on the controlled release of methane into the atmosphere in a hazard situation (S vs E) and proving the higher necessity of releasing methane.	I	R / A	C	I
K2: Reporting, MRV and Compliance	Quantification and verification of data (LDAR and MRV): Conducting cyclical equipment inspections, converting raw HSE data into standardised emissions reports at source level. Verification and approval of emissions data.	A	R	C	I
K3: Production-Safety Trade-off	ESG risk management and impact assessment: Incorporating environmental due diligence (CSDDD) and climate risks into operation plans and the company's extraction strategy.	A	R	C	I

K4: Real options theory (Uncertainty)	Environmental investments and sanctions: Decisions on capital allocation to new degasification systems under uncertainty, and accountability for potential financial penalties under EU directives.	A	R	C	I
K5: Industry 5.0, Leadership 5.0	Sustainability attestation and audit: Assessment of the compliance, reliability, and accuracy of reports with EU directives (CSRD, 2024/1787) based on the principle of „double materiality” prior to their publication.	A	I / C	R / C	I / C

Source: own elaboration.

Two overarching conclusions emerge from the proposed model:

Securing the safety priority (Cluster K1): In situations of immediate threat to life, the Technical Leader retains full and undivided operational decision-making authority and accountability (R/A). The board is only informed (I) of the actions taken. This arrangement guarantees compliance with the absolute requirements of national geological and mining law, protecting the engineer from the decision-making paralysis induced by EU prohibitions on methane release.

Transformation into an operational ESG manager (Clusters K2 and K3): In accordance with Directive 2022/2464 (including the amended Art. 33), ultimate collective financial and legal responsibility (A) for the sustainable development strategy and reporting rests with the Board. However, since the Board does not participate in extraction processes, the burden of physical execution, data quantification (MRV), and the incorporation of environmental requirements into operation plans is permanently assigned to the technical leader in the role of executor (R). As a result, the mining engineer ceases to be exclusively a guardian of infrastructure and becomes a generator of verifiable environmental data for independent auditors and

the first link in the due diligence chain. This, in turn, becomes a component of the social dimension ESG reporting, the scope of which has been defined in Directive 2022/2464 (CSRD) and in Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 supplementing Directive 2013/34/EU with regard to sustainability reporting standards concerning the own workforce. In accordance with these regulations, organisations are obliged to disclose information relating to employees in a measurable, comparable, and verifiable manner, encompassing in particular data relating to working conditions, occupational safety and health, employment structure, wage levels, access to training, and mechanisms of social dialogue. In operational terms, this means that – analogously to environmental data generated within MRV systems – social data is produced at the level of production and organisational process execution, and not solely at the management level. Consequently, their collection, verification, and preparation for reporting become elements of daily duties performed at the operational level. In the RACI model presented in this article, this leads to the maintenance of formal accountability (*Accountable*) at board level, while simultaneously assigning executive responsibility (*Responsible*) to the technical leader. This means that the operational manager becomes the direct executor of obligations related to both environmental and social data reporting.

At the same time, Directive 2022/2464 (CSRD) introduces the principle of double materiality, which requires that both the impact of the company's activities on employees and the impact of social factors on the organisation's economic situation be taken into account. In practice, this means the need to identify and monitor social risks such as accident rates, absenteeism, employee turnover, and working conditions, which further increases the scope of data processed at the operational level. As a consequence, the role of the technical leader expands further – from a function focused on technical and environmental supervision towards the operational management of an integrated ESG reporting system covering both environmental and social data. This means that social data – like environmental data – becomes a component of the operational management system, and not solely of reporting.

The concept of Industry 5.0, placing the human being at the centre of processes, therefore demands that the technical leader acquire new competences in the field of sustainable development, becoming *de facto* an operational ESG manager at the level of the mining establishment. At the same time, assigning decision-making roles (R/A) to the board in the area of multi-million investments (K4) and in determining the manner of ESG attestation (K5) removes from the engineer the risk of regulatory uncertainty associated with real options theory. The technical leader – by being given access to information and having their actions consulted – becomes a conscious link in the implementation of sustainable development policy. This model demonstrates that the effective implementation of Regulation (EU) 2024/1787 requires not only technology, but above all the introduction of a new

governance architecture in which the Leader 5.0 integrates engineering logic with the logic of sustainable development vis-à-vis dominant stakeholders (JST, WUG).

DISCUSSION AND FUTURE RESEARCH DIRECTIONS

The analysis conducted confirms that the methane regulation should not be conceived solely as an environmental instrument or as an additional reporting obligation, but as a factor reconfiguring the architecture of accountability within a mining enterprise. In this view, methane ceases to be merely a technical category and becomes a category of institutional legitimacy, while the MRV system serves as an infrastructure of transparency upon which the regulatory and social assessment of an organisation is based⁵¹.

A significant finding is also the change in JST's position in relation to the mine. Under conditions of increasing comparability, auditability, and public availability of emissions data, local government ceases to be a passive recipient of organisational communication and becomes a dominant stakeholder, whose significance derives simultaneously from public legitimacy, the urgency of claims, and growing informational power. Through MRV, information asymmetry is reduced, and emissions data becomes the basis for a more formalised and verifiable institutional dialogue⁵².

At the organisational level, the architecture of accountability takes on central significance. The article demonstrates that reporting without genuine decision-making mechanisms and without unambiguous role assignment risks reducing the entire system to the level of a compliance façade. For this reason, the RACI model should be treated not as an auxiliary tool but as a practical means of stabilising governance in the methane area. Its value lies in linking the board's accountability for reduction targets and the integrity of the MRV system with the accountability of technical functions for the execution of operational actions, and with the role of compliance and ESG functions in ensuring methodological, verification, and communication coherence⁵³.

An important interpretative dimension is introduced by the institutional logics perspective. Methane management does not take place within a field of homogeneous organisational rationality, but in a space of tensions between the production-economic logic, the safety logic, the regulatory-climate logic, and the community logic. At the same time, findings concerning Polish mines indicate that methane emissions are not a straightforward function of output volume, and their scale and structure depend on a range of geological, technical, and organisational

⁵¹ Regulation (EU) 2024/1787, Art. 2; M.C. Suchman, *Managing legitimacy...*, pp. 571–610.

⁵² R.E. Freeman, *Strategic Management...*, pp. 52, 69–72; R.K. Mitchell, B.R. Agle, D.J. Wood, *Toward a theory...*, pp. 853–886; Regulation (EU) 2024/1787, Art. 8.

⁵³ J. Bebbington, J. Unerman, B. O'Dwyer, *Sustainability Accounting...*, pp. 287–305.

factors. This means that organisational advantage in the governance area results not only from natural conditions but also from the quality of data management, the response to deviations, and the capacity to integrate reduction activities with investment decisions⁵⁴.

Of particular significance is also the redefinition of the technical leader's role. Under conditions of overlapping production, safety, environmental, and reporting pressures, the technical leader ceases to be merely a guardian of infrastructure and becomes an operational ESG manager, responsible for data integrity, the quality of the operational response, and the preparation of the organisation for external accountability. At the same time, regulatory uncertainty undermines the quality of investment decisions and reinforces a wait-and-see stance, which confirms the utility of real options theory in interpreting the behaviour of boards and technical functions⁵⁵.

In light of the above, it seems justified to develop further research in several complementary directions. First, empirical validation of the proposed methane governance model is needed — in particular the RACI logic — in the real operating conditions of extractive enterprises. For this purpose, the following performance indicators could be subjected to validation:

- **time to prepare an environmental incident report** – measured by comparing the time taken to complete a structured template against the time required to prepare it independently.
- **reduction of decision-making time** – measured by comparing the time taken to reach a decision under structured and unstructured conditions.
- **data correlation coefficient** – understood as the degree of consistency between data from MRV systems and data presented in ESG reports, verified using AI;
- **knowledge transfer effectiveness** – validated through knowledge tests using learning-enabled AI and without its support.

Second, comparative studies between mines would be valuable, aimed at establishing the extent to which differences in MRV quality, accountability structures, and methane capture efficiency translate into the level of institutional legitimacy and the capacity to manage conflict risks.

Third, a promising direction remains the development of a methane governance maturity assessment tool, covering data quality, role clarity, integration with the decision-making process, relationships with JST, and the capacity to manage the post-operational horizon.

⁵⁴ P.H. Thornton, W. Ocasio, M. Lounsbury, *The Institutional Logics...*, pp. 6, 78–83; M. Borowski, K. Zwolińska-Gładyś, J. Cheng, *Methane emissions...*, Article 174, pp. 18–20; M. Dreger, *Changes in the methane...*, pp. 159–174.

⁵⁵ R.S. Pindyck, *Irreversibility, uncertainty, and investment...*, pp. 1110–1148; M.U. Podobińska-Stanec et al., *Organisational culture...*, pp. 183–205.

Fourth, it seems justified to deepen research on the relationship between MRV data quality and the level of trust of public stakeholders, particularly JST, as well as on accountability for emissions from inactive and post-operational facilities – since this area most fully reveals the long-term, public, and territorial dimension of governance in the extractive sector⁵⁶.

The analysis was also aimed at determining the impact of ESG reporting obligations and the methane regulation on the role and scope of responsibility of the technical leader in extractive sector organisations. The results indicate that the implementation of new environmental regulations – in particular Regulation (EU) 2024/1787 on methane emission reduction – and the development of ESG reporting obligations entail a change in the nature of the technical leader's role⁵⁷. This function is no longer limited solely to supervision in the technical and environmental area but also encompasses tasks related to the collection, verification, and integration of data used in reporting processes, in accordance with the requirements of the monitoring, reporting, and verification (MRV) system arising from EU provisions⁵⁸. The consultative function (*Consulted* – C) of independent verifiers (ESG managers, sector experts, lawyers, etc.) designated in the RACI model should enable ongoing analysis of gaps and reporting errors, and thereby supplement the training of technical leaders and augment their knowledge concerning the credibility of ESG reports. This indicates an increase in the significance of the operational level in the fulfilment of reporting obligations – both in respect of environmental and social data – which is closely linked to the concept of double materiality developed within the framework of the CSRD directive and ESRS standards⁵⁹.

The results of the analysis also indicate the existence of a significant competence gap among technical leaders, arising from the discrepancy between their existing competence profile – based on engineering knowledge and operational experience – and the new requirements associated with the integration of ESG data into decision-making processes, including the use of artificial intelligence for this purpose.

In this context, the generational diversity of employees also takes on significance: younger generations (in particular Generation Z and Millennials) display a higher orientation towards environmental and social issues⁶⁰, while more experienced employees possess the tacit knowledge crucial for the operational functioning of the organisation⁶¹. As a consequence, one may conclude that effective implementation

⁵⁶ R.K. Mitchell, B.R. Agle, D.J. Wood, *Toward a theory...*, pp. 853–886; Regulation (EU) 2024/1787, Art. 24 and 25.

⁵⁷ Ibidem, Art. 20.

⁵⁸ Ibidem, Art. 23.

⁵⁹ Directive (EU) 2022/2464, Art. 19a, Art. 29a.

⁶⁰ Deloitte, 2023 Gen Z and Millennial Survey, 2023.

⁶¹ I. Nonaka, H. Takeuchi, *The Knowledge-Creating Company...*, pp. 59–73; R. Ribeiro, *Tacit knowledge...*, pp. 337–366.

of ESG requirements necessitates the integration of complementary competences encompassing both operational experience and growing environmental and social awareness. One possible direction of organisational action arising from the study conducted may be the use of intergenerational knowledge transfer mechanisms, including solutions analogous to the concept of reverse mentoring. In this variant, it would be valuable to examine how younger employees, by raising environmental (E) and social (S) issues, integrate and connect them with the knowledge of older employees who possess operational experience in (E) matters and participated in the development of (G) procedures. These conclusions are consistent with the findings of the literature, which indicates that sustainability reporting constitutes a significant element supporting strategic and operational management processes and influences decision-making in organisations⁶², while its mandatory character leads to an increase in regulatory pressure and greater complexity of organisational processes⁶³.

Forthcoming ESG audits – including in particular those related to environmental reporting such as that associated with Regulation 2024/1787 – will place significantly higher demands on the chartered accountants conducting them, who will need to interpret, in accordance with their professional training, financial data alongside non-financial social issues and hard data from technical MRV systems. This, in turn, opens the path to developing models for collaboration between technical and social sector experts and auditors, including their direct participation in the assessment of companies' ESG reports. In light of theoretical approaches to human resource management, it may additionally be noted that the increase in professional requirements arising from the need to ensure compliance with environmental and reporting regulations – against a backdrop of limited organisational resources – is conducive to overload and an increase in the level of occupational stress. This relationship is described in the Job Demands–Resources model⁶⁴. As a consequence, the development of ESG reporting – combined with sectoral regulations, including Regulation 2024/1787 – leads to an increase in the complexity of the operational manager's functioning. The effectiveness of reporting system implementation should therefore be analysed not only from the perspective of regulatory compliance, but also with regard to the organisational working conditions of those responsible for their execution. This may in turn lead to an attempt to define a model for assessing the credibility and transparency of ESG reports – one in which it will be necessary to determine what types of analyses will apply to matters not defined by hard numbers, as is the case with financial data.

⁶² A. Monazzam, F. Nilsson, *The role of sustainability reporting in strategic management*, "Journal of Applied Accounting Research" 2025, No. 26(4), pp. 811–828.

⁶³ H.B. Christensen, L. Hail, C. Leuz, *Mandatory CSR and sustainability reporting: economic analysis and literature review*, "Review of Accounting Studies" 2021, Vol. 26, No. 3, pp. 1176–1248.

⁶⁴ A. Bakker, E. Demerouti, *The Job Demands – Resources model: state of the art*, "Journal of Managerial Psychology" 2007, Vol. 22, No. 3, pp. 309–328.

The results of the analysis also indicate that the transformation of the technical leader's role towards that of an operational ESG manager constitutes a significant element of the functioning of organisations under Industry 5.0 conditions, in which the integration of technological, regulatory, and social aspects becomes one of the key dimensions of management. The identified research gap points to the need for further research focused on the operational dimension of ESG regulation implementation in extractive sector organisations. In particular, it is appropriate to conduct empirical studies analysing the functioning of technical leaders under simultaneous production, safety, environmental, and reporting pressure, as well as the influence of these factors on decision-making processes and the scope of responsibility at the operational level. Such research could determine whether any of the conditions of four-sided pressure can be reduced or eliminated through clear corporate procedures and governance structures.

The analysis leads to a concluding observation that ESG reporting is ceasing to be purely a reporting activity and is becoming an element supporting the ongoing management of the organisation – which means a partial shift of responsibility from the strategic level to the operational level. Under conditions of increasing complexity in decision-making processes and the need to integrate data from various areas of activity, the technical leader's role expands to include analytical and decision-making functions arising directly from the obligations imposed by EU regulations and their implementation within the national legal system. Sustainable development is playing an increasingly important role in decision-making at the level of company boards, and the centre of gravity of ESG implementation is beginning to shift to its centre: the human element in the entire process.

Bibliography

Literature

Bakker A., Demerouti E., *The Job Demands – Resources model: State of the art*, "Journal of Managerial Psychology" 2007, No. 22(3).

Bebbington J., Unerman J., O'Dwyer B. (eds.), *Sustainability accounting and accountability*, 2nd ed., Routledge, London 2014.

Borowski M., Zwolińska-Gładys K., Cheng J., *Methane emissions from coal mines: Quantification, capture, and utilization strategies for atmospheric impact mitigation – A case study from Poland*, "Atmosphere" 2025, No. 16(2).

Christensen H.B., Hail L., Leuz Ch., *Mandatory CSR and sustainability reporting: Economic analysis and literature review*, ECGI Working Paper No. 623/2019, European Corporate Governance Institute 2021.

Delmas M., Doctori Blass V., *Measuring corporate environmental performance: The trade-offs of sustainability ratings*, "Business Strategy and the Environment" 2010, No. 19(4).

DiMaggio P.J., Powell W.W., *The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields*, "American Sociological Review" 1983, No. 48(2).

Dreger M., *Changes in the methane emissions and hard coal output in the Brzeszcze mine (the Upper Silesian Coal Basin, Poland)*, "Geology, Geophysics & Environment" 2020, No. 46(2).

Freeman R.E., *Strategic management: A stakeholder approach*, Pitman, Boston 1984.

Gowrisankaran G., He C., Lutz E.A., Burgess J.L., *Productivity, safety, and regulation in underground coal mining: Evidence from disasters and fatalities*, NBER Working Paper 21129, National Bureau of Economic Research 2015.

Hashemian S.M., Triantis K., *Production pressure and its relationship to safety: A systematic review and future directions*, "Safety Science" 2023, No. 159.

Mitchell R.K., Agle B.R., Wood D.J., *Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts*, "Academy of Management Review" 1997, No. 22(4).

Monazzam A., Nilsson F., *The role of sustainability reporting in strategic management*, "Journal of Applied Accounting Research" 2025, No. 26(4).

Nonaka I., Takeuchi H., *The knowledge-creating company*, Oxford University Press, Oxford 1995.

Patyńska R., *Methane emissions from ventilation and degasification systems of hard coal mines in Poland in the years 2001–2010*, "Gospodarka Surowcami Mineralnymi – Mineral Resources Management" 2013, No. 29(1).

Pindyck R.S., *Irreversibility, uncertainty, and investment*, "Journal of Economic Literature" 1991, No. 29(3).

Podobińska-Staniec M.U., Sukiennik M., Kęsek M., Oleksak K., *Organisational culture based on ESG standards and knowledge management – premises for implementation for the mining industry*, "Gospodarka Surowcami Mineralnymi – Mineral Resources Management" 2024, No. 40(4).

Ribeiro R., *Tacit knowledge management*, „Phenomenology and the Cognitive Sciences" 2013, Vol. 12, No. 2, s. 337–366.

Suchman M.C., *Managing legitimacy: Strategic and institutional approaches*, "Academy of Management Review" 1995, No. 20(3).

Swolkień J., *Polish underground coal mines as point sources of methane emission to the atmosphere*, "International Journal of Greenhouse Gas Control" 2020, No. 94.

Thornton P.H., Ocasio W., Lounsbury M., *The institutional logics perspective: A new approach to culture, structure, and process*, Oxford University Press, Oxford 2012.

Reports and Studies

Deloitte, *2023 Gen Z and Millennial Survey*, Deloitte Touche Tohmatsu Limited 2023.

IPCC, *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report*, Cambridge University Press, Cambridge 2021.

Instrat, *Methane from coal mines – will Poland clarify doubts regarding emissions and their verification?*, Instrat, Warsaw 2025.

KOBiZE, *Calorific values (CV) and CO₂ emission factors (EF) in 2023 for reporting under the Emissions Trading System for 2026*, National Centre for Emissions Management, Warsaw 2025.

Legal Acts and Regulations

Act of 25 June 2025 amending the Act — Geological and Mining Law, Journal of Laws of 2025, item 1023.

Act of 9 June 2011 — Geological and Mining Law, Journal of Laws of 2024, item 1290.

Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 supplementing Directive 2013/34/EU with regard to sustainability reporting standards (ESRS), OJ EU L of 22.12.2023.

Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 on corporate sustainability reporting (CSRD), OJ EU L 322/15 of 16.12.2022.

Directive (EU) 2024/1760 of the European Parliament and of the Council of 13 June 2024 on corporate sustainability due diligence (CSDDD), OJ EU L of 5.07.2024.

Directive (EU) 2026/470 of the European Parliament and of the Council of 24 February 2026 amending Directives 2006/43/EC, 2013/34/EU, (EU) 2022/2464 and (EU) 2024/1760 (Omnibus), OJ EU L of 26.02.2026.

Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (SFDR), OJ EU L 317/1 of 9.12.2019.

Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on methane emission reduction in the energy sector, OJ EU L of 15.07.2024.

Regulation of the Minister of Energy of 23 November 2016 on detailed requirements for the operation of underground mining establishments, Journal of Laws of 2016, item 1118, as amended.

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