GERMAN - MONGOLIAN INSTITUTE FOR RESOURCES AND TECHNOLOGY

The present work was submitted to
the German-Mongolian Institute of Resources and Technology

Linking key performance indicators (KPIs) of Railroad construction to environmental outcomes

Bachelor's Thesis

By

CHINGUN Batdemberel

Study program: Industrial Engineering

Student ID: B2200159

1st Supervisor/Examiner: Dr. Bolormaa

2nd Supervisor/Examiner: Dr. Baigal-Amar

Nalaikh

2026

GERMAN - MONGOLIAN INSTITUTE FOR RESOURCES AND TECHNOLOGY

The present work was submitted to
the German-Mongolian Institute of Resources and Technology

Linking key performance indicators (KPIs) of Railroad construction to environmental outcomes

Bachelor's Thesis

By

Chingun Batdemberel

Study program: Industrial Engineering

Student ID: B2200159

1st Supervisor/Examiner: Dr.Bolormaa

2nd Supervisor/Examiner: Dr. Baigal-Amar

Nalaikh

2026

Statutory Declaration

Batdemberel, Chingun B2200159

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Linking key performance indicators (KPIs) of Railroad construction to environmental outcomes

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Nalaikh, 2026.05.31 Signature

Table of contents

1. *Introduction*

1.1 Background Context

1.2 Research Problem statement

1.3 Objectives of the Study

1.4 Scope and Limitations

1.5 Geographical Scope

2. *Literature Review*

2.1 Framework of Literature review

2.2 A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational

2.3 Environmental, Social and Governance Assessment of Mongolia's mining sector. Asian Development Bank

2.4 2024 Global Rail Sustainability Report (2024)

2.5 Summary of literature

3. *Methodology*

3.1 Research Philosophy

3.2 Research Approach

3.3 Case Study Area

3.4 Data Sources

3.5 KPI selection

3.6 KPI Mapping Framework

3.7 Data Processing

3.8 Data Analysis Method

3.9 Environmental Outcome Categories

3.10 Development of the KPI Framework

3.11 Validity and Reliability

3.12 Limitations of the Methodology

3.13 Ethical Considerations

3.14 Summary of Methodology

4. *Results*

4.1 Overview of Findings

4.2 Water consumption by Activity

4.3 Water Use Intensity per Kilometer

4.4 Activity Based Water Intensity

4.5 Dust Suppression and Air Quality

4.6 Biodiversity and Wildlife Protection Measures

4.7 Infrastructure Measures Related to Environmental Mitigation

4.8 KPI and Environmental Outcome Mapping

4.9 Identification of Environmental Hotspots

4.10 Summary of Results

5. *Discussion*

5.1 Interpretation of Results

5.2 Comparison with Literature

5.3 Linking KPIs to Environmental Outcomes

5.4 Implications for Railroad Construction Management

5.5 Limitations of the Study

5.6 Contribution of the Study

6. *Conclusion*
7. *References*

Acknowledgements

I would like to express my sincere gratitude to **Dr. Bolormaa** and **Dr. Baigal-Amar** for their invaluable guidance, support, and expertise throughout the development of this thesis. Their mentorship has been instrumental in the successful completion of this research.

Furthermore, I would like to extend my appreciation to the **German-Mongolian Institute for Resources and Technology (GMIT) and also G.Demberelsuren and TTGS project** for the comprehensive education and academic opportunities provided to me. This thesis is a culmination of the knowledge and skills I have acquired during the entirety of my studies at the institute.

Finally, I hereby declare that this work has been composed independently. I have utilized only authorized materials and academic sources, ensuring that this project reflects the professional and ethical standards established during my time at GMIT.

Declaration of Academic Integrity

I hereby declare that this Bachelor's thesis is the result of my independent academic work. I confirm that all sources have been properly cited and that no unauthorized assistance has been used.

I acknowledge that AI tools were used only as supportive instruments for structuring, language refinement, and guidance, and that all content has been critically reviewed and verified by myself. I take full responsibility for all ideas, analysis, and conclusions presented in this thesis.

1. Introduction.

1. 1. Background and Context

Railroad infrastructure plays a critical role in supporting economic development, particularly in resource-intensive regions such as Mongolia. At the same time, large-scale infrastructure projects generate significant environmental impacts, including water consumption, dust emissions, land disturbance, and biodiversity disruption. As global industries move toward sustainability-oriented practices, there is increasing pressure to measure and manage these environmental impacts more effectively.

Traditionally, construction performance has been evaluated using operational key performance indicators such as cost, time, productivity, and efficiency. However, environmental impacts are often monitored separately through environmental impact assessments or compliance reports, rather than being integrated into daily operational performance systems. This separation creates a disconnect between construction activities and their environmental consequences.

In the context of railroad construction, especially in environmentally sensitive regions such as the Gobi Desert, this gap becomes particularly important. Construction activities such as material handling, water use, dust suppression, and infrastructure development directly influence environmental outcomes. Therefore, there is a need to link operational key performance indicators to environmental performance in a structured and measurable way.

1.2 Research Problem Statement

Despite the widespread use of operational KPIs in construction management, these indicators are rarely designed to capture environmental outcomes in an integrated manner. As a result, project-level decision-making remains disconnected from environmental performance, limiting the ability to identify and manage sustainability impacts in real time. This gap is particularly critical in environmentally sensitive regions such as Mongolia’s Gobi Desert, where construction activities directly influence scarce water resources, air quality, and biodiversity.

In practice, environmental indicators such as water use, dust generation, and biodiversity impacts are often reported separately from operational KPIs. This limits the ability of project managers to understand how construction decisions influence environmental outcomes in real time. As a result, opportunities for improving environmental performance through operational changes are often missed.

This problem is particularly relevant in Mongolia’s Umnugovi Province, where large-scale mining and railway projects operate in a fragile desert ecosystem. Environmental pressures such as water scarcity, dust generation, and habitat disruption require more integrated performance measurement approaches.

1.3. Objectives of the Study

Main Research Question:
"How can operational key performance indicators in railroad construction be systematically linked to environmental outcomes?"

Sub-questions:

• Which operational KPIs are most relevant for environmental performance in railroad construction?

• How can construction activities be mapped to measurable environmental outcomes?

• What environmental hotspots can be identified through KPI-based analysis?

The main objective of this thesis is to develop a framework that links key performance indicators of railroad construction to environmental outcomes.

The specific objectives are:

1. To identify operational and environmental KPIs relevant to railroad construction
2. To analyze how construction activities influence environmental outcomes
3. To develop a KPI mapping framework linking construction activities to environmental impacts
4. To apply the framework to a real case study in Mongolia
5. To identify environmental hotspots and improvement opportunities

1.4. Structure and Limitations

"This thesis contributes to sustainable infrastructure research by developing a structured KPI mapping framework that links operational construction indicators to measurable environmental outcomes."The framework is supported by empirical evidence from the Tavantolgoi–Gashuunsukhait railway project in Mongolia, demonstrating how project-level data can be used to integrate environmental considerations into construction performance management.

The structure of the thesis is organized as follows. Chapter 1 introduces the research background, problem, objectives, and scope. Chapter 2 reviews relevant literature on sustainability performance measurement, ESG frameworks, and rail infrastructure sustainability, and identifies the research gap addressed in this study. Chapter 3 presents the research methodology, including data sources, KPI selection, and the analytical approach. Chapter 4 provides the results based on project data analysis. Chapter 5 discusses the findings in relation to existing literature and highlights key implications. Finally, Chapter 6 presents the conclusions and recommendations for future research.

Despite its contributions, this study has several limitations. First, the analysis is based on a single case study, which may limit the generalizability of the findings to other regions or projects with

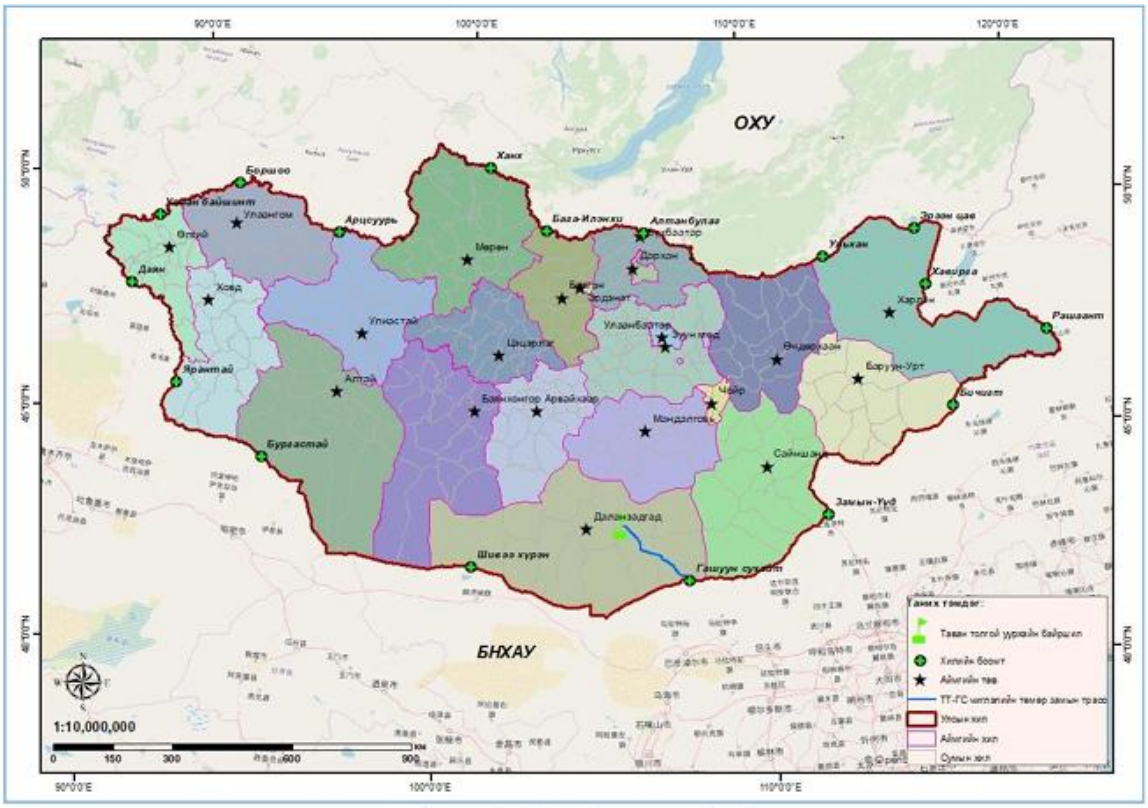
different environmental and operational conditions. Second, the available dataset is stronger in environmental management indicators, such as water use and biodiversity monitoring, than in detailed operational indicators such as fuel consumption and equipment-level emissions. Third, some environmental outcomes are assessed using proxy indicators rather than direct measurements, which may reduce the precision of the analysis. These limitations highlight the need for future research incorporating more comprehensive datasets and multiple case studies.

1.5 Geographical scope

The Geographic scope of my study focuses on mainly Mongolian railroad construction Especially the railroad project “Tavantolgoi-Gashuunsuhait” direction of 2023 in Umnugovi province. Umnugovi province, located in southern Mongolia, is characterized by an arid desert-steppe climate, fragile ecosystems, and unique geoecological conditions shaped by the Gobi Desert. Its landscapes are dominated by true deserts, sparse vegetation, and limited water resources, making it both ecologically vulnerable and environmentally significant.

Nr	**Province and Soum name**	**Size of each Soum** **in km²**	**The length of railroad through each soum in km**	**Percentage of each soum** **in %**
1	Umnugovi, Tsogtsetsii	7246.4	55.13	0.76
2	Umnugovi, Bayan-Owoo	10473,7	82,79	0.79
3	Umnugovi, Khnabogd	15151,6	110,58	0.72
Overall		32871,7	248,5	2.27

Table 1 (General information of Soums and railroad length through each)



Зураг 1. Төслийн ерөнхий байршил

Picture 1. General Location of the Tavantolgoi to Gashuunsuhait railroad (G, 2023, 4)

Explanation of the picture is as follows. The green flag indicates the “Tavan tolgoi” mine . The green plus sign is the Gashuunsuhait border checkpoint. The Black star indicates The province center. The blue line indicates the railroad construction between “Tavantolgoi” mine and “Gashuunsuhait” border checkpoint. Red line indicates the border of mongolia.

2. Literature review

2.1. Framework of literature review

This chapter reviews literature on sustainability performance measurement, ESG frameworks, and rail sector sustainability, with the aim of identifying how operational indicators can be linked to environmental outcomes. The literature review is structured to examine sustainability performance measurement, ESG frameworks, and rail infrastructure sustainability in a logical and thematic sequence. While the review does not follow a fully systematic methodology due to the breadth of available sources, it is guided by the central research question: how operational key performance indicators in railroad construction can be linked to environmental outcomes, and how a consolidated KPI framework can be derived from existing studies. I will be studying materials in a chronologically order with suggestions from my supervisor. Also, i won’t have done a systematic review where there was too much of materials and choices. As it is a Literature review, I will follow my research question: How do operational key performance indicators specifically the ones used with railroad construction link to environmental outcomes in the academic and practitioner literature, and what consolidated KPI framework can be derived from existing Railroad construction studies and reports? What kind of environmental importance do

some KPI's have that can be used or how can I find meaningful yet useful KPI's in the context of this research.

2.2 A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes.

To clearly understand what kind of metrics and integration could be used I chose this study as a basis for my understanding and research focused on GRI metrics in operational process. As Railway process metrics are a part of process metrics and one of my goals for the completion of this thesis is a framework to guide, this study would help me a lot.

The evolution of "Green process framework" as per my word, has had a long history starting From SBSC (Sustainability Balanced Scoreboard) which one of the earliest and most effective frameworks for process/environmental correlations. As time went on newer metrics emerged such as **Green Business Process Management:** aimed to integrate sustainability into operational frameworks but frequently lacked robust measurement standards and guidance for implementation. (Alsayegh, n.d.). Overall the a framework needs to interlink an operational process with sustainability metric to drive improvement within organizations.

In the context of mining as a general field this study was addressing the gap between sustainability aspirations and actual performance by proposing a conceptual framework which leverages mining techniques to measure and improve sustainability especially using GRI metrics. To explain what GRI metrics are: GRI metrics are essential for organizations to measure and disclose their significant ESG impacts. These metrics help in understanding the organization's material topics, their related impacts, and how they are managed. The GRI Standards are modular and designed to be used together, providing a comprehensive picture of an organization's sustainability performance (*Global Reporting*, n.d.). To develop a comprehensive framework that leverages process mining techniques for sustainability performance measurement across environmental, social, and economic dimensions.

- To establish methodological principles for integrating standardized GRI metrics into process mining approaches, enabling consistent sustainability analysis at the operational level.
- To validate the framework's applicability through a case study demonstrating how process variants affect sustainability performance indicators.

A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes, 2025)

As stated by the Goals and objectives the studies methodologies use a standard with advanced process analysis. This study has some indicators such as energy use, emissions, waste generation and the likes of economic value. To completely utilize its data to integrate it to framework some techniques like the Triple bottom line (TBL) and Purchase to pay (P2P). This approach as said by the author addresses the key gaps in current sustainability hotspots within the process. (*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

The materials and methods described below translate that approach to the context of railroad construction and the thesis objective of linking key performance indicators of railroad construction

to environmental outcomes. The section defines the research design, data sources, KPI selection and mapping, event log construction and enrichment, process mining analyses, statistical modeling, visualization, and validation procedures.

Research design

This research uses a mixed methods design combining conceptual development with empirical validation. The methodological stages are as follows.

1. Framework adaptation and KPI selection. Adapt the GRI and Triple Bottom Line concepts to identify environmental KPIs relevant to railroad construction.
2. Data collection and event log construction. Collect operational records, telemetry, procurement and environmental monitoring data and transform them into structured event logs.
3. Log enrichment. Map and attach KPI values to event instances to create enriched event logs.
4. Process mining and statistical analysis. Apply discovery, conformance checking, variant analysis, root cause analysis and regression modeling to link process features to environmental outcomes.
5. Visualization and stakeholder validation. Produce process maps, heatmaps and Petri net models and validate findings with domain experts and site managers.

KPI selection and metric mapping

KPI selection follows the GRI taxonomy adapted to construction. Environmental KPIs prioritized for railroad construction include energy consumption, fuel use per machine hour, direct greenhouse gas emissions, embodied carbon of materials, waste generation and diversion rates, water use, and dust exceedance events. Social and economic KPIs are recorded where relevant but the primary focus for this thesis is environmental attribution.

Metric mapping is operationalized through a mapping table that links each KPI to one or more construction activities and to the data source that will supply values. Each mapping entry contains the following fields: activity identifier, KPI name, KPI unit, data source, measurement method, conversion factor if applicable, and uncertainty estimate. Example mapping entries include track laying mapped to diesel liters per crew hour with telematics as the data source and to embodied carbon per meter of rail installed with supplier environmental product declarations as the data source.

Data sources and collection

Primary data sources include equipment telematics, fuel purchase logs, delivery manifests, weighbridge records, supplier environmental product declarations, site waste logs, environmental sensor networks, and project management systems. Secondary sources include industry benchmarks and conversion factors for fuel to CO2e and embodied carbon factors for common materials.

Data collection procedures emphasize timestamped records and unique case identifiers. Where telemetry is not available, manual logs and receipts are digitized and time aligned. All data are standardized to common units and time formats during preprocessing.

Event log construction

Cases are defined to reflect meaningful units of work. Candidate case definitions include work order ID, track segment ID, or delivery batch ID. Each event record contains at minimum the following attributes: case identifier, activity name, start timestamp, end timestamp, resource identifier, location coordinates, quantity or volume, and links to procurement or supplier records when applicable.

Preprocessing steps include cleaning, deduplication, timestamp normalization, unit standardization, and the resolution of resource identifiers. The goal is to ensure completeness, consistency and traceability of process instances.

Log enrichment with KPIs

Enrichment attaches KPI values to event instances. Direct measurements such as fuel consumed from telematics are attached to the corresponding activity events. Indirect measures such as CO2e are computed using documented conversion factors and appended as attributes. Supplier related KPIs such as embodied carbon are joined to events that reference material deliveries using delivery manifest identifiers.

Enrichment rules are documented and version controlled. Each enriched attribute includes provenance metadata indicating the original source, the transformation applied and an uncertainty estimate.

Process mining analyses

Process discovery is used to extract actual execution models from the enriched event logs. Algorithms are selected to handle concurrency and noise typical of construction operations. Conformance checking compares discovered models to planned procedures or sustainability aware protocols to identify deviations.

Variant analysis groups common execution patterns and compares their environmental KPI profiles. Root cause analysis traces high impact events to upstream causes such as supplier delays, rework or equipment failure.

The process mining analyses are complemented by sequence and temporal analyses that examine activity durations, waiting times and parallelism across crews.

Statistical modeling and hypothesis testing

Statistical analyses quantify relationships between process features and environmental outcomes. Candidate models include multivariate linear regression, generalized linear models and mixed effects models to account for nested data structures such as activities nested within work orders and work orders nested within projects.

Independent variables include process features such as activity duration, rework frequency, crew size, and supplier lead time. Dependent variables include KPI outcomes such as CO2e per meter installed, fuel consumption per crew hour and waste generated per ton of material handled. Model diagnostics and robustness checks include residual analysis, multicollinearity assessment and sensitivity analysis to conversion factor uncertainty.

Tools and implementation

The analytical pipeline is implemented in R. Core packages include process mining and visualization libraries, data manipulation packages and statistical modeling tools. Petri nets are used to represent concurrent activities and to annotate transitions and places with KPI values for interpretability. Reproducible analysis is maintained through scripted workflows and version-controlled code.

Visualization and reporting

Visual outputs include process maps annotated with KPI heatmaps, radar charts for variant KPI comparison, time series of KPI evolution, and Petri net diagrams showing concurrency and KPI annotations. Dashboards for site managers present near real time or daily aggregated KPI summaries and highlight hotspots and suggested interventions.

Validation and stakeholder engagement

Findings are validated through triangulation with independent data sources and through workshops with construction managers, equipment operators and procurement specialists. Validation activities include walkthroughs of process maps, review of mapping rules and joint interpretation of root cause analyses. Interventions proposed by the analysis are pilot tested on selected work fronts and monitored for KPI changes.

Data quality limitations and uncertainty management

Data heterogeneity and missing telemetry are anticipated. The methods include explicit documentation of conversion factors and uncertainty propagation in KPI calculations. Where direct measurement is unavailable, sensitivity analyses quantify the impact of assumptions. Social KPIs are treated separately and require bespoke data collection protocols.

Ethical and governance considerations

Data governance procedures ensure that supplier and personnel data are handled in accordance with privacy and contractual constraints. Aggregation rules are applied to avoid exposing sensitive operational details in public reporting.

Expected outputs

The materials and methods produce an enriched event log for railroad construction, process models annotated with environmental KPIs, statistical models quantifying drivers of environmental outcomes, and a set of validated recommendations for process and procurement changes that reduce environmental impact.

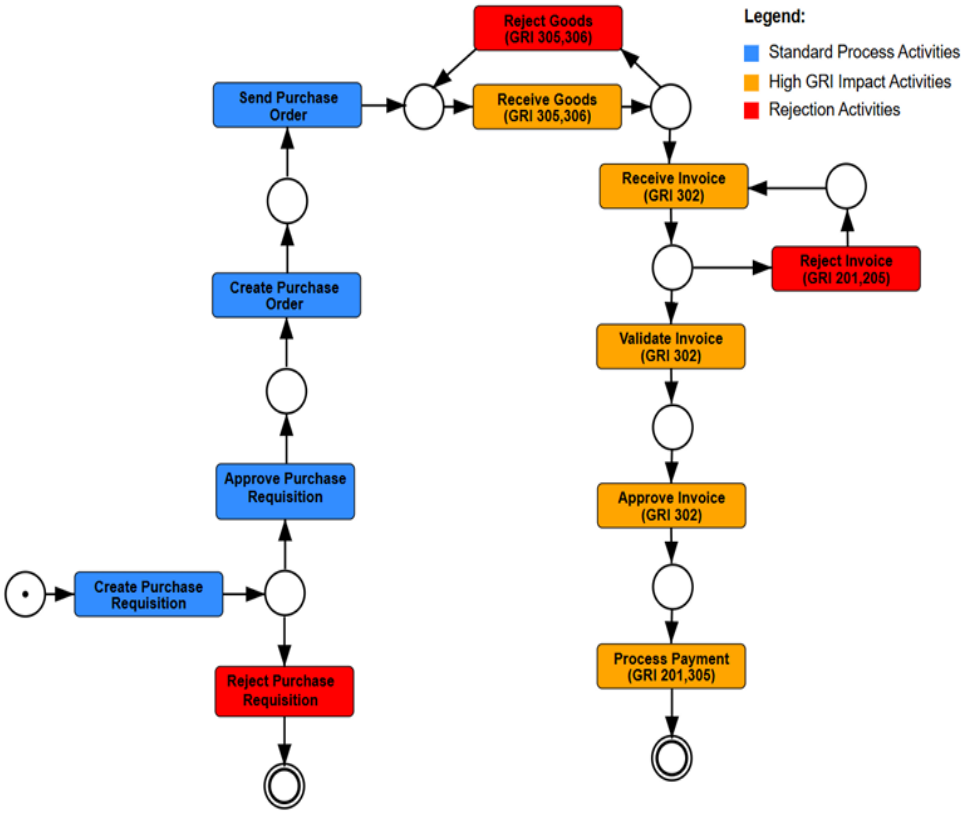


Figure 2. Petri net representation of the Purchase-to-Pay (P2P) process. From (*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

Figure 2 presents the Purchase-to-Pay (P2P) process as a Petri net, illustrating procurement as a sequence of interrelated activities extending from purchase requisition to payment processing. The model distinguishes between standard process activities, high GRI impact activities, and rejection activities, thereby showing that procurement is not merely an administrative function but also a relevant figure for sustainability assessment. The integration of GRI references into specific process steps demonstrates how operational workflows can be linked with environmental and governance reporting. In particular, activities related to receiving goods, validating invoices, approving invoices, and processing payments are highlighted as especially significant for sustainability-oriented monitoring. The inclusion of rejection paths further emphasizes that process inefficiencies, non-compliance, or material mismatches may generate additional waste, delays, and environmental burdens. For infrastructure sectors such as railroad construction, this type of process model is highly relevant because it suggests that key performance indicators should be embedded in operational stages where environmental impacts are generated and controlled, rather than being assessed only at the final reporting stage.

The Paper has had included very many cases included with and had their had system ran through them. Which sorted them into different types of variants.

- Variant 1: Standard process flow (most common, 14,069 cases)
- Variant 2: Involves requisition rejection (5218 cases)
- Variant 3: Highest impact, such as rejected goods with rework (5174 cases)

- Variant 4: Rejected goods without rework (3580 cases)
- Variant 5: Invoice rejection and revalidation (3411 cases)
- Variant 6: Altered sequence, such as invoice before (1843 cases)
- Variant 7: Bypasses approval step, such as lowest emissions (1705 cases)

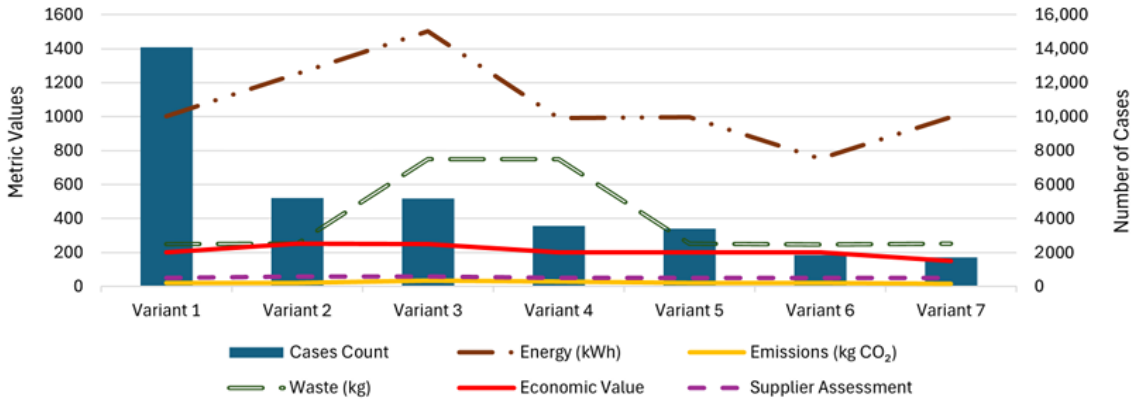


Figure 3. Process variants and sustainability performance. (*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

Figure 3 demonstrates that sustainability performance varies considerably across the seven identified process variants of the Purchase to Pay process. The comparison includes both operational and sustainability related dimensions, namely case frequency, energy consumption, emissions, waste generation, economic value, and supplier assessment. The results show that Variant 3 is associated with the highest energy consumption and emissions, while Variants 3 and 4 generate the highest levels of waste. In contrast, Variant 7 presents the lowest emission impact, although its energy use remains moderate. This variation confirms that different process paths produce different sustainability consequences and highlights the importance of process level analysis for identifying inefficiencies, environmental hotspots, and tradeoffs between economic and environmental objectives.

(*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

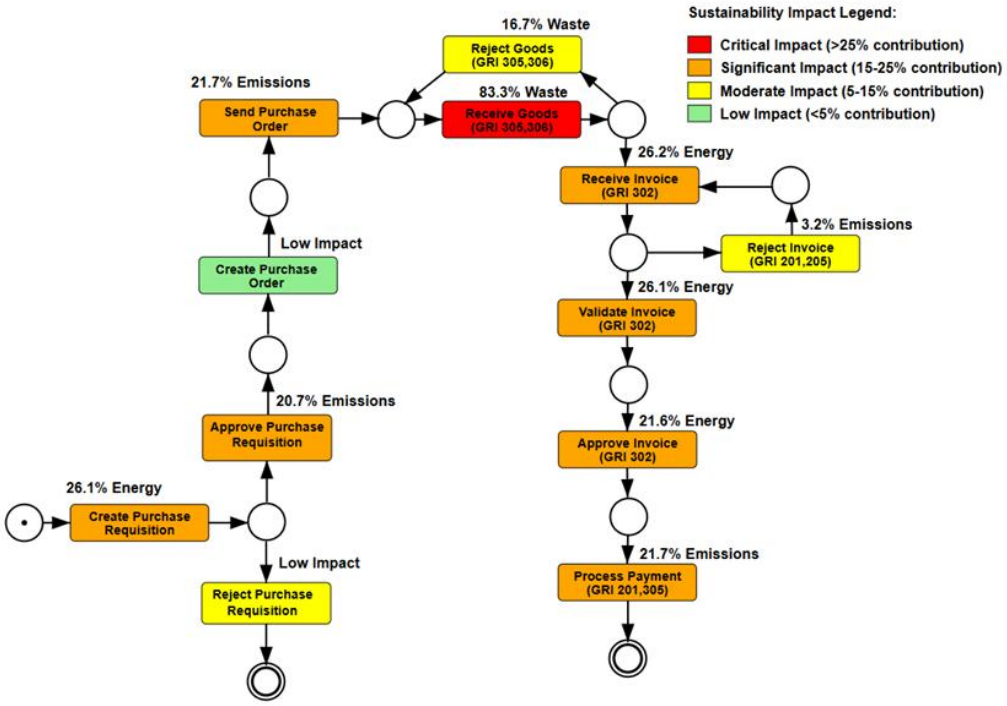


Figure 4. Petri net representation of Purchase-to-Pay process with sustainability performance metrics.(*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

Figure 4 presents a Petri net representation of the Purchase to Pay process in which sustainability performance metrics are directly embedded into the process model. The figure is important because it moves beyond a simple procedural description and shows how individual activities contribute differently to environmental impact. In this model, process states are represented by circles and activities by rectangles, while the color coding highlights the magnitude of sustainability impact, ranging from low to critical. The figure identifies “Receive Goods” as the most critical hotspot, accounting for 27.3 percent of emissions and 83.3 percent of waste, while “Send Purchase Order,” “Process Payment,” and “Approve Purchase Requisition” are shown as significant emission related activities. At the same time, activities such as “Create Purchase Requisition,” “Receive Invoice,” and “Validate Invoice” emerge as energy intensive stages. For the literature review, this figure is valuable because it demonstrates that sustainability performance can be linked to specific operational steps rather than being treated only as an aggregated organizational outcome. This supports the broader argument in the literature that process mining and GRI based metrics can improve the granularity, visibility, and practical usefulness of sustainability assessment by revealing where environmental hotspots actually occur in a workflow.

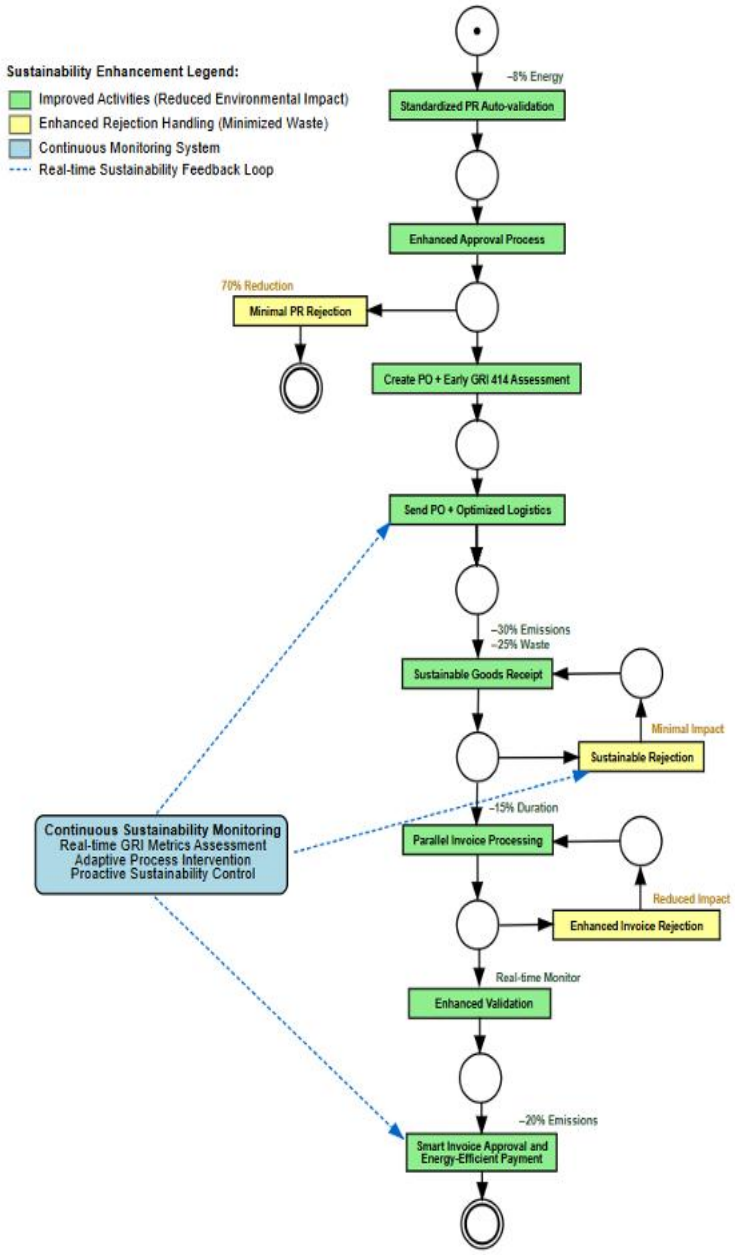


Figure 5. Redesigned P2P process with sustainability improvements, (*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

Figure 5 illustrates a redesigned Purchase to Pay process in which sustainability improvements are incorporated directly into the workflow through process redesign and continuous monitoring. Unlike the earlier model, this figure emphasizes improvement measures such as standardized purchase requisition auto validation, enhanced approval procedures, early supplier sustainability assessment, optimized logistics, sustainable goods receipt, parallel invoice processing, enhanced validation, and smart invoice approval with energy efficient payment. The figure also introduces a continuous sustainability monitoring system and real time feedback loops, showing that sustainability management can become an active and adaptive control mechanism rather than a

retrospective reporting exercise. According to the study, these redesign measures are intended to reduce requisition rejection, lower energy use, decrease emissions and waste in goods receipt, shorten process duration, and improve overall sustainability performance while maintaining operational efficiency. In the context of the literature review, this figure is especially useful because it shows that process mining does not only help identify sustainability hotspots, but can also support the redesign of operational processes to achieve measurable environmental improvements. This is highly relevant for research on construction and infrastructure systems, where environmental outcomes depend not only on final outputs but also on how project related processes are structured, monitored, and continuously improved.

The discussion following the process redesign model suggests that the integration of process mining with GRI based sustainability metrics offers a more operational and actionable way of understanding sustainability performance than conventional reporting approaches, because it enables organizations to identify where emissions, energy use, waste, and other impacts are generated within specific workflow activities rather than only at an aggregated level. The study shows that no single process variant performs best across all sustainability dimensions, which highlights the need for a multidimensional assessment of performance and for balanced optimization rather than narrow efficiency driven decision-making. It also emphasizes the practical value of real-time monitoring, standardized metric mapping, and targeted process redesign, since these mechanisms allow managers to move from retrospective compliance toward proactive sustainability control and continuous improvement. For the purpose of this thesis, this insight is highly relevant to railroad construction, where environmental outcomes are shaped by a sequence of interrelated project activities such as material procurement, logistics, equipment use, approvals, inspections, and payment processes. In this sense, the literature supports the argument that linking KPIs of railroad construction to environmental outcomes requires not only selecting suitable indicators, but also embedding them into project processes so that environmental hotspots, tradeoffs, and opportunities for intervention can be identified early and managed systematically throughout the construction lifecycle. (*A Framework for Sustainability Performance Measurement Through Process Mining: Integration of GRI Metrics in Operational Processes*, 2025)

2.3 Environmental, Social, and Governance Assessment of Mongolia's mining sector. Asian Development Bank

Recent literature has increasingly emphasized that the sustainability of extractive industries must be evaluated through an integrated environmental, social, and governance framework rather than through economic performance alone. In this context, the Asian Development Bank's *Environmental, Social, and Governance Assessment of Mongolia's Mining Sector* provides an important policy-oriented contribution by examining the alignment between Mongolia's mining sector and international ESG expectations. The report argues that Mongolia has a strategic opportunity to position itself as a supplier of critical minerals for the global clean energy transition, but that this opportunity is constrained by persistent environmental degradation, social vulnerability, and governance weaknesses within the mining sector (Asian Development Bank, 2026). The report is especially relevant to research on infrastructure and resource-based development because it shows that sectoral growth alone does not guarantee sustainable

outcomes unless environmental protection, community safeguards, and institutional accountability are embedded in sector governance (Asian Development Bank, 2026).

A major contribution of the report lies in its methodological approach, which combines a review of Mongolian laws and policies with benchmarking against international frameworks such as the United Nations Guiding Principles on Business and Human Rights, the Extractive Industries Transparency Initiative, the OECD guidance frameworks, and the Paris Agreement (Asian Development Bank, 2026). This comparative approach is useful in the literature because it does not assess mining performance only in domestic legal terms, but instead evaluates whether national systems are capable of meeting internationally recognized standards of responsible mining. The report also incorporates consultation with civil society organizations and government stakeholders, which strengthens its practical relevance by grounding the analysis in both formal policy review and stakeholder experience (Asian Development Bank, 2026). This is significant for thesis work because it shows that sustainability assessment in extractive sectors should be understood not only as a technical exercise, but also as a governance and stakeholder engagement process.

From an environmental perspective, the report identifies biodiversity loss, water insecurity, land degradation, poor post mining rehabilitation, weak tailings management, and high carbon intensity as central risks in Mongolia's mining sector (Asian Development Bank, 2026). Particularly important is its argument that mining activities in ecologically sensitive and water stressed areas create long term environmental pressures that extend beyond the immediate extraction site. The report notes that existing regulations do not sufficiently ensure biodiversity protection, sustainable water use, or effective mine closure and land restoration, while climate mitigation measures remain underdeveloped in mining policy (Asian Development Bank, 2026). This part of the literature is highly relevant to a thesis concerned with linking KPIs to environmental outcomes, because it demonstrates that environmental impacts emerge from multiple operational dimensions, including water extraction, energy use, waste handling, land disturbance, and rehabilitation performance. In other words, environmental outcomes in heavy industries are shaped by measurable operational practices, which can be translated into performance indicators for sustainability assessment.

The report also makes an important contribution to the social dimension of sustainability by highlighting the extent to which mining can disrupt livelihoods, deepen inequality, and weaken community resilience when safeguards are inadequate. It discusses the displacement of pastoralist communities, the erosion of grazing routes, weak compensation mechanisms, labor rights violations, gender inequality, child labor risks in artisanal mining, and unequal distribution of mining benefits (Asian Development Bank, 2026). Of particular relevance is the report's treatment of nomadic herders, whose relationship to land is not only economic but also cultural. By stressing that mining impacts on herders should also be understood as impacts on cultural heritage and traditional ways of life, the report broadens the concept of sustainability beyond environmental damage alone (Asian Development Bank, 2026). For literature review purposes, this is important because it reinforces the idea that sustainability indicators in project and sector evaluation should not be restricted to emissions and waste, but should also account for livelihood security, labor conditions, equity, consultation quality, and social well-being.

Governance is presented in the report as the critical enabling condition for environmental and social sustainability. The assessment finds that many of Mongolia's mining sector problems are not caused simply by the absence of laws, but by weak enforcement, fragmented institutional responsibilities, poor transparency, limited accountability, and corruption risks, particularly in

licensing, state-owned enterprise management, and revenue allocation (Asian Development Bank, 2026). The report further notes that local communities often lack formal grievance channels and meaningful participation in decision making, which undermines social trust and weakens the legitimacy of mining governance (Asian Development Bank, 2026). This is a particularly useful insight for your thesis because it suggests that KPIs linked to environmental outcomes must also reflect governance capacity. Environmental performance does not depend only on technical efficiency, but also on whether institutions can enforce standards, monitor compliance, disclose information, and respond to stakeholder concerns.

Another strong element of the report is its identification of policy gaps. It argues that environmental impact assessments are conducted too late in the permitting process, that cumulative impact assessments are not effectively used, that social impact assessments are not systematically required, and that legal provisions on consultation, resettlement, benefit sharing, mine closure, and climate transition remain incomplete or too vague (Asian Development Bank, 2026). These findings are valuable in the literature because they show that sustainability failure often results from gaps between formal policy intent and practical regulatory design. The report therefore supports a broader scholarly argument that sustainability management in resource intensive sectors requires clear indicators, enforceable rules, and early-stage integration of environmental and social considerations into project planning (Asian Development Bank, 2026).

The recommendations advanced by the report are equally important for the literature review. The ADB proposes stronger environmental impact assessment procedures, participatory monitoring, more robust biodiversity and water protections, improved mine closure obligations, better tailings regulation, climate smart mining measures, stronger labor and gender protections, more meaningful community consultation, clearer benefit sharing mechanisms, and improved revenue transparency and anticorruption measures (Asian Development Bank, 2026). These recommendations suggest that the path toward sustainable mining is not limited to better reporting, but requires institutional reform and operational redesign. In a wider research context, this supports the view that sustainability performance should be managed through linked policy, operational, and governance indicators rather than through isolated environmental statistics.

For the present thesis, the paper is especially useful because it provides a framework for understanding how sectoral activities can be connected to broader environmental and sustainability outcomes through structured indicators and governance mechanisms. Although the ADB report focuses on Mongolia’s mining sector rather than railroad construction, its core insight is transferable: environmental outcomes are produced through the interaction of operational activities, social safeguards, and governance quality. This means that in railroad construction, as in mining, KPIs should not be limited to cost and schedule performance, but should also capture land disturbance, water use, emissions, rehabilitation, stakeholder engagement, worker protection, and compliance performance (Asian Development Bank, 2026). Therefore, the report strengthens the argument that linking KPIs of railroad construction to environmental outcomes requires a multidimensional framework in which environmental, social, and governance variables are treated as interdependent components of project performance rather than as secondary reporting categories.

2.4 2024 Global Rail Sustainability Report. (2024)

Recent literature increasingly positions rail transport as a central component of sustainable mobility due to its relatively low environmental footprint, its contribution to inclusive access, and its capacity to support climate-aligned infrastructure development. The *2024 Global Rail*

Sustainability Report frames rail as the backbone of sustainable mobility and argues that rail systems are uniquely placed to contribute to the Sustainable Development Goals through lower emissions, improved safety, accessibility, economic productivity, and climate resilience **(**International Union of Railways [UIC], 2025, pp. 3–9). For a thesis focused on linking key performance indicators of railroad construction to environmental outcomes, this perspective is important because it shows that rail sustainability should not be evaluated only at the transport operations level, but also through infrastructure planning, energy use, resilience, and supply chain practices.

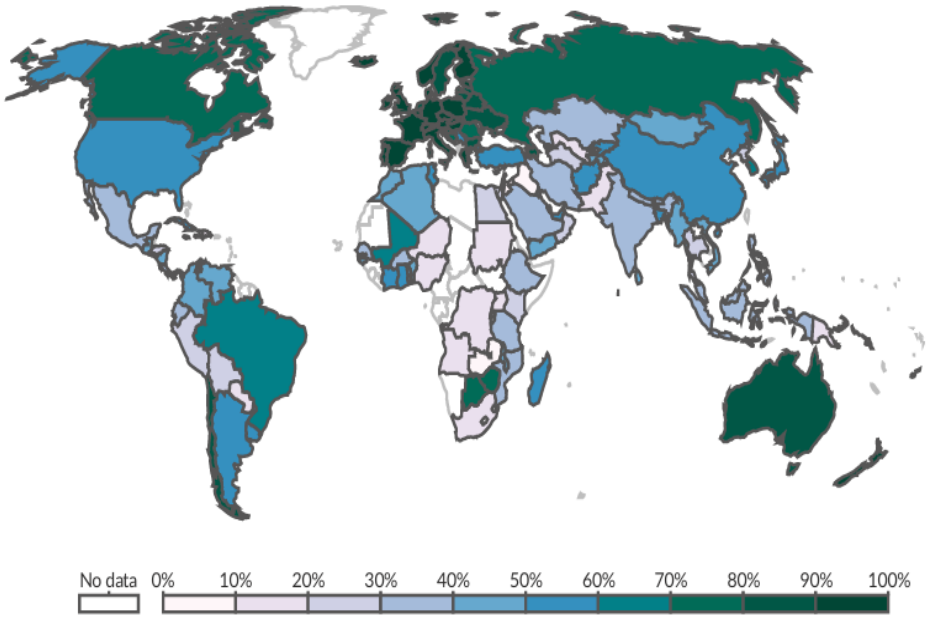


Figure 6. Share of urban populations with convenient access to public transport (United Nations (2023) - processed by Global rail sustainability world data)

A major contribution of the report is its clear positioning of rail as a lower impact transport mode in comparison with road transport. The report notes that although rail carries a meaningful share of global passenger and freight activity, it accounts for only around 1 percent of transport emissions, which highlights its strategic value in decarbonization pathways (UIC, 2025, pp. 20–23). In addition, the report stresses that rail produces substantially lower external costs than road transport, including lower accident, pollution, congestion, and climate related costs (UIC, 2025, p. 14). This is highly relevant to the present thesis because it supports the argument that railroad construction and expansion can generate positive environmental outcomes when assessed through indicators such as modal shift potential, emissions intensity, energy consumption, and avoided external costs.

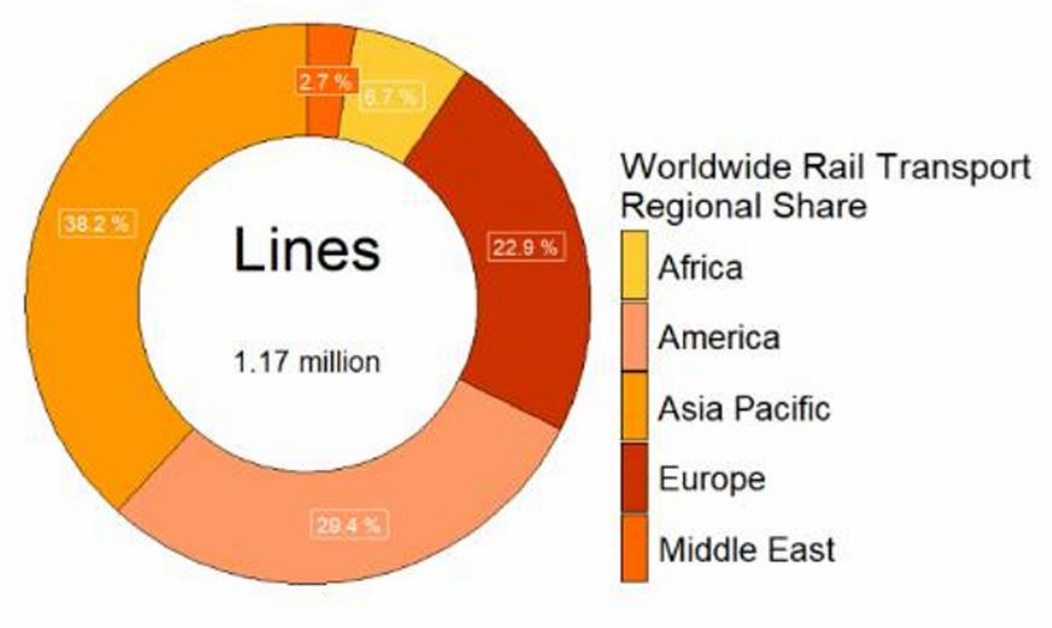


Figure 7. Global rail network size and regional share. (*International Union of Railways [UIC]*, 2025)

The report also strengthens the literature on climate mitigation by showing that electrification remains one of the most important drivers of rail sustainability. According to the report, electrified rail significantly reduces direct carbon emissions, while continued progress in decarbonization depends on expanding electrification, deploying hydrogen and low carbon fuels, and improving energy efficiency (UIC, 2025, pp. 20–25). The report further notes that European rail emissions in 2023 had already fallen well beyond earlier reduction targets, indicating that measurable progress can be achieved when emissions reduction is supported by sector wide monitoring and coordinated climate policy (UIC, 2025, pp. 29–34) (UIC, 2025, pp. 29–34)**]**. For your thesis, this is important because it suggests that KPIs related to track electrification readiness, energy source, traction systems, and construction decisions affecting future operational energy demand may be directly linked to long term environmental outcomes.

Another valuable aspect of the report is its emphasis on **energy consumption, efficiency, and savings**. The report explains that railways are becoming increasingly central to low carbon mobility, but it also notes that diesel still dominates much freight activity, which means that sustainability performance depends on both infrastructure and energy transition measures (UIC, 2025, pp. 29–34). It highlights that renewable energy targets have expanded across reporting rail companies and that energy efficiency improvements have reduced consumption per passenger kilometre and per tonne kilometre over time (UIC, 2025, pp. 29–34). This part of the literature is especially useful for your topic because it shows that environmental outcomes can be connected to measurable indicators such as energy mix, energy intensity, electrification coverage, fuel substitution, and efficiency gains. These variables can inform a KPI framework for railroad construction by linking project design choices with future operational sustainability.

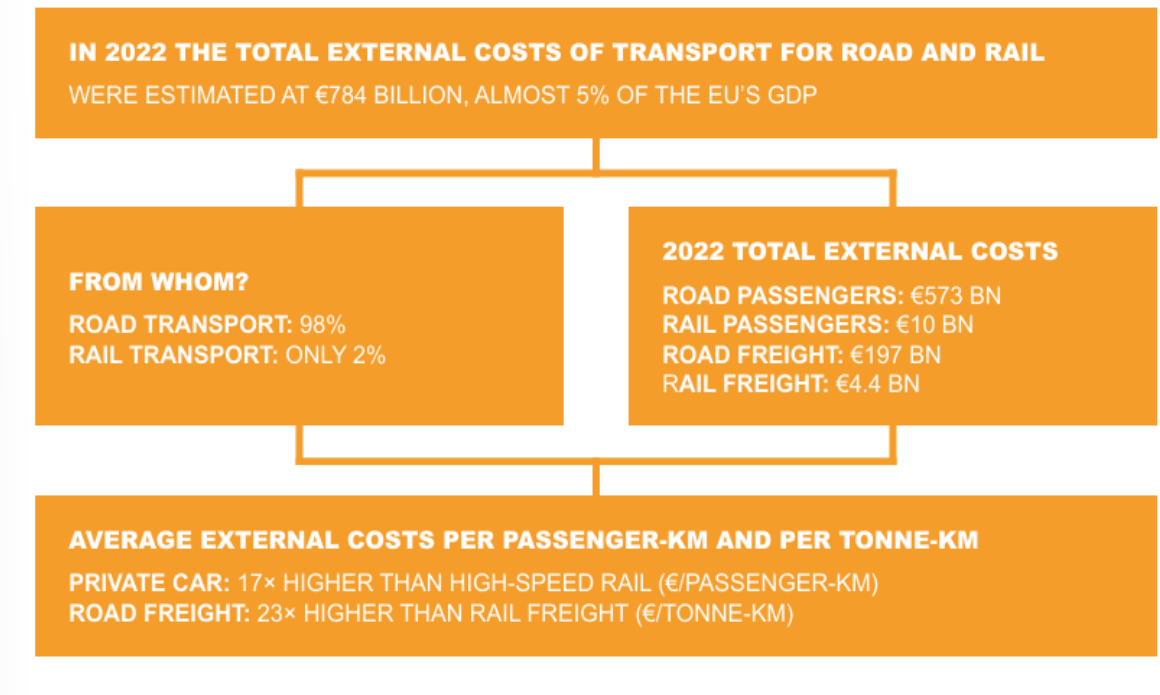


Figure 8. Total external costs of transport for road and rail 2022 (*International Union of Railways)*

[UIC], 2025)

The report also makes an important contribution through its discussion of **climate adaptation and resilient infrastructure**. It argues that rail infrastructure is increasingly exposed to climate related hazards such as flooding, heatwaves, drought, storms, and sea level rise, and that traditional planning based only on historical climate conditions is no longer sufficient (UIC, 2025, pp. 25–30). The report emphasizes the need for resilience based planning, improved maintenance, advanced monitoring, and the use of structured climate risk methodologies in infrastructure decision making (UIC, 2025, pp. 25–30). Of particular relevance to your thesis is the example showing that resilience can be measured through practical KPIs such as climate related incidents and delay minutes, which directly connects infrastructure condition and climate exposure to measurable performance outcomes (UIC, 2025, p. 28). This provides a very strong literature basis for arguing that railroad construction KPIs should include environmental and resilience indicators, not only cost, time, and quality measures.



Figure 9. Climate actions of the RSi reporting companies (*International Union of Railways [UIC]*, 2025)

In addition to environmental performance, the report highlights the broader sustainability role of rail through accessibility, workforce inclusion, and social value creation. It presents rail as a transport mode that contributes to safer and more accessible mobility, particularly for persons with disabilities and vulnerable groups, while also supporting employment and economic growth (UIC, 2025, pp. 13–21). Although your thesis is focused on environmental outcomes, this literature is still useful because it demonstrates that sustainability in rail is inherently multidimensional. Therefore, environmental KPIs in railroad construction should ideally be interpreted within a broader sustainability framework that recognizes interactions between infrastructure, service accessibility, safety, labor conditions, and regional development.

The report further underlines that sustainability performance depends not only on technical design but also on institutional commitment and governance. It notes that board level oversight of climate issues, emissions targets, collaboration with governments, and participation in climate initiatives have all increased across reporting rail companies (UIC, 2025, pp. 21–23). This is important for your thesis because it suggests that environmental outcomes are shaped not only by engineering and construction inputs, but also by governance related KPIs such as target setting, monitoring systems, reporting structures, and climate strategy integration. In this sense, the literature

supports a broader understanding of construction performance in which environmental results are tied to both project execution and organizational capacity.

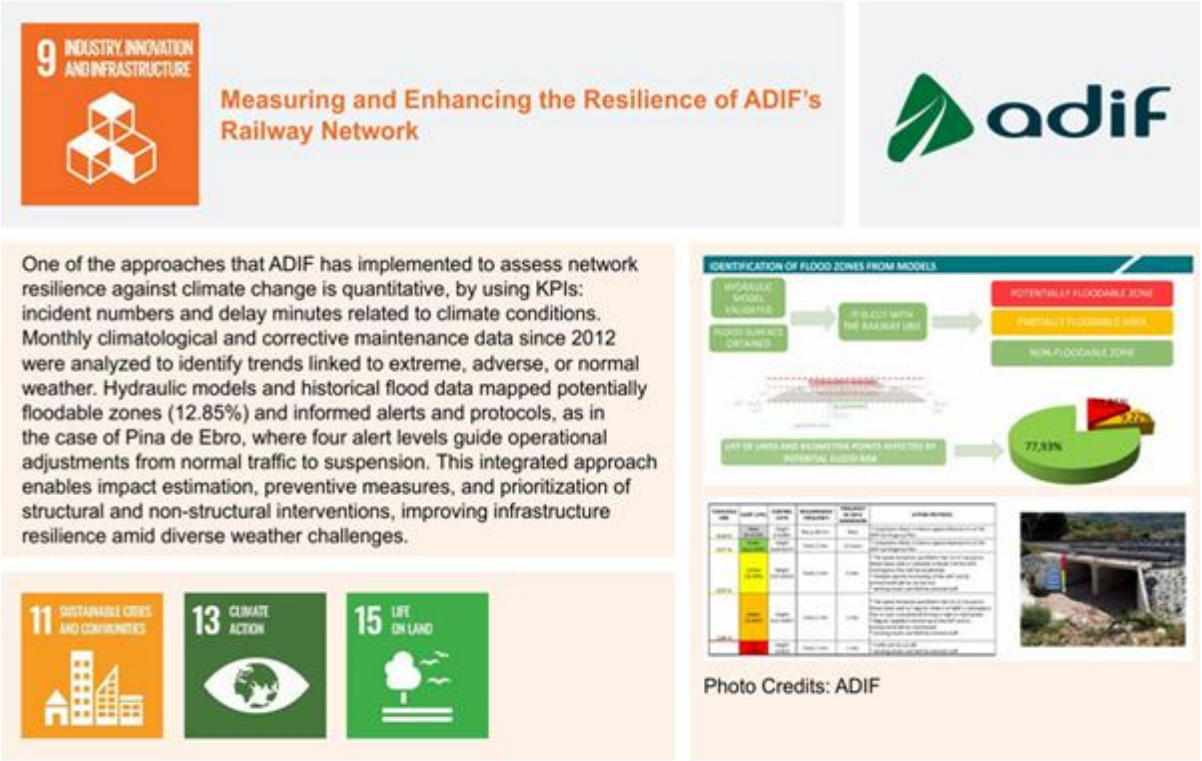


Figure 10. Measuring and enhancing the resilience of ADIF's Railway Network. (*International Union of Railways [UIC]*, 2025)

Another strong point in the report is its treatment of supply chains, biodiversity, air quality, noise, and wildlife impacts, which broadens the sustainability discussion beyond energy and emissions alone (International Union of Railways [UIC], 2025, pp. 3, 5, 58). Even where detailed construction KPIs are not specified, the report implies that the sustainability of rail infrastructure should be understood across the full asset lifecycle, including material sourcing, land use effects, habitat disruption, and impacts on surrounding communities (UIC, 2025, pp. 25–30, 58). For a thesis on railroad construction, this strengthens the case for selecting KPIs that reflect both direct project impacts and downstream environmental outcomes, such as embodied carbon, land disturbance, ecological fragmentation, noise mitigation, and resource efficiency.

Overall, the *2024 Global Rail Sustainability Report* provides a strong sector specific basis for arguing that rail infrastructure should be evaluated through a comprehensive sustainability lens. The report shows that rail can support climate mitigation, lower external costs, higher energy efficiency, and greater infrastructure resilience, but it also makes clear that these outcomes depend on measurable management practices and investment choices (UIC, 2025, pp. 14, 20–34). For this thesis, the report is especially valuable because it helps justify the development of a KPI framework that links railroad construction activities to environmental outcomes through indicators related to emissions, energy use, resilience, accessibility, biodiversity, and governance performance. In this way, the literature supports the view that railroad construction should not be assessed solely by conventional project delivery metrics, but by its ability to produce verifiable environmental and sustainability outcomes over the infrastructure lifecycle.

2.5 Summary of Literature and Research Gap

Although existing studies address sustainability performance, there is limited integration between operational KPIs and environmental outcomes at the construction activity level. The reviewed literature provides a strong foundation for understanding sustainability performance in infrastructure and industrial systems. The process mining framework demonstrates that environmental performance can be linked to operational activities through structured metrics such as GRI indicators. This approach highlights the importance of analyzing sustainability at the process level rather than only at aggregated organizational levels.

The ESG assessment of Mongolia's mining sector further emphasizes that environmental outcomes are influenced by operational practices, governance structures, and regulatory frameworks. It shows that sustainability challenges in Mongolia are closely related to water use, land disturbance, biodiversity loss, and weak integration of environmental monitoring into operational decision-making.

The Global Rail Sustainability Report complements this perspective by presenting rail as a relatively sustainable transport mode, while also highlighting the importance of energy efficiency, emissions reduction, climate resilience, and infrastructure design. The report demonstrates that sustainability in rail systems depends on measurable indicators and performance management practices.

However, despite these contributions, several important gaps remain in the literature.

First, existing studies do not clearly link **construction-level KPIs** to **environmental outcomes**, especially in the context of railroad infrastructure. Most research focuses either on high-level sustainability indicators or operational efficiency, but not on their integration.

Second, there is limited research applying KPI frameworks to **real construction projects**, particularly in developing regions such as Mongolia. This limits the practical applicability of existing models.

Third, environmental indicators such as water use, dust control, and biodiversity protection are often treated as **separate monitoring activities**, rather than being integrated into operational performance systems.

Finally, there is a lack of **activity-based environmental KPI mapping**, which makes it difficult to identify environmental hotspots within construction processes. Current literature either focuses on high-level sustainability indicators or on operational efficiency metrics, but rarely combines the two into a unified framework. In addition, process-based approaches such as process mining remain largely conceptual and are seldom applied using real construction project data.

This study addresses these gaps by developing an activity-based KPI framework that links construction processes to environmental outcomes using empirical data from a railroad construction project in Mongolia.The next chapter translates these identified gaps into a structured methodology, explaining how KPI mapping and case study analysis are operationalized.

3. Methodology and research

3.1 Research Philosophy

This study follows a pragmatic research philosophy. A pragmatic approach is appropriate because the aim of the research is not only to understand environmental performance theoretically, but also to develop a practical framework that can be applied to a real railroad construction project. The thesis focuses on how construction related key performance indicators can be linked to measurable environmental outcomes in the context of the Tavantolgoi to Gashuunsukhait railroad project in Umnugovi Province, Mongolia.

The study is based on the assumption that environmental outcomes in railroad construction are influenced by operational decisions such as water use, dust suppression, material handling, waste management, equipment activity, construction sequencing, and monitoring practices. Therefore, the research combines concepts from sustainability reporting, environmental management, and operational KPI analysis to produce a practical framework for evaluating environmental performance in railroad construction. This approach supports the development of a practical and applicable KPI framework while maintaining analytical rigor through systematic data interpretation. It is important to note that although process mining concepts are discussed in the literature review, they are used only to inform the conceptual structure of the KPI framework and are not directly implemented in the empirical analysis."

3.2 Research Approach

This research uses a case study approach supported by document analysis and KPI mapping. The case study is the Tavantolgoi to Gashuunsukhait railroad construction project, which is an important railway infrastructure project in southern Mongolia. The project is suitable for this study because it is located in the Gobi region, where environmental issues such as water scarcity, dust generation, land disturbance, and biodiversity protection are particularly important.

The research approach is mainly qualitative and quantitative. The qualitative part involves reviewing project reports, environmental management documents, monitoring materials, and KPI files to identify relevant environmental and operational indicators. The quantitative part involves extracting measurable data such as water consumption, dust suppression water use, monitoring activities, waste management records, and project related KPI values. These indicators are then organized into a framework that links construction activities to environmental outcomes.

Main references are:

- process mining algorithms
- regression modeling
- event logs

This research adopts a case study approach combined with descriptive and comparative analysis of project-level data. While concepts from process mining and statistical modeling are reviewed in the literature to inform the conceptual design of the framework, these advanced techniques are not empirically applied in this study. Instead, the methodology focuses on identifying, classifying, and mapping KPIs to environmental outcomes using descriptive and comparative analysis of project-level data."

3.3 Case Study Area

The geographical focus of this research is the Tavantolgoi to Gashuunsukhait railroad project in Umnugovi Province, Mongolia. The railway passes through Tsogtsetsii, Bayan-Ovoo, and

Khanbogd soums. The total length of the railway is approximately 248.5 km, passing through an arid and environmentally sensitive region of the Gobi Desert.

The project area is characterized by limited water resources, fragile vegetation, dust prone landscapes, and wildlife habitats. These characteristics make environmental management especially important during railroad construction. Construction activities in such areas can affect water use, soil stability, air quality, vegetation cover, and wildlife movement. Therefore, the case study provides a suitable context for examining the relationship between construction KPIs and environmental outcomes.

3.4 Data Sources

The study uses secondary project data obtained from environmental and operational documents related to the Tavantolgoi to Gashuunsukhait railroad project. The data includes environmental management reports, water use reports, KPI Excel files, monitoring reports, and supporting project documents.

The main data sources used in the methodology are:

1. Environmental Management Plan implementation reports for the project
2. Water usage reports for 2021, 2022, and 2023
3. KPI Excel files from the project period
4. Environmental monitoring appendices and supporting documentation
5. Existing thesis notes and project location information

These documents provide information on construction related environmental activities such as water consumption, dust suppression, waste management, monitoring activities, wildlife protection, and environmental compliance. The data is suitable for developing a KPI framework because it contains both operational indicators and environmental outcome indicators.

Data source	Year	Type of Data	Relevance to Thesis
Environmental Management Plan Implementation Report	2023	Environmental management activities	Identifies environmental mitigation and monitoring actions
Water usage report	2021	Water consumption data	Supports analysis of water use trends
Water usage report	2022	Water consumption data	Supports comparison across years
Water usage report	2023	Water consumption by activity	Supports calculation of water-related KPIs
KPI excel files	2022 - 2025	Project performance indicators	Supports identification of operational KPI categories
Monitoring appendices	2023	Environmental monitoring records	Supports validation of environmental outcomes

Table 2. Data sources used in the study

3.5 KPI Selection

The KPI selection process was based on the research objective and the available data. Since the thesis focuses on linking railroad construction KPIs to environmental outcomes, the selected KPIs were divided into two groups: **Operational KPIs and Environmental KPIs.**

Operational KPIs represent construction activities or project management performance. These may include railway length, work progress, construction activities, equipment use, dust suppression activity, water use for construction, material handling, and monitoring implementation.

Environmental KPIs represent measurable environmental outcomes. These include water consumption, dust control, waste management, environmental monitoring, land disturbance, vegetation protection, and wildlife protection.

The selected KPIs were chosen based on three criteria:

1. The KPI must be relevant to railroad construction activity.
2. The KPI must have a direct or indirect connection to an environmental outcome.
3. The KPI must be measurable using available project data.

Because not all operational data such as fuel use, machine hours, and daily construction progress were available in complete form, the study focuses mainly on the environmental indicators that are clearly supported by the available project documents. These include water use, dust suppression, environmental monitoring, waste management, and biodiversity related activities.

KPI category	Example KPI	Unit	Environmental outcome
Water use	Total water consumption	m^3	Pressure on local water resources
Dust control	Water used for road watering or dust suppression	m^3	Reduction of fugitive dust
Construction water	Water used for railway construction or repair	m^3	Resource use intensity
Concrete works	Water used for concrete mixing	m^3	Material-related water demand
Waste management	Waste collected, transported or treated	Kg or tons	Pollution prevention
Wildlife protection	Number of monitoring cameras or wildlife support measures	number	Biodiversity protection
Monitoring	Number of monitoring locations or inspections	number	Environmental compliance and control

Table 3. Selected KPI categories for railroad construction environmental assessment.

Due to data limitations, the study prioritizes indicators that are consistently available and measurable, which results in a stronger focus on environmental KPIs rather than detailed operational efficiency metrics.

3.6 KPI Mapping Framework

The core methodological step of this thesis is KPI mapping. KPI mapping means linking construction activities to environmental outcomes through measurable indicators. This is important because environmental impacts do not occur separately from construction activities. They are produced through specific actions such as water extraction, road watering, earthworks, material transport, waste disposal, and land occupation.

For this study, each KPI is mapped using four elements:

1. Construction activity
2. Operational indicator
3. Environmental outcome
4. Data source

For example, dust suppression is a construction related activity. The operational indicator is the volume of water used for road watering. The environmental outcome is reduced dust generation and improved air quality. The data source is the project water usage report or environmental management report.

Construction activity	Operational KPI	Environmental KPI	Expected environmental outcome	Data source
Road watering	Amount of water used for dust suppression	Dust suppression water use	Lower dust generation	Water usage report, EMP(environmental management plan) report
Concrete works	Water used for concrete mixing	Construction water intensity	Resource consumption	Water usage report
Railway repair or construction	Water used for construction activity	Water consumption per project activity	Water pressure in arid region	Water usage report
Waste handling	Waste collected or disposed	Waste management performance	Reduced pollution risk	EMP report
Wildlife monitoring	Number of cameras and monitoring points	Biodiversity monitoring effort	Improved wildlife protection	Monitoring report
Environmental inspection	Number of inspections or monitoring events	Compliance monitoring	Better environmental control	EMP implementation report

Table 4. KPI mapping between railroad construction activities and environmental outcomes.

This mapping framework serves as the central analytical tool of the study, enabling the translation of construction activities into measurable environmental performance indicators.

3.7 Data Processing

The data processing stage involved reviewing the available project documents and extracting relevant information into a structured format. Since the data was stored in different formats, including PDF reports, Word documents, PowerPoint files, and Excel files, the first step was to identify which files contained measurable values and which files contained supporting explanations.

The extracted data was organized into categories such as water use, dust control, construction activity, environmental monitoring, waste management, and wildlife protection. Values were standardized into common units where possible. For example, water use was recorded in cubic meters. Where the documents provided descriptive information rather than numerical values, the information was used as qualitative evidence to support the KPI framework.

The purpose of data processing was not only to calculate totals, but also to make the data usable for environmental performance interpretation. This means that each value was connected to its environmental meaning. For instance, water used for concrete mixing was interpreted as a construction resource consumption indicator, while water used for dust suppression was interpreted as both a resource use indicator and a dust control measure.

Step	Procedure	Purpose
Document screening	Identify relevant project reports and KPI files	Select useful data sources
Data extraction	Extract numerical and descriptive indicators	Build KPI database
Unit standardization	Convert values into consistent units	Enable comparison
KPI classification	Classify indicators into operational and environmental categories	Link KPIs to outcomes
Interpretation	Explain environmental meaning of each KPI	Support discussion and conclusion

Table 5. Data processing procedure.

3.8 Data Analysis Method

The analysis was conducted using descriptive and comparative methods. Descriptive analysis was used to present the available environmental indicators from the project data, such as total water consumption, water use by activity, dust suppression water use, and wildlife monitoring activities.

Comparative analysis was used where data from different years or different activity categories were available. For example, water use data from 2021, 2022, and 2023 can be compared to identify changes in resource consumption over time. Activity based comparison can also be used to identify which construction activities consume the largest amount of water.

The analysis follows three stages:

1. Identification of available KPIs from the project data
2. Classification of KPIs into operational and environmental categories
3. Interpretation of how each KPI relates to environmental outcomes

The analysis focuses on identifying relationships and associations between KPIs and environmental outcomes rather than establishing statistically validated causal relationships.Instead, it focuses on the indicators that are supported by the available project documents. This makes the research realistic and transparent.

3.9 Environmental Outcome Categories

The environmental outcomes considered in this study are grouped into five categories.

3.9.1 Water Resource Use

Water use is a central environmental issue in the project area because the railway is located in the arid Gobi region. Water related KPIs include total water consumption, domestic water use, construction water use, concrete mixing water, dust suppression water, and green area watering. These indicators are important because they show how construction activities place pressure on local water resources.

3.9.2 Air Quality and Dust Control

Dust generation is a major environmental issue in railroad construction, especially in dry and windy areas. Dust related KPIs include water used for dust suppression, temporary road watering, and dust control activities. These indicators show how construction operations attempt to reduce fugitive dust and protect air quality.

3.9.3 Waste Management

Waste management indicators show how construction related waste is controlled, collected, transported, reused, or disposed of. This category is important because poor waste management can lead to soil pollution, visual pollution, and risks to local ecosystems.

3.9.4 Biodiversity and Wildlife Protection

The project area includes fragile ecosystems and wildlife movement zones. Biodiversity related KPIs include the number of wildlife crossings, monitoring cameras, wildlife monitoring points, and

protection measures such as hay distribution or habitat support. These indicators show how the project addresses ecological fragmentation and wildlife protection.

3.9.5 Environmental Monitoring and Compliance

Monitoring indicators show the extent to which the project follows environmental management requirements. These may include inspection frequency, monitoring points, reporting activities, and implementation of mitigation measures. This category is important because environmental outcomes depend not only on technical measures, but also on continuous monitoring and management.



Figure 11. Environmental outcome categories used in the study

3.10 Development of the KPI Framework

After selecting and analyzing the available indicators, the study develops a KPI framework for linking railroad construction activities to environmental outcomes. The framework is designed to be practical and suitable for project managers, environmental officers, and researchers.

The proposed framework has three layers:

1. Construction activity layer
2. KPI measurement layer
3. Environmental outcome layer

The construction activity layer identifies the activity, such as road watering, concrete mixing, material transport, railway construction, or monitoring. The KPI measurement layer defines the indicator, unit, and data source. The environmental outcome layer explains what the KPI means for environmental performance.

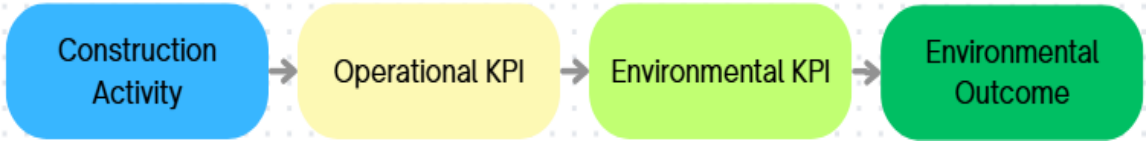


Figure 12. Proposed KPI framework linking railroad construction activities to environmental outcomes.

(Example: Dust suppression activity to Water used for watering to Dust control KPI to Reduced dust impact)

3.11 Validity and Reliability

To improve the validity of the study, the research uses project documents that are directly related to the Tavantolgoi to Gashuunsukhait railway project. The use of multiple document types, such as

environmental reports, water use reports, KPI files, and monitoring appendices, allows the findings to be checked across different sources.

Reliability is supported by using clear KPI definitions and consistent measurement units. For example, water use is measured in cubic meters, and monitoring effort is measured by number of cameras, monitoring points, or activities. The methodology also clearly separates measured data from interpretation. This helps avoid overstating findings that are not fully supported by the available data.

However, the reliability of some indicators is limited by the completeness and quality of the available records. Some important operational variables, such as fuel consumption, equipment working hours, diesel use by machine type, and daily progress rates, were not fully available in the current dataset. Therefore, the analysis focuses on indicators that can be supported by the available documents.The absence of detailed operational data limits the ability to perform advanced quantitative analysis; therefore, findings should be interpreted as indicative rather than definitive.

3.12 Limitations of the Methodology

This study has several methodological limitations.

First, the analysis is based on one case study, the Tavantolgoi to Gashuunsukhait railway project. Therefore, the findings may not be directly generalizable to all railway projects in Mongolia or other countries.

Second, the available data is stronger for environmental management indicators than for detailed operational performance indicators. For example, the dataset contains useful information on water use, monitoring, dust suppression, and wildlife protection, but it does not yet provide complete machine level data such as fuel consumption, equipment idle time, or emissions by equipment type.

Third, some environmental outcomes are difficult to measure directly using the available project documents. For example, dust reduction, biodiversity improvement, or long term habitat recovery may require field measurements over a longer time period. In this thesis, such outcomes are interpreted through available proxy indicators such as dust suppression water use, monitoring activity, and wildlife protection measures.

Finally, the study relies partly on secondary project documents, meaning that the researcher did not personally collect all field data. This limits control over how the original measurements were made.

3.13 Ethical Considerations

The study uses project level documents and does not involve personal data from workers or local residents. Any sensitive project information should be reported only in aggregated form. The thesis should avoid publishing confidential internal data unless permission has been granted by the project organization.

The research also aims to use the data responsibly by presenting limitations clearly and avoiding unsupported claims. Where values are estimated or interpreted, this should be stated transparently.

3.14 Summary of Methodology

In summary, this methodology uses a case study approach to examine how railroad construction KPIs can be linked to environmental outcomes. The Tavantolgoi to Gashuunsukhait railway project was selected because of its importance in Mongolia's mining logistics network and its location in an environmentally sensitive Gobi region. The research uses project environmental reports, water usage reports, KPI files, and monitoring documents to identify measurable indicators related to water use, dust control, waste management, biodiversity protection, and environmental compliance.

The main output of the methodology is a KPI framework that links railroad construction activities to environmental outcomes. This framework provides the basis for the results and discussion chapters, where the available project data will be analyzed and interpreted in relation to the thesis objective.The results of the KPI-based environmental analysis are presented in the following chapter.

4. Results

4.1 Overview of Findings

This chapter presents the results obtained from the project documents and environmental data of the Tavantolgoi–Gashuunsukhait railway project. The analysis focuses on the environmental indicators that are most clearly available in the project data, especially water use, dust suppression, biodiversity protection, wildlife monitoring, and environmental management measures. These indicators were selected because they directly support the thesis objective of linking railroad construction KPIs to environmental outcomes.

The results show that the environmental performance of the project can be understood through measurable construction related indicators. In particular, water consumption, dust control, concrete works, wildlife monitoring, and ecological mitigation measures appear as key areas where construction activities are connected to environmental outcomes. Since the project is located in the arid Gobi region, water use and dust suppression are especially important environmental indicators.

4.2 Water Consumption by Activity

Water use was one of the most important environmental indicators identified in the project data. In 2023, the total recorded water consumption for the project was **56,796.9 m³**. This total was distributed across domestic use, railway construction and repair, concrete mixing, dust suppression, and green area watering.

Activity	Water use, m³	Share of total, %
Domestic use	25902.8	45.6
Railway construction and repair	16075.9	28.3
Concrete mixing	8543.2	15.0

Dust Suppression	5400.0	9.5
Green area watering	875.0	1.5
Total	56796.9	100.0

Table 6. Water consumption by activity for the Tavantolgoi-Gashuunsukhait railway project, 2023

Table 6. shows that domestic water use accounted for the largest share of total water consumption, representing approximately 45.6 percent of the total. Railway construction and repair was the second largest category, accounting for 28.3 percent, followed by concrete mixing at 15.0 percent. Dust suppression represented 9.5 percent, while green area watering accounted for the smallest share at 1.5 percent.

These results indicate that water consumption in railroad construction is not limited to direct construction activities. Workforce related domestic use also forms a major part of total water demand. However, construction and material related activities together still represent a significant share of water use. This is important because the project is located in a water scarce region, meaning that water consumption should be treated as a key environmental KPI.

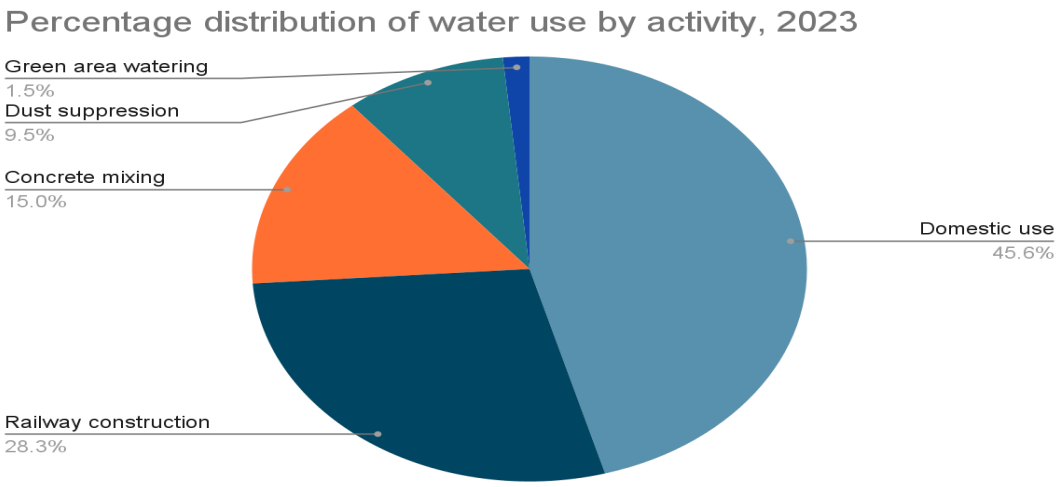


Figure 13. Percentage distribution of water use by activity, 2023

Figure 13 illustrates the proportional distribution of water use across project activities. The figure shows that domestic water use and railway construction activities are the dominant water consuming categories. Concrete mixing and dust suppression also represent important environmental management and construction related uses. The distribution confirms that water related environmental outcomes are influenced by several project activities rather than one single source. Therefore, water use should be evaluated as both an operational KPI and an environmental outcome indicator. This confirms that water consumption is a critical environmental KPI in arid-region infrastructure projects and should be prioritized in performance monitoring systems.

4.3 Water Use Intensity per Kilometer

To make the water consumption data more useful for performance evaluation, total water use was converted into a water intensity indicator. Since the total length of the railway is approximately **248.5 km**, water use per kilometre can be calculated.

Indicator	Value
Total water use	56,796.9m³
Total railway length	248.5km
Water use per kilometer	228.6m³/km

Table 7. Water consumption intensity per kilometer of railway

Table 7 shows that the project used approximately **228.6 m³ of water per kilometer** of railway. This indicator is useful because it normalizes environmental resource use against the physical scale of the project. Instead of only reporting total water consumption, water use per kilometre allows comparison with future railway construction projects in similar arid regions.

This KPI is especially relevant for the thesis because it directly links a construction output, railway length, with an environmental outcome, water consumption. It demonstrates how an operational construction measure can be transformed into an environmental performance indicator.

Total water use	56796.9m³
Water intensity	228.6m³/km

Table 8. Water consumption intensity per kilometer of railway

Table 8 presents total water consumption together with the calculated water intensity per kilometer of railway. While total water use reflects the overall environmental pressure of the project, water intensity provides a more standardized KPI. This type of indicator is useful for comparing projects of different sizes and for evaluating whether environmental performance improves over time.This indicator provides a standardized metric that enables comparison across projects and supports benchmarking of environmental performance.

4.4 Activity Based Water Intensity

To understand which activities contributed most to water consumption, water use was also calculated per kilometre for each activity category.

Activity	Water use, m³	Water intensity, m³/km

Domestic use	25902.8	104.2
Railway construction and repair	16075.9	64.7
Concrete mixing	8543.2	34.4
Dust suppression	5400.0	21.7
Green are watering	875.0	3.5

Table 9. Activity based water intensity per kilometer

Table 9. shows that domestic water use produced the highest water intensity, followed by railway construction and repair. Construction and repair activities consumed approximately 64.7 m³/km, while concrete mixing required approximately 34.4 m³/km. Dust suppression required approximately 21.7 m³/km.

These results suggest that water efficiency in railroad construction should be evaluated at the activity level. If only total water use is considered, it is difficult to identify where improvement is needed. However, activity based water intensity shows which activities are most resource intensive and where environmental management measures should be prioritized.

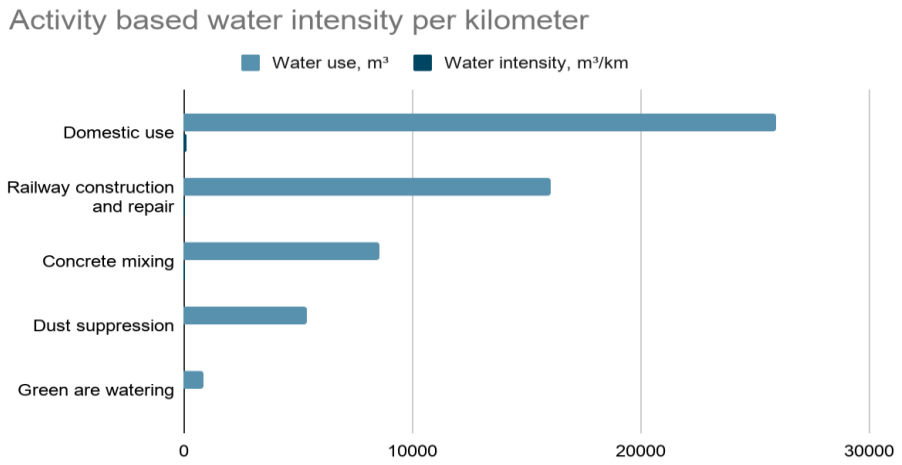


Figure 14. Activity based water intensity per kilometer

Figure 14. compares water intensity across project activities. Domestic use and railway construction activities show the highest water intensity, while green area watering has the lowest intensity. This figure helps identify water consumption hotspots within the project and supports the use of activity based KPIs for environmental performance assessment.

4.5 Dust Suppression and Air Quality Control

Dust suppression was another important environmental management activity identified in the project data. In 2023, **5,400 m³** of water was used for dust suppression. In addition, project environmental management records show **809 m³** of water used for temporary road watering during part of the reporting period.

Indicator	**Value**
Total dust suppression water	5,400 m³
Dust suppression share of total water use	9.5%
Dust suppression water intensity	21.7 m³/km
Temporary road watering, partial reported value	809 m³

Table 10. Dust suppression and road watering indicators

Table 10. shows that dust suppression represented approximately 9.5 percent of total water use. Although this is smaller than domestic use and railway construction water use, it is environmentally important because it directly relates to air quality management. In the Gobi region, temporary roads, construction traffic, earthworks, and material transport can generate fugitive dust. Therefore, dust suppression water use can be interpreted as a practical KPI that links construction activity to air quality control.

The 809 m³ value for temporary road watering should be treated as a partial or specific reported value rather than added directly to the annual total unless the project report confirms that it is separate from the 5,400 m³ dust suppression total.

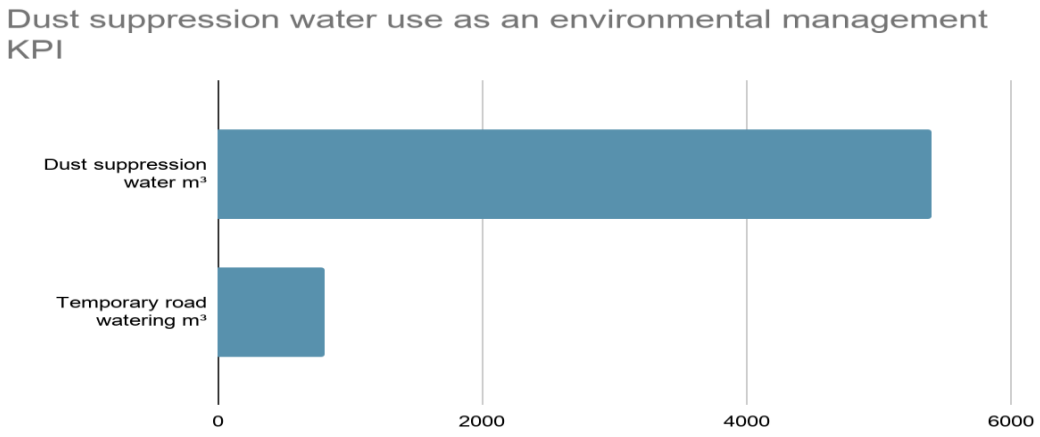


Figure 15. Dust suppression water use as an environmental management KPI

Figure 15 shows the water used for dust suppression and temporary road watering. These values demonstrate that dust control is an active environmental management measure within the railway construction project. The figure also shows that some environmental KPIs represent mitigation

activities rather than negative impacts alone. In this case, water use creates resource pressure, but it is also used to reduce dust and improve local air quality. This illustrates the dual role of certain KPIs, which simultaneously represent environmental impact and mitigation effort.

4.6 Biodiversity and Wildlife Protection Measures

Biodiversity protection was also identified as an important environmental outcome category. The available project data indicates that the project included wildlife monitoring and mitigation measures.

Indicator	**Value**
Wildlife monitoring cameras	69
Wildlife monitoring location	25
Average cameras per monitoring location	2.76
Wildlife crossing	21
Hay bales distributed for support	400
Average distance between wildlife crossings	11.8km

Table 11. Biodiversity and wildlife protection indicators

Table 11. presents the biodiversity and wildlife protection indicators identified from the project data. The project used 69 monitoring cameras across 25 monitoring locations, which equals approximately 2.76 cameras per monitoring location. In addition, the railway design included 21 wildlife crossings. Based on the total railway length of 248.5 km, this equals approximately one wildlife crossing every 11.8 km. The project also provided 400 hay bales as a wildlife support measure.

These indicators show that biodiversity protection can be represented through measurable KPIs. Unlike emissions or water consumption, biodiversity outcomes are more difficult to quantify directly. However, monitoring cameras, monitoring locations, wildlife crossings, and wildlife support measures provide practical indicators of biodiversity management effort.

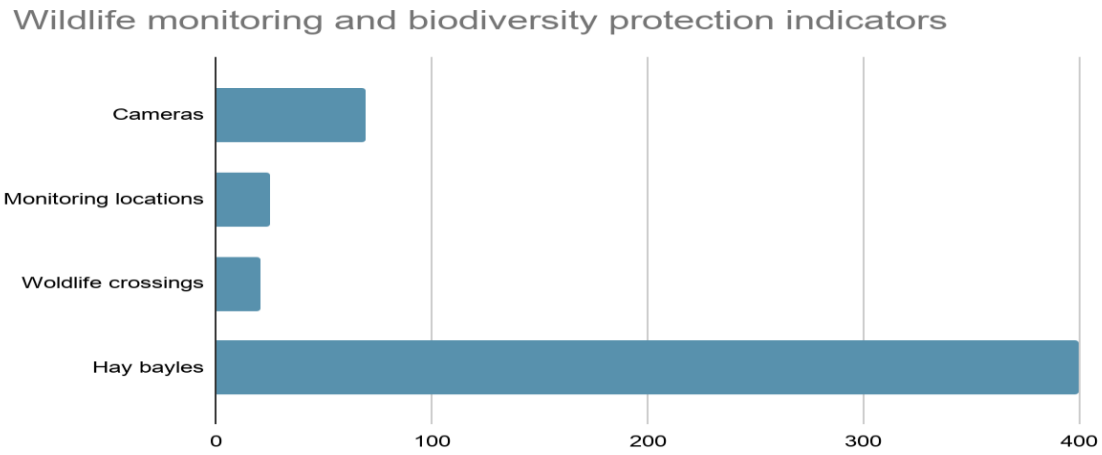


Figure 16. Wildlife monitoring and biodiversity protection indicators

Figure 16 presents the main biodiversity protection measures identified in the project data. The figure shows that the project used both monitoring measures and physical mitigation measures. Monitoring cameras and observation locations support the tracking of wildlife activity, while wildlife crossings are intended to reduce habitat fragmentation caused by railway infrastructure. These indicators demonstrate how ecological considerations can be included in a railroad construction KPI framework.

4.7 Infrastructure Measures Related to Environmental Mitigation

The project design also included structures that can contribute to environmental and ecological mitigation. These include bridges, culverts, and wildlife crossings.

Infrastructure feature	**Value**
Bridges	19
Culverts	126
Wildlife crossings	21
Total listed crossings and drainage related structures	166

Table 12. Infrastructure related environmental mitigation features.

Table 12 shows the main infrastructure features relevant to environmental mitigation. Bridges and culverts are primarily engineering structures, but they can also support drainage, reduce flood related impacts, and limit some forms of land disturbance when properly designed. Wildlife crossings are directly related to ecological connectivity and biodiversity protection.

These results show that environmental outcomes are influenced not only by operational management activities but also by infrastructure design choices. For railroad construction, this

means that environmental KPIs should include both construction activity indicators and design-based mitigation indicators.

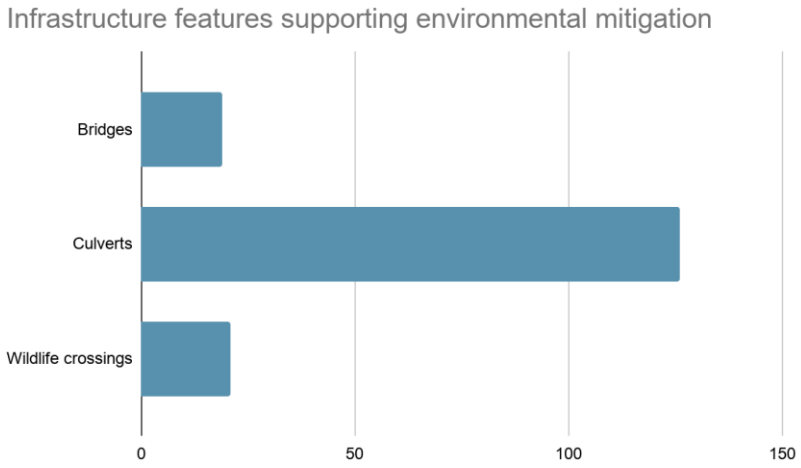


Figure 17 Infrastructure features supporting environmental mitigation

Figure 17 summarizes the infrastructure features that support environmental mitigation in the railway project. Culverts represent the largest number of structures, followed by wildlife crossings and bridges. These structures are important because railroad construction can affect drainage patterns, land continuity, and wildlife movement. Including these features in the results supports the argument that environmental performance in railroad construction depends on both management practices and infrastructure design.

4.8 KPI and Environmental Outcome Mapping

Based on the project data, the identified KPIs were mapped to their related environmental outcomes. This mapping shows how construction activities are linked to measurable environmental effects.

KPI	**Construction or management activity**	**Environmental outcome**
Total water consumption	Overall project activity	Pressure on local water resources
Water use per kilometer	Railway construction output	Resource intensity of construction
Construction water use	Railway construction and repair	Direct construction resource demand
Concrete mixing water	Concrete production	Material related water demand

Dust suppression water	Road watering and dust control	Reduction of fugitive dust
Monitoring cameras	Wildlife monitoring	Biodiversity observation
Wildlife crossings	Infrastructure design	Reduced habitat fragmentation
Hay bales distributed	Wildlife support	Biodiversity mitigation
Bridges and culverts	Drainage and crossings structures	Reduced hydrological and land disturbance risk
Environmental monitoring activities	Compliance and control	Improved environmental management

Table 13. Relationship between railroad construction KPIs and environmental outcomes.

Table 13 summarizes the relationship between the selected KPIs and environmental outcomes. The results show that the project contains several measurable indicators that can be used to evaluate environmental performance. Some indicators, such as water use and concrete mixing water, represent direct resource consumption. Others, such as dust suppression water, monitoring cameras, and wildlife crossings, represent mitigation and management actions.

This confirms the central argument of the thesis: railroad construction KPIs can be linked to environmental outcomes when indicators are clearly defined and mapped to construction activities.



Figure 18. KPI to environmental outcome mapping framework based on project results

Example branches:

Railway construction → Water use per km → Water resource pressure

Temporary road use → Dust suppression water → Dust reduction

Railway alignment → Wildlife crossings → Habitat connectivity

Environmental management → Monitoring cameras → Biodiversity control

Figure 18 presents the KPI mapping framework developed from the project results. The diagram shows that environmental outcomes can be connected to specific construction activities through measurable KPIs. This structure is useful because it turns environmental management from a general reporting activity into a practical performance measurement system.This mapping confirms that environmental outcomes can be operationalized through construction-related indicators, supporting integration into project management systems.

4.9 Identification of Environmental Hotspots

The analysis identified several environmental hotspots within the project. These are activities or project areas where environmental pressure is relatively high or where environmental control is especially important.

Environmental hotspot	**Supporting result**	**Main environmental concern**
Water consumption	56796.9 m³ total water use	Pressure on scarce water resources
Domestic and workforce water use	45.6% of total water use	Resource demand from supporting activities
Railway construction and repair	28.3% of total water use	Direct construction water demand
Concrete mixing	8543.2m³ water use	Material production resource demand
Dust suppression	5400m³ water use	Air quality and dust control
Wildlife moment	21 wildlife crossings and 69 cameras	Habitat fragmentation and biodiversity protection

Table 14. Environmental hotspots identified from the project data

Table 14 identifies the main environmental hotspots in the project. Water consumption is the most important hotspot because of the arid regional context. Dust suppression is also important because construction roads and vehicle movement can generate fugitive dust. Biodiversity protection is another hotspot because railway infrastructure can interrupt wildlife movement and fragment habitats.

These results show that environmental management in railroad construction requires a multi-indicator approach. A single KPI is not sufficient to capture all environmental outcomes. Instead, water, dust, biodiversity, and infrastructure design indicators should be evaluated together.



Figure 19. Main environmental hotspots in the Tavantolgoi–Gashuunsukhait railway project

This Figure shows the main environmental hotspots identified from the project data. Water use is the most significant issue due to the project's location in the Gobi region. Dust generation is closely linked to construction traffic and temporary roads. Concrete production contributes to material related water demand, while railway alignment and land occupation create potential risks for wildlife movement. These hotspots provide the basis for selecting environmental KPIs in railroad construction. These hotspots indicate priority areas where targeted interventions can significantly improve environmental performance.

4.10 Summary of Results

The results demonstrate that environmental outcomes in railroad construction can be linked to measurable KPIs. In the Tavantolgoi–Gashuunsukhait railway project, the most important measurable indicators were water consumption, water intensity, dust suppression water use, wildlife monitoring, wildlife crossings, and infrastructure related mitigation features.

The key findings are as follows. First, total water consumption in 2023 was 56,796.9 m^3, equal to approximately 228.6 m^3 per kilometre of railway. Second, domestic use and railway construction activities were the largest contributors to water consumption. Third, dust suppression required 5,400 m^3 of water, showing that air quality control is directly connected to construction activity and water resource use. Fourth, biodiversity protection was reflected through 69 monitoring cameras, 25 monitoring locations, 21 wildlife crossings, and 400 hay bales distributed for wildlife support. Finally, infrastructure features such as bridges, culverts, and wildlife crossings show that environmental mitigation is partly embedded in the design of the railway itself.

Overall, the results support the thesis argument that railroad construction should be assessed through integrated KPIs that connect construction activities to environmental outcomes. The findings also show that the most useful KPIs in this case are not only traditional construction indicators, but also environmental intensity and mitigation indicators such as water use per kilometre, dust suppression water, wildlife monitoring effort, and ecological connectivity measures. These findings are interpreted and contextualized in relation to existing literature in the following chapter.

5. Discussion

5.1 Interpretation of Results

The results of this study demonstrate that environmental outcomes in railroad construction are directly linked to operational activities and can be measured using project-level key performance indicators. The analysis of the Tavantolgoi–Gashuunsukhait railway project shows that indicators

such as water consumption, dust suppression, biodiversity protection, and environmental monitoring provide meaningful insights into environmental performance.

One of the most significant findings is the role of **water consumption as a dominant environmental indicator**. The total water use of 56,796.9 m³, equivalent to approximately 228.6 m³ per kilometre, highlights the scale of resource use in an arid environment. The fact that domestic water use accounts for the largest share suggests that environmental impacts are not limited to construction activities alone but are also influenced by workforce-related demands. This reinforces the idea that environmental performance in infrastructure projects must consider both direct and indirect sources of impact.This finding emphasizes the importance of incorporating resource-use indicators into construction performance management systems, particularly in environmentally sensitive regions

Another important finding is the dual role of **dust suppression water use**. On one hand, it contributes to total resource consumption, increasing pressure on water resources. On the other hand, it functions as an environmental mitigation measure that reduces dust emissions and improves air quality. This demonstrates that some KPIs cannot be interpreted in a linear way as either positive or negative. Instead, they reflect trade-offs between different environmental outcomes. This insight is important for KPI design, as it shows that environmental performance assessment requires a balanced interpretation of indicators.

The results also show that **biodiversity protection can be represented through measurable indicators**, such as the number of monitoring cameras, wildlife crossings, and mitigation measures. While biodiversity impacts are often difficult to quantify, the project demonstrates that monitoring and infrastructure design can provide practical proxies for ecological performance. This suggests that environmental KPIs in railroad construction can extend beyond resource use and emissions to include ecological and spatial indicators.

Finally, the identification of **environmental hotspots**, including water consumption, dust generation, concrete production, and wildlife disruption, confirms that environmental impacts are concentrated in specific construction activities. This supports the argument that environmental performance should be assessed at the activity level rather than only at the project level.

5.2 Comparison with Literature

The findings of this study are consistent with previous research on sustainability performance measurement and infrastructure environmental management. In particular, the results support the process-based perspective presented in the literature, which emphasizes that environmental outcomes are generated through specific operational activities rather than aggregated project outputs.

The process mining framework discussed in the literature review highlights that sustainability performance varies across different process activities and that environmental hotspots can be identified within operational workflows. The results of this study align with this perspective by showing that water consumption, dust suppression, and construction activities are key drivers of environmental impact. The identification of activity-based water intensity and environmental hotspots confirms that environmental performance is not uniform across the project but depends on how construction processes are executed. However, unlike many existing studies, this research demonstrates practical application using real project data, thereby strengthening the empirical relevance of KPI-based sustainability assessment.

The study also aligns with ESG based research, which emphasizes the importance of integrating environmental, social, and governance considerations into operational decision-making. The inclusion of biodiversity protection measures, wildlife monitoring, and environmental compliance indicators in the results reflects a broader understanding of sustainability that goes beyond emissions and energy use. This supports the argument that environmental performance should be evaluated within a multidimensional framework.

In addition, the findings are consistent with rail sustainability literature, which identifies rail as a relatively low-emission transport mode but also highlights the importance of infrastructure design, resource use, and climate resilience. The results of this study show that while rail infrastructure can contribute to long-term environmental benefits, the construction phase still involves significant environmental pressures, particularly in terms of water use and land disturbance. This reinforces the need to evaluate railroad construction not only in terms of its long term benefits but also in terms of its short-term environmental impacts.

5.3 Linking KPIs to Environmental Outcomes

A central objective of this thesis was to examine how KPIs in railroad construction can be linked to environmental outcomes. The results provide clear evidence that such linkages can be established using project-level data.

The KPI mapping developed in this study shows that each environmental outcome can be associated with a specific construction activity and corresponding indicator. For example:

- Water consumption is linked to construction activity, domestic use, and concrete production
- Dust suppression water use is linked to road watering and air quality control
- Wildlife crossings and monitoring are linked to biodiversity protection
- Environmental inspections are linked to compliance and management performance

This mapping demonstrates that KPIs can serve as a bridge between construction processes and environmental outcomes. Instead of treating environmental performance as a separate reporting requirement, it can be integrated into operational performance measurement.

An important insight from the results is that **environmental KPIs should include both impact indicators and mitigation indicators**. For example, water use represents environmental pressure, while dust suppression water represents an environmental control measure. Similarly, wildlife crossings represent mitigation efforts rather than direct impacts. This suggests that a comprehensive KPI framework should include both types of indicators. This confirms that KPIs can function as an effective bridge between operational decision-making and environmental performance evaluation.

5.4 Implications for Railroad Construction Management

The findings of this study have several implications for railroad construction management.

First, the results show that environmental performance can be improved by focusing on **activity-level efficiency**. For example, reducing unnecessary water use in construction processes or improving water efficiency in concrete mixing could significantly reduce overall resource consumption.

Second, the study highlights the importance of **integrating environmental KPIs into project management systems**. Instead of monitoring environmental performance only through external reporting, project managers can use KPIs such as water use per kilometre, dust suppression intensity, and monitoring activity levels to guide decision-making during construction.

Third, the results suggest that **environmental management should be proactive rather than reactive**. The presence of monitoring systems, wildlife crossings, and dust suppression measures indicates that environmental impacts can be managed during the construction process rather than after they occur.

Finally, the study shows that **infrastructure design plays a role in environmental outcomes**. Features such as wildlife crossings, bridges, and culverts are not only engineering elements but also environmental mitigation measures. This implies that environmental considerations should be integrated into design decisions from the early stages of project planning.

5.5 Limitations of the Study

This study has several limitations that should be considered when interpreting the results.

First, the analysis is based on a single case study. While the Tavantolgoi–Gashuunsukhait railway project provides valuable insights, the findings may not be directly generalizable to other projects with different environmental conditions or construction methods.

Second, the available data is stronger for environmental management indicators than for detailed operational indicators. For example, the dataset does not include complete information on fuel consumption, equipment usage, or emissions at the machine level. As a result, the analysis focuses primarily on water use, monitoring, and biodiversity indicators.

Third, some environmental outcomes are represented by proxy indicators rather than direct measurements. For example, dust suppression water use is used as an indicator of dust control, but actual air quality measurements were not available. Similarly, biodiversity indicators are based on monitoring and mitigation measures rather than direct ecological outcomes.

Fourth, a key limitation is the absence of detailed operational data such as fuel consumption and equipment usage, which restricts the ability to quantify emissions and perform deeper analytical modeling.

Finally, the study relies on secondary project documents, which limits control over data collection methods and measurement accuracy.

5.6 Contribution of the Study

Despite these limitations, this study makes an important contribution to the field of infrastructure sustainability.

The main contribution is the development of a **practical KPI framework that links railroad construction activities to environmental outcomes**. Unlike traditional approaches that focus on high-level environmental indicators, this framework connects specific construction activities to measurable environmental effects.

The study also contributes by demonstrating that environmental performance can be assessed using **real project data**, even when detailed operational data is limited. This is particularly relevant for developing countries, where data availability may be constrained.

In addition, the study expands the concept of environmental KPIs by including **biodiversity and monitoring indicators**, which are often overlooked in construction performance measurement.

Overall, the research provides a foundation for integrating environmental considerations into railroad construction management and supports the development of more sustainable infrastructure practices.These insights provide the basis for the final conclusions and recommendations presented in the next chapter.

6. Conclusion

To conclude my study it set out to examine how key performance indicators in railroad construction can be linked to environmental outcomes, with a specific focus on the Tavantolgoi–Gashuunsukhait railway project in Mongolia. The study addressed a gap in existing research, where environmental performance is often assessed at an aggregated level without clear connections to operational construction activities. By combining literature insights with real project data, this research demonstrates that environmental outcomes can be meaningfully linked to measurable construction-related indicators.

The findings show that environmental impacts in railroad construction are not abstract or external to the construction process. Instead, they are directly generated through specific activities such as water use, concrete production, dust suppression, material handling, and infrastructure design. Among these, water consumption emerged as the most significant environmental indicator in the project, with a total use of 56,796.9 m^3 in 2023, equivalent to approximately 228.6 m^3 per kilometre of railway. This highlights the importance of resource management in arid environments and confirms that water use should be treated as a central environmental KPI in railroad construction.

The study also identified that certain indicators play a dual role. For example, dust suppression water contributes to overall resource consumption while simultaneously acting as a mitigation measure to reduce dust emissions and improve air quality. This demonstrates that environmental KPIs must be interpreted carefully, as they may represent both environmental pressure and environmental control. Similarly, biodiversity protection measures such as wildlife crossings, monitoring cameras, and habitat support actions show that environmental performance can include both impact indicators and mitigation indicators.

A key outcome of this research is the development of a KPI mapping framework that links construction activities to environmental outcomes. This framework shows that operational indicators such as water use, monitoring activities, and construction processes can be directly connected to environmental effects such as resource depletion, air quality, and biodiversity protection. The results confirm that environmental performance can be integrated into construction management by embedding environmental KPIs into operational workflows, rather than treating sustainability as a separate reporting requirement.

The findings also highlight the importance of evaluating environmental performance at the activity level. The identification of environmental hotspots, including water consumption, dust generation, concrete production, and wildlife disturbance, demonstrates that environmental impacts are concentrated in specific parts of the construction process. This suggests that targeted improvements in these areas can significantly enhance overall environmental performance.

Furthermore, the study shows that infrastructure design elements, such as wildlife crossings and culverts, play an important role in mitigating environmental impacts, indicating that sustainability considerations should be integrated into both construction activities and design decisions.

Despite these contributions, the study has several limitations. The analysis is based on a single case study, which limits the generalizability of the findings. In addition, the available data is stronger for environmental management indicators than for detailed operational indicators such as fuel consumption and equipment usage. Some environmental outcomes were also assessed using proxy indicators rather than direct measurements. These limitations suggest that future research should include more detailed datasets, multiple case studies, and direct environmental measurements to strengthen the analysis.

Future research could expand this work by applying the KPI framework to other railroad construction projects in different environmental contexts, integrating real-time monitoring systems, and incorporating additional indicators such as emissions, energy use, and equipment performance. The integration of digital tools and data analytics could further enhance the ability to monitor and optimize environmental performance during construction.

In conclusion, this thesis demonstrates that it is both feasible and valuable to link key performance indicators of railroad construction to environmental outcomes. By using project-level data and a structured KPI mapping approach, the study provides a practical method for integrating environmental considerations into construction performance evaluation. This contributes to the development of more sustainable railroad infrastructure by supporting data-driven decision-making and improving the ability of project managers to identify, monitor, and reduce environmental impacts throughout the construction lifecycle. The proposed KPI framework has practical applicability for infrastructure project beyond the case study and can support improved environmental performance monitoring in similar arid and resource-constrained regions.”

7. References

- Alsayegh, O., & others. (2025). *A framework for sustainability performance measurement through process mining: Integration of GRI metrics in operational processes*. Systems, 13(7), 547. https://doi.org/10.3390/systems13070547
- Asian Development Bank. (2026). *Environmental, social, and governance assessment of Mongolia’s mining sector*. Asian Development Bank. https://doi.org/10.22617/TCS260087-2
- International Union of Railways. (2025). *2024 global rail sustainability report*. UIC.
- Global Reporting Initiative. (2024). *GRI standards*. https://www.globalreporting.org/
- Gankhuyag, D. (2023). *“Тавантолгой–Гашуунсухайт чиглэлийн төмөр зам барих төсөл”-ийн 2023 оны байгаль орчны менежмент төлөвлөгөөний биелэлтийн*

майлан [Environmental management plan implementation report]. Unpublished project report.

- Тавантолгой–Гашуунсухайт төмөр замын ус ашиглалтын тайлан. (2021–2023). *Water usage report*. Unpublished project documents.
- Тавантолгой–Гашуунсухайт төмөр замын KPI мэдээллийн файл. (2022–2025). *KPI dataset*. Unpublished project data.
- Dugarjav, G. (2023). Effective integrated frameworks for assessing mining sustainability. *Environmental Science and Pollution Research*. https://www.sciencedirect.com/science/article/pii/S2666188825004010
- Zhang, X., & others. (2022). Sustainability performance in construction projects: A review. *Journal of Cleaner Production*, 350, 131403.
- Marzouk, M., & Azab, S. (2014). Environmental and economic impact assessment of construction projects. *HBRC Journal*, 10(3), 275–282.
- Olawumi, T., & Chan, D. (2018). A scientometric review of global research on sustainability and construction. *Journal of Cleaner Production*, 183, 231–250