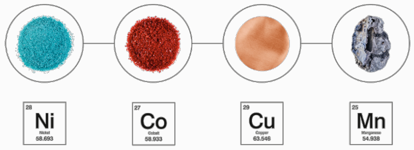
Ecoquant

ISO 14044 Compliant
Comparative Life Cycle Assessment



the metals company

I. Statement

This report was prepared by Ecoquant (t/a Ecoquant Consulting) for the sole and exclusive use by The Metals Company (TMC) for the purpose of quantifying and reporting the environmental impacts associated with the production of their products from the NORI-D Polymetallic Nodules Project from a life cycle perspective while considering all available environmental impact categories currently available through the Environmental Footprint (EF) 3.1 life cycle impact assessment method. This report also contains comparisons of TMC products from the NORI-D Polymetallic Nodules Project to the same products produced via key terrestrial routes.

The information contained within this report has been derived from TMC's primary data, and for the comparison routes, when available, from published company sustainability and ESG reports, and other literature sources. Results that differ from company reported values are modelled estimates derived using the methodology described throughout this report and may differ from the selected companies' own reporting frameworks and boundaries.

Ecoquant does not endorse nor oppose specific technologies assessed in this study. The sole objective of this analysis is to provide an impartial quantification on aspects of their environmental impacts. This report has undergone an external critical panel review in line with ISO 14044 and ISO 14071, and the results are intended to support public comparative assertions.

This report is the LCA study commissioned by TMC to Ecoquant on March 3rd, 2025. This report should be read in its entirety to prevent misinterpretation of individual sections. The information contained in this report is specific to the NORI-D Polymetallic Nodules Project and is not intended for use outside of this context. As it pertains to the comparisons, the results contained in this report are limited by the accuracy and data availability from published sources. Although primary data was prioritized and precise LCA and engineering principles were applied in this report, the nature of LCAs involves various uncertainties that may change as new information becomes available. Therefore, the results of this study can be considered generally indicative of certain process technologies but are not definitive.

II. Executive Summary

II.I Goal & Scope

The Metals Company (TMC) is engaged in deep-sea exploration and aims to extract base metals from polymetallic nodules located in the Clarion-Clipperton Zone (CCZ) of the Pacific Ocean. These nodules are rich in nickel, copper, cobalt, and manganese—key materials for infrastructure, energy systems, and batteries.

On March 3, 2025, TMC commissioned environmental consultancy Ecoquant to conduct a life cycle assessment (LCA) of the NORI-D project, covering aspects of the environmental impacts associated with the full process from seabed collection of nodules to the production of $MnSiO_3$, Ni-Cu-Co matte, copper cathode, nickel sulfate hexahydrate ($NiSO_4 \cdot 6H_2O$), and cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$). The production of silicomanganese (SiMn) from TMC's $MnSiO_3$ was also assessed. The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A.

There are three distinct goals of this study. They are:

1. To quantify aspects (as defined) of the environmental impacts associated with the production of 1kg of MnSiO3, Ni-Cu-Co Matte, NiSO4.6H2O, copper cathode, CoSO4.7H2O, and the impact associated with the collection and processing of 1kg of dry nodules from the NORI-D Polymetallic Nodules Project across the full spectrum of impact categories offered by the EF 3.1 methodology.

2. To quantify aspects (as defined) of the environmental impacts associated with the production of SiMn using TMC's MnSiO3 from the NORI-D Polymetallic Nodules

Project in relation to the full spectrum of impact categories available within the Environmental Footprint (EF) methodology.

3. To compare the difference in the environmental impacts of producing TMC's products from the NORI-D Polymetallic Nodules Project versus the same products produced via key terrestrial production routes that account for a significant share of global supply.

The intended application of this study is to provide TMC with additional environmental impact insights of their production process and highlight emission reduction pathways through scenario/sensitivity analyses. While all impact categories assessed in this report are valuable, climate change is one that LCA methodologies do particularly well. In addition to its global urgency, universal relevance, and public focus, it is widely recognized as the most established impact category and benefits from global frameworks and guidance's such as the greenhouse gas (GHG) protocol and ISO 14067. As a result, the GHG emission data generated in this this study can be used as a part of TMC's application for an exploration and commercial recovery/permit license. Accordingly, the climate change impact category will receive the most detailed interpretation in this report, including contribution, sensitivity, and scenario analyses.

The target audience of this study includes regulators, investors, customers, and anyone interested in deep-sea mining. Ecoquant recognizes the debate on the technology that is studied in this report and the possibility of selective use of individual data to support claims. As the target audience includes anyone interested in deep-sea mining, it should be noted that the authors and commissioning party do not assume responsibility for the interpretations made by parties who lack the necessary technical background. Misinterpretation or selective use of individual findings outside the context of the complete study may lead to inaccurate conclusions. A summarized, third-party version of this report will be prepared by the commissioner of this study for communication purposes.

This study does not measure the environmental impacts on the seabed from nodule collection, nor does it adequately capture the full scope of impacts on forest and other ecosystems from terrestrial mining activities such as deforestation and large-scale impoundment. The life cycle assessment methodology currently lacks a methodologically sound framework for adequately quantifying these impacts[6,7]; thus, this should be considered a limitation of this study.

As this study contains comparative assertions on the production of the refined products analyzed, a critical review by an external panel was conducted. This study meets the requirements of the international standards for Life Cycle Assessment (LCA) according to ISO 14040:2006 and ISO 14044:2006.

Key details of TMC's NORI-D offshore and onshore operations, as well as key difference in this study and a previous study conducted for the TMC NORI-D project are summarized in Tables E1 – E4. TMC's system boundary analyzed in this study is shown in Figure E1.

Table E 1:TMC NORI-D offshore production details

	Location	Annual Collection (wet)	Annual Collection (dry)
TMC NORI-D Nodule Collection	Clarion Clipperton Zone (CCZ)	12.0 Mtpa	8.64 Mtpa

Table E 2: TMC NORI-D onshore details

Downstream processing of TMC's $MnSiO_3$	Products	Electricity Generation sources
China	SiMn	**CN. Grid** · 62% coal · 15% hydro · 8.5% wind · 4.7% Nuclear · 9.8% other

Table E 3: Details on the downstream processing of TMC's $MnSiO_3$

	Onshore Pyro Locations	Products	Electricity Generation sources	Onshore Hydro Location	Products	Electricity Generation sources
TMC NORI-D Indonesia	Indonesia	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**IND. Grid** o 63% Coal o 23% natural gas o 7% hydropower o 7% other	South Korea	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	South Korea Grid o 34% nat gas. o 33% coal o 28% Nuclear o 2% Hydro o 3% other
TMC NORI-D Japan	Japan	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**JP Grid** o 35% nat.gas o 31% coal o 9% solar o 9% hydro o 9% nuclear o 7% other	South Korea	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	South Korea Grid o 34% nat gas. o 33% coal o 28% Nuclear o 2% Hydro o 3% other
TMC NORI-D Texas	Texas	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**US-TRE grid** o 49% Nat. Gas o 24% Wind o 17% Coal o 10% other	Texas	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	**US-TRE grid** o 49% Nat. Gas o 24% Wind o 17% Coal o 10% other

Table E 4: Difference between previous TMC NORI-D LCA study and this study

TMC NORI-D LCA Report - Minviro	TMC NORI-D LCA Report - Ecoquant
Offshore marine fuel based on 2024 PFS	Offshore marine fuel usage updated based on updated PFS (2025).
24% moisture content of nodules	28% moisture content of nodules
Ecoinvent 3.10	Ecoinvent 3.11
Indonesia and Japan NORI-D Routes	Texas, Indonesia, and Japan NORI-D Routes
Production of SiMn not considered	TMC's system boundary extended to include the production of SiMn from TMC'S $MnSiO_3$
No comparative assertions	Comparative assertions on SiMn, $NiSO_4.6H_2O$, copper cathode and $CoSO_4.7H_2O$

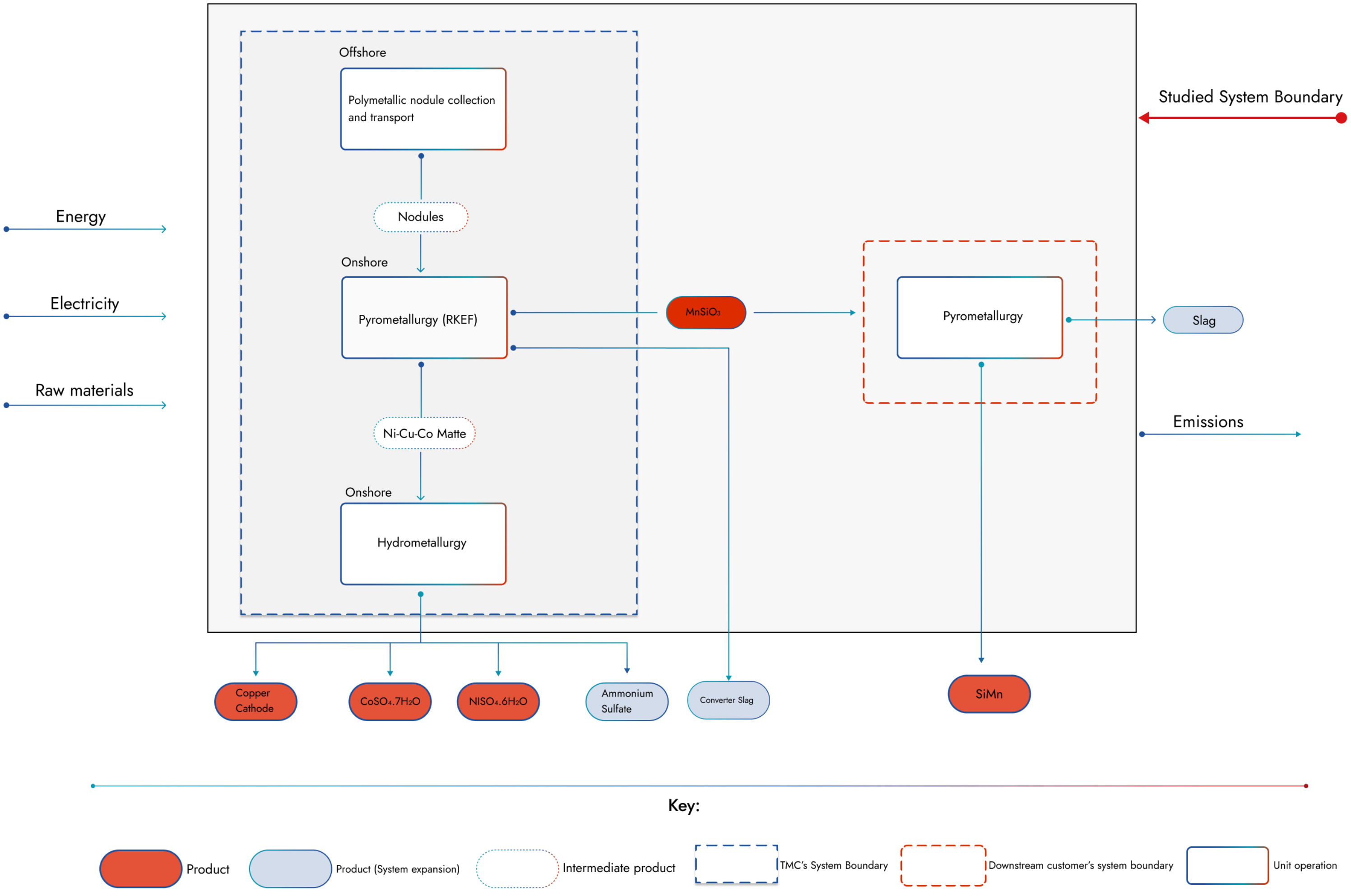


Figure E 1: Analyzed system boundary, including TMC's system boundary and the system boundary downstream customers.

II.II TMC NORI-D Data & Results

TMC's process were modelled using data from their latest PFS (2025). In their internal pre-feasibility study (PFS), annual marine fuel usage was calculated with data provided by Allseas, an offshore contractor who designed and retrofitted the production vessel; as well as information provided by large shipping companies that have worked with TMC.

For onshore operations, the process data employed as input to the LCA was derived from mass and energy balance models. The mass and energy balance modelling were conducted by Hatch, an engineering and development consultancy, who utilized the industry standard Metsim™ software package and qualified experienced process engineers. The design basis for the model development included analogous commercial operations in nickel processing, test-work results by TMC as well as employing extensive data from literature, and fundamental thermodynamics.

A comprehensive assessment for each functional unit was conducted across the full spectrum of EF 3.1 impact categories. The results for every impact category for each functional unit are summarized in Tables A1-A7 in Annex A. The climate change impact of each functional unit for TMC's NORI-D operations are shown in Figures E2 – E8.
TMC has the opportunity for access to low-carbon and renewable electricity through market instruments.

Results from scenario analysis involving low-carbon and renewable electricity sources are shown in Figure E9-E15. A sensitivity analysis was conducted to analyze the variation in the climate change impact results when metal mass allocation was considered. The results are shown in Figure E16.
*Note: Figures may be subject to minor rounding differences and thus may not total precisely.

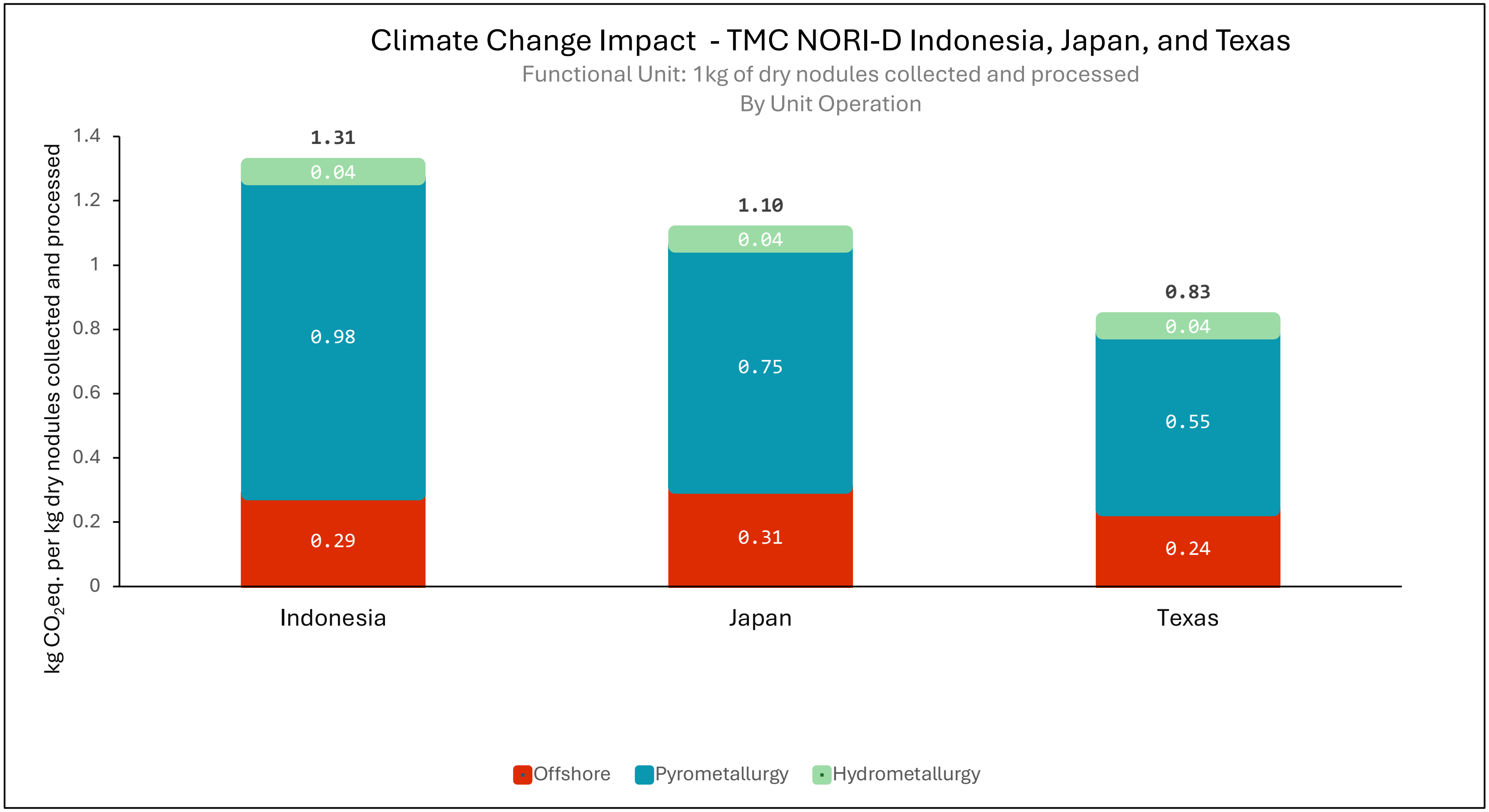


Figure E 2: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of dry nodules collected and processed, net results.

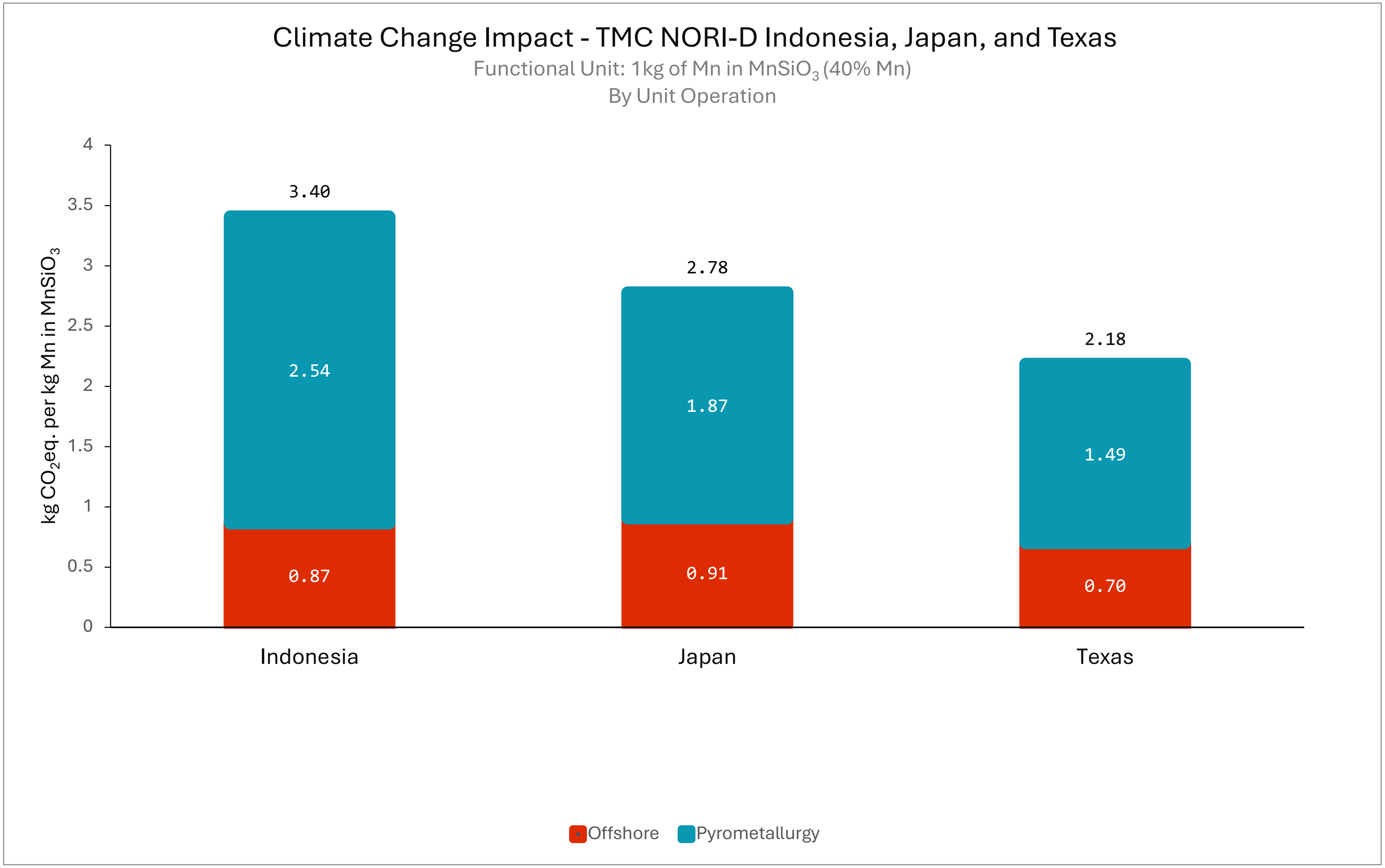


Figure E 3: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Mn in $MnSiO_3$, net results.

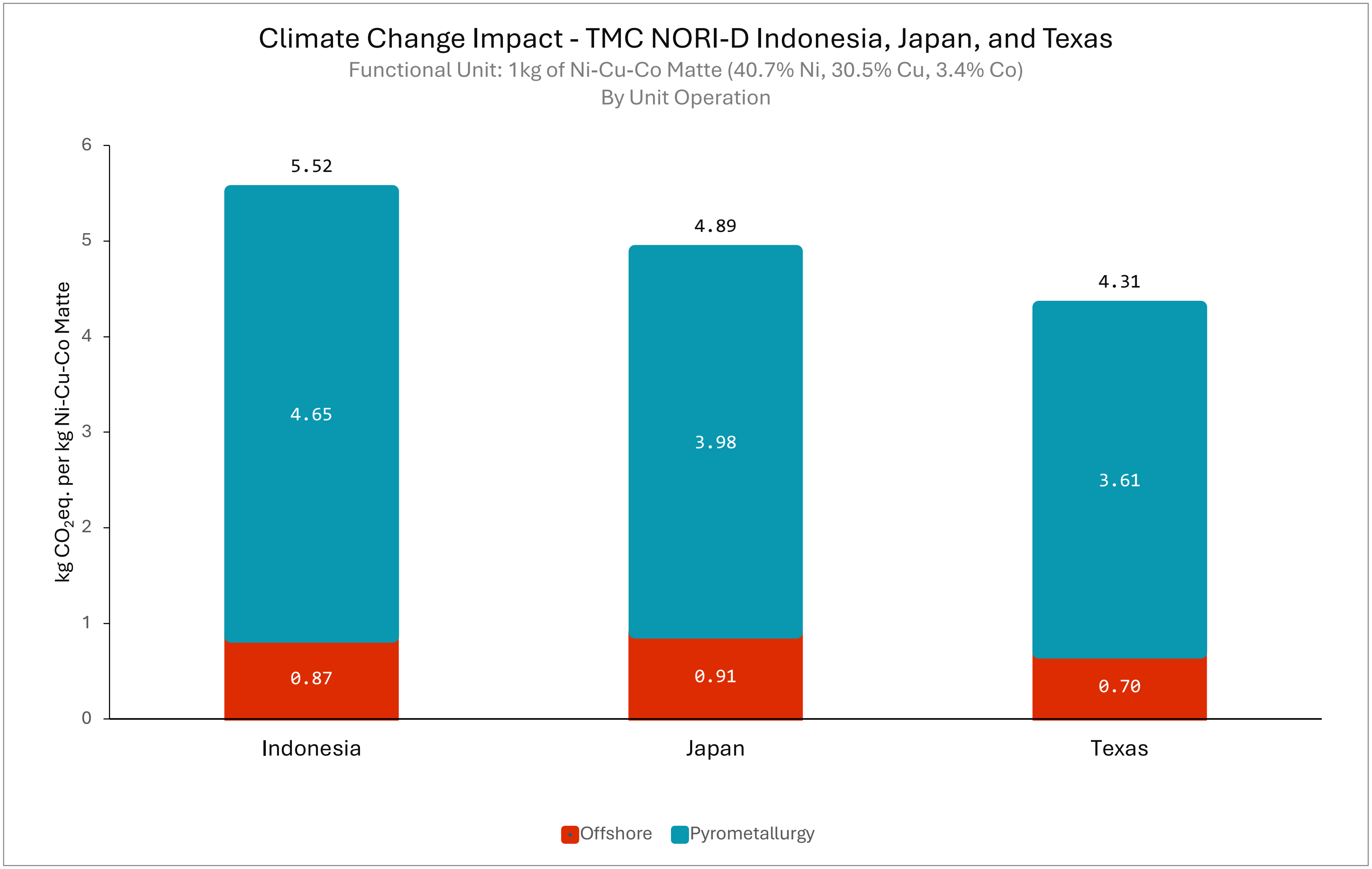


Figure E 4: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Ni-Cu-Co Matte, net results.

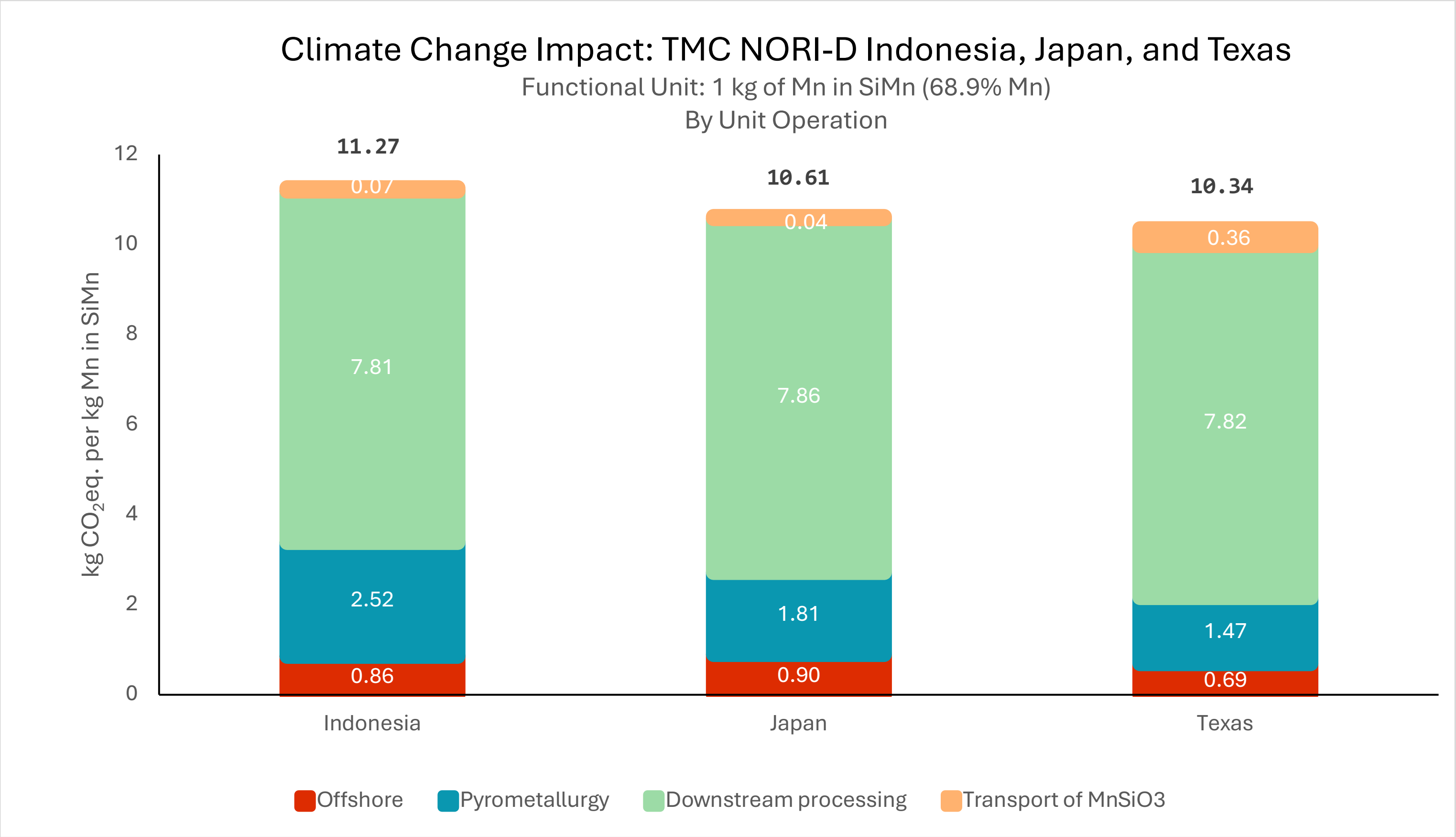


Figure E 5: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Mn in SiMn, net results.

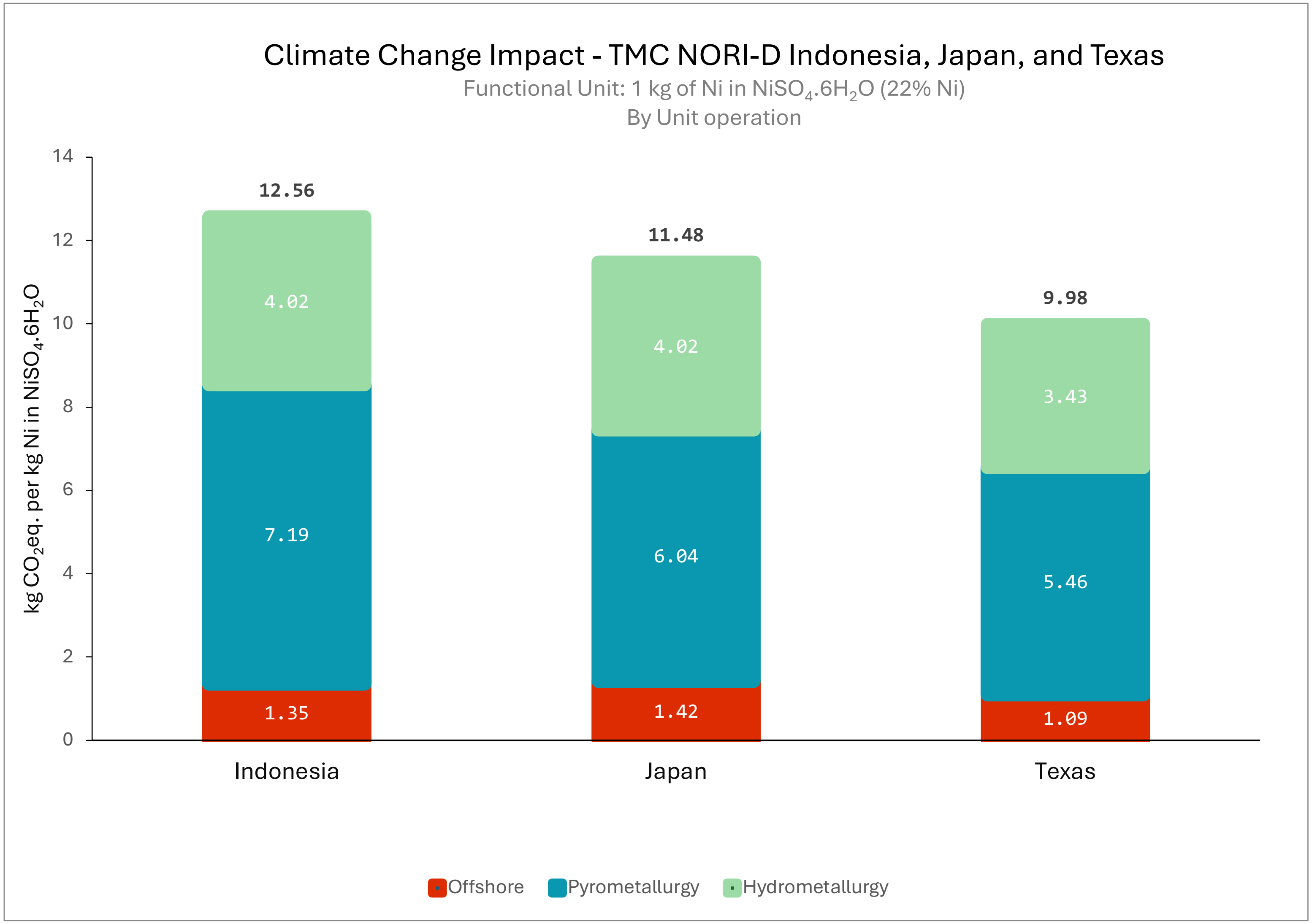


Figure E 6: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Ni in NiSO4.6H_2O, net results.

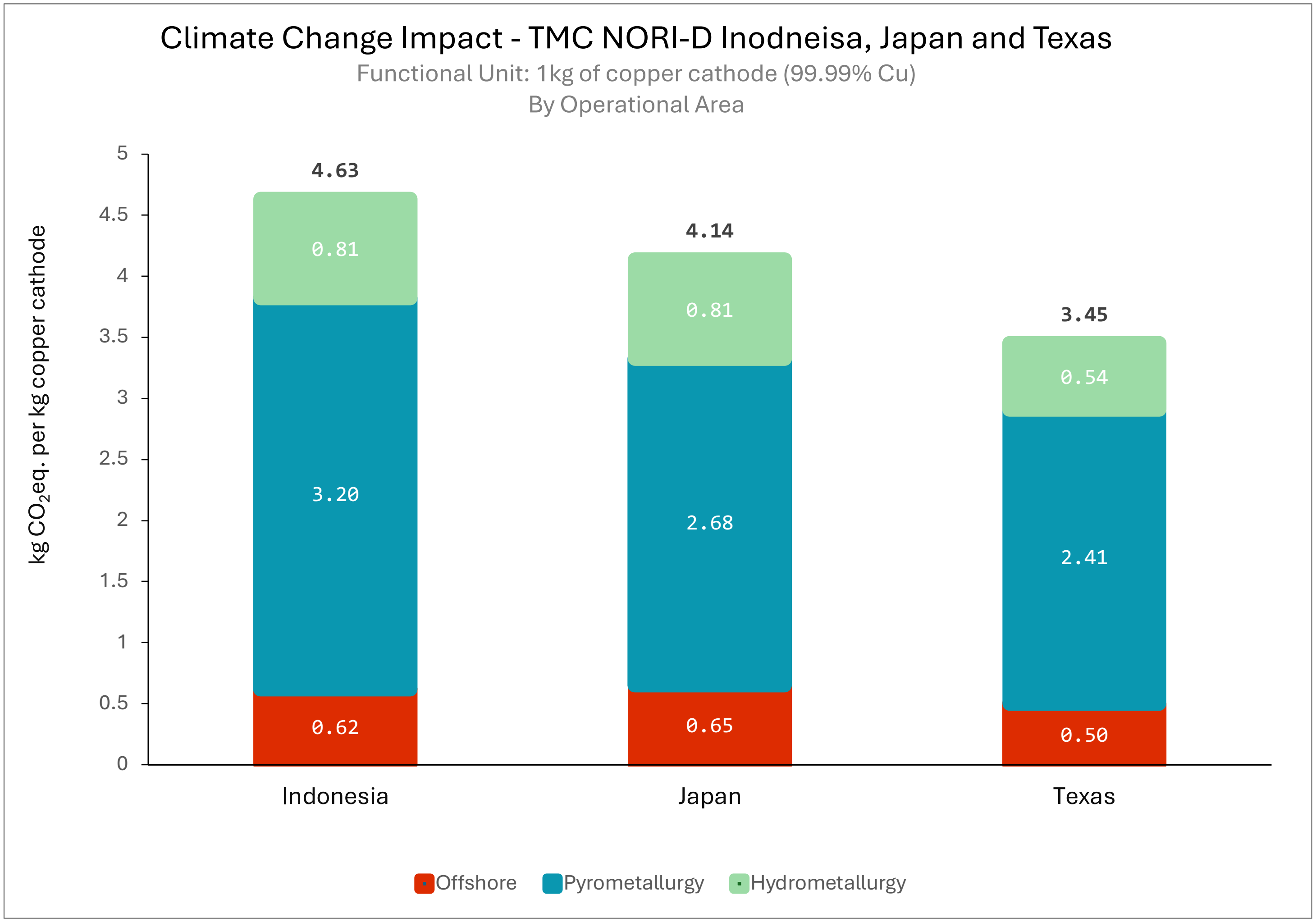


Figure E 7: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Copper Cathode, net results.

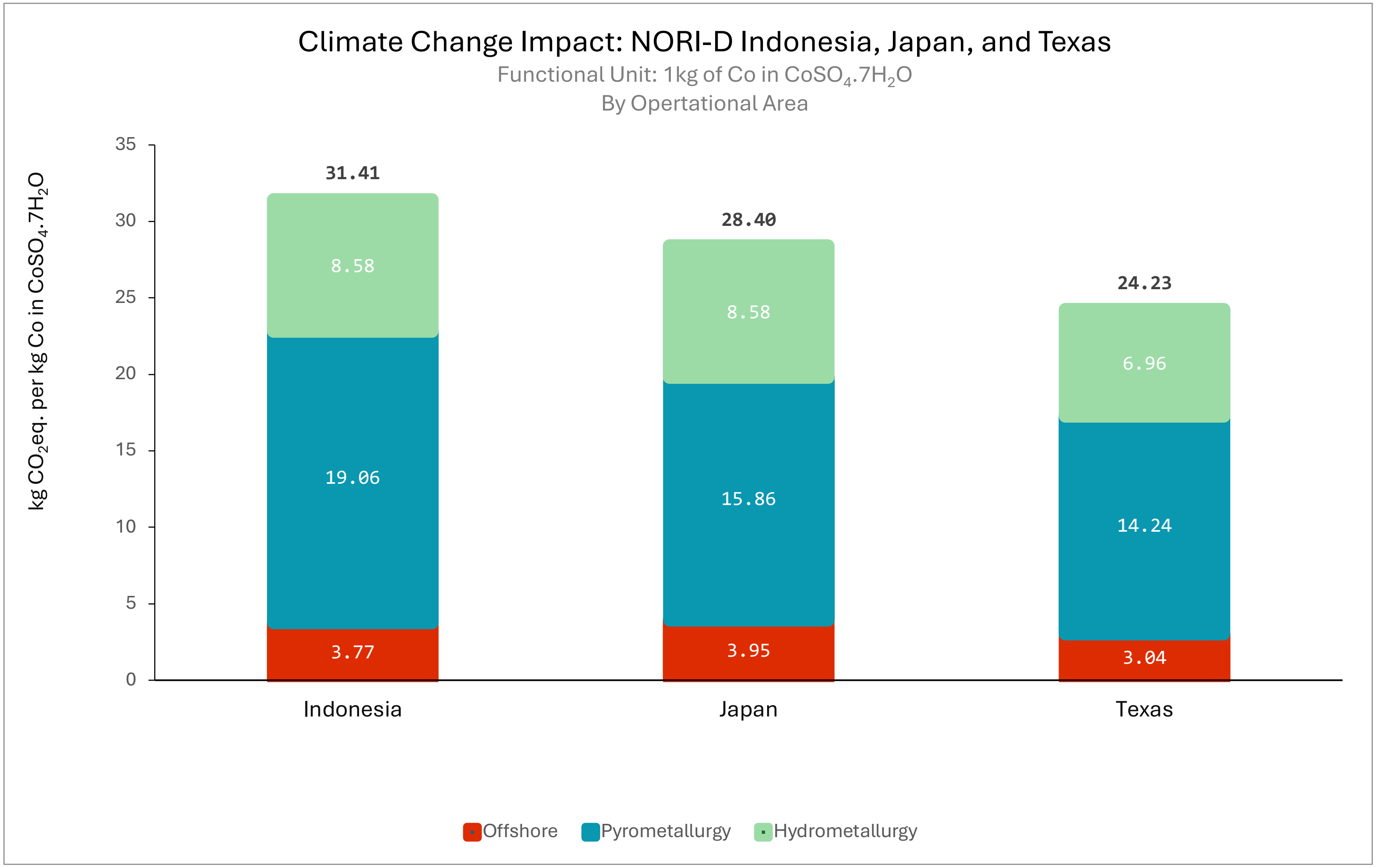


Figure E 8: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Co in $CoSO_4.7H_2O$, net results.

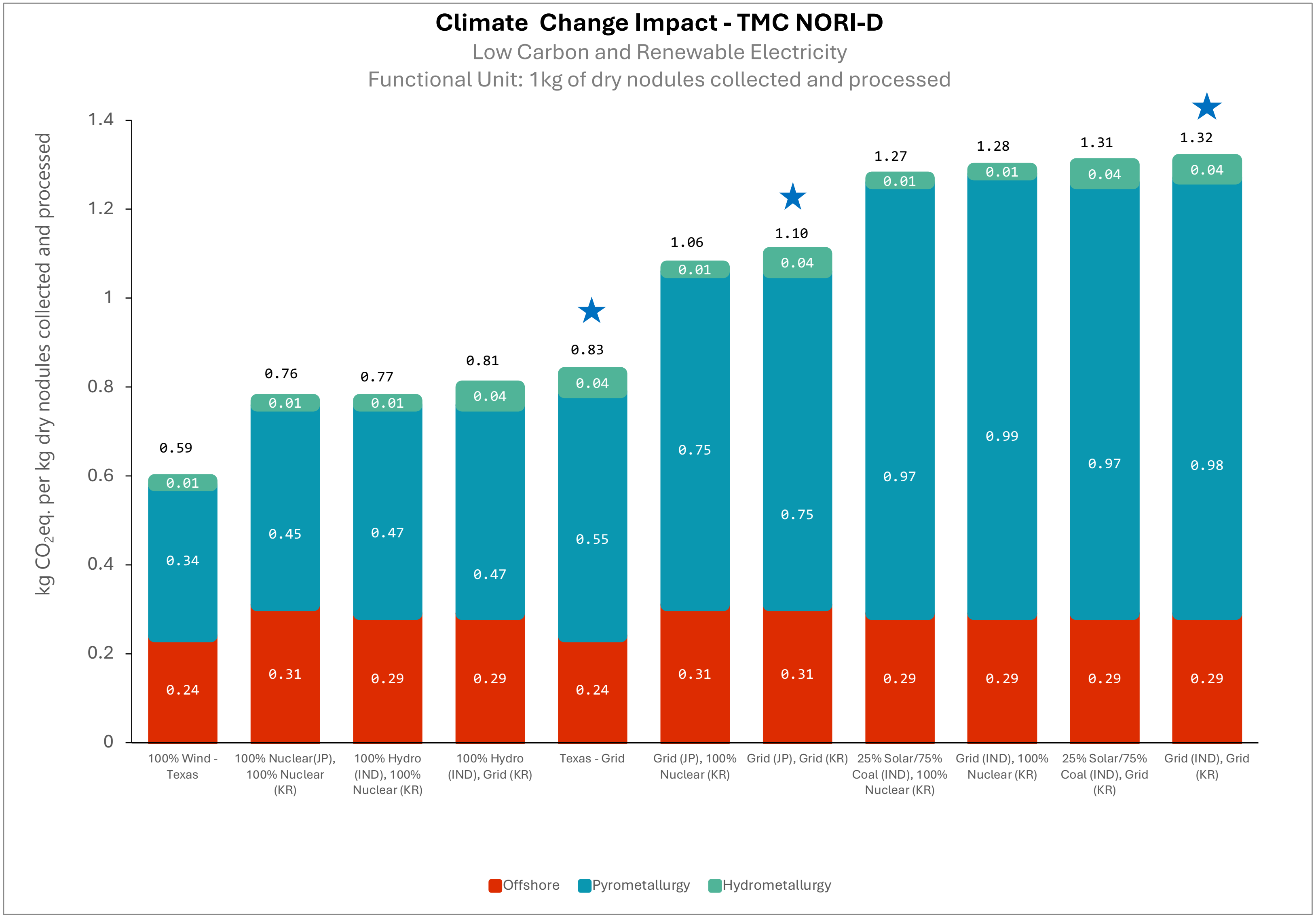


Figure E 9: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of dry nodules collected and processed, net results.
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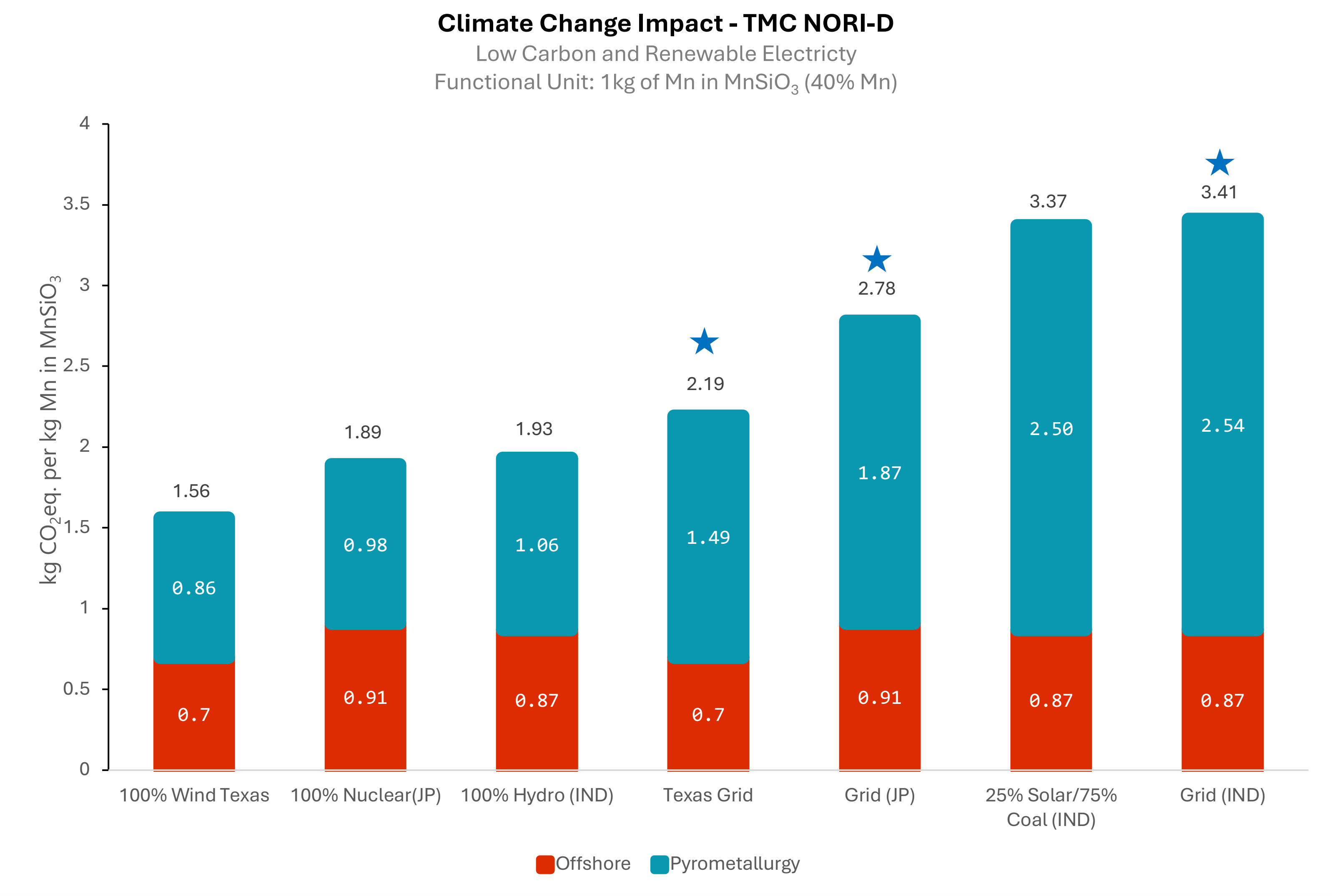

Figure E 10: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Mn in $MnSiO_3$, net results. ★ *= base case*

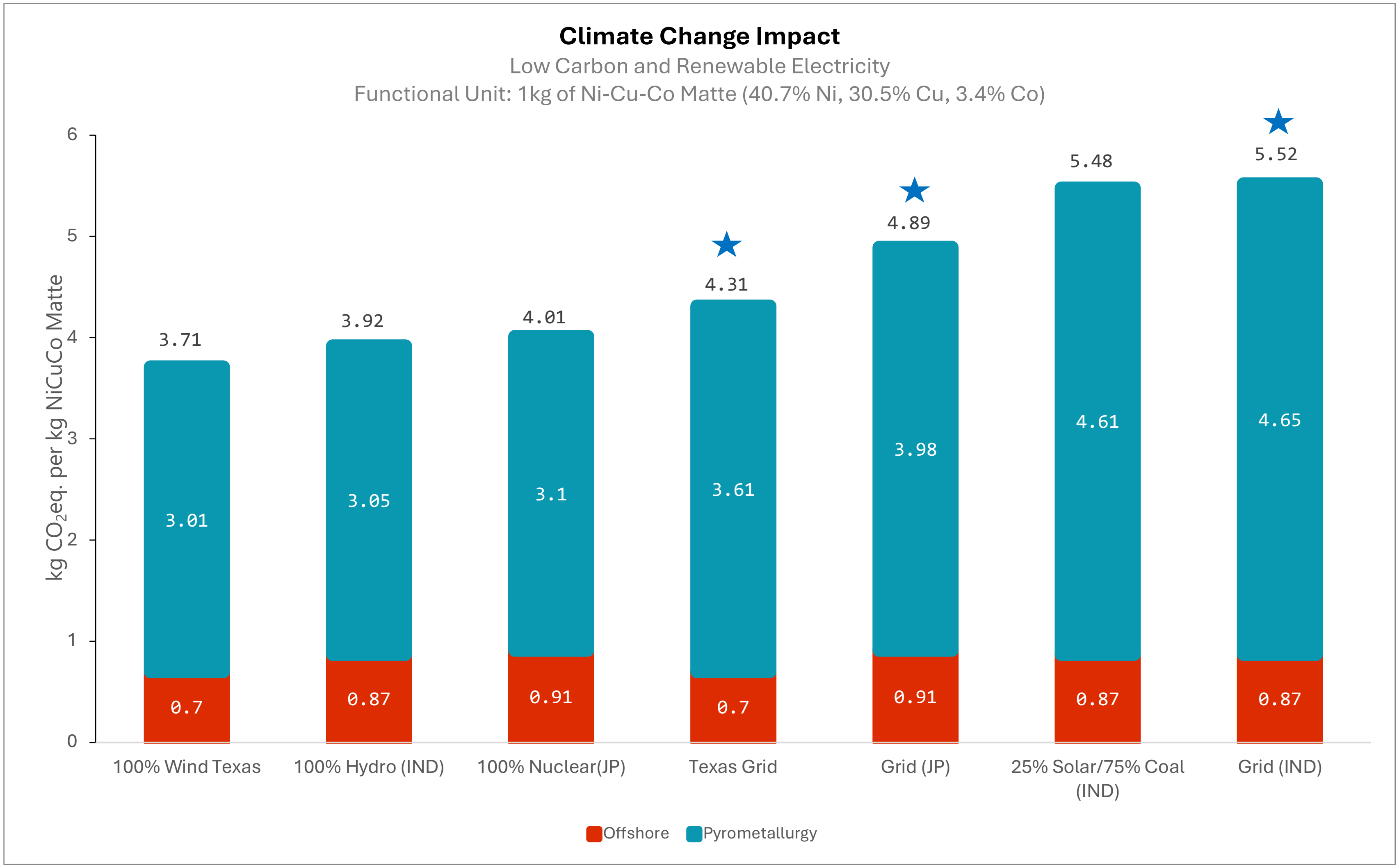

Figure E 11: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of NiCuCo Matte, net results.
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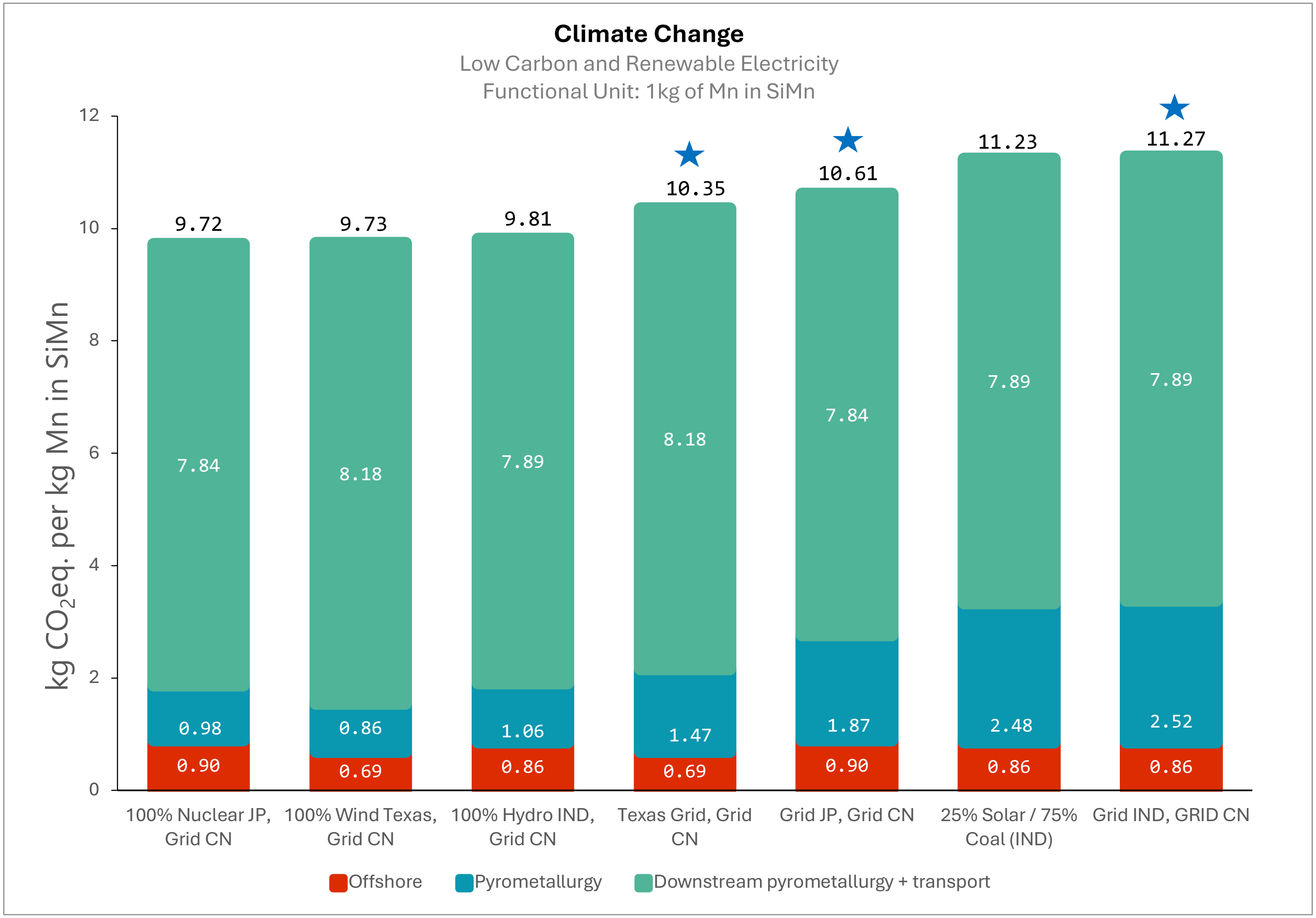

Figure E 12: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Mn in SiMn, net results. ★ *= base case*

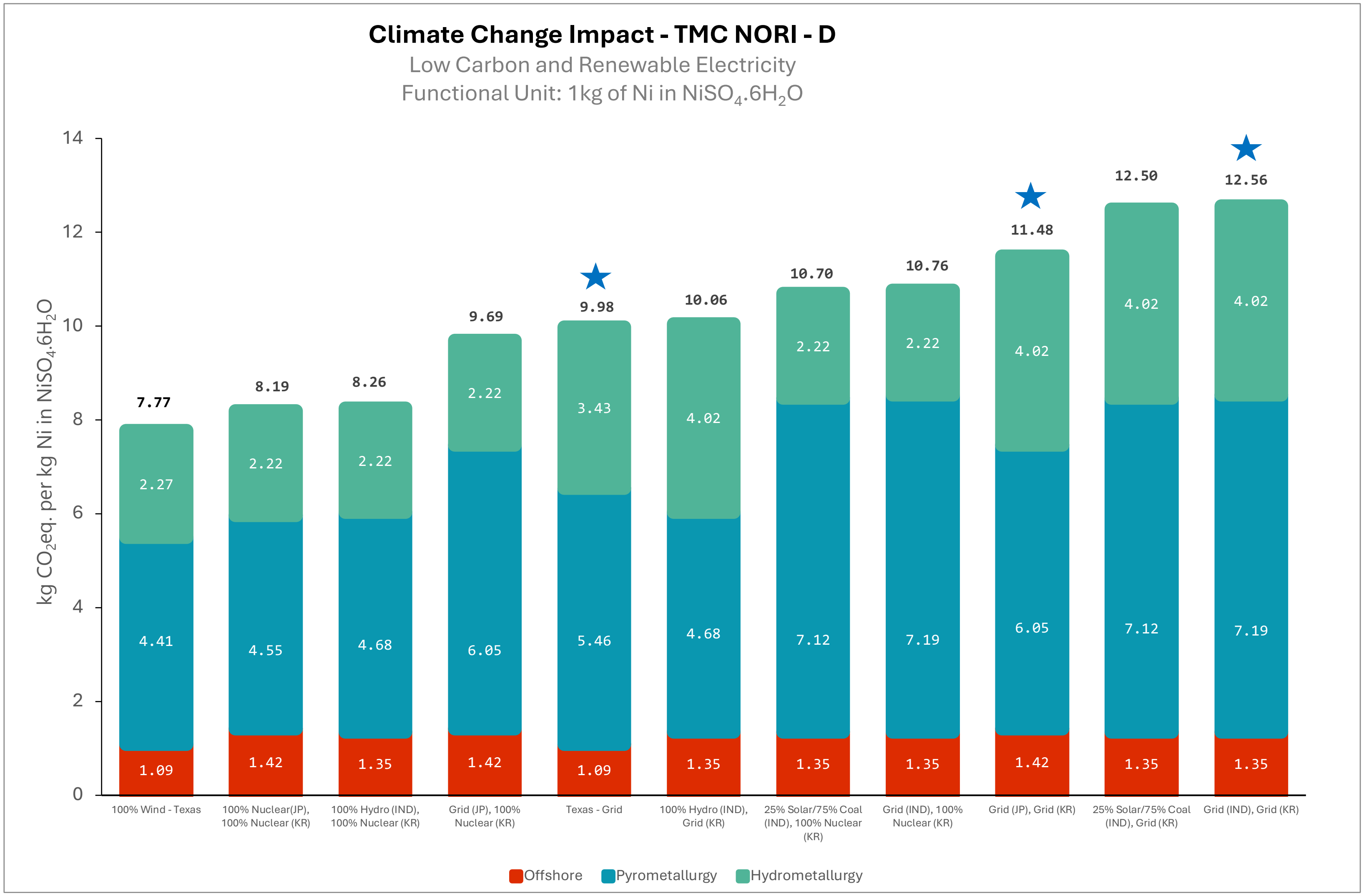

Figure E 13: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Ni in $NiSO_4.6H_2O$, net results.
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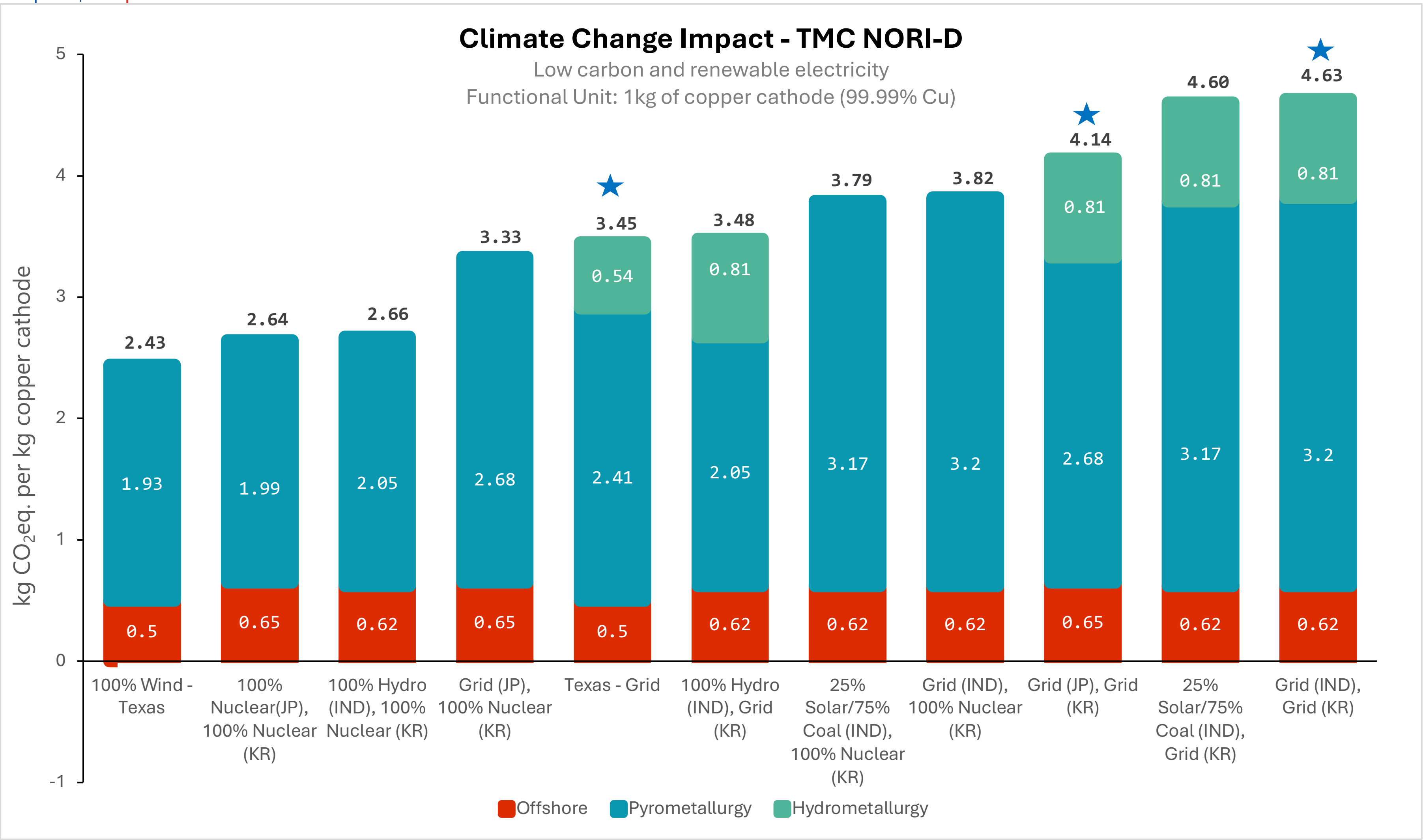

Figure E 14: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Copper Cathode, net results.

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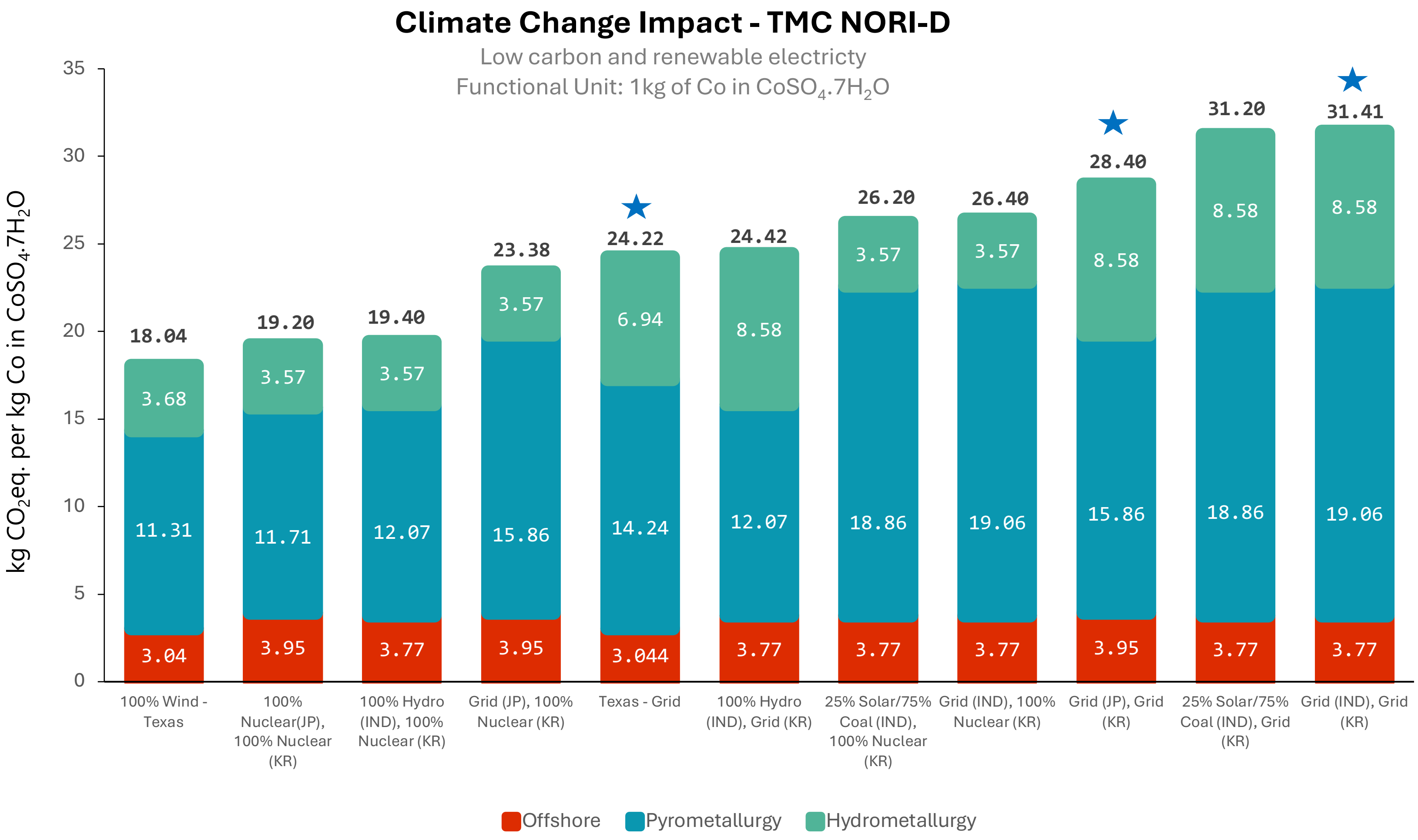

Figure E 15: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Co in $CoSO_4.7H_2O$, net result.
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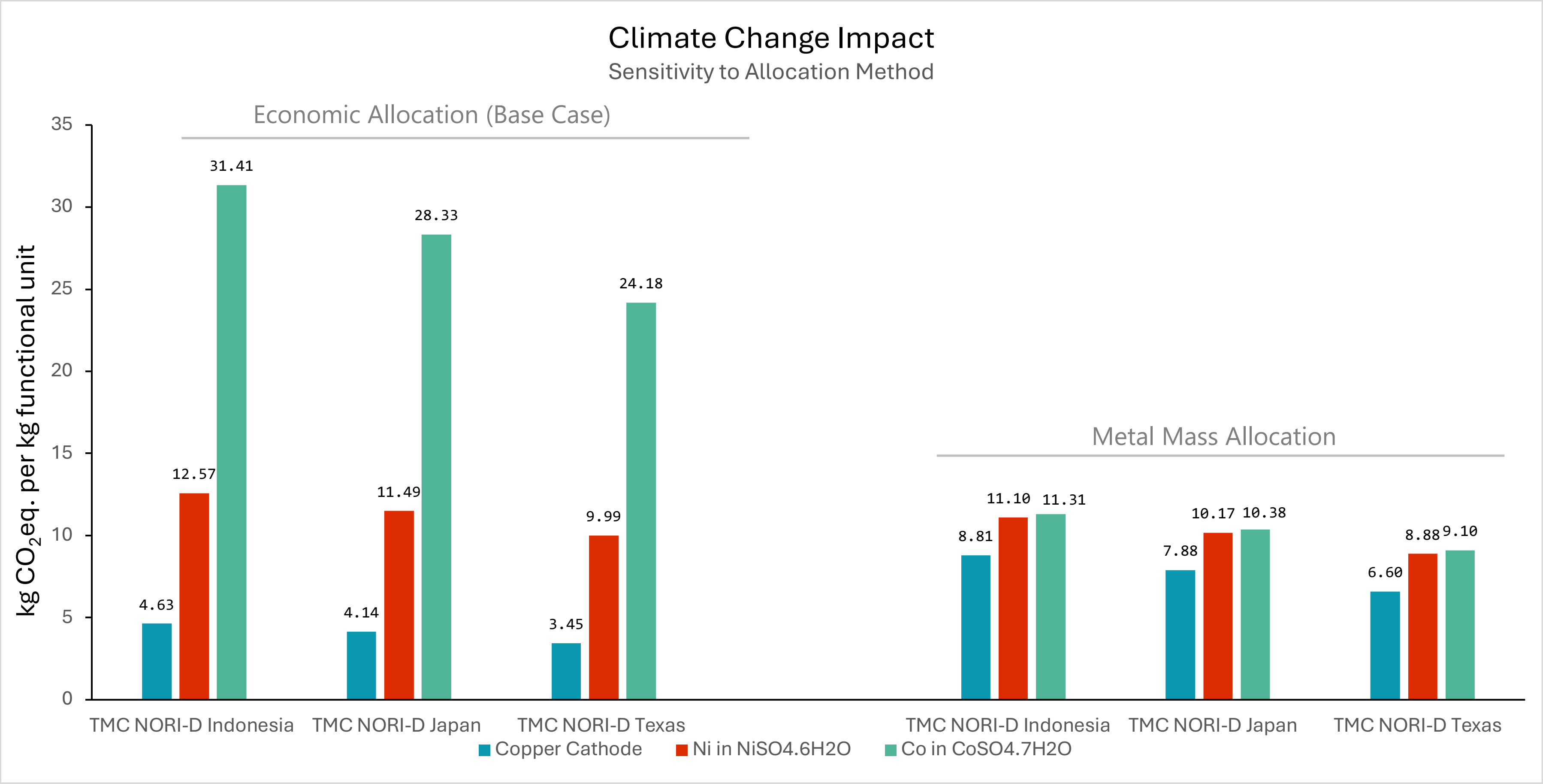


Figure E 16:Sensitivity Analysis – Economic vs Metal Mass Allocation

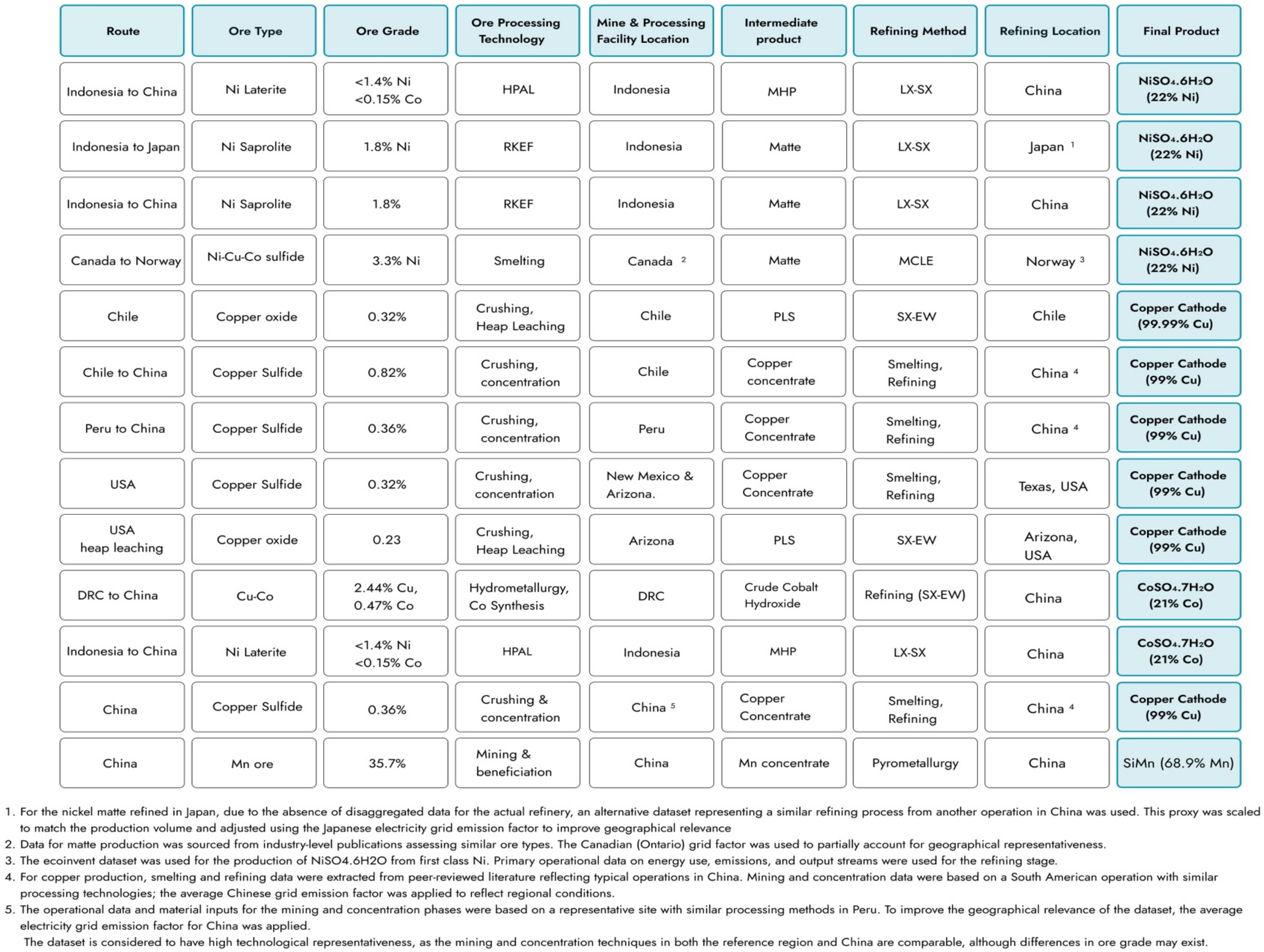
II.III Terrestrial Comparisons

For the terrestrial comparisons each route was based on the best available data which can be found in credible, published literature sources such as company and governmental reports. Where data was not available, mass and energy balances, or proxy data was used. Key details on each route such as ore grade and technology are shown in Table E5.

The chosen routes are used to display the environmental impacts for producing the respective product using the stated technologies. The selection of the routes reflects the most common current pathways for sourcing these metals, while also including a few lower-impact routes for comparison, providing a broader and more balanced perspective. However, the impacts of the same product produced using the same technologies may vary depending on parameters such as technological efficiencies, geographies, power sources, ore grades, etc.

As the products being produced from TMC's product system and the terrestrial systems are similar, the functional units, performance, and reference flows for the analyzed products are all the same. The terrestrial comparisons were modelled using the same methodological considerations such as allocation procedure, and impact assessment method. Like TMC's product system, the system boundary for each terrestrial route is cradle-to-gate. The climate change impact results of each route are shown in Figures E17 – E20.

Table E 5: Processing technologies and location of each product produced via land-based routes used for the terrestrial comparisons.



Route	Ore Type	Ore Grade	Ore Processing Technology	Mine & Processing Facility Location	Intermediate product	Refining Method	Refining Location	Final Product
Indonesia to China	Ni Laterite	<1.4% Ni <0.15% Co	HPAL	Indonesia	MHP	LX-SX	China	**$NiSO_4.6H_2O$ (22% Ni)**
Indonesia to Japan	Ni Saprolite	1.8% Ni	RKEF	Indonesia	Matte	LX-SX	Japan [1]	**$NiSO_4.6H_2O$ (22% Ni)**
Indonesia to China	Ni Saprolite	1.8%	RKEF	Indonesia	Matte	LX-SX	China	**$NiSO_4.6H_2O$ (22% Ni)**
Canada to Norway	Ni-Cu-Co sulfide	3.3% Ni	Smelting	Canada [2]	Matte	MCLE	Norway [3]	**$NiSO_4.6H_2O$ (22% Ni)**
Chile	Copper oxide	0.32%	Crushing, Heap Leaching	Chile	PLS	SX-EW	Chile	**Copper Cathode (99.99% Cu)**
Chile to China	Copper Sulfide	0.82%	Crushing, concentration	Chile	Copper concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
Peru to China	Copper Sulfide	0.36%	Crushing, concentration	Peru	Copper Concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
USA	Copper Sulfide	0.32%	Crushing, concentration	New Mexico & Arizona.	Copper Concentrate	Smelting, Refining	Texas, USA	**Copper Cathode (99% Cu)**
USA heap leaching	Copper oxide	0.23	Crushing, Heap Leaching	Arizona	PLS	SX-EW	Arizona, USA	**Copper Cathode (99% Cu)**
DRC to China	Cu-Co	2.44% Cu, 0.47% Co	Hydrometallurgy, Co Synthesis	DRC	Crude Cobalt Hydroxide	Refining (SX-EW)	China	**$CoSO_4.7H_2O$ (21% Co)**
Indonesia to China	Ni Laterite	<1.4% Ni <0.15% Co	HPAL	Indonesia	MHP	LX-SX	China	**$CoSO_4.7H_2O$ (21% Co)**
China	Copper Sulfide	0.36%	Crushing & concentration	China [5]	Copper Concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
China	Mn ore	35.7%	Mining & beneficiation	China	Mn concentrate	Pyrometallurgy	China	SiMn (68.9% Mn)

1. For the nickel matte refined in Japan, due to the absence of disaggregated data for the actual refinery, an alternative dataset representing a similar refining process from another operation in China was used. This proxy was scaled to match the production volume and adjusted using the Japanese electricity grid emission factor to improve geographical relevance
2. Data for matte production was sourced from industry-level publications assessing similar ore types. The Canadian (Ontario) grid factor was used to partially account for geographical representativeness.
3. The ecoinvent dataset was used for the production of NiSO4.6H2O from first class Ni. Primary operational data on energy use, emissions, and output streams were used for the refining stage.
4. For copper production, smelting and refining data were extracted from peer-reviewed literature reflecting typical operations in China. Mining and concentration data were based on a South American operation with similar processing technologies; the average Chinese grid emission factor was applied to reflect regional conditions.
5. The operational data and material inputs for the mining and concentration phases were based on a representative site with similar processing methods in Peru. To improve the geographical relevance of the dataset, the average electricity grid emission factor for China was applied.
   The dataset is considered to have high technological representativeness, as the mining and concentration techniques in both the reference region and China are comparable, although differences in ore grade may exist.

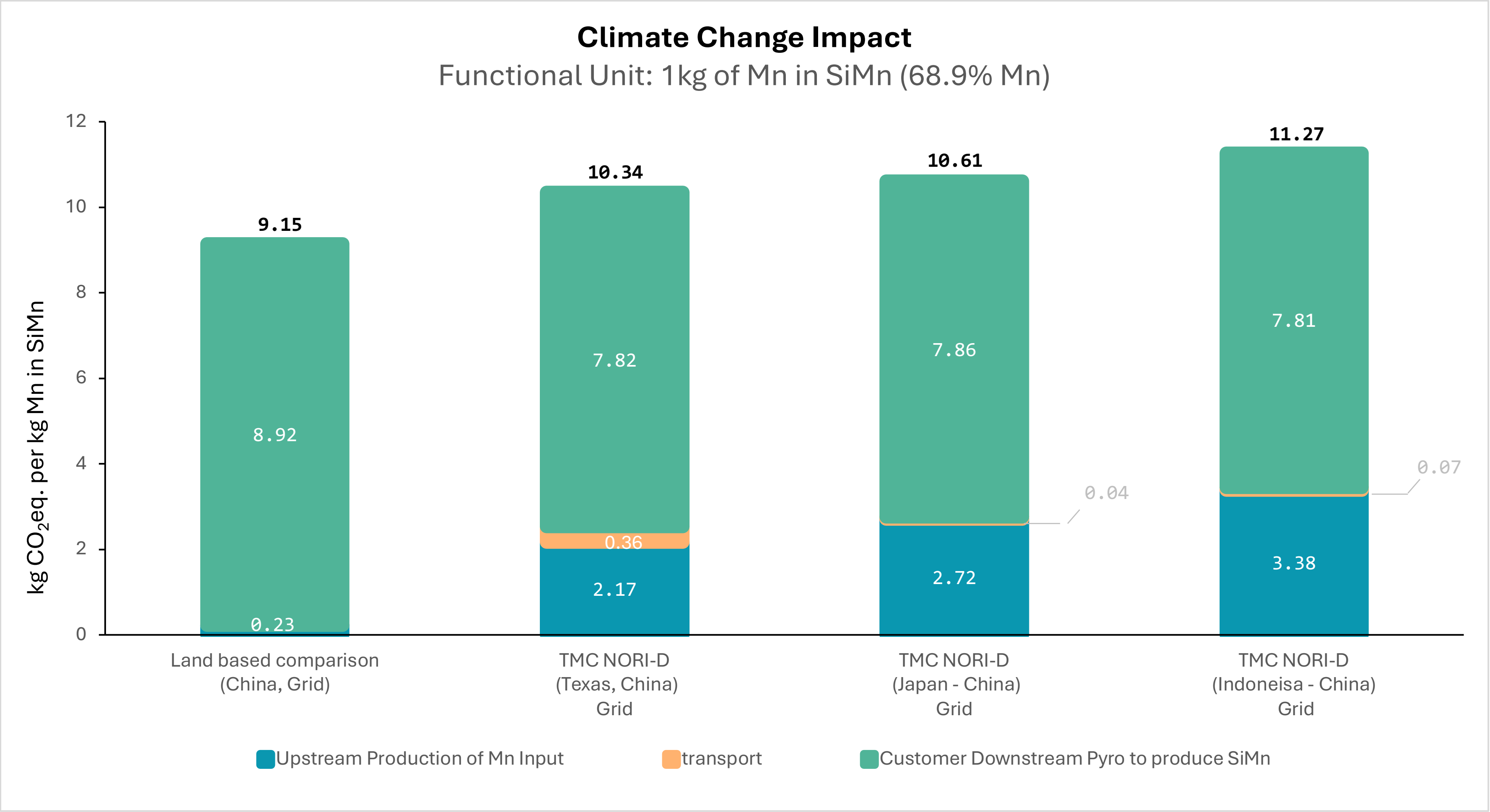


Figure E 17: Comparison of the climate change impact from the production of 1kg of Mn in SiMn produced using traditional manganese ores vs TMC's $MnSiO_3$, net results.

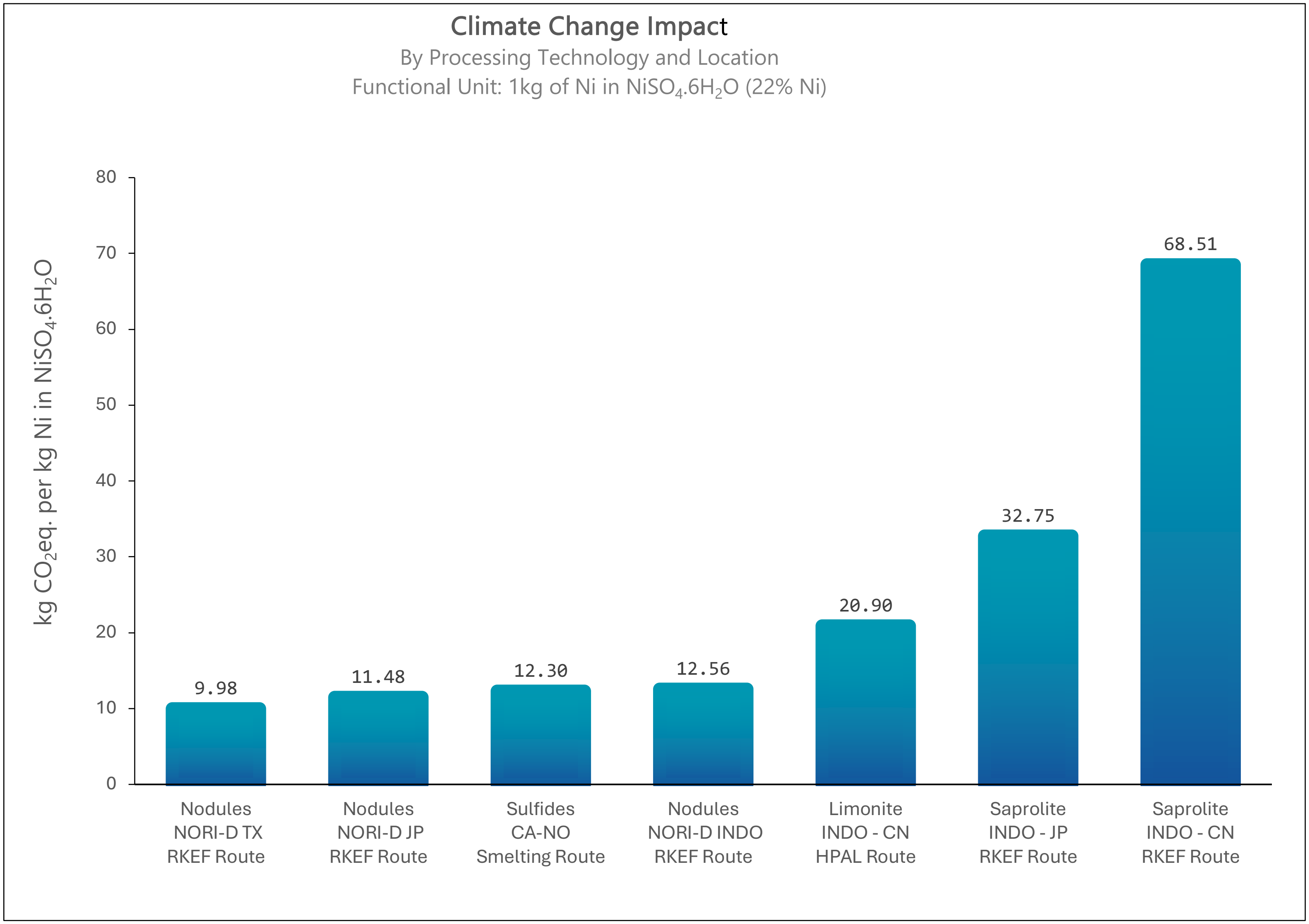


Figure E 18: Comparison of the climate change impact of 1 kg of Ni in NiSO4.6H2O produced via various land-based routes vs TMC's NORI-D processing routes, net results.

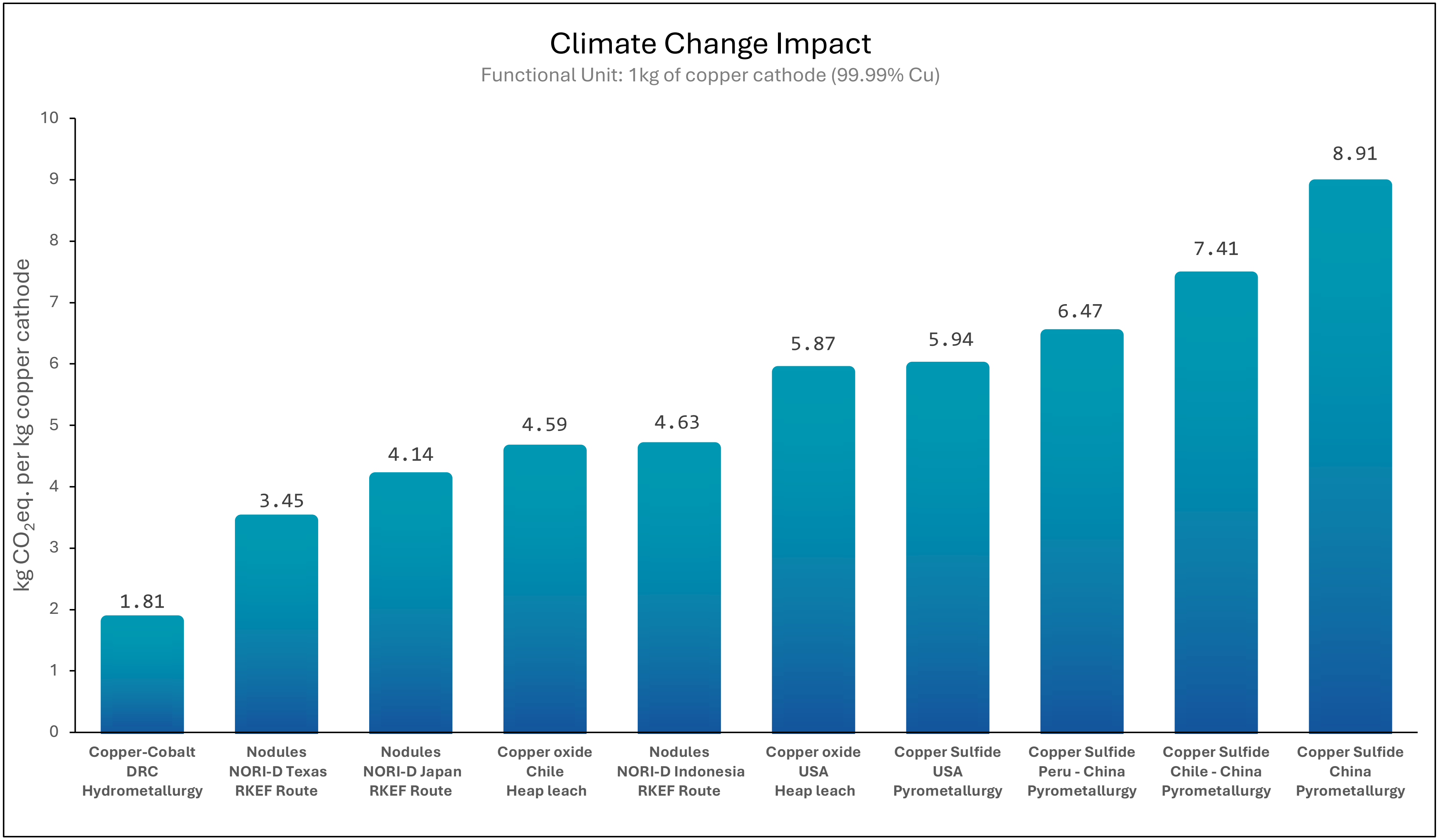


Figure E 19: Comparison of the climate change impact of 1 kg of copper cathode produced via various land-based routes vs TMC's NORI-D processing routes, net results.

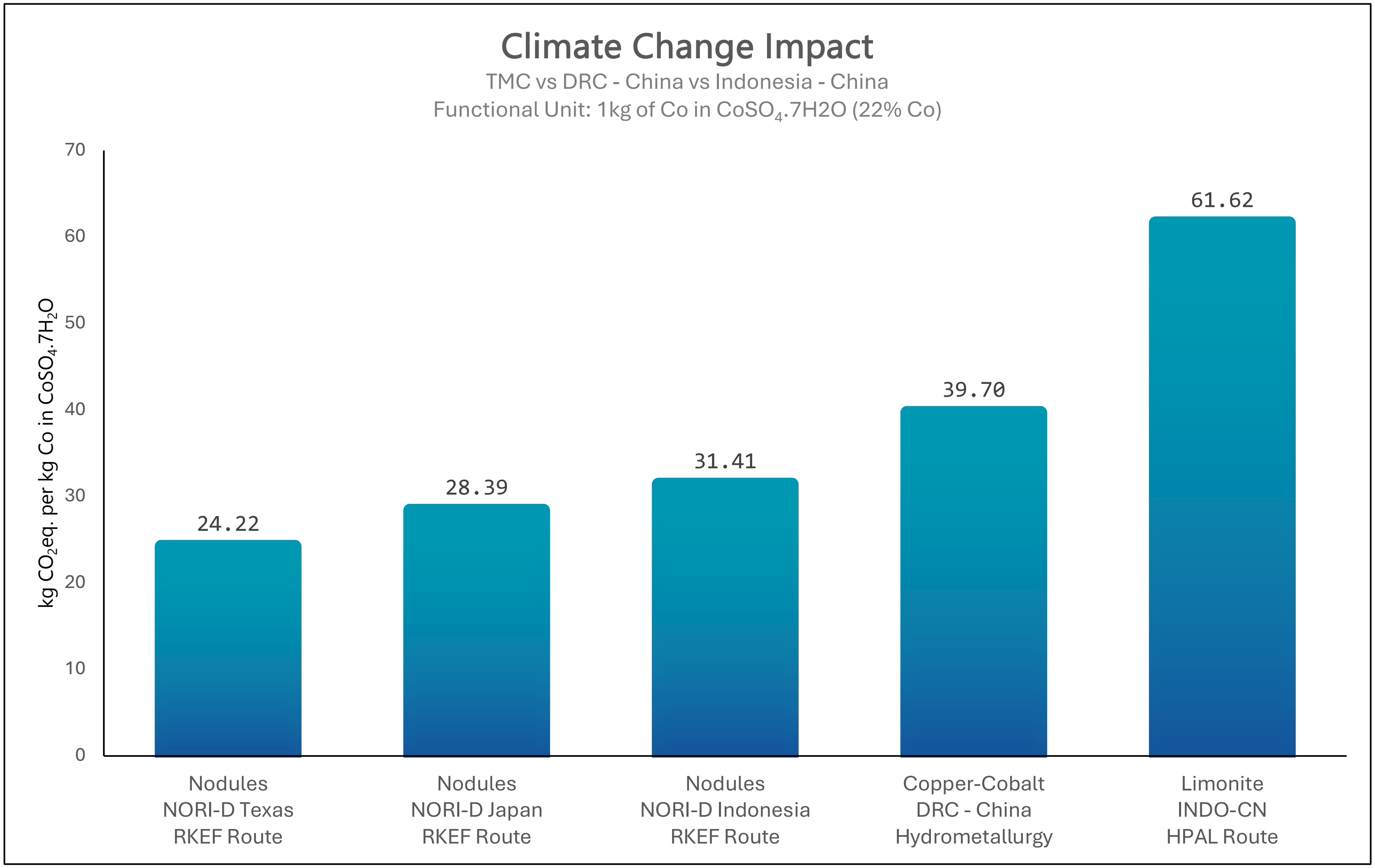


Figure E 20: Comparison of the climate change impact of 1 kg of Co in CoSO4.7H2O produced via various land-based routes vs TMC's NORI-D processing routes, net results.

Glossary

CA	Canada
CAPEX	Capital Expenditure
CCZ	Clarion Clipperton Zone
CN	China
$CoSO_4.7H_2O$.	Cobalt sulfate heptahydrate
CO_2	Carbon dioxide
Cu cathode	Copper cathode
DRC	Democratic Republic of Congo
EF	Environmental Footprint
eq.	Equivalents
EV	Electrical Vehicle
GHG	Greenhouse Gas
HPAL	High Pressure Acid Leaching
INDO	Indonesia
ISO	International Organisation for Standardization
JP	Japan
kg	kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LX-SX	Leaching-Solvent Extraction
LX-SX-EW	Leaching-Solvent Extraction-Electrowinning
MCLE	Matte Chlorine Leaching
MHP	Mixed-Hydroxide Precipitate
Mn	Manganese
$MnSiO_3$	Manganese metasilicate
Mtpa.	Million tonnes per annum

$NiSO_4.6H_2O$	Nickel sulfate hexahydrate
Ni-Cu-Co	Nickel-Copper-Cobalt
NI 43-101	National Instrument 43-101
NO	Norway
NORI-D	Nauru Ocean Resources Incorporated - Section D
P eq.	Phosphorous Equivalent
PFS	Pre-Feasibility Study
RKEF	Rotary Kiln-Electric Furnace
SiMn	Silico-Manganese
SK	South Korea
TMC	The Metals company
TX	Texas
USA	United States of America
USA TRE	United States of America Texas Regional Entity

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1. Introduction

1.1 Background

According to the U.S Geological Survey (USGS), mineral deposits on the ocean floor in the Clarion Clipperton Zone (CCZ) alone eclipses those found in global terrestrial reserves[1]. These deep-sea deposits can be put into 3 main categories, polymetallic nodules, seafloor sulphides, and cobalt-rich crusts.[2]

The metals company is a deep-sea mining and exploration company who seeks to produce base metals from polymetallic nodules found on the deep seafloor in the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean, an area which contains a significant source of polymetallic nodules containing nickel, copper, cobalt, and manganese. The produced raw materials can be used for infrastructure, power generation, transmission, and batteries.

TMC commissioned environmental consultancy Ecoquant on March 3rd 2025 to perform a life cycle assessment on their full process for the NORI-D polymetallic nodules project from the collection of nodules on the seabed to the production of their products, namely, $MnSiO_3$, Ni-Cu-Co matte, copper cathode, nickel sulphate hexahydrate ($NiSO_4.6H_2O$) and cobalt sulphate heptahydrate ($CoSO_4.7H_2O$).

The study also extends the system boundary of TMC to include the production of silicomanganese (SiMn) from TMC's $MnSiO_3$ which will be performed by TMC's customers in the steel industry. Furthermore, the study contains a life cycle comparison on the production of TMC's products and SiMn produced from TMC's $MnSiO_3$ from the NORI-D polymetallic nodules project against the same products produced via terrestrial routes.

This study was conducted according to ISO-14040:2006 and ISO-14044:2006 supplemented with other sectoral specific standards and the greenhouse gas protocol product standard.

1.2 Life Cycle Assessment Overview

Life Cycle Assessment (LCA) is a systematic methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle. This involves modeling each process involved—from raw material extraction to disposal—considering the materials and energy consumed, as well as the emissions and waste generated. LCA is the most widely accepted and comprehensive approach for measuring environmental performance and is standardized under ISO 14040/44:2006. According to the ISO 14040 standard, conducting an LCA involves four key phases: goal and scope definition, inventory analysis, impact assessment, and interpretation (Figure 1).[3,4]

The goal sets the context of the study, defining its purpose, the intended audience, and how the results will be used. The scope outlines the level of detail and establishes the system boundaries, specifying which processes and activities are included or excluded. It also defines the functional unit and the geographical and temporal coverage of the study.

In the inventory analysis phase, data is compiled and analyzed to quantify inputs such as resources extracted from the environment and outputs such as emissions and waste released back into it. The results of this phase form the basis for the life cycle impact assessment (LCIA).

The LCIA phase translates the inventory data into environmental impacts by assigning the life cycle inventory (LCI) results to impact categories. For each category (e.g., climate change, acidification), an appropriate impact category indicator is selected, and an indicator result is calculated to represent the potential environmental consequences.[5]

The results of the impact assessment are then evaluated in the final phase, known as the interpretation phase. Here, key findings such as environmental hotspots and significant issues are identified. The quality of the data and results are critically assessed, and uncertainties and limitations are evaluated. Like the others, this phase is iterative, meaning it may lead to revisiting earlier phases to refine assumptions, improve data quality, or adjust the system boundaries to ensure robust and consistent conclusions.[5]

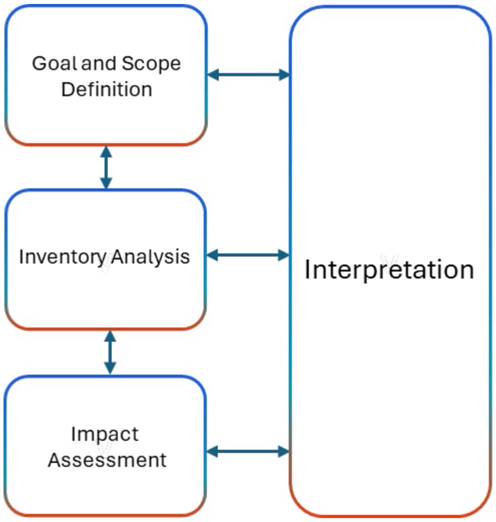


Figure 1: Life Cycle Assessment Framework

2. Goal

TMC commissioned life cycle assessment services from Ecoquant for the purpose of quantifying and reporting aspects of the environmental impacts associated with the production of their products from the NORI-D Polymetallic Nodules Project. The aspects quantified are the LCIA categories available in the EF 3.11 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A. The assessment is from a cradle-to-gate life cycle perspective. This report also presents cradle-to-gate life cycle comparisons of TMC products from the NORI-D Polymetallic Nodules Project with equivalent products produced via key terrestrial production routes that account for a significant share of global supply. The goals of the study are:

- To quantify aspects (as defined) of the environmental impacts associated with the production of 1kg of $MnSiO_3$, Ni-Cu-Co Matte, $NiSO_4.6H_2O$, copper cathode, $CoSO_4.7H_2O$, and the impact associated with the collection and processing of 1kg of dry nodules from the NORI-D Polymetallic Nodules Project.

- To quantify aspects (as defined) of the environmental impacts associated with the production of SiMn using TMC's $MnSiO_3$ from the NORI-D Polymetallic Nodules Project.

- To compare the difference in the environmental impacts of producing TMC's products from the NORI-D Polymetallic Nodules Project versus the same products produced via traditional terrestrial routes. Including the environmental impacts of producing SiMn from terrestrial manganese ores. The comparisons are made along the same aspects defined above.

It should be noted that while producing SiMn is not part of TMC's NORI-D Project scope, the project produces $MnSiO_3$, a pre-reduced intermediate. This intermediate product is expected to lower downstream emissions for those producing SiMn from conventional land-based manganese ores. Therefore, TMC was interested to understand the lifecycle emissions from mining to downstream production of SiMn.

This study does not measure the environmental impacts on the seabed or deep-sea ecosystems from nodule collection, nor does it adequately capture the full scope of impacts on forest and other ecosystems from terrestrial mining activities such as deforestation and large-scale impoundment. The life cycle assessment methodology currently lacks a methodologically sound framework for adequately quantifying these impacts[6,7]; thus, this should be considered a limitation of this study.

TMC has an environmental research program that assesses the impacts of their operations on the ecosystem in NORI-D. This involves data collection through multiple offshore campaigns followed by analysis by academic and industry organizations. This LCA report is only one of the studies that TMC will use to get a better understanding on aspects of their environmental impact while comparing those aspects to similar products produced via traditional land-based routes. Thus, the intended application of this study is to provide TMC with additional environmental impact insights of their production process and highlight emission reduction pathways through scenario/sensitivity analyses. Further applications include comparing the environmental impacts of the NORI-D project to current terrestrial alternatives.

While all impact categories assessed in this report are valuable, climate change is one that LCA methodologies do particularly well. In addition to its global urgency, universal relevance, and public focus, it is widely recognized as the most established impact category and benefits from global frameworks and guidance's such as the greenhouse gas (GHG) protocol and ISO 14067. As a result, the GHG emission data generated in this this study can be used as a part of TMC's application for an exploration and commercial recovery/permit license. Accordingly, the climate change impact category will receive the most detailed interpretation in this report, including contribution, sensitivity, and scenario analyses.

The target audience of this study includes regulators, investors, customers, and anyone interested in deep-sea mining. Ecoquant recognizes the debate on the technology that is studied in this report and the possibility of selective use of individual data to support claims. As the target audience includes anyone interested in deep-sea mining, it should be noted that the authors and commissioning party do not assume responsibility for the interpretations made by parties who lack the necessary technical background. Misinterpretation or selective use of individual findings outside the context of the complete study may lead to inaccurate conclusions. A summarized, third-party version of this report will be prepared by the commissioner of this study for communication purposes.

3. Scope

The following sections examine the product system studied, including the function of the system, functional units, system boundary, allocation procedures, LCIA methodology and type of impacts covered, limitations, and type of critical review performed.

3.1 Product System

Deep-sea nodules from the Clarion-Clipperton Fracture Zone (CCZ) in the Pacific Ocean represent the largest known resource of nickel, cobalt and manganese[1]. TMC has identified this opportunity and developed a metallurgical flowsheet based on existing technologies to process these key metals from the nodules to high value products once collected. The produced metals will aid in meeting the rising demand for infrastructure and energy transition technologies. Unlike terrestrial mining which produces large volumes of waste, deep-sea nodules lie unattached on the seafloor, thus their collection is not associated with the generation of waste and overburden.[8] TMC's offshore nodule collection in the CCZ, transport to onshore, and processing of the nodules onshore to refined products comprise the product system under study.

TMC has a NI 43-101 compliant Preliminary Economic Assessment and SK-1300 compliant Initial Assessment for the aforementioned product system, and a further internal Pre-Feasibility Study (PFS) for the year 2025 for the NORI-D Project scenario which is analyzed in this report. Key details of the PFS for the NORI-D Project Scenario can be found in table 1. TMC's onshore processing consists of a high temperature pyrometallurgical circuit followed by a hydrometallurgical circuit. This study examines the environmental impact when the nodules are processed to produce refined products at each location. This is important for TMC as they will be able to use these results to communicate the environmental impact of their products to their customers depending on processing location. One of TMC's sold products ($MnSiO_3$) is an intermediate Mn product that will undergo further downstream processing by customers. The impacts of this downstream processing are also analyzed. Key details of the PFS for the NORI-D Project Scenario such as product/intermediate production and processing locations can be found in Tables 1-3. Differences between this LCA study and a previous LCA study conducted for the TMC NORI-D project is summarized in Table 4.

Table 1: TMC NORI-D: Offshore details

	Location	Annual Collection (wet)	Annual Collection (dry)
TMC NORI-D Nodule Collection	Clarion Clipperton Zone (CCZ)	12.0 Mtpa	8.64 Mtpa

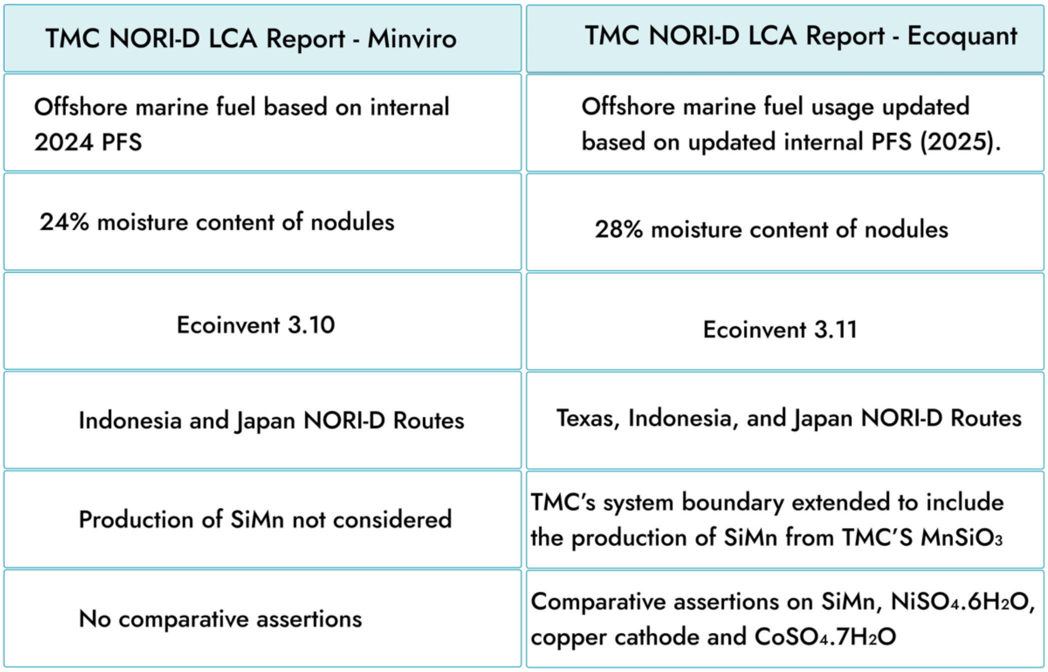
Table 2: TMC NORI-D: Onshore details

	Onshore Pyro Locations	**Products**	**Electricity Generation sources**	**Onshore Hydro Location**	**Products**	**Electricity Generation sources**
TMC NORI-D Indonesia	Indonesia	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**IND. Grid** o 63% Coal o 23% natural gas o 7% hydropower o 7% other	South Korea	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	South Korea Grid o 34% nat gas. o 33% coal o 28% Nuclear o 2% Hydro o 3% other
TMC NORI-D Japan	Japan	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**JP Grid** o 35% nat.gas o 31% coal o 9% solar o 9% hydro o 9% nuclear o 7% other	South Korea	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	South Korea Grid o 34% nat gas. o 33% coal o 28% Nuclear o 2% Hydro o 3% other
TMC NORI-D Texas	Texas	o $MnSiO_3$ o Ni-Cu-Co Matte o Converter slag	**US-TRE grid** o 49% Nat. Gas o 24% Wind o 17% Coal o 10% other	Texas	o $NiSO_4.6H_2O$ o $CoSO_4.7H_2O$ o Cu Cathode o Ammonium sulfate	**US-TRE grid** o 49% Nat. Gas o 24% Wind o 17% Coal o 10% other

Table 3: Details on downstream processing of TMC's $MnSiO_3$

Downstream processing of TMC's $MnSiO_3$	**Products**	**Electricity Generation sources**
China	SiMn	**CN. Grid** · 62% coal · 15% hydro · 8.5% wind · 4.7% Nuclear · 9.8% other

Table 4: Differences between previous TMC NORI-D LCA Study and this study.



TMC NORI-D LCA Report - Minviro	TMC NORI-D LCA Report - Ecoquant
Offshore marine fuel based on internal 2024 PFS	Offshore marine fuel usage updated based on updated internal PFS (2025).
24% moisture content of nodules	28% moisture content of nodules
Ecoinvent 3.10	Ecoinvent 3.11
Indonesia and Japan NORI-D Routes	Texas, Indonesia, and Japan NORI-D Routes
Production of SiMn not considered	TMC's system boundary extended to include the production of SiMn from TMC'S $MnSiO_3$
No comparative assertions	Comparative assertions on SiMn, $NiSO_4.6H_2O$, copper cathode and $CoSO_4.7H_2O$

3.2 System Boundary

The study is a cradle-to-gate study, meaning it evaluates the impacts of all inputs and outputs from raw material extraction up to the point of production of the product(s) under study. This system boundary is considered appropriate as it aligns with the goal of quantifying the environmental impacts associated with producing TMC's products. The system boundary for the NORI-D project, including downstream processing of $MnSiO_3$, is shown in Figure 2.

Table 5 summarizes inclusions and omissions from the system boundary. In general, only the inputs/outputs which are material to the production of the products are included in the system boundary. Other activities linked to company operations that are not specific to the production of products should be included in the corporate scope 3 inventories.

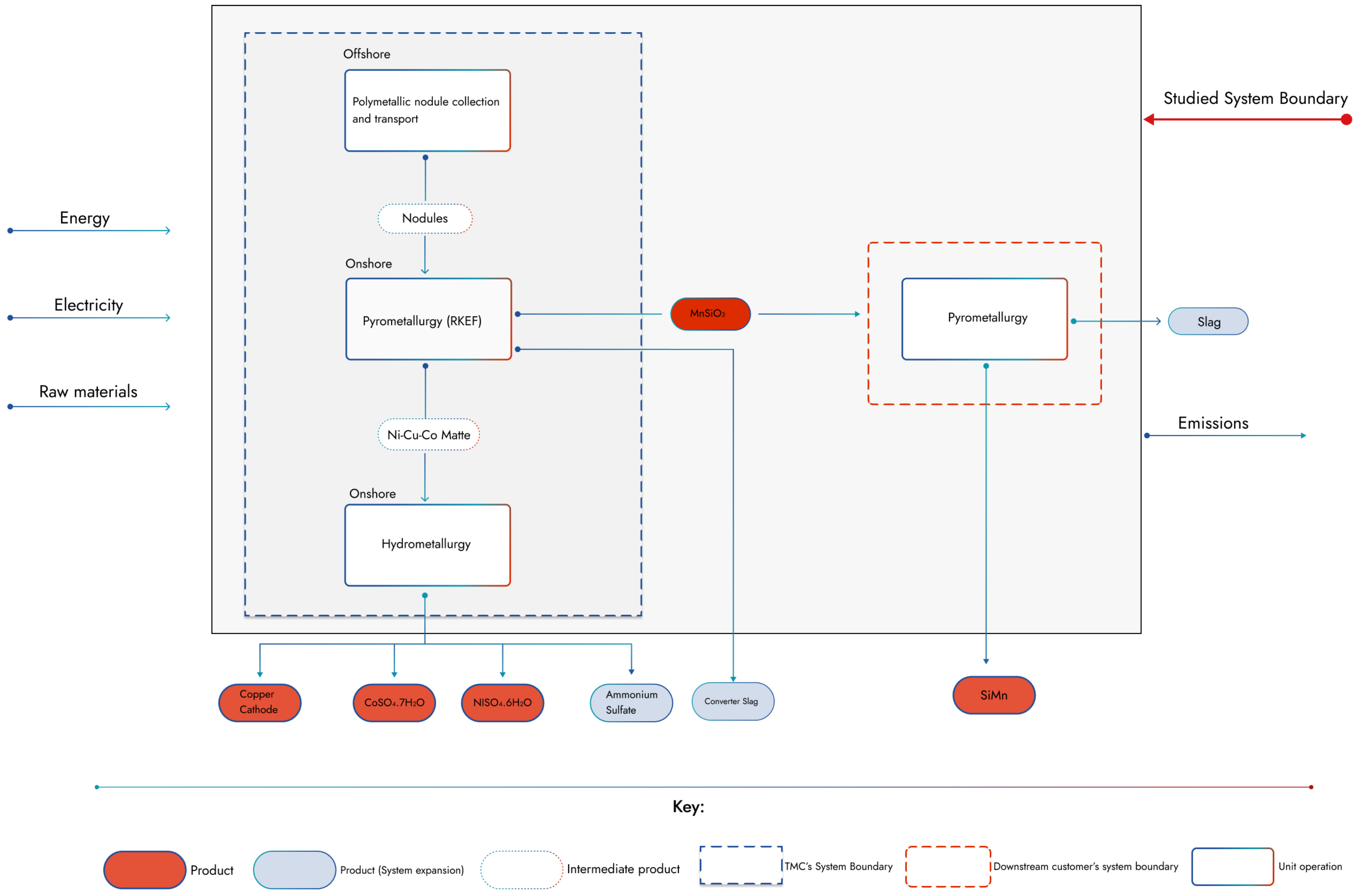


Figure 2: Analyzed system boundary, including TMC's system boundary and the system boundary of downstream customers.

Table 5: Table of inclusions and omissions from TMC's system boundary

Included in system boundary	Omitted from system boundary
· All inputs and outputs including raw materials, energy, and emissions for the production of $MnSiO_3$, Ni-Cu-Co matte, SiMn, $NiSO_4.6H_2O$, copper cathode, $CoSO_4.7H_2O$, ammonium sulfate, and slags. · Marine fuel used in the nodule collection process and the transport of the nodules to onshore processing facilities. · Transport of matte from Indonesia or Japan to south Korea for refining. · Transport of $MnSiO_3$ to China for downstream processing.	· Capital goods and infrastructure such as the production of offshore vessels and mining machinery. · Treatment of residues formed during hydrometallurgical processing. · Packaging materials · Sediment and other impacts from dislodging of nodules on the seafloor. · Business travel by personnel · Travel to and from offshore vessels and onshore locations · Maintenance of machinery

3.3 Functional Unit & Reference Flows

The functional unit provides the reference to which the input (materials and energy) and output (such as products, byproducts, waste) are quantified. The functional unit is also essential to ensure that systems with matchable functions are compared. The reference flow is the amount of product needed from the system to fulfill the functional unit. Typically, the reference flow matches the functional unit when the product system delivers the function directly without transformations, scaling, or additional services, as is the case with this study. To align with the goals and intended application of this study, the functional units, and consequently reference flows, were chosen as:

- 1kg of dry nodules collected and processed
- 1kg of Mn in $MnSiO_3$ (40% Mn)
- 1kg of Ni-Cu-Co Matte (40.7% Ni, 30.5% Cu, 3.4% Co)
- 1kg of Mn in SiMn (68.9% Mn)
- 1kg of Ni in $NiSO_4.6H_2O$ (22% Ni)
- 1kg of copper cathode (99.99% Cu)
- 1kg of Co in $CoSO_4$.7H2O (21% Co)

3.4 Product Function

The evaluated products are $MnSiO_3$, Ni-Cu-Co matte, SiMn, $NiSO_4.6H_2O$, Copper cathode, and $CoSO_4.7H_2O$. Each of these products serve a distinct function:

- $MnSiO_3$: The Mn contained in TMC's $MnSiO_3$ is integral to global steelmaking and construction and will support in strengthening the materials that make bridges, buildings, railways and other infrastructure.[9] TMC's $MnSiO_3$ can also be used as a precursor to produce SiMn.
- SiMn: Silicomanganese is a useful alloy in the steel industry functioning as an alloying element to purify, strengthen, and improve the properties of steels and cast irons.
- Ni-Cu-Co matte: The matte is rich in Ni, Cu, and Co, and undergoes further processing via hydrometallurgy to produce refined nickel, copper, and cobalt products.
- $NiSO_4.6H_2O$: This product plays a key role in battery technologies as it functions as a key component for energy storage and electric mobility, enabling greater storage capacity and longer range for EV's. This product is also used in electroplating and also used for other nickel-based compounds used in industrial processes like catalysis, textile dyeing, and agriculture.[10]

- Copper cathode: From vehicle chargers to high-voltage lines, copper enables the flow of electricity and supports the infrastructure powering the energy transition. This product will also play a key role in battery technologies for energy storage.
- $CoSO_4.7H_2O$: This product also plays a key role in battery technologies as it enhances the energy density, safety, and lifespan of batteries used in everything from grid storage to EVs. It is also used in electroplating, the paint industry, and as a catalyst.[11]

3.5 Product System boundary description

NORI-D project polymetallic nodules are found scattered on the ocean floor, unattached, at depths nearing 4500 meters within the abyssal plains of the CCZ. These nodules are made up of a central core surrounded by layered deposits of manganese and iron hydroxides. They form over time through the gradual accumulation of metals from both the seawater and the water found in sediment pores. Valuable elements like nickel, cobalt, and copper are integrated within the mineral structure during this process.

3.5.1 Offshore operations

The offshore operations involve a combination of specialized machinery and vessels. Key components include tracked underwater collector vehicles, a riser system, and several types of vessels such as production, support, and transfer ships. The collection process begins with the remotely operated vehicles, which are powered by electricity supplied through umbilical cables from surface vessels. These vehicles use water jets to lift the nodules from the seabed. At the depths of the operations, there is no/very minimal amounts of CO_2 that is released to the surface. The nodules, along with some water and sediment, form a slurry that is gathered by the collectors. Within the vehicle, more than 90% of the sediment is filtered out and discharged from the collector back to the seafloor without any chemical change. A dilute slurry is then pumped up through a steel riser pipe using an airlift system to bring it to the surface. Once topside, the nodules are dewatered, transferred to another ship and eventually loaded onto bulk carriers, which transport them to designated facilities for further processing. Offshore operations are fully fueled with marine gas oil

(MGO). The production vessel uses the ships power plant and diesel generator that provide electricity for vessel operations, the collector vehicles, and compressor.

3.5.2 Onshore Processing – Pyrometallurgy

The initial processing of the nodules follows a high-temperature treatment pathway, starting with the use of a Rotary Kiln Electric Furnace (RKEF). This step is followed by sulphidation and conversion to produce a sulfide matte.

The pyrometallurgical stage produces several by-products. Firstly, a manganese-rich silicate ($MnSiO_3$) from the RKEF process, which has potential use in the production of silicon-manganese alloys. Secondly a fayalite slag from the later converting stage, which may be utilized in road construction as an aggregate. Finally, the main metal product—a matte containing nickel, copper, and cobalt, which is sent for further refining through hydrometallurgical methods to yield high-purity metals.

3.5.2.1 Rotary Kiln Electric Furnace (RKEF) Process

Once polymetallic nodules arrive at the pyrometallurgical facility, they are directed into storage bins that feed into rotary kilns. These coal-fired kilns receive a mixture of nodules, coal as a reducing agent, and silica-based flux, which helps form a suitable slag during processing. Inside the kilns, the nodules undergo high-temperature roasting and partial reduction by the coal. Gases generated from this process are extracted from the kiln's feed end and sent through electrostatic precipitators to remove particulate matter.

The hot nodules are transferred to electric arc furnaces. Here, the smelting process separates the material into two immiscible phases: a molten metal alloy and a manganese-rich silicate ($MnSiO_3$) product. The molten alloy then granulated before undergoing sulfidation and conversion to produce a matte primarily composed of nickel, copper, and cobalt. Meanwhile, the $MnSiO_3$ product is cast into solid form, crushed, and transported to the port for export. It is mainly used in silico-manganese alloy production. Notably, TMC's $MnSiO_3$ differs from conventional manganese silicates due to its pre-reduced form and high manganese content.

3.5.3 Hydrometallurgical Refining

Following the pyrometallurgical step, the nickel-copper-cobalt (Ni-Cu-Co) matte is refined through hydrometallurgical techniques. This stage transforms the matte into high-purity products: copper cathodes, nickel sulfate hexahydrate ($NiSO_4·6H_2O$), cobalt sulfate heptahydrate ($CoSO_4·7H_2O$). Ammonium sulfate is also generated during this stage as a co-product as well, not from the matte itself but as a byproduct of the processing operations.

The hydrometallurgical circuit begins with a two-stage leaching process. Initially, atmospheric leaching is used to dissolve nickel and cobalt, while copper remains in solid form. The leftover copper-rich matte is then subjected to pressure oxidation leaching (POX), producing a copper-rich solution. This solution is purified and directed to the electrowinning section, where copper metal is recovered. Meanwhile, the nickel and cobalt-rich leachate undergoes purification and solvent extraction, eventually leading to crystallization steps that yield battery-grade nickel and cobalt salts. Ammonium sulfate is separately crystallized as a co-product.

3.5.3.1 Leaching and Copper Recovery

Before leaching, the matte undergoes grinding to reduce its particle size and is then mixed with water to form a slurry. This slurry is pumped into the atmospheric leaching stage, where sulfuric acid, oxygen, and recycled electrolyte are added to dissolve nickel and cobalt into the solution.

In later stages of this leaching phase, oxygen is removed from the process, triggering reactions that replace the remaining nickel in the sulfide phases with copper from the solution. This results in a nickel- and cobalt-enriched solution, while the solid residue becomes more copper-concentrated.

This copper-upgraded matte is then treated in an autoclave at around 220°C under pressure, using fresh acid, recycled electrolyte, and oxygen. The resulting copper solution is treated with potassium metabisulfite to eliminate unwanted elements, then cooled and processed via electrowinning to yield copper cathodes.

3.5.3.2 Cobalt Recovery through Solvent Extraction

The solution rich in nickel and cobalt from atmospheric leaching is first treated to remove iron by increasing the pH with ammonia, causing iron to precipitate out. The clarified solution then undergoes cobalt solvent extraction using an organic extractant (Cyanex-272), which selectively pulls cobalt into the organic phase.

Afterward, cobalt is stripped from the organic solution with dilute acid. The resulting cobalt-rich solution is cleaned further using ion exchange columns to eliminate copper and manganese. Finally, the purified solution undergoes evaporation, crystallization, and centrifugation to produce cobalt sulfate heptahydrate crystals of battery-grade quality.

Note: The iron-containing residue is assumed to be landfilled, although it has not been included in this assessment due to data limitations. However, the environmental contribution from this step is expected to be minimal.

3.5.3.3 Nickel Recovery through Solvent Extraction

The cobalt-depleted solution, known as the raffinate, is then processed for nickel recovery. Nickel is extracted using neodecanoic acid as the solvent. The nickel-loaded organic phase is scrubbed to remove contaminants and stripped with sulfuric acid to retrieve nickel into an aqueous solution.

This solution is then subjected to evaporation, crystallization, and centrifugation, eventually yielding nickel sulfate hexahydrate crystals, suitable for battery applications. The remaining solution, still containing a high concentration of ammonia, is further processed through similar crystallization and drying steps to produce ammonium sulfate

3.6 Allocation

Whenever co-products are produced in a product system in an LCA study, allocation must be carried out. Allocation is the partitioning of the environmental load of the inputs and outputs to the co-products of a product system that share the same unit processes. ISO-14044:2006 defines co-products as any of two or more products coming from the same product system. However, allocation does not exactly follow strict scientific analysis, thus the environmental burdens may be unevenly distributed among co-products. It is this reason why ISO-14044 first states that allocation should be avoided where possible.[5]

Allocation may be avoided by subdividing the product system into sub-processes that are specific to each co-product. This approach avoids allocation because the inputs and outputs are directly related to the manufacturing of the studied product and not shared with any other co-products. However, subdivision may not be possible for complex, multi-output processes where disaggregating the common processes between the co-products is not possible.

Allocation may also be avoided by system expansion via substitution. System expansion eliminates the co-product under study from the system by subtracting the environmental burden of a functionally equivalent product produced by an alternative, mono-output process. In other words, the production of the same product being produced elsewhere is displaced by production of the co-product in the product system. When allocation cannot be avoided, the environmental load of the inputs and outputs of the product system must be partitioned based on some relationship between the co-products.

3.6.1 Physical Allocation

Physical allocation requires that the environmental loads of all inputs and outputs are partitioned according to a physical relationship between the co-products such as their mass ratio, volumetric ratio, molar ratio, or calorific value/ energy. Physical allocation, most commonly mass, is the preferred approach for systems containing metals when the economic value per unit of output between coproducts is similar.

3.6.2 Economic Allocation

Economic allocation is also primarily as mass-based allocation, though averaged by price. This form of allocation entails partitioning the environmental loads of the inputs and outputs to the co-products based on the market value of each when they exit the common process. The market values of the outputs are averaged over a certain time-period; longer periods are recommended in order to reduce the impact of random price spikes and drops. For metals, a 10-year average price is recommended.[12] This form of allocation is recommended when the price of the co-products vary by a factor greater than 5.[12,13,14]

3.6.3 Allocation in TMC's System Boundary

TMC's system boundary consists of 3 main operational/processing stages, nodule collection and transport to shore, pyrometallurgy, and hydrometallurgy. To partition the environmental impacts between the co-products, allocation was applied to each of these stages following sector specific guidelines for metal co-products and ISO 14044.[12,13,14] Depending on the functional unit analyzed the system boundary and allocation procedures differ.

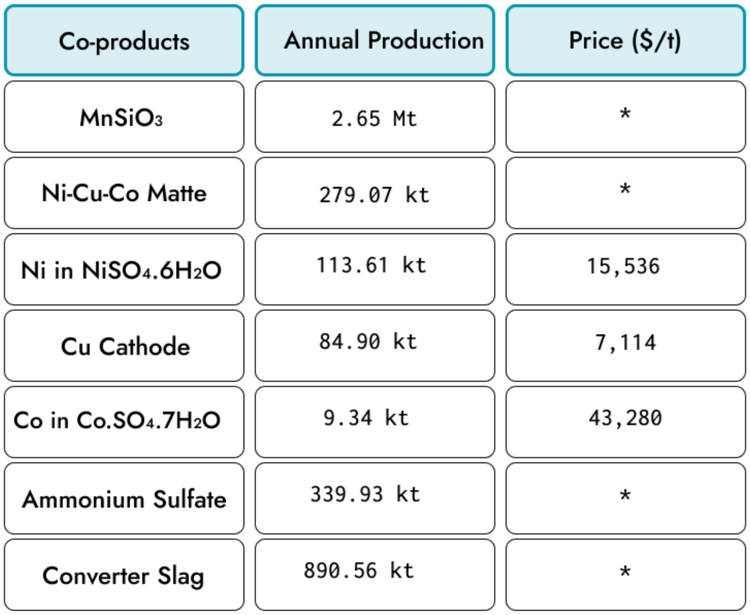
3.6.3.1 Functional Units: Ni-Cu-Co Matte & $MnSiO_3$

For the nodule collection stage, when the Ni-Cu-Co matte and $MnSiO_3$ are the studied functional units, the inputs and outputs are allocated using mass allocation based on the annual production of the co-products. For the pyrometallurgy stage, the inputs containing energy and heat, namely coal, natural gas, and process electricity, were allocated on an energy basis based on the amount of heat required by each co-product from thermodynamic first principles. Subdivision was applied on the inputs and outputs where the co-products did not share similar processes (i.e liquid sulfur used in the sulfidation stage). When Ni-Cu-Co Matte was the functional unit, system expansion by substitution was applied on the converter slag as it is assumed to serve as aggregate in the construction industry.

3.6.3.2 Functional Units: Ni in $NiSO_4.6H_2O$, Copper cathode, Co in $CoSO_4.7H_2O$

For the nodules collection stage, since the nickel, copper, and cobalt products are contained in the matte, only those loads associated with the production of the matte are allocated to these co-products. Those environmental loads are allocated to the co-products on an economic basis using the 10-year average price from 2015-2024 as recommended by Santero and Hendry and most other LCA sector agnostic guidelines. Subdivision was applied on the environmental loads where the co-products did not share similar processes (i.e ammonia used in the selective extraction of cobalt and nickel, & KOH used during cobalt solvent extraction). As ammonium sulfate is a non-metal co-product generated in a product mix with metals, avoiding allocation by system expansion is the recommended approach.[12] System expansion by substitution was applied to the product mix of the entire system for the ammonium sulfate which was assumed to substitute globally produced ammonium sulfate for the chemicals and agriculture industry. The attribution of environmental burdens for each co-product, as well as annual production capacities, and metal prices, where relevant, are summarized in Table 6 and Table 7.

*Table 6: Annual production of price of TMC's Co-products. * = price not relevant for those co-products.*



Co-products	Annual Production	Price ($/t)
$MnSiO_3$	2.65 Mt	*
Ni-Cu-Co Matte	279.07 kt	*
Ni in $NiSO_4.6H_2O$	113.61 kt	15,536
Cu Cathode	84.90 kt	7,114
Co in $Co.SO_4.7H_2O$	9.34 kt	43,280
Ammonium Sulfate	339.93 kt	*
Converter Slag	890.56 kt	*

Table 7: Allocation of environmental burdens from inputs and outputs to each co-product

Co-products	MGO	Coal (P)		Coal for heating (nat.gas replacement) (P)	Electricity (P)	Liquid Sulfur	Electricity (H)	Natural Gas (H)	Ammonia	KOH	All other inputs
		Reduction	Heating								
MnSiO$_3$	90.5 %	49.6 %	18.5%	92.5 %	92.5 %	-	-	-	-	-	90.5%
Ni-Cu-Co Matte	9.5 %	30.4 %	1.5%	7.5 %	7.5 %	100%	-	-	-	-	9.5%
Ni in NiSO$_4$.6H$_2$O	63.6 %	63.6 %		63.6%	63.6%	63.6 %	63.6%	63.6%	92.4%	-	63.6%
Cu Cathode	21.8 %	21.8 %		21.8 %	21.8 %	21.8%	21.8%	21.8%	-	-	21.8%
Co in Co.SO$_4$.7H$_2$O	14.6 %	14.6 %		14.6 %	14.6 %	14.6%	14.6%	14.6%	7.6%	100%	14.6%

🟦	Mass Allocation
🟩	Economic Allocation
🟨	Energy Allocation
🟥	Metal Mass Allocation

*Note – Only those impacts associated the production of the matte are allocated to the NiSO$_4$.6H$_2$O, CoSO$_4$.7H$_2$O, and Copper cathode.

3.7 Cut-off criteria

Cut-off criteria in Life Cycle Assessment (LCA) establish the thresholds for including or excluding inputs based on considerations of mass, energy, or environmental relevance. In the present study, all flows provided by TMC that fall within the defined system boundary were fully considered, with no exclusions applied based on cut-off criteria.

3.8 Data

Activity data is a quantitative measure of inputs and inputs (i.e. a level of activity) that results in GHG emissions. Activity data can be considered primary or secondary. Primary data are data that is collected from specific processes in the studied product's life cycle. If the data is physically measured, monitored, or found through mass balance, stoichiometry or similar methods and is from a specific site, it is considered primary data. Secondary data are data that is not from specific processes within the studied products life cycle, including proxy data.[13]

It should be noted that companies typically do not have control over the source of emission factors used to calculate the emissions associated with their foreground data. Therefore, the source of emission factor has no bearing on the classification to meet the primary data requirement and emission factors do not need to be classified as primary or secondary.[16]

3.8.1 Data Collection

3.8.1.1 Offshore Data Collection

Annual marine fuel usage was calculated with data provided by Allseas, an offshore contractor who designed and retrofitted the production vessel; as well as information provided by large shipping companies that have worked with TMC. Allseas provided average daily marine fuel use rate for the production vessel, the compressor, spread, and the transfer vessel considering actual usable energy or lower heating values (LHV). This data was used along with the production schedule to calculate annual fuel use. Bulk carriers fuel usage was calculated using cycle durations and by splitting the time into steaming, port, and idle to attribute accordingly different fuel usage rates.

3.8.1.2 Onshore Data Collection

The process data employed as input to the LCA was from TMC's pre-feasibility study (2025). The data for onshore operations is contained in the technical report summary.[15] The data for offshore operations are not yet publicly available.

In mining project development, pre-feasibility studies are more detailed than initial assessment and scoping studies as they contain preliminary engineering, metallurgical tests, and environmental baseline studies. However, they are less detailed than feasibility studies which entail detail engineering, final CAPEX and OPEX estimates, and execution plans.

The process data in TMC's PFS was derived from mass and energy balance models. The mass and energy balance modelling were conducted by Hatch, an engineering and development consultancy, who utilized the industry standard Metsim™ software package and qualified experienced process engineers. The design basis for the model development included analogous commercial operations in nickel processing, test-work results by TMC as well as employing extensive data from literature, and fundamental thermodynamics.

For combustible fuels, LHV's were used in their calculations. Beyond the data validation from the mass balances conducted by Hatch, the data was compared to existing systems that produce similar products to deduce if there were any major inconsistencies. None were found.

3.8.2 Data Quality & Requirements

According to ISO 14044:2006, the following data quality requirements should be addressed:

- Temporal coverage: The age of the data.
- Geographical coverage: The degree to which the data reflects actual geographic location of the processes within the inventory boundary

- Technological Representativeness: The degree to which the data reflect the actual technologies used in the process.
- Completeness: The percentage of the data that is measured or estimated.
- Precision: Measure of the variability of the data.
- Representatives: The degree to which the dataset reflects the true population of interest.
- Sources of the data
- Reproducibility.

With companies able to calculate the environmental footprint of their product using several data types, data quality assessments provide users with a better understanding of the overall integrity of the data and the resulting LCA. Though Data quality is a requirement by ISO-14044, they do not provide data quality levels or scores. Therefore, the GHG protocol product standard data quality ratings are used in this report.[16] An excerpt of the ratings are shown in Table 8.

Data is scored on a scale from 1 to 4, where 1 indicates very good quality, 2 indicates good quality, 3 indicates fair quality, and 4 indicates poor quality. As both emission factors and activity data receive a data quality ranking, the data quality of each indicator is given by:

$$\frac{\sum DQ_{AD_i} + \sum DQ_{EF_i}}{n}$$

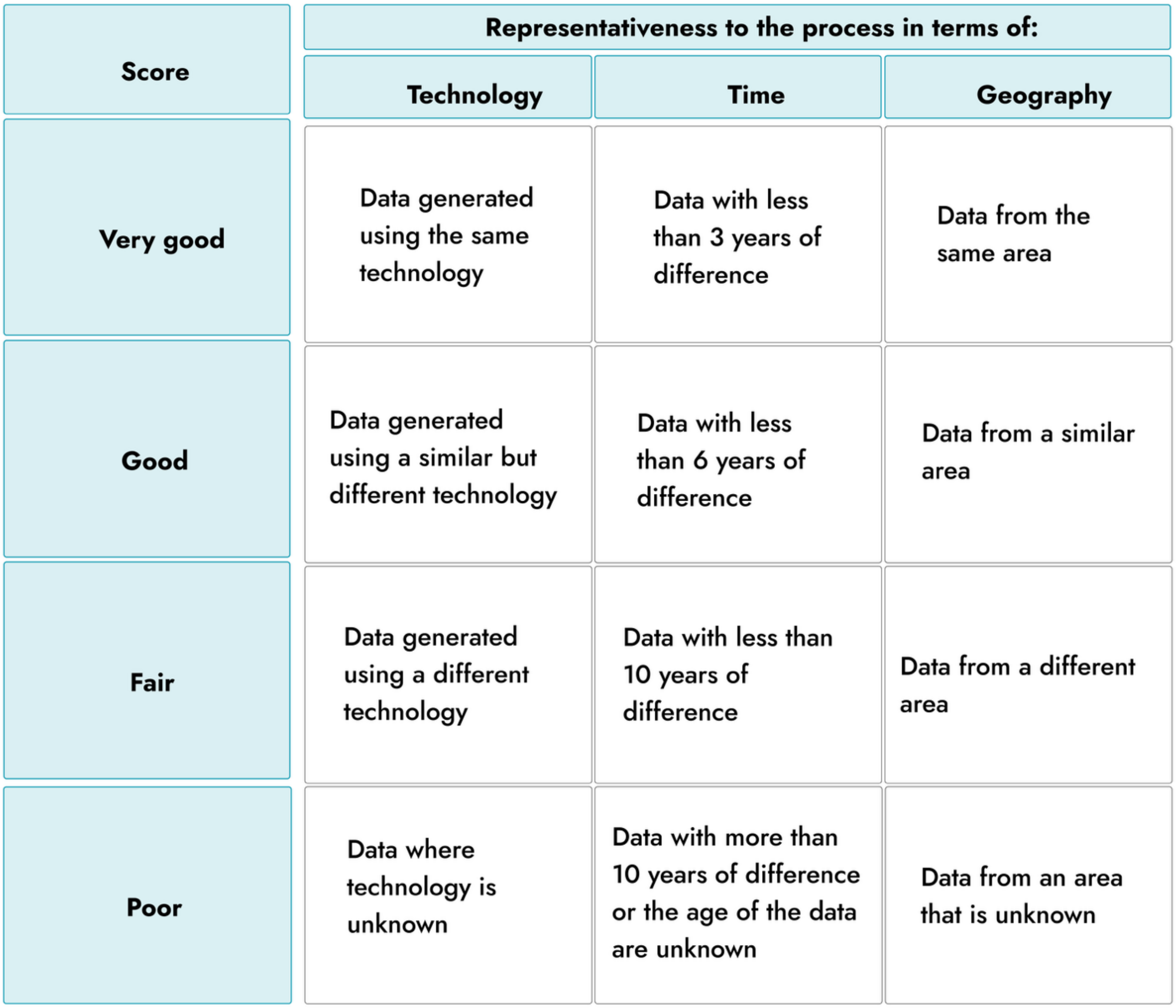
Where

DQ_{AD_i} = data quality of the activity data

DQ_{EF_i} = data quality of the emission factor

n = number of datapoints

Table 8: Data Quality Rating Excerpt from the GHG Protocol Standard



Score	**Representativeness to the process in terms of:**		
	Technology	**Time**	**Geography**
Very good	Data generated using the same technology	Data with less than 3 years of difference	Data from the same area
Good	Data generated using a similar but different technology	Data with less than 6 years of difference	Data from a similar area
Fair	Data generated using a different technology	Data with less than 10 years of difference	Data from a different area
Poor	Data where technology is unknown	Data with more than 10 years of difference or the age of the data are unknown	Data from an area that is unknown

3.8.2.1 Temporal Representativeness, Precision & Completeness

Mining processes are usually well established and rarely undergo drastic changes over short periods. Considering this, the minimum requirement for the temporal precision and completeness indicator in this study is data with less than a 10-year difference, collected from an adequate number of sites over a sufficient period to smooth out normal fluctuations. This corresponds to a data quality rating of 3 (fair).

The LCI data for the product system was measured as 12-month averages representing the year 2024 to compensate for seasonal influence and variability of data. The dataset was modelled using the latest production mix for electricity available in ecoinvent 3.11 at the time of this study. The results of this dataset are expected to be relevant until there is a significant change in the electricity production mix (for location-based modelling) or processing technology. For the temporal, precision and completeness indicators, the data quality for TMC's product system is approximately 1 and thus meets the minimum data requirements, as shown in Tables 9 and 10.

3.8.2.2 Technological Representativeness, Consistency & Sources of Data

With mining LCA's, it is possible that data, such as emission factors, are not readily available for certain materials, leading to the use of proxies. Considering this, the minimum requirement for the technological indicator is data for the same materials and processes under study but from different technologies. This corresponds to a data quality rating of 3 (fair).

The production processes within TMC's system boundary were modelled using specific values from primary data collection based on TMC's internal pre-feasibility study and initial technical assessment. These values were calculated by Hatch who used the Metsim software, mass and energy balance, as well as analogous commercial operation for the design basis. This data is contained in the technical report summary.[15] The production processes within the system boundary of the downstream processing of TMC's $MnSiO_3$ was based on material, mass, and energy balances constructed from HSC chemistry software and provided by an external research company, SINTEF. All activity data were complemented with emission factors from ecoinvent 3.11 with characterization factors from EF 3.1. For the technological indicator, the data quality for TMC's product system is approximately 2 and thus meets the minimum data requirements, as shown in Tables 9 and 10.

3.8.2.3 Geographical Representativeness

For both activity data and emission factors, it is possible that data specific to a particular country may not be readily available. In such cases, proxy data from another country where data is available may be used. Considering this, the minimum requirement for the geographical indicator is data sourced from a different area, corresponding to a data quality rating of 3 (fair).

Primary production data for TMC is the same for each unit operation at different processing locations (Indonesia, Japan, Texas and South Korea). However, marine fuel inputs into the system vary depending on the processing location. The emission factor corresponding to the electricity production mix for each country was applied based on the location where onshore processing occurred. For the geographical indicator, the data quality TMC's product system is approximately 2 and thus meets the minimum data requirements as shown in Tables 9 and 10.

3.8.3 Data Quality Score

The total data quality score is calculated by taking the weighted average data quality of the indicators and is given by:

$$\text{DQR} = \frac{TeR+GeR+TiR}{3}$$

Where

TeR = Technological representativeness
GeR = Geographical representativeness
TiR = temporal representativeness

Thus, the total data quality rating of TMC's system is approximately 2, which is good quality.

Table 9: Data quality for TMC's activity data and emission factors

	Marine Fuel		Coal		Electricity	
Data quality indicator	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**
Technological representativeness	🟨 Primary data based on TMC'sNORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟧 Default global emission factor used. Combustion technology and efficiency not considered.	🟨 Primary data based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟧 Default global emission factor used. Combustion technology and efficiency not considered.	🟨 Primary data based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟨 Production mix reflects technologies in use but is not highly specific to a particular plant, provider, or technology type
Temporal representativeness	🟩 Reference period for data calculations are 2024.	🟩 Supply chain and combustion technology valid for 2024	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟨 Emission factors reflect the situation in 2021.
Geographical representativeness	🟩 The activityis based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021)and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered.	🟩 The activity is based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021) and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered	🟩 The activity is based is based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021) and remains the same independent of geographic location.	🟩 Country specific emission factor applied.
	Liquid Sulfur		**Natural Gas**		**Ammonia**	
Data quality indicator	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**
Technological representativeness	🟨 Primary data based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟧 Default global emission factor used. No supplier specific emission factor known or available.	🟨 Primary data based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟧 Default global emission factor used. Combustion technology and efficiency not considered.	🟨 Primary data based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021). Not based on actual operational data.	🟧 Production mix reflects technologies in use but is not highly specific to a particular plant, provider, or technology type
Temporal representativeness	🟩 Reference period for data calculations are 2024.	🟩 Supply chain and combustion technology valid for 2024	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟩 Emission factors reflect the situation in 2021.
Geographical representativeness	🟩 The activityis based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021)and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered.	🟩 The activity is based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021) and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered	🟩 The activity is based is based on TMC's NORI-D Project PFS (2025) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March2021) and remains the same independent of geographic location.	🟧 Country specific emission factor applied.

🟩	**Very good**	🟨	**Good**	🟧	**Fair**	🟥	**Poor**

***Note: Precision and completeness is contained within technological and temporal representativeness. I.e. The data is precise as it is from TMC's internal PFS and is based on yearly average limit variability in the data.**

Table 10: Data Quality for the Production of SiMn from TMC's MnSiO$_3$

	MnSiO3		Coke		Electricity	
Data quality indicator	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**
Technological representativeness	🟧 Based on mass and energy balances from HSC software.	🟩 Emission factor is specific to TMC's processes flowsheet.	🟧 Based on mass and energy balances from HSC software.	🟧 Default global emission factor used. Combustion technology and efficiency not considered.	🟧 Based on mass and energy balances from HSC software.	🟨 Production mix reflects technologies in use but is not highly specific to a particular plant, provider, or technology type
Temporal representativeness	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟨 Emission factors reflect the situation in 2021.
Geographical representativeness	🟩 The activity is based on mass and energy balances and remains the same independent of geographic location.	🟩 Specific to TMC's production process in IND, JP, or TX.	🟩 The activity is based on mass and energy balances and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered	🟩 The activity is based on mass and energy balances and remains the same independent of geographic location.	🟩 Country specific emission factor applied.

	Dolomite		Quartzite		Iron Ore	
Data quality indicator	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**	**Activity data**	**Emission factor**
Technological representativeness	🟧 Based on mass and energy balances from HSC software.	🟧 Default market global emission factor used. No supplier specific emission factor known or available.	🟧 Based on mass and energy balances from HSC software.	🟧 Default global emission factor used. Combustion technology and efficiency not considered	🟧 Based on mass and energy balances from HSC software	🟧 Default global emission factor used. Combustion technology and efficiency not considered.
Temporal representativeness	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.	🟩 Reference period for data calculations are 2024.	🟩 Data point valid for 2024.
Geographical representativeness	🟩 The activity is based is based on mass and energy balances and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered.	🟩 The activity is based on mass and energy balances and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered	🟩 The activity is based on mass and energy balances and remains the same independent of geographic location.	🟧 Default global emission factor used, location of production not considered.

🟩	**Very good**	🟨	**Good**	🟧	**Fair**	🟥	**Poor**

***Note: Precision and completeness is contained within technological and temporal representativeness. I.e. The data is precise and complete as it contains all inputs and is based on mass balances from HSC chemistry software.**

3.9 LCIA Methodology

The life cycle impact assessment method applied in this study is the Environmental Footprint (EF) method version 3.1. All environmental impact categories available in this version of the method were considered, with the report detailing select categories. The impact categories are described in the Table 11. The EF method was developed by the European Commission's Joint Research Centre (JRC) and is considered to be one of the most robust and up-to-date methods.[17] The EF method builds upon established international practices and standards, such as ISO 14040/44.[18] The latest ecoinvent 3.11 version was used for all emission factors applied in this study.

The LCA in this study is an attributional LCA. This type of LCA aims to detail the environmental impacts directly linked with production by attributing the environmental burdens within the system boundary to the product system. Additionally, the recycled content, or 'cut-off' method was applied. This means that recycled materials are treated as burden-free when entering the product system.

3.9.1 Impact Category Selection

All impact categories contained in the EF 3.1 method were assessed in this report. Although each offer value, the climate change impact category is one that the EF method, and other LCIA methodologies, do particularly well. It is widely recognized as the most understood and robustly characterized impact category and benefits from global frameworks and guidance's such as the GHG protocol and ISO 14067. It has the lowest level of uncertainties among the 16 EF 3.1 impact categories. This is why this report goes into the greatest detail in this impact category in particular.

Though not carried out to the same level of detail as climate change, the analysis of acidification, energy use, and freshwater eutrophication contain visualizations and interpretations of the main attributable flows.

Acidification is usually a recommended impact category for mining LCA's since inputs such as sulfuric acid, sulfur, and fossil fuels are commonly used. These inputs tend to release air pollutants which are transformed to acid, leading to acidification impacts.[12] Therefore, acidification was chosen as an impact category that would be interpreted in more detail.

Generally, the energy use and climate change impact category are closely correlated which leads to the lack of additional insights in mining related LCA’s. However, some of the production pathways for terrestrial comparisons occur in countries that contain significant amounts of nuclear in their energy grid mix. Although this use of nuclear would lead to lower impact in the climate change impact category, it would lead to higher impacts in the energy resources impact category. Thus, the results would be interesting for the comparative analysis.

Eutrophication is also a recommended impact category for mining LCA’s as large quantities of wastewater and tailings are generated during processing, which typically contain phosphates.[12] As phosphorous is the limiting nutrient for the algae growth in freshwater systems, the enrichment of nutrients in water from even small amounts of phosphate containing compounds can lead to disproportionate algal blooms.

Table 11: EF 3.1 Environmental Impact Categories.[18]

Impact Category	Description	Units	Characterisation model
Climate Change	This indicator refers to the increase in the average global temperatures as a result of greenhouse gas (GHG) emissions.	kg CO_2eq.	Bern model – Global warming potentials (GWP) over a 100-year time horizon (based on IPCC 2013)
Ozone depletion	This indicator measures the depletion of the stratospheric ozone (O3) layer which protects us from hazardous ultraviolet radiation (UV-B)	kg CFC-11eq.	EDIP model based on the ODPs of the World Meteorological Organisation (WMO) over an infinite time horizon (WMO 2014 + integrations)
Human Toxicity, cancer effects	This indicator refers to potential impacts, via the environment, on human health caused by absorbing substances from the air, water and soil.	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018
Human Toxicity, non-cancer effects	This indicator refers to potential impacts, via the environment, on human health caused by absorbing substances from the air, water and soil.	CTUh	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018
Particulate Matter	This indicator measures the adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO2)	Disease incidence	PM model (Fantke et al., 2016 in UNEP 2016)
Ionising Radiation	This indicator measures the adverse impacts from the exposure to ionising radiation (radioactivity) on human health. The EF method only considers emissions under normal operating conditions (no accidents in nuclear plants are considered).	kg U235eq	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al., 2000)
Photochemical ozone formation	This indicator refers to the formation of ozone in the trophosphere from substances, resulting in harmful impacts to plants, animals, and leading to respiratory issues for humans.	kg NMVOCeq.	LOTOS-EUROS model (Van Zelm et al., 2008) as applied in ReCiPe 2008
Acidification	This indicator measures the potential impact from acidification caused by emissions to the air and deposition of emissions in water. Acidification has contributed to a decline of coniferous forests and an increase in fish mortality.	mol H+ eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al., 2008)
Eutrophication, terrestrial	Eutrophication arises when substances containing nitrogen (N) or phosphorus (P) are released to ecosystems. These nutrients cause a growth of algae or specific plants and thus limits growth in the original ecosystem.	mol N eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al., 2008)
Eutrophication, freshwater	Substances containing nitrogen or phosphorus promotes growth of algae or specific plants. If algae grows too rapidly, it can leave water without enough oxygen for fish to survive. This indicator measures the potential impact of substances contributing to freshwater eutrophication.	kg P eq	EUTREND model (Struijs et al., 2009) as applied in ReCiPe
Eutrophication, marine	Eutrophication in ecosystems happens when substances containing nitrogen or phosphorus are released to the ecosystem. For the marine environment this will be mainly due to an increase of nitrogen. This indicator measures the potential impact of substances contributing to marine eutrophication	kg N eq	EUTREND model (Struijs et al., 2009) as applied in ReCiPe
Ecotoxicity, freshwater	This indicator refers to potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem.	CTUe	based on USEtox2.1 model (Fantke et al. 2017), adapted as in Saouter et al., 2018
Land use	This is the use and transformation of land for agriculture, roads, housing, mining or other purposes. The impacts can vary and include loss of species, of the organic matter content of soil, or loss of the soil itself (erosion). This is a composite indicator measuring impacts on four soil properties (biotic production, erosion resistance, groundwater regeneration and mechanical filtration)	Pts.	Soil quality index based on LANCA model (De Laurentiis et al. 2019) and on the LANCA CF version 2.5 (Horn and Maier, 2018)
Water use	The abstraction of water from lakes, rivers or groundwater can contribute to the 'depletion' of available water. The impact category considers the availability or scarcity of water in the regions where the activity takes place, if this information is known	m^3	Available WATER Remaining (AWARE) model (Boulay et al., 2018; UNEP 2016)
Resource Use, fossil	The earth contains a finite amount of non-renewable resources, such as fossil fuels like coal, oil and gas. The basic idea behind this impact category is that extracting resources today will force future generations to extract less or different resources. This indicator measures the amount of fossil resources extracted.	MJ	van Oers et al., 2002 as in CML 2002 method, v. 4.8
Resource Use, minerals metals	Extracting a high concentration of resources today will force future generations to extract lower concentration or lower value resources. This indicator measures the amount of non-fossile resources extracted.	kg Sb eq.	van Oers et al., 2002 as in CML 2002 method, v. 4.8

3.10 Limitations

The primary limitation of this study is that it is prospective. TMC's production process is not yet in full industrial operation and thus the LCI is based on their initial technical report and pre-feasibility study that may be subject to change once the project proceeds to full operation. A further limitation, as stated in the goal section of this report, is that the impacts on the sea-bed and deep-sea ecosystems from nodule collection are not captured. The LCA methodology lacks a framework for capturing these impacts. Similarly, the impacts on forest and some land ecosystems due to large scale deforestation and impoundments from mining, in the case of the terrestrial comparison (section 7), are also not adequately captured.

LCA's do not capture the spatial and transient state of biodiversity or ecosystems from the environmental impact of anthropogenic production systems.[6,7] There are also variations in the precision of impact categories available in the EF method. Social impacts are not quantified in this study, nor the impacts from potential failures of tailing dams.

As this is a comparative LCA, these limitations should be considered when interpreting the findings of this report and the results do not provide the sole basis for overall environmental superiority between product systems.

3.11 Interpretation

The results will be interpretated in relation to the goal and scope. Contribution analysis will be conducted for TMC's LCA to identify hotspots along the climate change impact category. Significant issues and major attributable processes for the products produced from the systems of both TMC and the land-based comparisons will be discussed for select impact categories (see section 7). The full list of impacts for the 16 EF impact categories for the product system of TMC and the terrestrial comparisons are given in annex A.

As stated in the goal section, sensitivity and scenario analysis will be conducted for TMC's system to provide TMC with additional environmental impact insights of their production process and highlight emission reduction pathways. As TMC system in not yet in full operation, uncertainty analysis will be conducted on the major attributable inputs found from the contribution analysis to analyze how the impacts may vary with these key inputs. Conclusions and recommendations will be made based on the findings. This will include highlighting the variation in the measured environmental impacts of TMC's products in comparison to the same products produced from each of the terrestrial production pathways. Parameters, processes, and flows in the production systems that leads to one product performing better than another within an environmental impact category will be underlined.

3.12 Critical Review

This LCA study contains comparative assertions against products produced with an equivalent system boundary. To ensure compliance with the ISO14040/44:2006, a critical panel review was conducted. The panel was selected by considering experts who had experience reviewing mining LCA's and who had good knowledge of the ISO 14044/44:2006 standards. The critical review panel consists of:

Matthew Fishwick (Chair): Founder of Fishwick Environmental (Environmental consultancy). Approved individual verifier for the International EPD System and IBU.

Dr. Cynthia Adu: Sustainability Manager and chartered environmentalist.

Elke Breitmayer: Founder of 360° Sustainability and environmental expert.

Following ISO 14044 clause 6.1, the review process covered the methods used to carry out this LCA, ensuring that they were scientifically and technically valid and consistent with the relevant international standards. The review also covered whether the data used was appropriate and reasonable in relation to the goal of study. The review also ensured that the interpretation reflected the limitations and if the overall report was transparent and consistent.

The review was carried out at the end of the project and was accomplished based on version 1.0 of this report submitted in June 2025, version 1.1 submitted in July 2025, and version 1.2 submitted in August 2025. The critical review statement, reviewer competencies, as well as all comments and suggestions made by the reviewers are summarized in annex B of this report.

Ecoquant provided formal responses to all reviewer comments. A structured dialogue between Ecoquant and the reviewers was established, aimed at achieving consensus. Consensus was either reached by implementing the necessary modifications to the study or, where appropriate, by providing substantiated justifications that satisfied the reviewers that no changes were required.

4. LCI

The life cycle inventory, along with each background datapoint for the analyzed system boundary is shown in Tables 12 and 13.

Table 12: Cradle to gate life cycle inventory for TMC's NORI-D Project based on their updated PFS (2025).

Inventory Item	Exchange Type	Quantity	Unit	ecoinvent process	Country Code
Offshore mining					
Marine Fuel (IE+DE)-Indonesia	Input	626,949	tonnes / yr	heavy fuel oil, burned in refinery furnace	RoW
Marine Fuel (IE+DE)- Japan	Input	692,943	tonnes / yr	heavy fuel oil, burned in refinery furnace	RoW
Marine Fuel (IE+DE)- Texas	Input	541,094	tonnes / yr	heavy fuel oil, burned in refinery furnace	
Total dry Nodules collected	Output	8.640	Mt / yr	-	-
Pyrometallurgy (Production of $MnSiO_3$ and Ni-Cu-Co Matte)					
Total Dry Nodules	Input	8.640	Mt/ yr	-	-
Silica	Input	504,083.	tonnes / yr	Market for silica sand	GLO
Reductant coal	Input	837,527.	tonnes / yr	Heat and power co-generation, hard coal	RoW
Coal for heat (Indonesia, Japan)	Input	591,986	tonnes / yr	market for hard coal	RoW
Natural Gas for heat (only for Texas	Input	329,292.	tonnes / yr	market for natural gas liquids	GLO
Make up water	Input	9,175,425	m3/yr	Market for tap water	RoW
Electrode paste	Input	10,447.67	tonnes / yr	50% 'graphite production' - RoW 50% 'market for carbon black' - GLO	RoW GLO
Liquid sulfur	Input	60,241	tonnes / yr	market for sulfur	GLO
Electricity (operations)	Input	3,948,375.54	Mwh / yr	electricity, high voltage, production mix market for electricity, high voltage	ID JP
Diesel (vehicles)	Input	1,666,344.39	liters / yr	Market for diesel, burned in diesel-electric set, 18.5 kW	GLO
MnSiO3	Output	6,622,344.00	tonnes / yr	-	-
Converter Slag	Output	890,557.38	tonnes / yr	market for gravel, crushed	RoW
Ni-Cu-Co matte	Output	279,072.00	tonnes / yr	-	-
Hydrometallurgy					
Ni-Cu-Co matte	Input	279,072.00	tonnes / yr	-	
H2SO4 (93%)	Input	311,959	tonnes / yr	market for sulfuric acid	RoW
Anhydrous liquid ammonia	Input	85,628	tonnes / yr	market for ammonia, anhydrous, liquid	RoW
Cyanex 272	Input	104.46	tonnes / yr	market for organophosphorus-compound, unspecified	GLO
SX Diluent	Input	210.6885246	tonnes / yr	market for kerosene	RoW
Potassium Metabisulfite	Input	4	tonnes / yr	market for potassium sulfate	RoW
Potassium hydroxide	Input	2,852	tonnes / yr	market for potassium hydroxide	GLO
Natural Gas	Input	63,005.327	tonnes / yr	heat production, natural gas, at boiler modulating >100kW	RoW
Electricity (vehicles)	Input	568,446.49	liters / yr	electricity, high voltage, production mix	KR
Electricity (Operations)	Input	471,304.92	Mwh/ yr	electricity, high voltage, production mix	KR
Ni in NiSO4.6H2O	Output	113,610.82	tonnes / yr	-	
Cu Cathode	Output	84,903.55	tonnes / yr	-	
Co in CoSO4.7H2O	Output	9,338.11	tonnes / yr	-	
Ammonium sulfate	Output	339,934.426	tonnes / yr	market for ammonium sulfate	RoW

Table 13: Cradle to gate life cycle inventory for the production of SiMn from TMC's $MnSiO_3$

Inventory Item	Exchange Type	Quantity	Unit	ecoinvent process	Country Code
Pyrometallurgy					
$MnSiO_3$	Input	6,622,344	tonnes/ yr	-	-
Dolomite	Input	108,436	tonnes / yr	Market fordolomite	RoW
Quartzite	Input	906,215	tonnes / yr	Market for Silica Sand	GLO
Coke	Input	1,874,394	tonnes / yr	market for coke	CN
Iron ore	Input	468,598	tonnes / yr	market for iron ore concentrate	GLO
Electricity	Input	4331	Kwh/per tonnes of SiMn	Market for electricity, high voltage	CN
Transport ID to CN	Input	24,502,672,800	t*km	Market for transport, freight, sea, bulk carrier for dry goods, heavy freight	GLO
Transport JP to CN	Input	15,893,625,600	t*km	Market for transport, freight, sea, bulk carrier for dry goods, heavy freight	GLO
Transport TX to CN	Input	134,910,391,968	t*km	Market for transport, freight, sea, bulk carrier for dry goods, heavy freight	GLO
SiMn	Output/product	3,872,715	tonnes	-	-
Process emissions (CO_2 eq)	Output	11,016,000	tonnes	-	-

5. TMC NORI-D Climate Change Impact Results & Interpretation

This section presents the environmental impacts associated with each unit operation included within the system boundaries defined in Section 3.2. The results are disclosed per functional unit and for each processing location. For the climate change impact category, results are first presented graphically by unit operation for each location. These are subsequently followed by graphical contribution analyses for each respective location. The reporting is consistent with the stated goal and intended application described in Section 2. The results for other impact category within the EF 3.1 methodology will be shown in section 7. Figures may be subject to minor rounding differences and thus may not total precisely.

5.1 Climate Change Impact

5.1.1 Functional Unit: 1kg of dry nodules collected and processed.

The total climate change impact associated with the collection and processing (pyrometallurgy and hydrometallurgy) of 1kg of dry nodules is **1.32 kg CO_2eq**., **1.10 kg CO_2eq**., and **0.83 kg CO_2eq**. when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 3).

At each location, the pyrometallurgy stage carries the highest impact ranging from 66% - 75% of the total impact depending on processing location. This impact is highest when processing occurs in Indonesia due to its relatively carbon-intensive electricity grid-mix which is dominated by lignite, and lowest in Texas which contains a significant amount of wind energy in its production mix.

For the nodules collection stage, the TMC NORI-D Japan route has the highest impact as this route has the greatest distance travelled from the CCZ to the processing location site (note: the dry nodules are shipped to Japan after a logistical pause in Indonesia), and thus the greatest marine fuel use. Conversely, the TMC NORI-D Texas route has the lowest impact for the nodule collection stage as this route is the shortest distance travelled from the CCZ to the processing location site.

The impact of the hydrometallurgical stage remains consistent across TMC NORI-D operations in Indonesia, Japan, and Texas, as the inputs and outputs are identical at each processing location. Additionally, the similarity in electricity grid mixes between South Korea and Texas contributes to comparable impacts from energy use.

A consistent trend is observed wherein the TMC NORI-D Indonesia processing route exhibits the highest overall climate change impact, primarily due to the contributions from the pyrometallurgical stage. Conversely, the Texas route consistently demonstrates the lowest climate change impact, attributable to the relatively lower emissions from the pyrometallurgical stage and the shorter transport distance from the CCZ to the processing facility in Texas. These trends persist across all subsequent functional units described. To maintain conciseness and avoid redundancy, these trends will not be restated for each additional functional unit unless deviations are identified, in which case they will be explicitly discussed in the text.

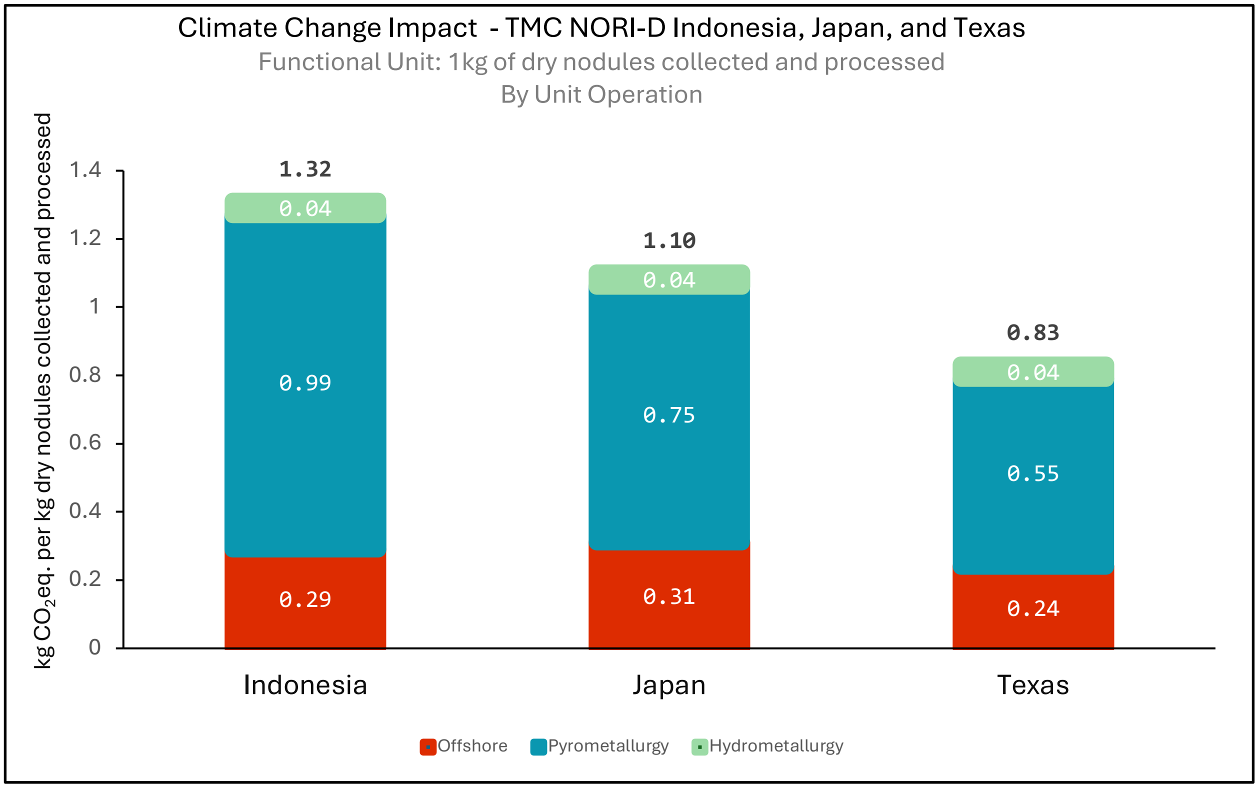


Figure 3: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of dry nodules collected and processed

5.1.1.1 Contribution Analysis – 1kg of dry nodules collected and processed

The results of the contribution analysis can be seen in Figures 4 to 6. For all processing locations, the main contributors remain the same. They are:

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **0.54 kg CO_2eq.** (41% of the total impact), **0.31 kg CO_2eq.** (28% of the total impact) and **0.22 kg CO_2eq.** (27% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively. This is due to the RKEF process being energy intensive coupled with the carbon intensity of the production mix of the grid at each processing location. Since Indonesia has the most carbon intensive production mix on its grid of the 3 locations, it carries the highest impact.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **0.29 kg CO_2eq.** (22% of the total impact), **0.31 kg CO_2eq**. (28% of the total impact) and **0.24 kg CO_2eq**. (29% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively. This is driven by the combustion of marine fuel oil, which has a significant carbon footprint.

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **0.25 kg CO_2eq**. for each location, representing 19%, 23%, and 30% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively. This is driven by the direct emissions released from the combustion of the coal, its high carbon content leads to significant emissions when combusted.

For TMC NORI-D Indonesia and Japan routes, the model assumes that coal is utilized as an auxiliary heat source during the pyrometallurgical process. This substitution arises due to limited availability of natural gas in these regions, coupled with the relative abundance of coal. Conversely, in Texas operations, natural gas remains the primary heat source for the pyrometallurgical process, owing to its greater regional availability.

There is an environmental credit received for the converter slag, that will be used as gravel for the construction of road, and the ammonium sulphate which is assumed to replace ammonium sulphate primarily used as fertilizer in the agriculture industry. The traditional pathway of producing ammonia is from the reaction of ammonia and sulfuric acid.

Note: (O) = Offshore, (P) = Pyrometallurgy, (H) = Hydrometallurgy, (IE) = Indirect Emissions, (DE) Direct Emissions, "other" = sum of inputs whose individual impact contributes < 1% of the total impact.

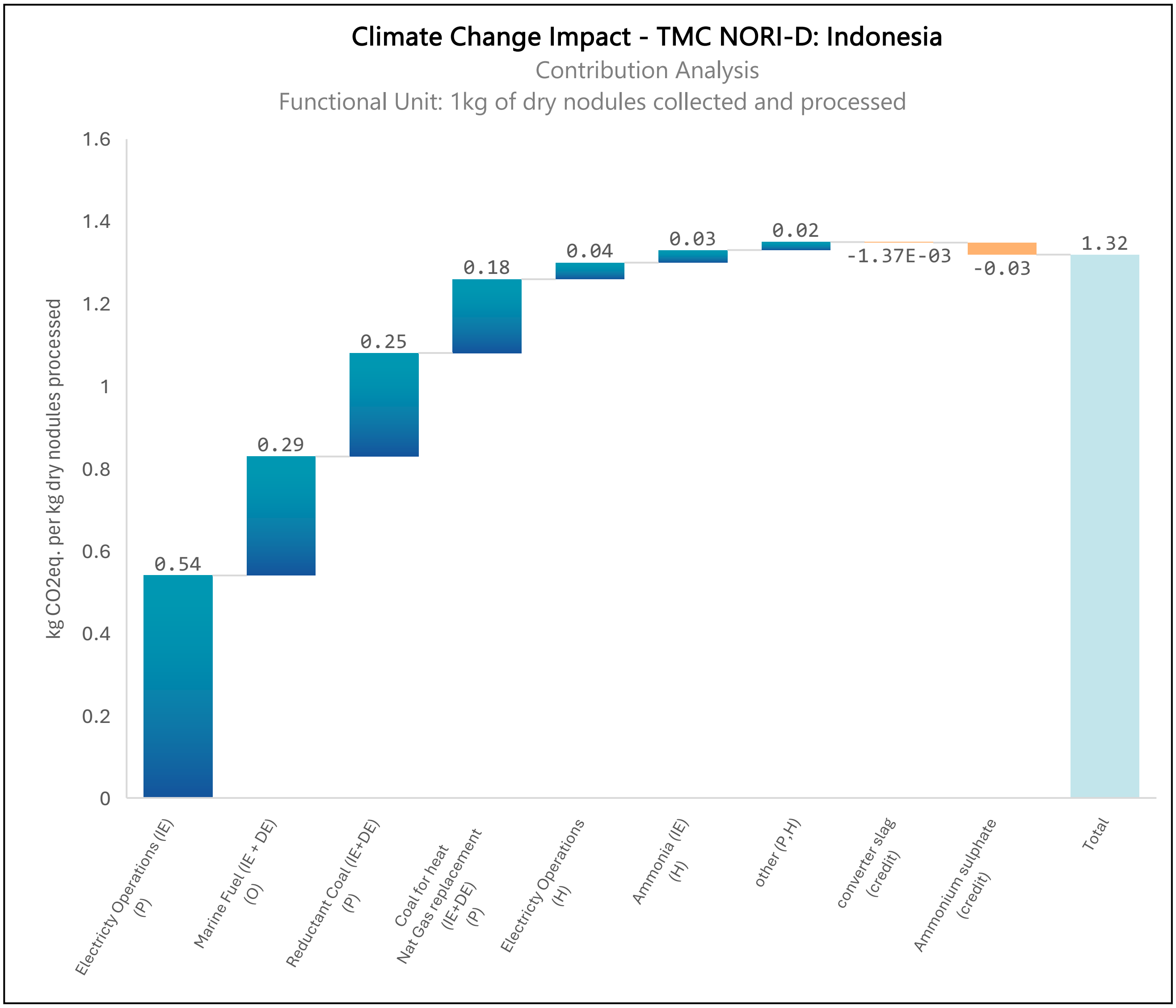


Figure 4: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of dry nodules collected and processed

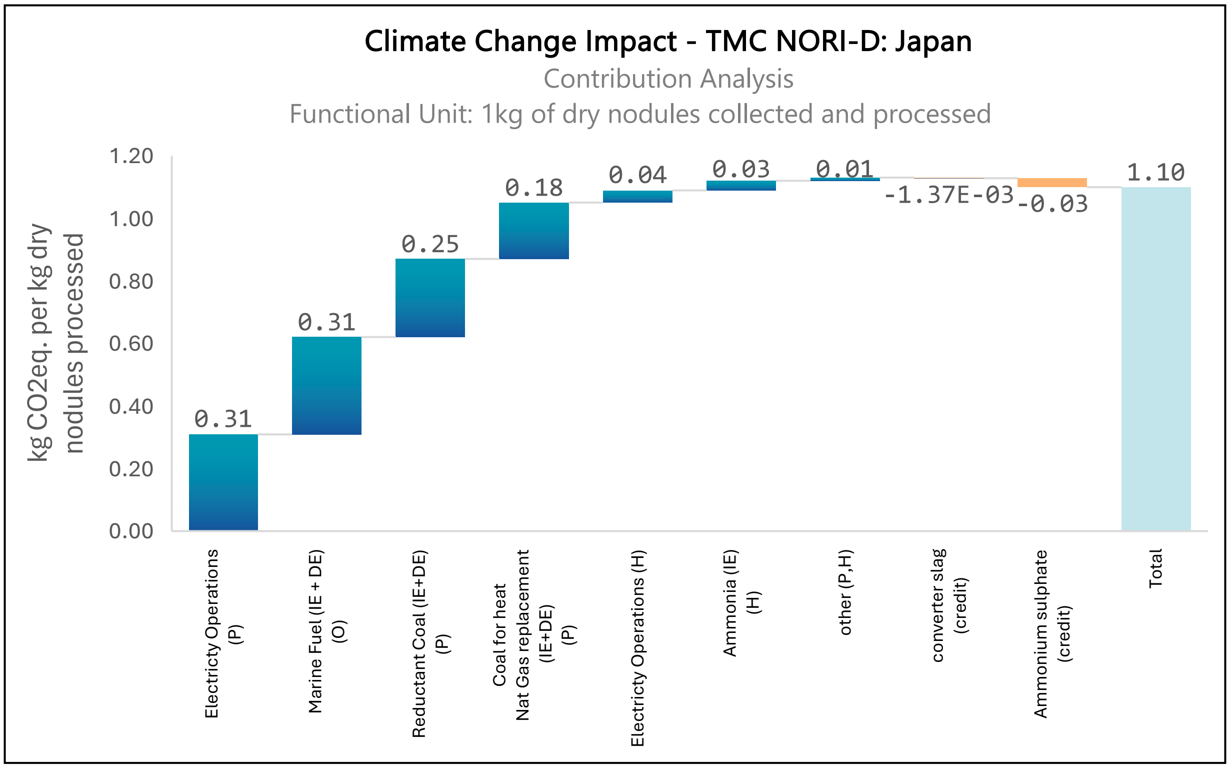


Figure 5: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of dry nodules collected and processed

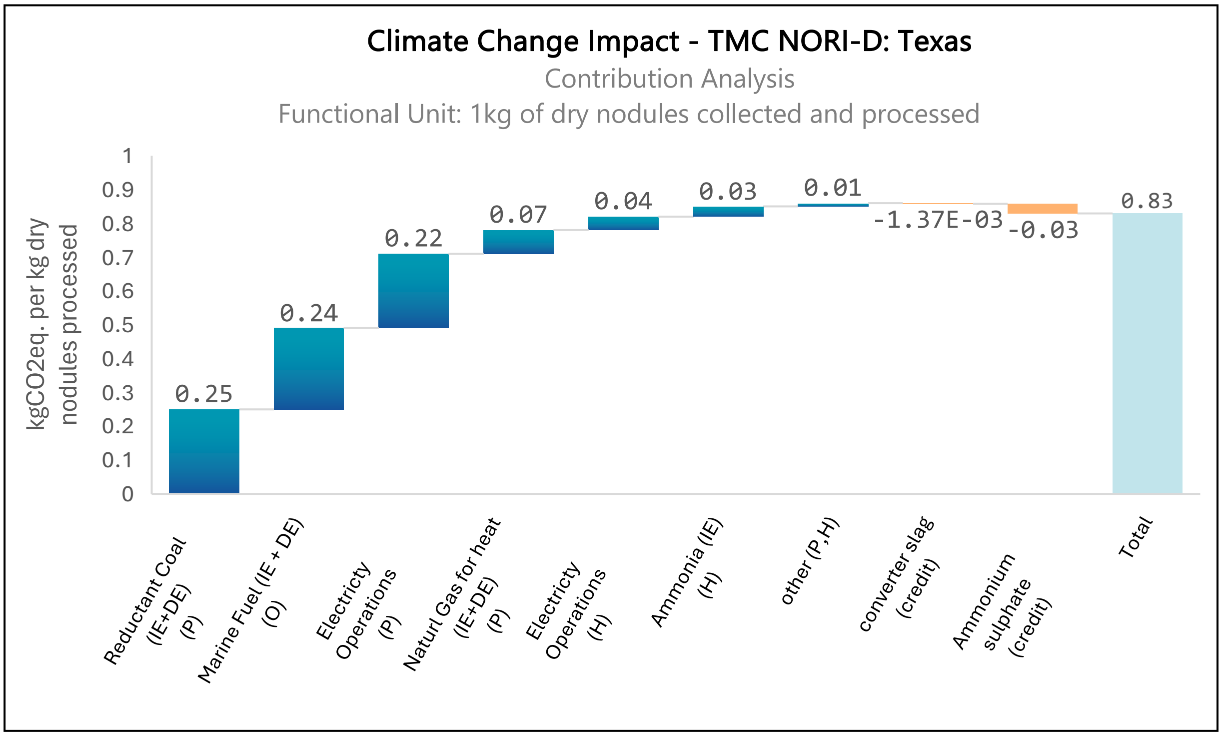


Figure 6: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of dry nodules collected and processed

5.1.2 Functional Unit: 1kg of Mn in $MnSiO_3$ (40% Mn).

The total climate change impact from nodule collection and pyrometallurgy associated with the production of 1kg of Mn in $MnSiO_3$ is **3.41 kg CO_2eq.**, **2.78 kg CO_2eq.**, and **2.19 kg CO_2eq.** when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 7). The pyrometallurgy stage carries the highest impact ranging from 67% - 74% of the total impact depending on processing location.

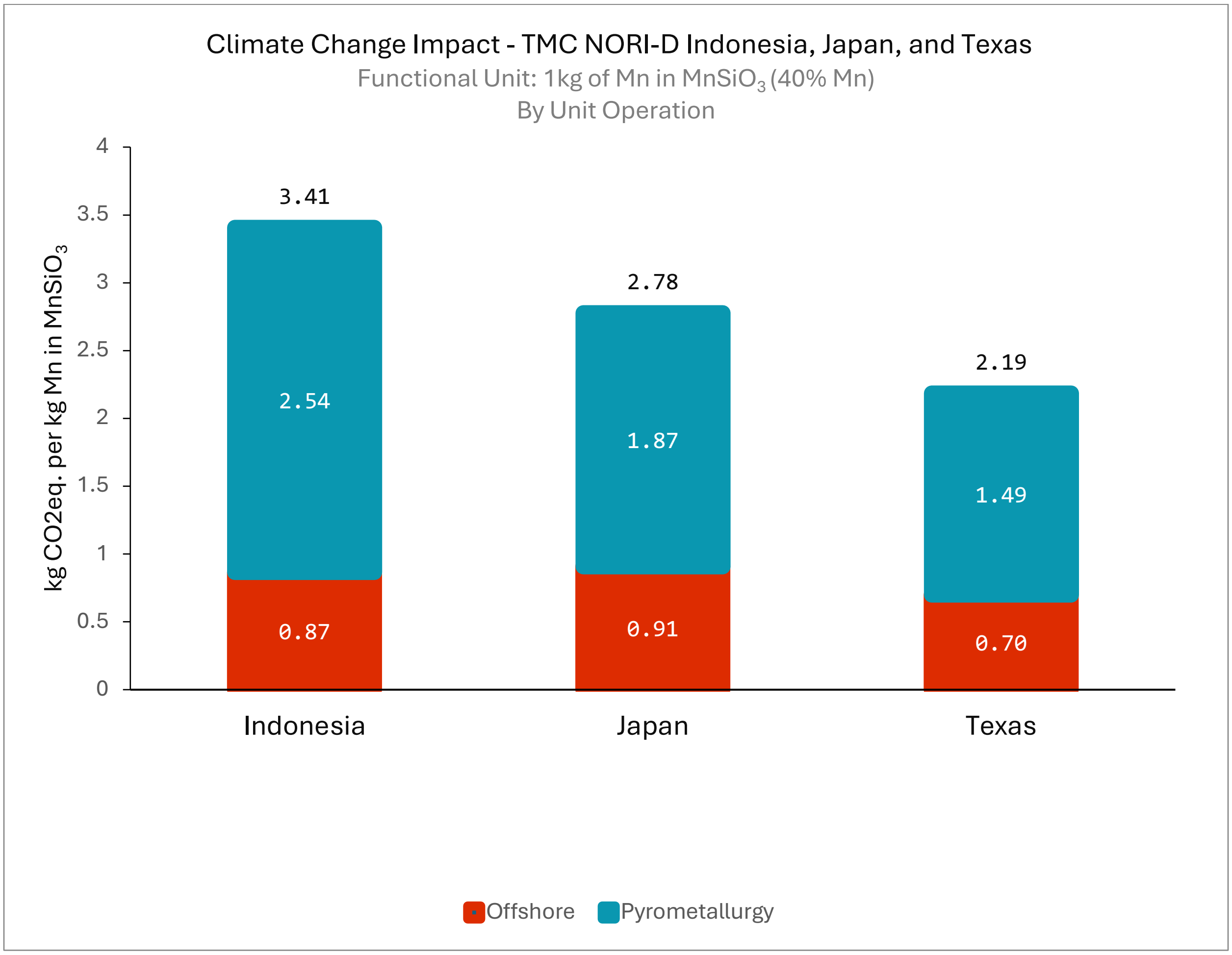


Figure 7: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1kg of Mn in MnSiO3 processed

5.1.2.1 Contribution Analysis - 1kg of Mn in $MnSiO_3$.

The results of the contribution analysis can be seen in Figures 8 to 10. For all processing locations, the main contributors remain the same. They are:

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **1.58 kg CO_2eq.** (46% of the total impact), **0.90 kg CO_2eq.** (32% of the total impact) and **0.65 kg CO_2eq.** (30% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **0.87 kg CO_2eq.** (26% of the total impact), **0.91 kg CO_2eq**. (33% of the total impact) and **0.70 kg CO_2eq**. (32% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **0.60 kg CO_2eq**. for each location, representing 18%, 22%, and 28% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

There is no credit received for the converter slag when $MnSiO_3$ is the considered functional unit as the $MnSiO_3$ product exits the system before the converter slag is produced.

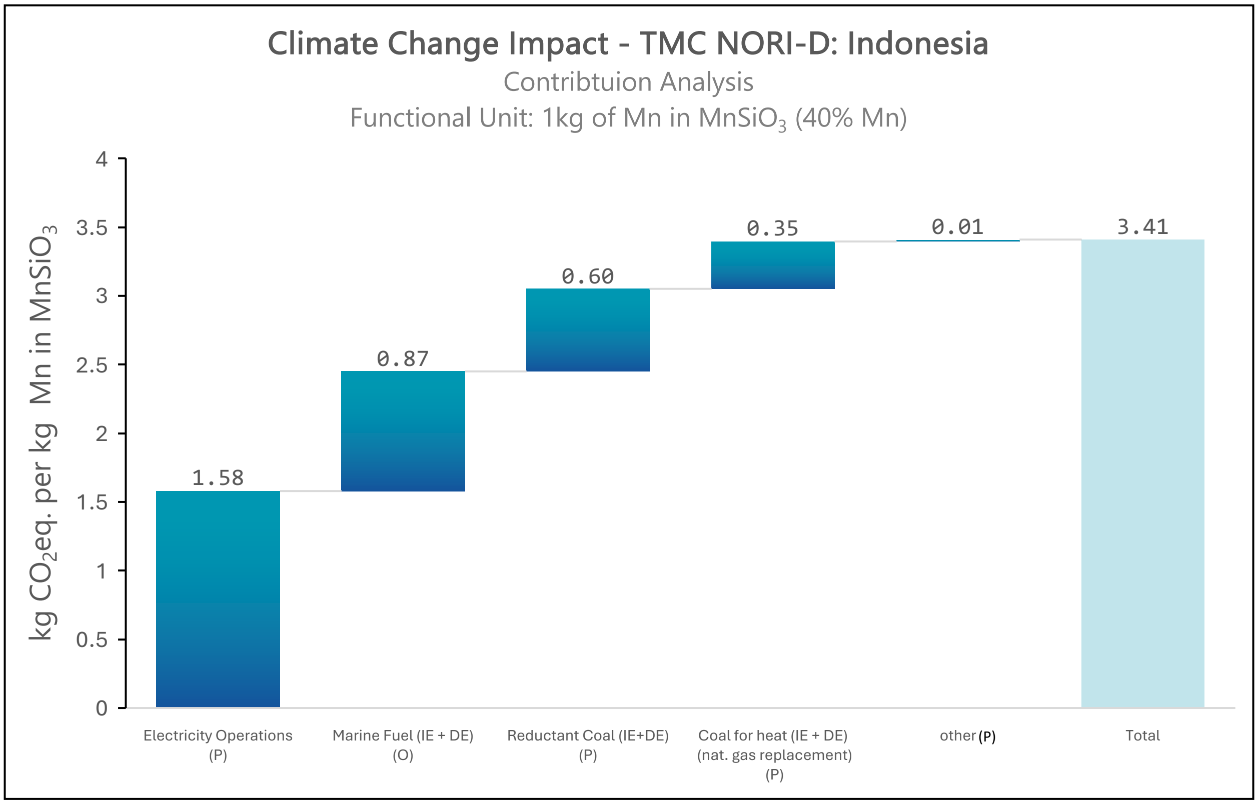


Figure 9:Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of Mn in $MnSiO_3$

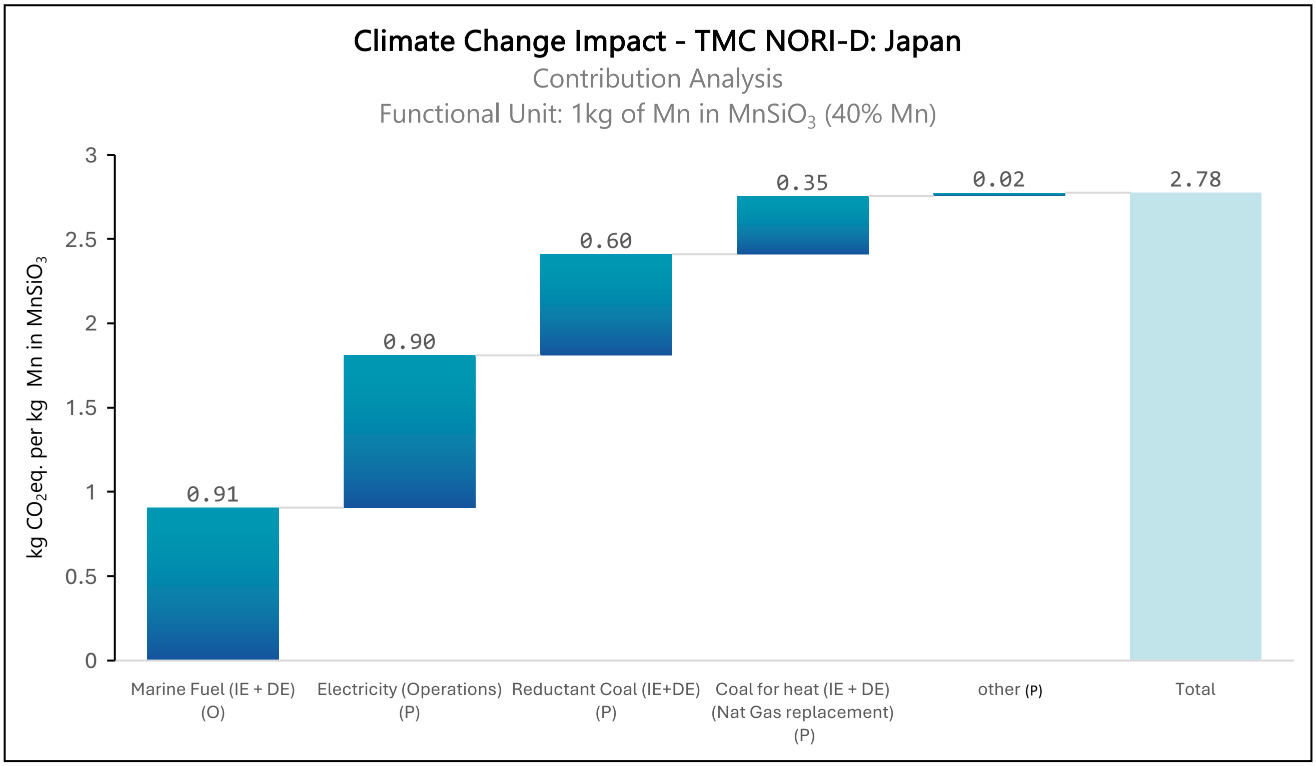


Figure 8: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of Mn in $MnSiO_3$

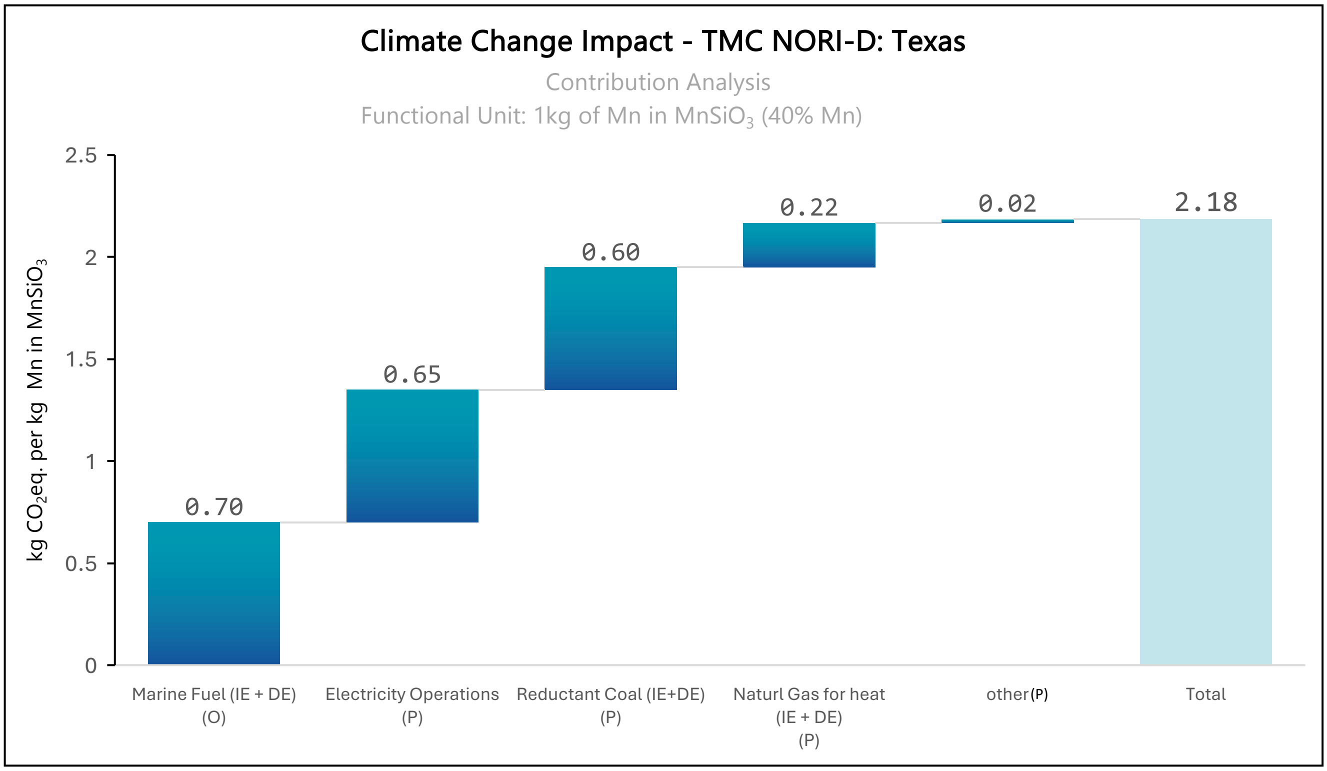


Figure 10: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of Mn in MnSiO₃

5.1.3 Functional Unit: 1kg of Ni-Cu-Co Matte (40.7% Ni, 30.5% Cu, 3.4% Co).

The total climate change impact from nodule collection and pyrometallurgy associated with the production of 1kg of Ni-Cu-Co matte is **5.52 kg CO_2eq.**, **4.89 kg CO_2eq.**, and **4.31 kg CO_2eq.** when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 11). The pyrometallurgy stage contributes the highest impact ranging from 81% - 84% of the total impact depending on processing location.

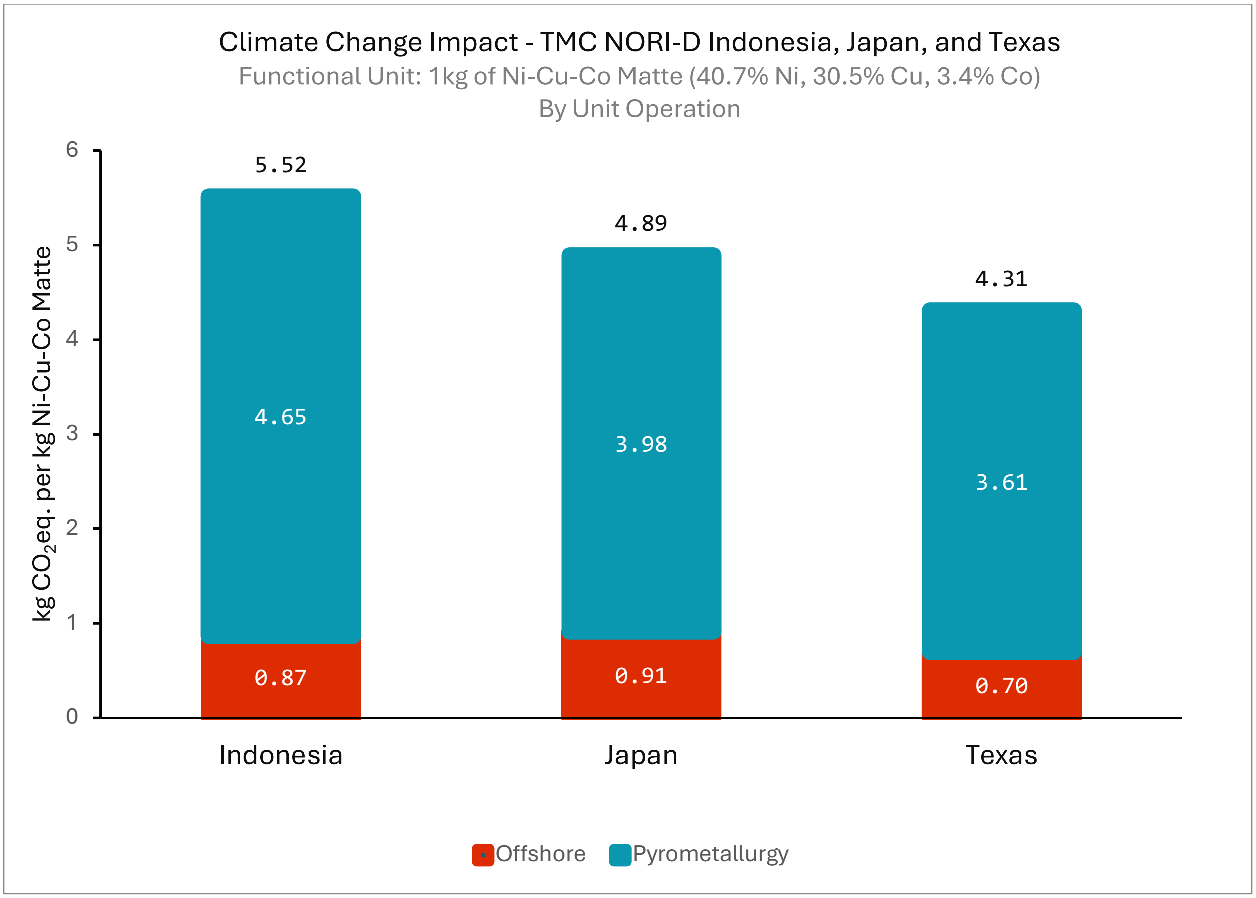


Figure 11: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1 kg of Ni-Cu-Co Matte

5.1.3.1 Contribution Analysis - 1kg of Ni-Cu-Co Matte

The results of the contribution analysis can be seen in Figures 12 to 14. For all processing locations, the main contributors remain the same. They are:

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **2.65 kg CO_2eq**. for each location, representing 48%, 54%, and 61% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **1.71 kg CO_2eq.** (31% of the total impact), **0.98 kg CO_2eq.** (20% of the total impact) and **0.70 kg CO_2eq.** (16% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **0.87 kg CO_2eq.** (16% of the total impact), **0.91 kg CO_2eq**. (19% of the total impact) and **0.70 kg CO_2eq**. (16% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

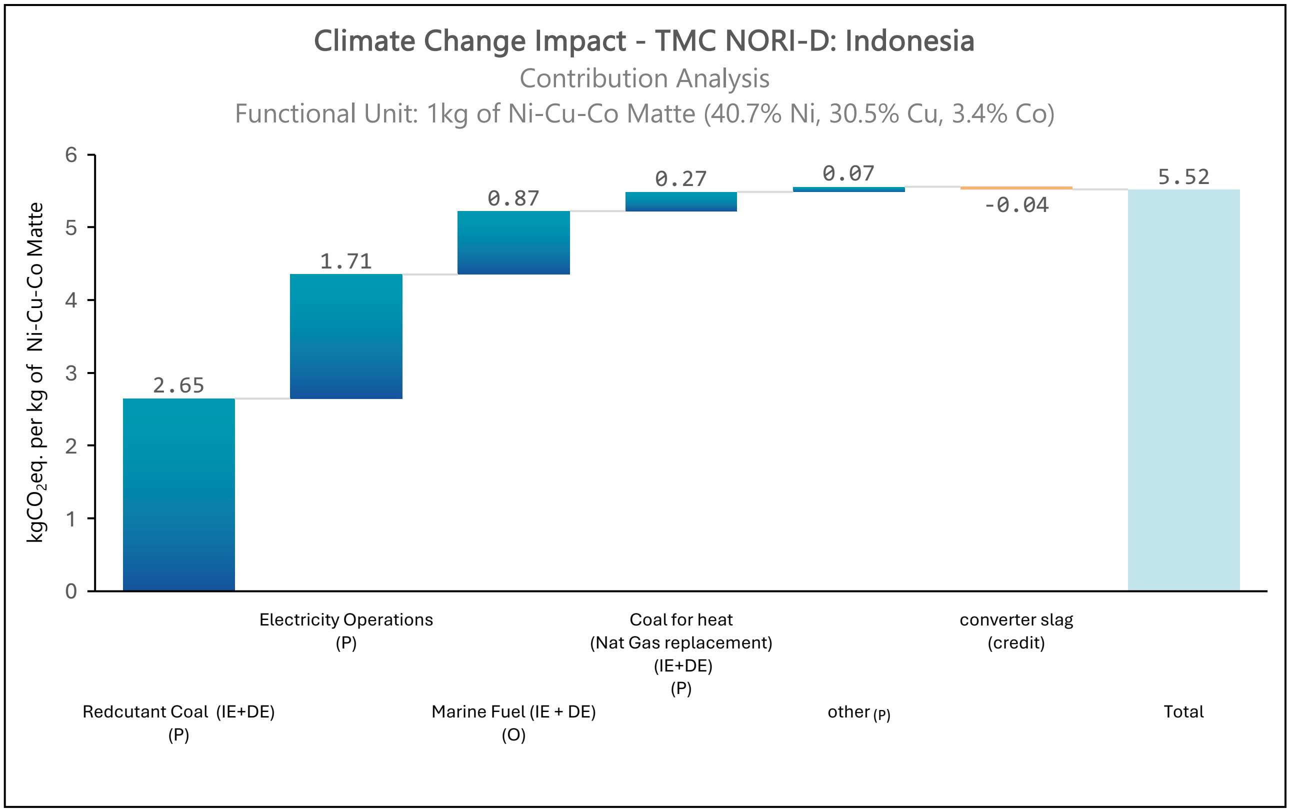


Figure 12: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of Ni-Cu-Co Matte

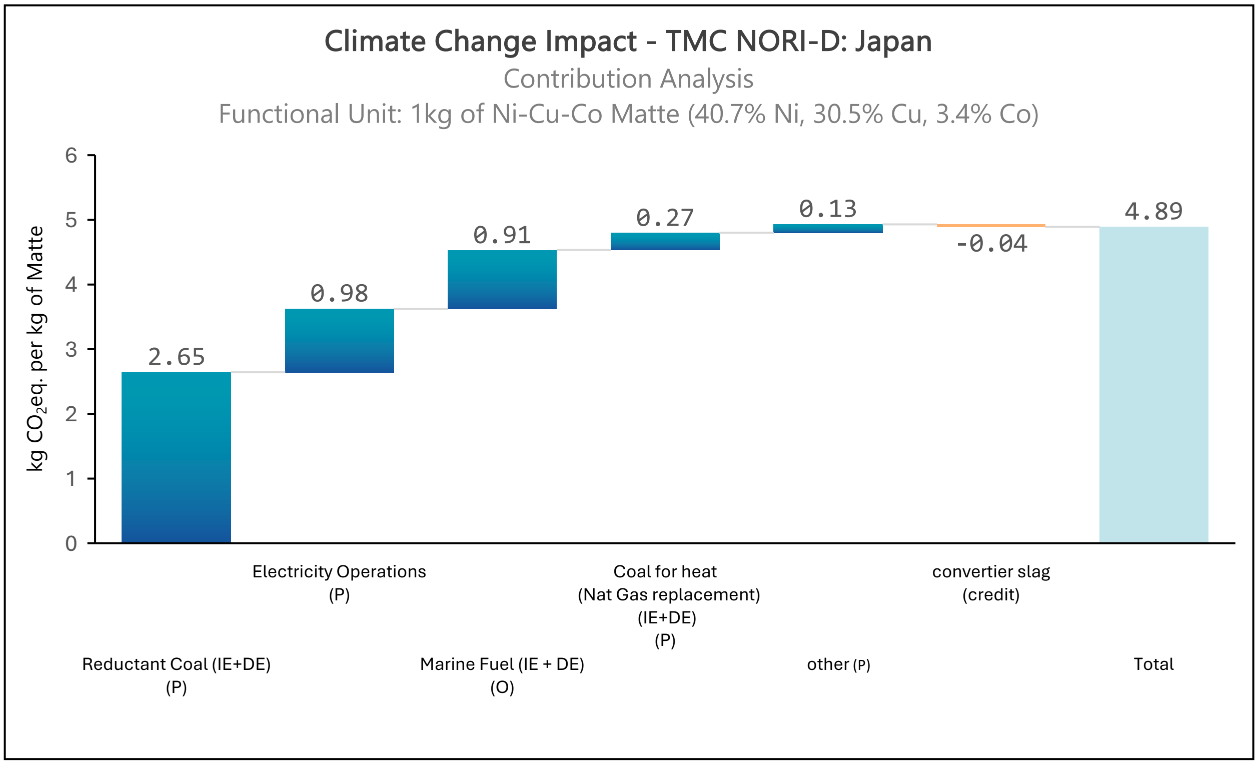


Figure 13: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of Ni-Cu-Co Matte

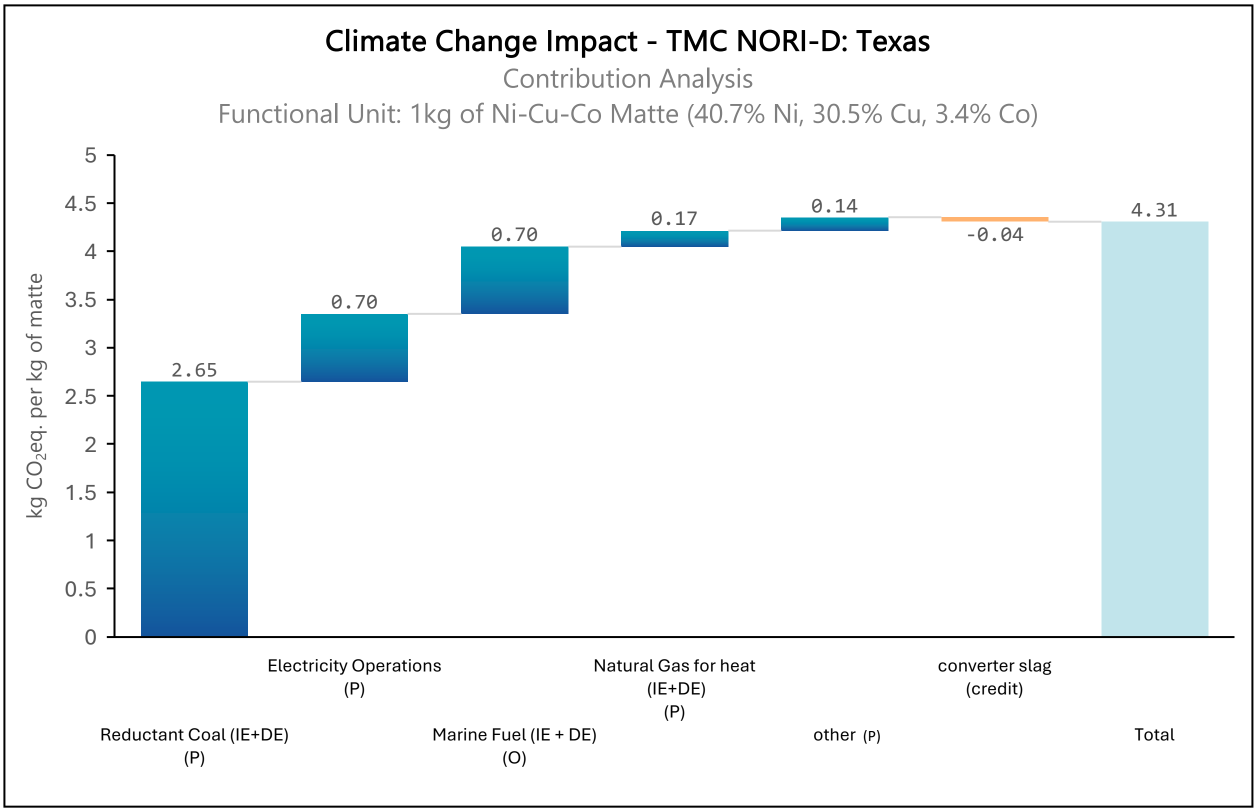


Figure 14: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of Ni-Cu-Co Matte

5.1.4 Functional Unit: 1kg of Mn in SiMn (68.9% Mn)

The total climate change impact from nodule collection and pyrometallurgy associated with the production of 1kg of SiMn, including downstream customer pyrometallurgical processing is **11.27 kg CO_2eq**., **10.61 kg CO_2eq**., and **10.34 kg CO_2eq**. when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 15).

The downstream processing of TMC's $MnSiO_3$ constitutes the largest impact, contributing 69% - 76% of the total impact depending on processing location. A detailed assessment of this contribution will be provided in the subsequent contribution analysis. For the TMC NORI-D Texas route, the impact from the transport of $MnSiO_3$ to China for processing is greater than that of the Indonesia and Japan route due to the longer transport distance involved.

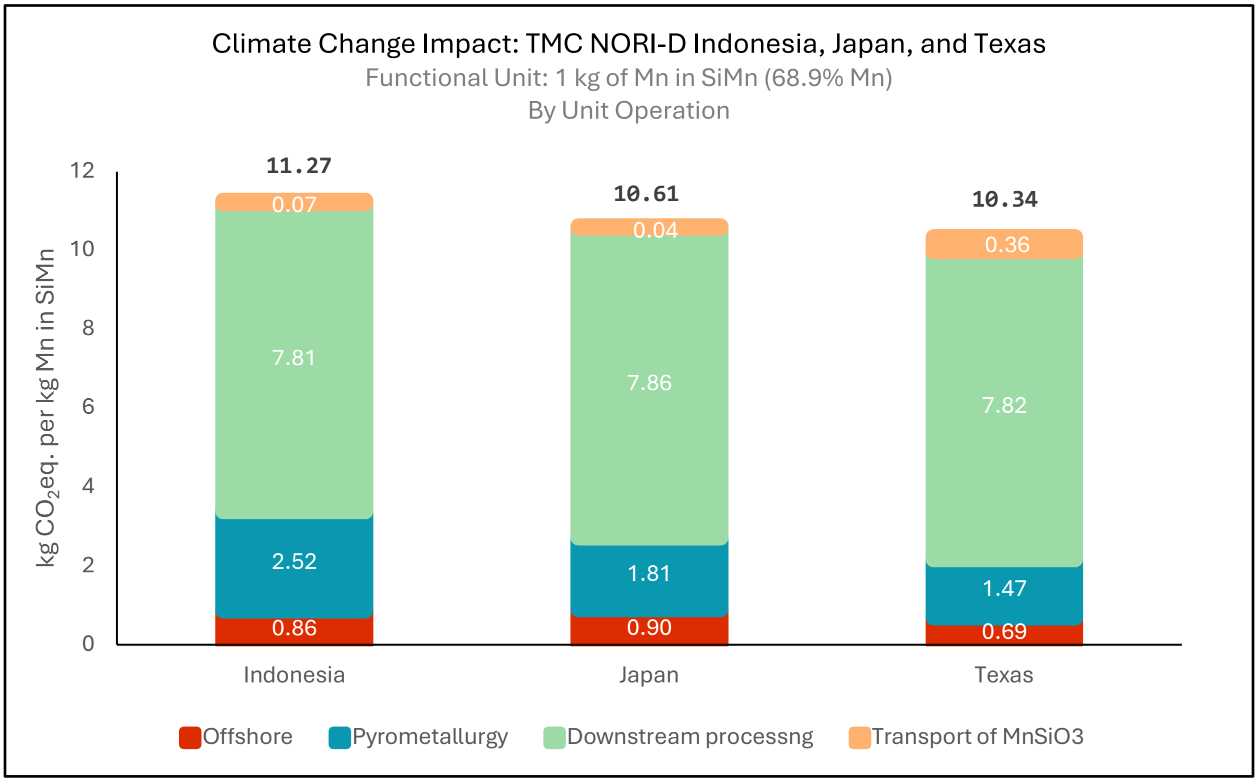


Figure 15: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1 kg of Mn in SiMn

5.1.4.1 Contribution Analysis - 1kg of Mn in SiMn

The results of the contribution analysis can be seen in Figures 16 to 18. For all processing locations, the main contributors remain the same. They are:

- Customer electricity required for downstream processing. More specifically, for the carbothermic reduction of TMC $MnSiO_3$ to SiMn, contributing 5.27 kg CO_2eq. which represents 47%, 50%, and 51% of the total impact when the $MnSiO_3$ is produced via the TMC NORI-D Indonesia, Japan, and Texas routes respectively. This large impact is because the reduction of manganese oxides and silicon dioxide to elemental manganese and silicon are very energy intensive, requiring temperatures in excess of 1500 degrees Celsius. Coupling this with the relatively carbon-intensive electricity grid-mix of China leads to the high impact.

- Direct emissions from coke use during downstream processing relating to the carbothermic reduction of TMC's $MnSiO_3$ to SiMn. This contributes 1.85 kg CO2eq. which represents 16%, 17%, and 18% of the total impact when the $MnSiO_3$ is produced via the TMC NORI-D Indonesia, Japan, and Texas routes respectively. These emissions result from CO_2 -forming reactions in the reduction process, primarily from coke.

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **1.57 kg CO_2eq.** (14% of the total impact), **0.90 kg CO_2eq.** (8% of the total impact) and **0.65 kg CO_2eq.** (6% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

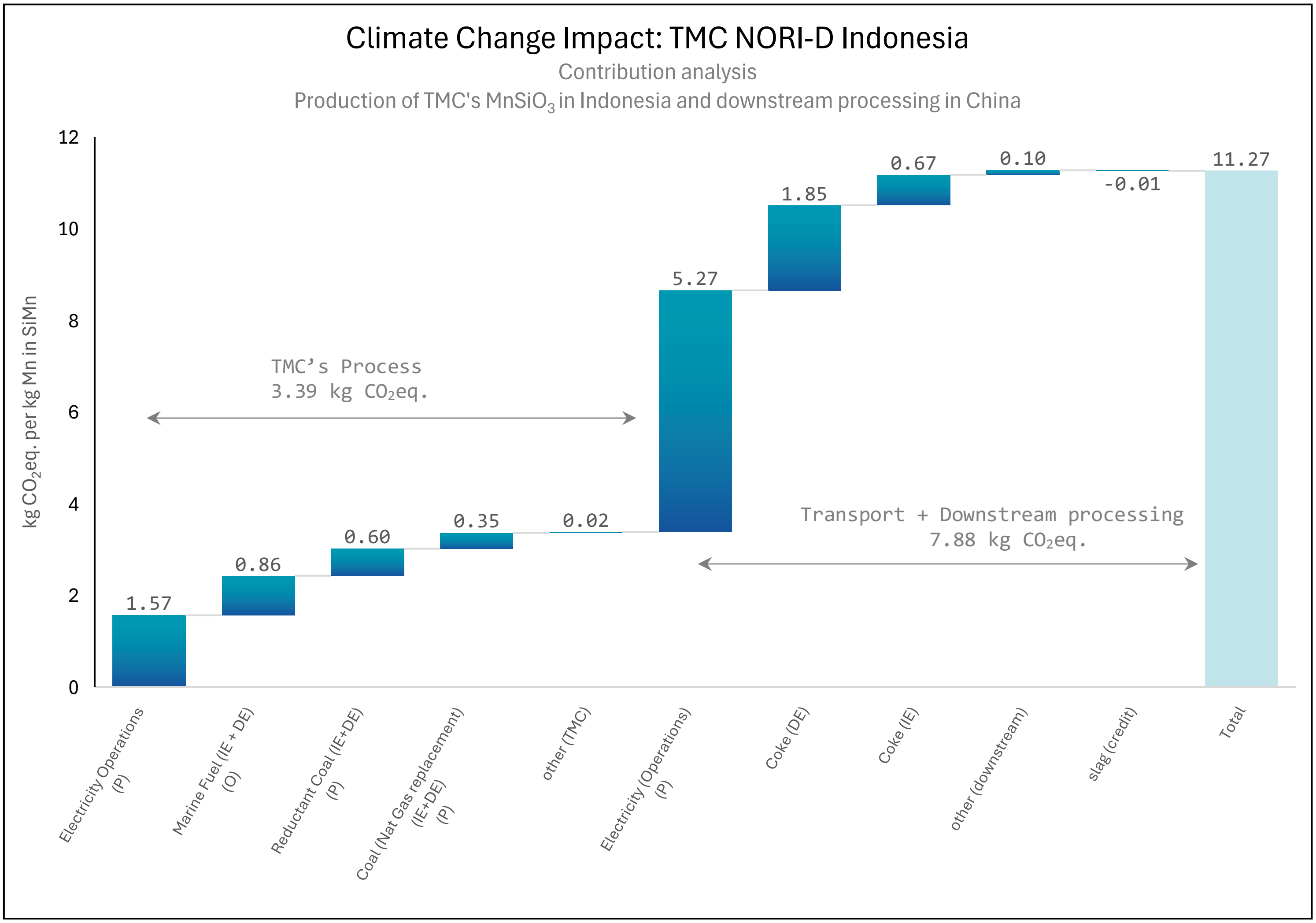


Figure 16: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of Mn in SiMn

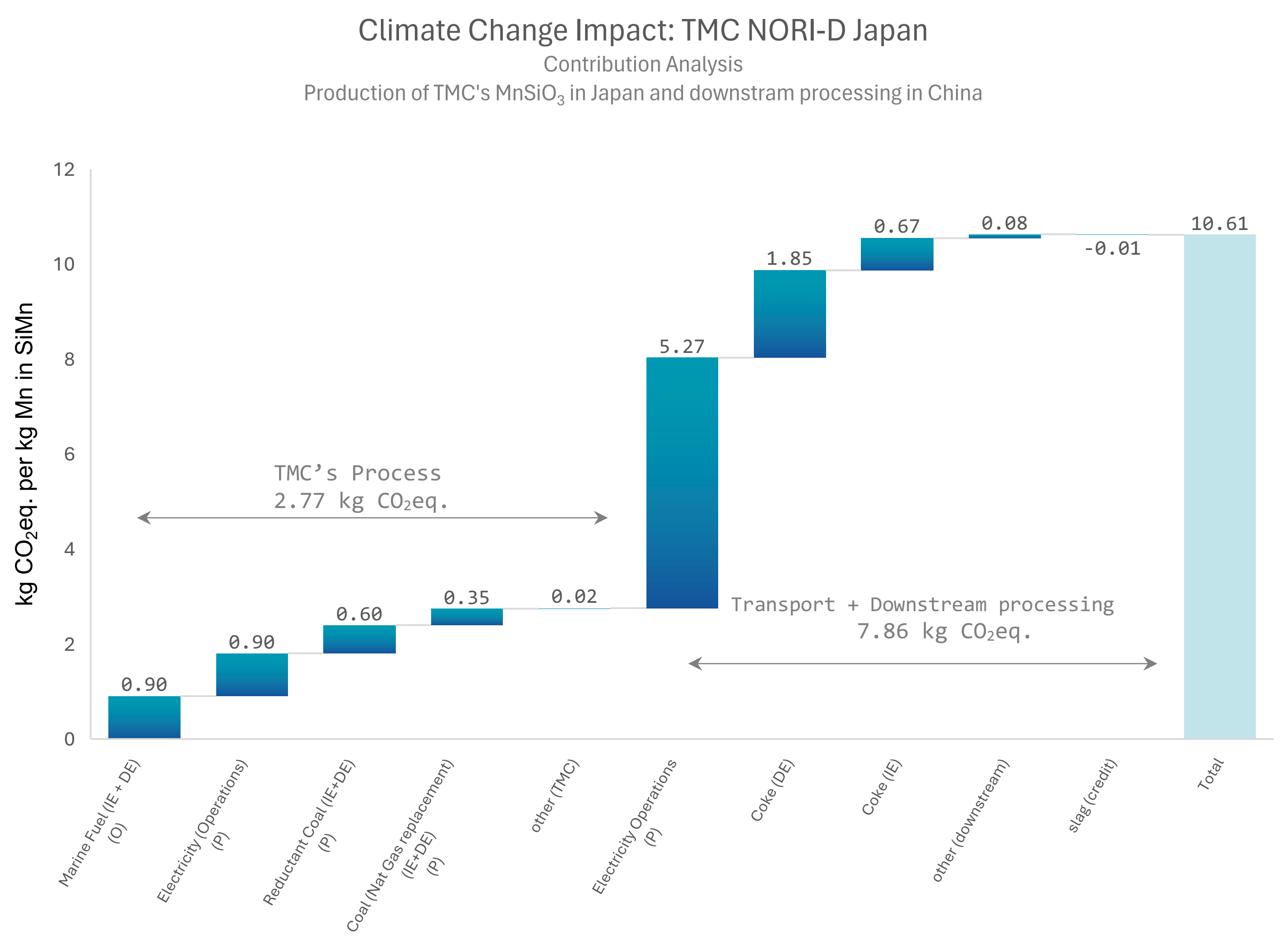


Figure 17: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of Mn in SiMn

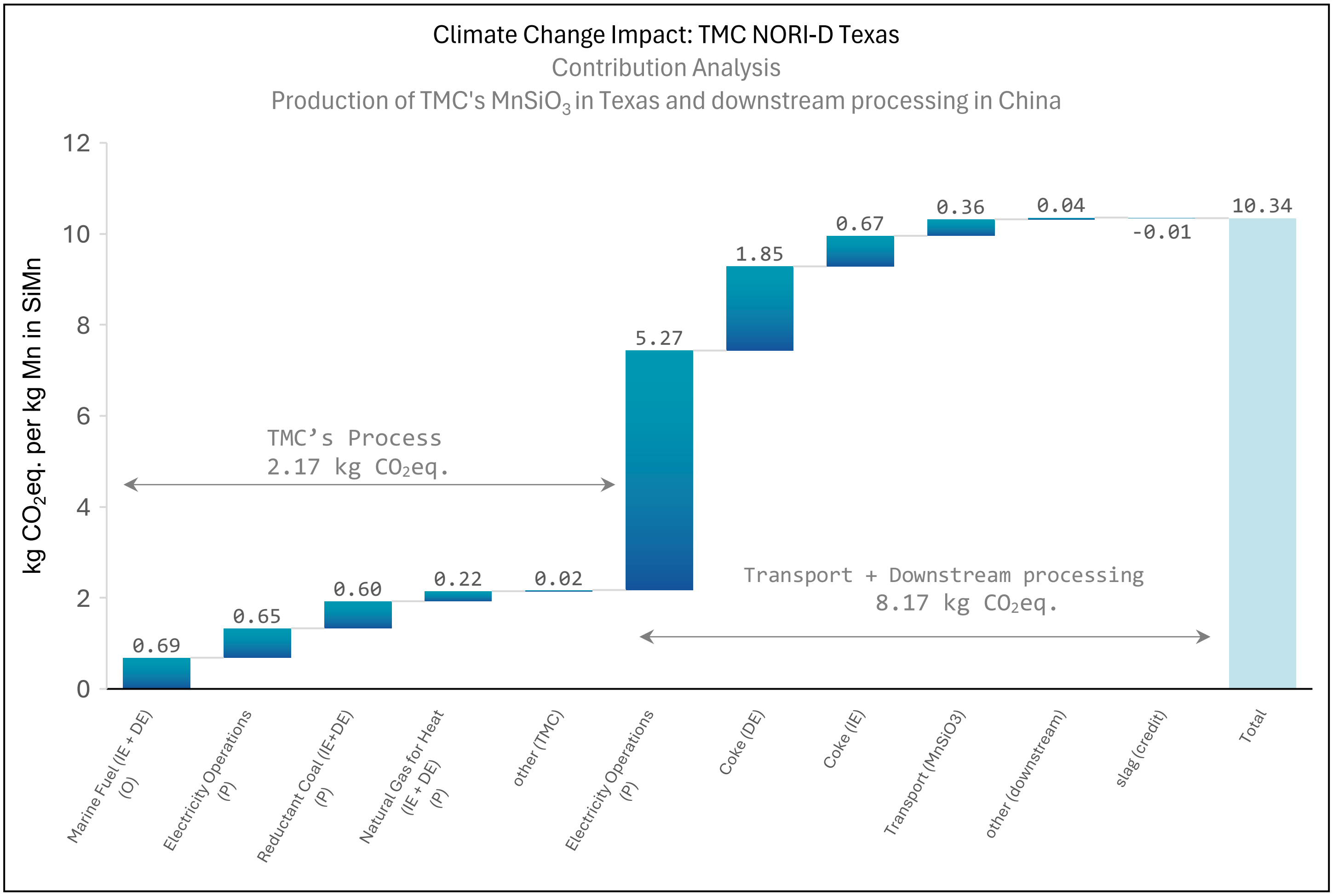


Figure 18: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of Mn in SiMn

5.1.5 Functional Unit: 1kg of Ni in $NiSO_4.6H_2O$ (22% Ni)

The total climate change impact associated with nodule collection and processing (pyrometallurgy and hydrometallurgy) of 1kg of Ni in $NiSO_4.6H_2O$, is **12.56 kg CO_2eq.**, **11.48 kg CO_2eq.**, and **9.98 kg CO_2eq**. when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 19).

The pyrometallurgy stage is the most impactful stage, representing 53% - 57% of the total impact depending on processing location. The hydrometallurgy stage also has a significant impact, contributing 32% - 35% of the total impact depending on processing location.

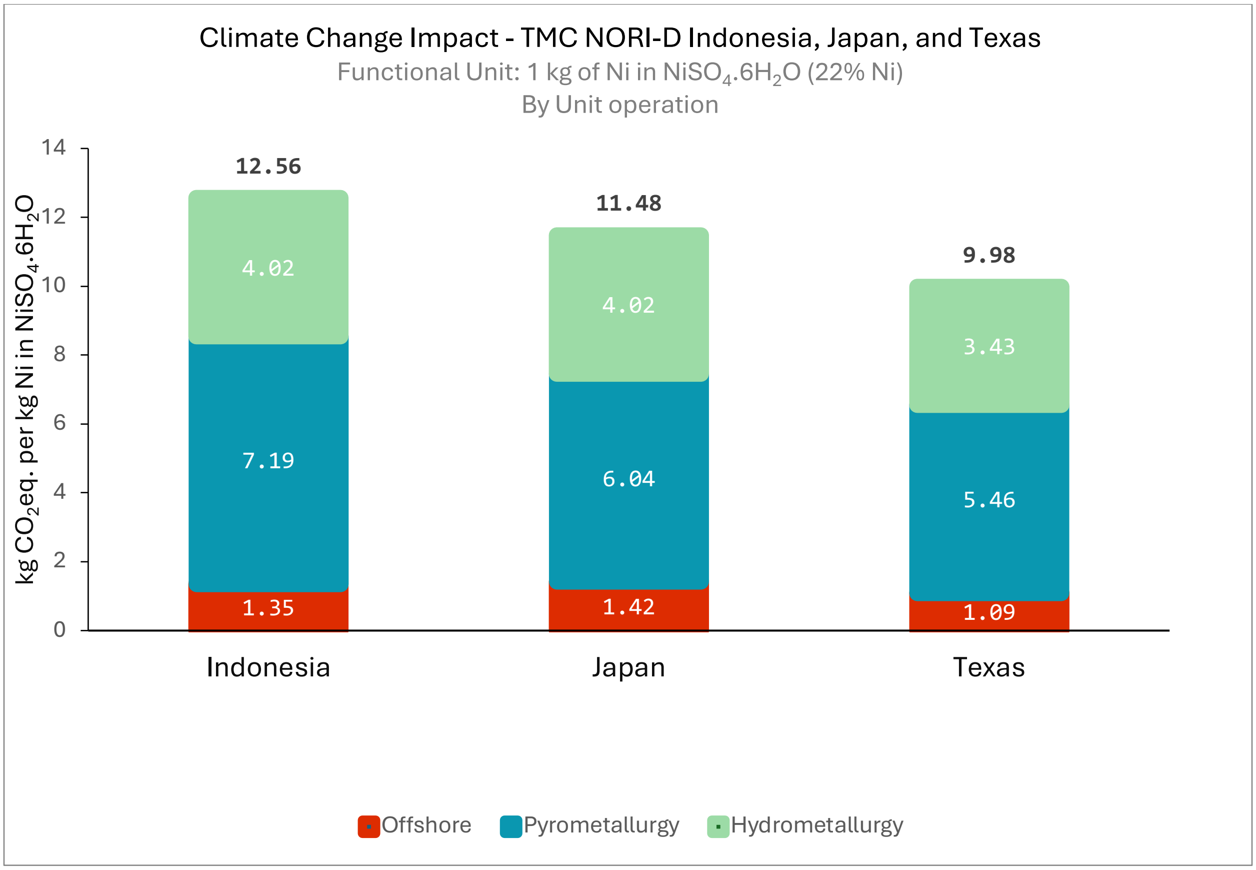


Figure 19: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1 kg of Ni in $NiSO_4.6H_2O$

5.1.5.1 Contribution Analysis - 1kg of Ni in $NiSO_4.6H_2O$

The results of the contribution analysis can be seen in Figures 20 to 22. For all processing locations, the main contributors remain the same. They are:

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **4.14 kg CO_2eq**. for each location, representing 33%, 38%, and 41% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **2.67 kgCO_2eq.** (21% of the total impact), **1.53 kg CO_2eq.** (13% of the total impact) and **1.10 kgCO_2eq.** (11% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's hydrometallurgical operations, contributing approximately **1.79 kgCO_2eq.,** for the TMC NORI-D Indonesia and Japan route (14% and 16% of total impact respectively) and **1.22 kgCO_2eq.** for the Texas route (12% of the total impact).

- The indirect emissions from the production of liquid ammonia used in the iron removal stage prior to solvent extraction, contributing **2.24 kgCO_2eq.** for each location, representing 18%, 19%, and 22% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively. Ammonia is primarily made from the Haber-Bosch process, this process uses high temperatures and pressures, leading to ammonia's high embodied emissions.

- The production and combustion of natural gas used in the hydrometallurgy process to provide heat and steam, contributing **1.30 kgCO_2eq.** for each location, representing 10%, 11%, and 13% of the total climate change impact respectively.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **1.35 kg CO_2eq.** (11% of the total impact), **1.42, kg CO_2eq**. (12% of the total impact) and **1.10 kg CO_2eq**. (11% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- There is a significant environmental credit of **-1.63 kg CO_2eq**. received for the ammonium sulphate generated during hydrometallurgy at each processing location. The magnitude of the credit is due to the volume of ammonium sulphate generated, coupled with its embodied emissions.

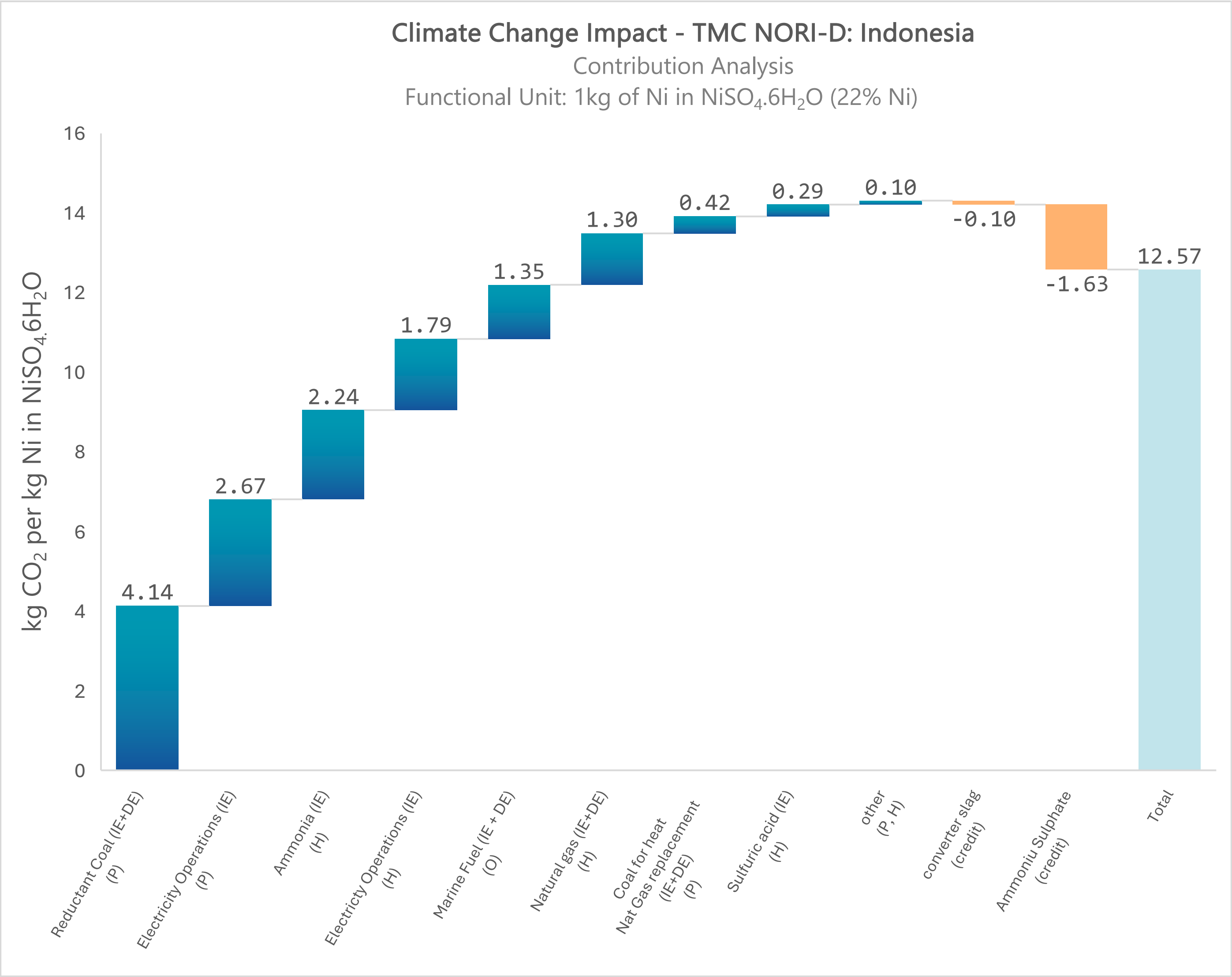


Figure 20: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of Ni in $NiSO_4.6H_2O$

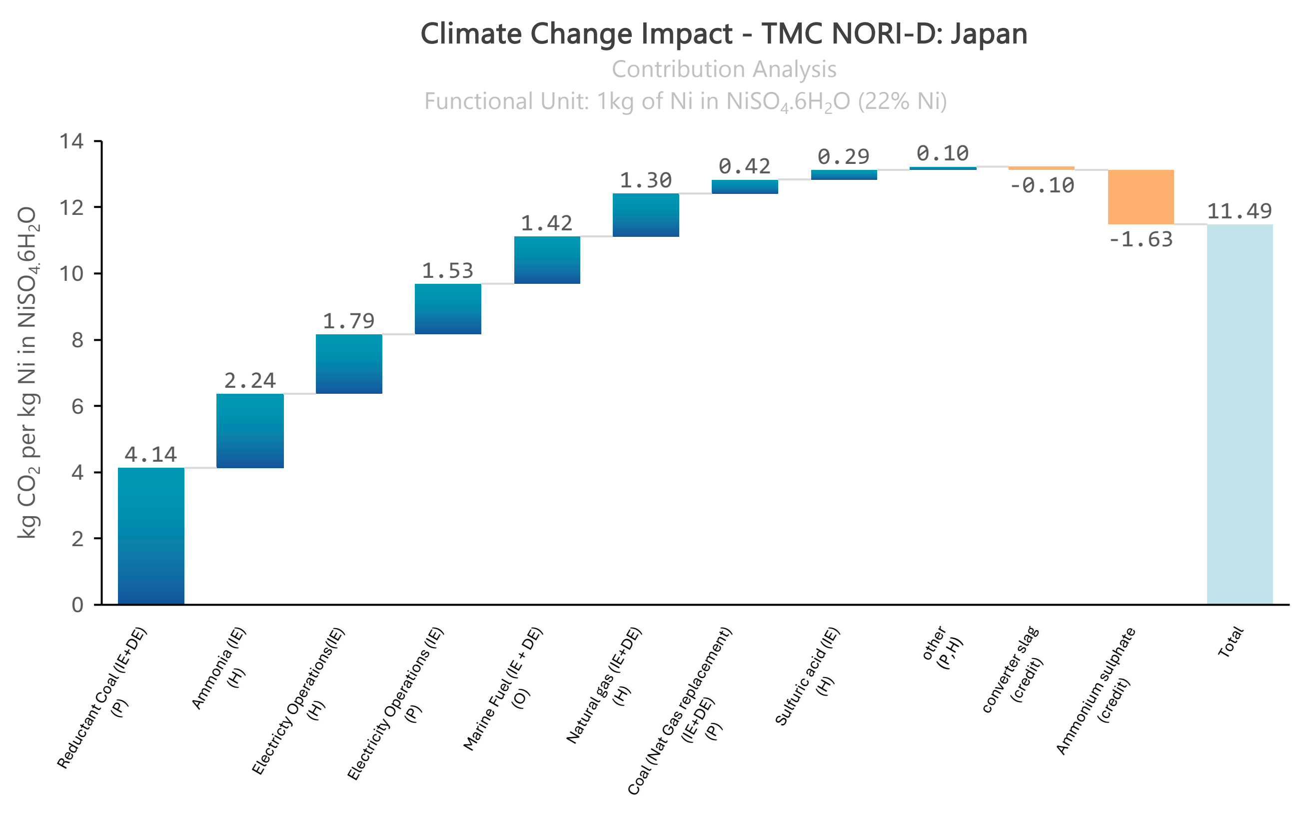


Figure 21: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of Ni in $NiSO_4.6H_2O$

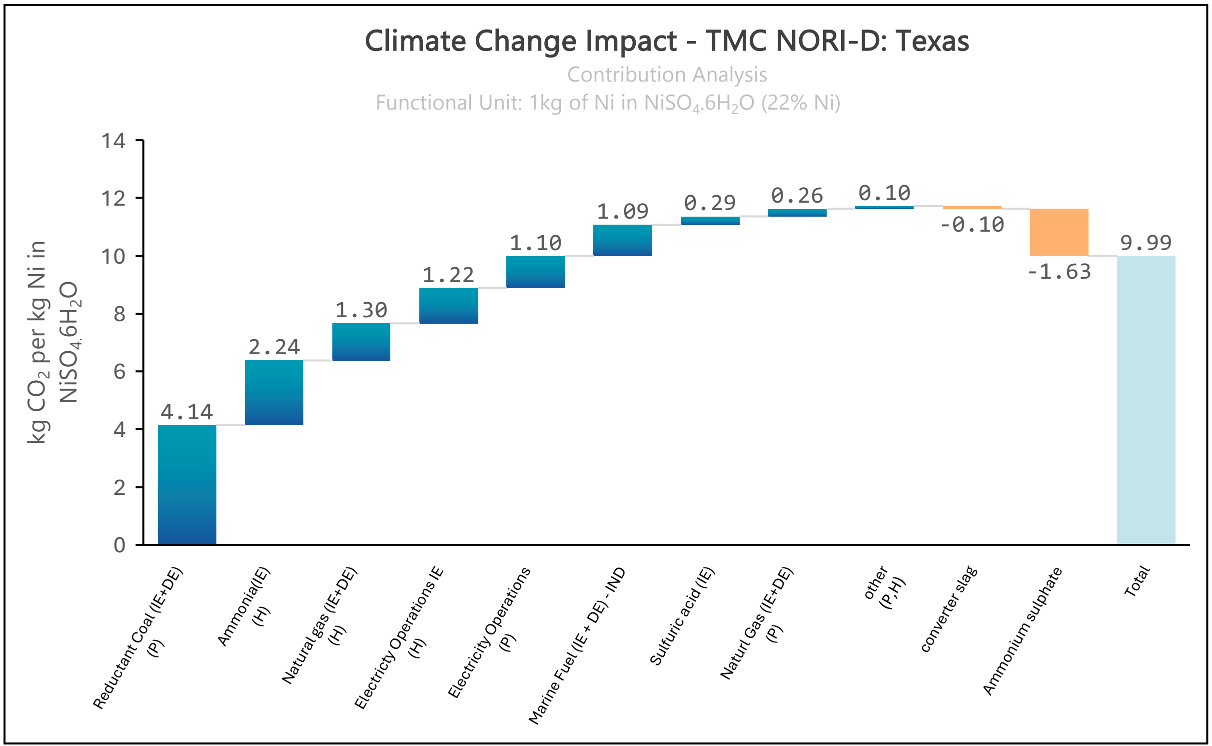


Figure 22: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of Ni in $NiSO_4.6H_2O$

5.1.6 Functional Unit: 1kg of copper cathode (99.99% Cu)

The total climate change impact associated with nodule collection and processing (pyrometallurgy and hydrometallurgy) of 1kg of copper cathode, is **4.63 kg CO_2eq.**, **4.14 kg CO_2eq.**, and **3.45 kg CO_2eq**. when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 23).

The pyrometallurgy stage is the most impactful stage, representing 65% - 70% of the total impact depending on processing location.

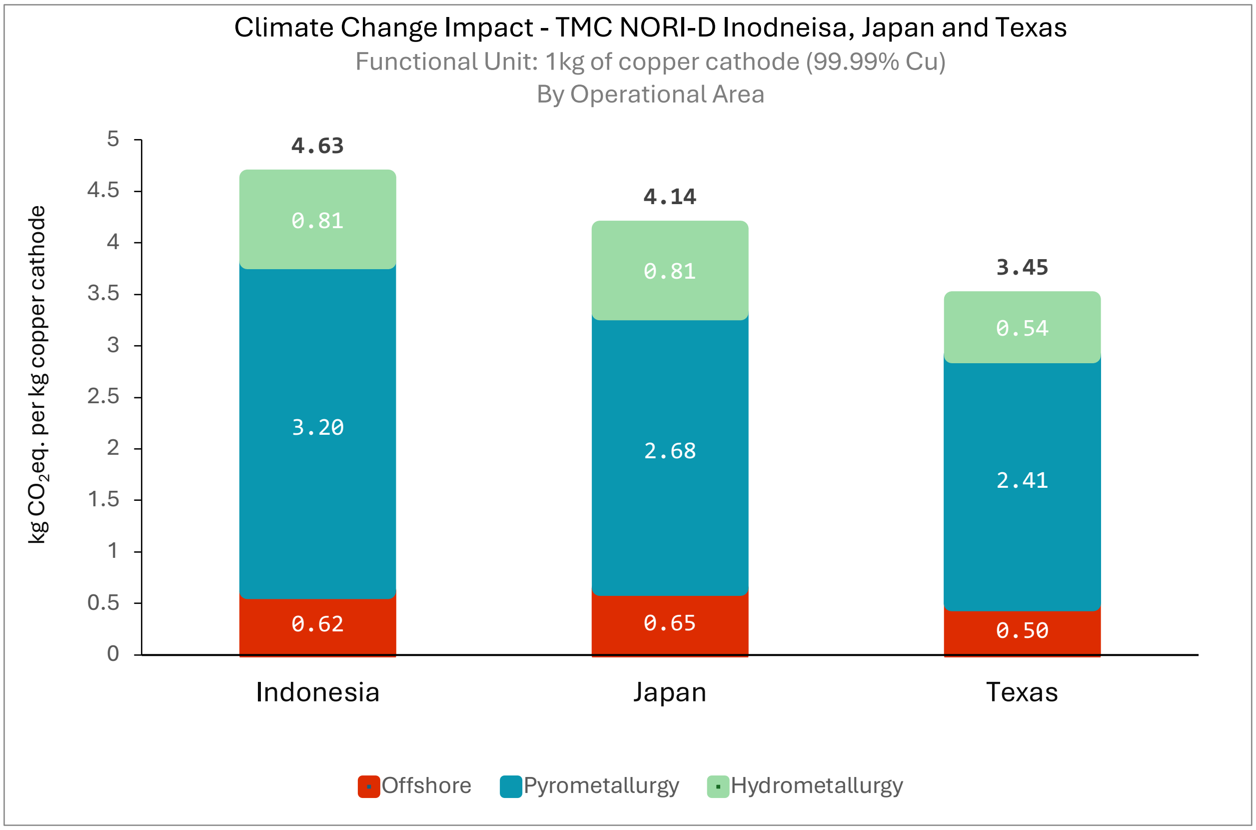


Figure 23: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1 kg of copper cathode

5.1.6.1 Contribution Analysis - 1kg of copper cathode

The results of the contribution analysis can be seen in Figures 24 to 26. For all processing locations, the main contributors remain the same. They are:

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **1.89 kg CO_2eq**. for each location, representing 41%, 46%, and 55% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **1.22 kg CO_2eq.** (26% of the total impact), **0.70 kg CO_2eq.** (17% of the total impact) and **0.50 kg CO_2eq.** (14% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's hydrometallurgical operations, contributing approximately **0.82 kg CO_2eq.,** for the TMC NORI-D Indonesia and Japan route (18% and 20% of total impact respectively) and **0.56 kg CO_2eq.** for the Texas route (16% of the total impact).

- The production and combustion of natural gas used in the hydrometallurgy process to provide heat and steam, contributing **0.59 kgCO_2eq.** for each location, representing 13%, 14%, and 17% of the total climate change impact respectively.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **0.62 kg CO_2eq.** (13% of the total impact), **0.65, kg CO_2eq**. (16% of the total impact) and **0.50 kg CO_2eq**. (14% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

There is a significant environmental credit of **-0.75 kg CO_2eq**. received for the ammonium sulphate generated during hydrometallurgy at each processing location. The magnitude of the credit is due to the volume of ammonium sulphate generated, coupled with its embodied emissions.

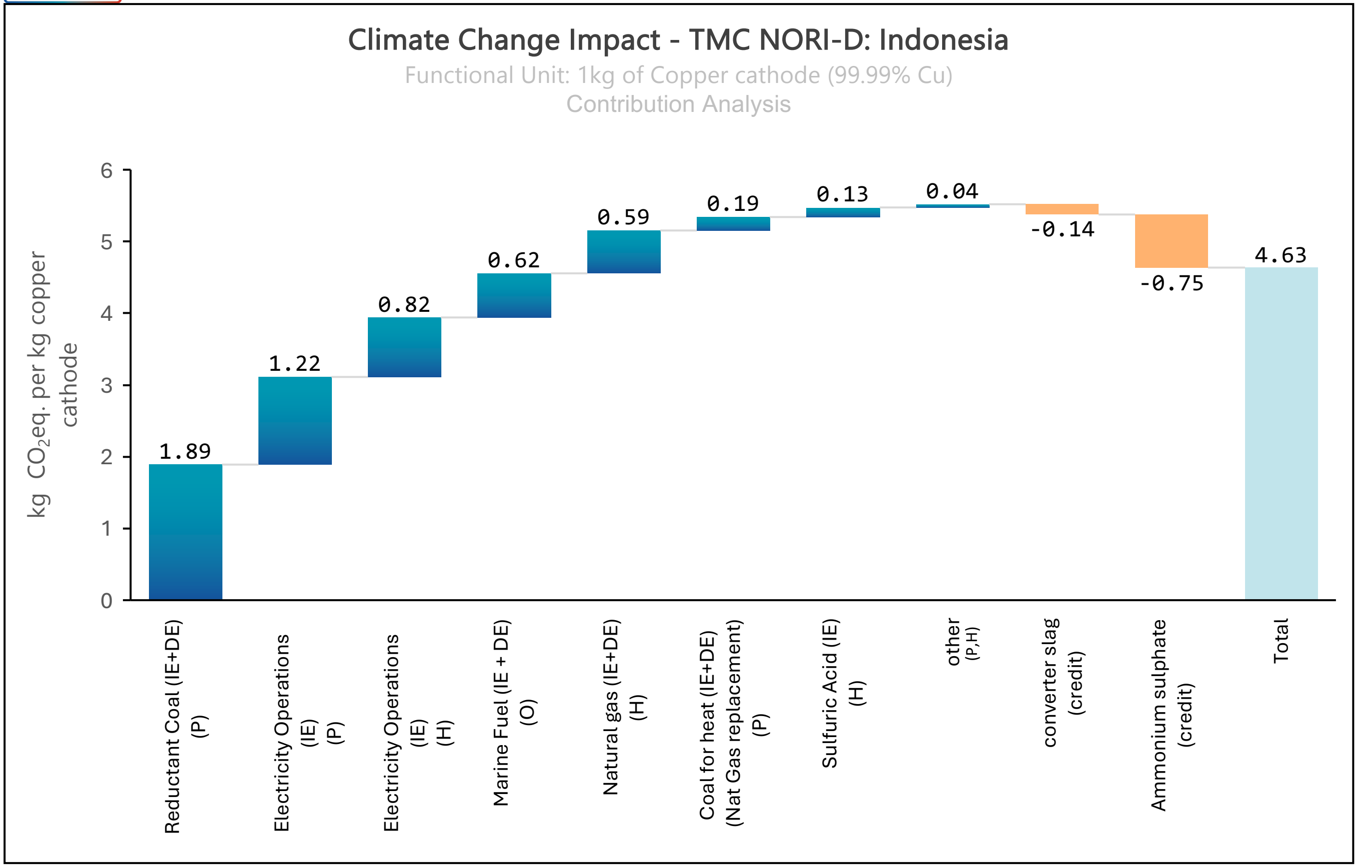


Figure 24: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of copper cathode

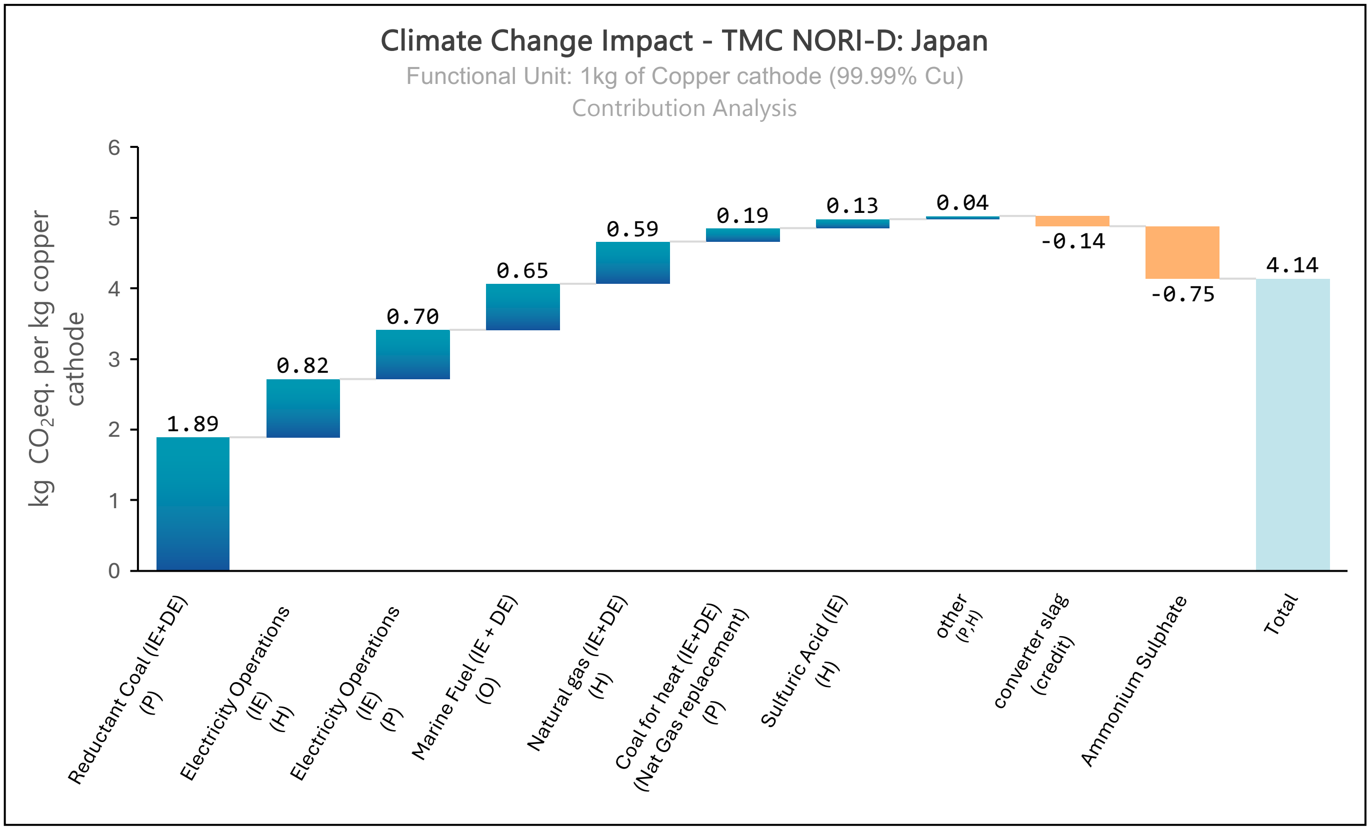


Figure 25: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of copper cathode

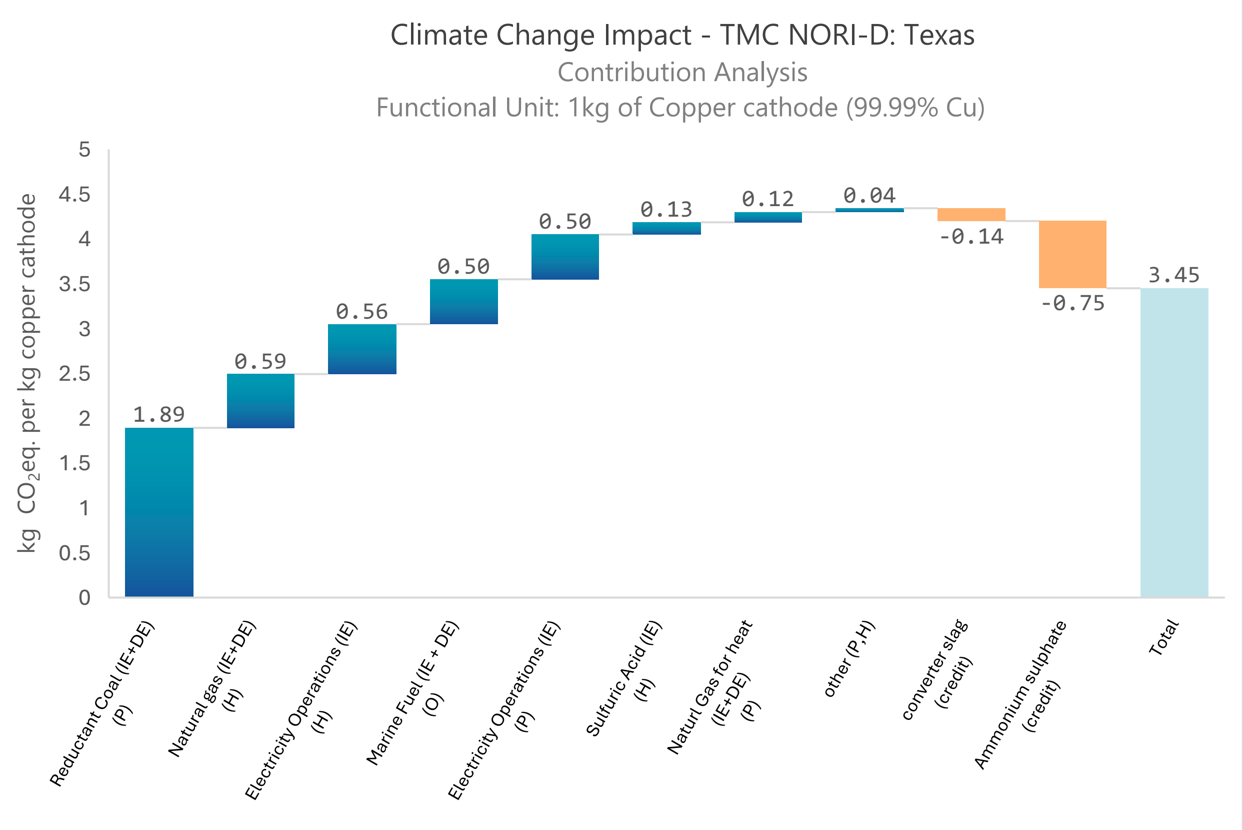


Figure 26: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas– 1kg of copper cathode

5.1.7 Functional Unit: 1kg of Co in $CoSO_4.7H_2O$ (21% Co)

The total climate change impact associated with nodule collection and processing (pyrometallurgy and hydrometallurgy) of 1kg of Co in $CoSO_4.7H_2O$, is **31.41 kg CO_2eq.**, **28.40 kg CO_2eq.**, and **24.23 kg CO_2eq**. when the nodules are transported and processed via the TMC NORI-D Indonesia, Japan, and Texas routes respectively (Figure 27).

The pyrometallurgy stage is the most impactful stage, representing 56% - 61% of the total impact depending on processing location.

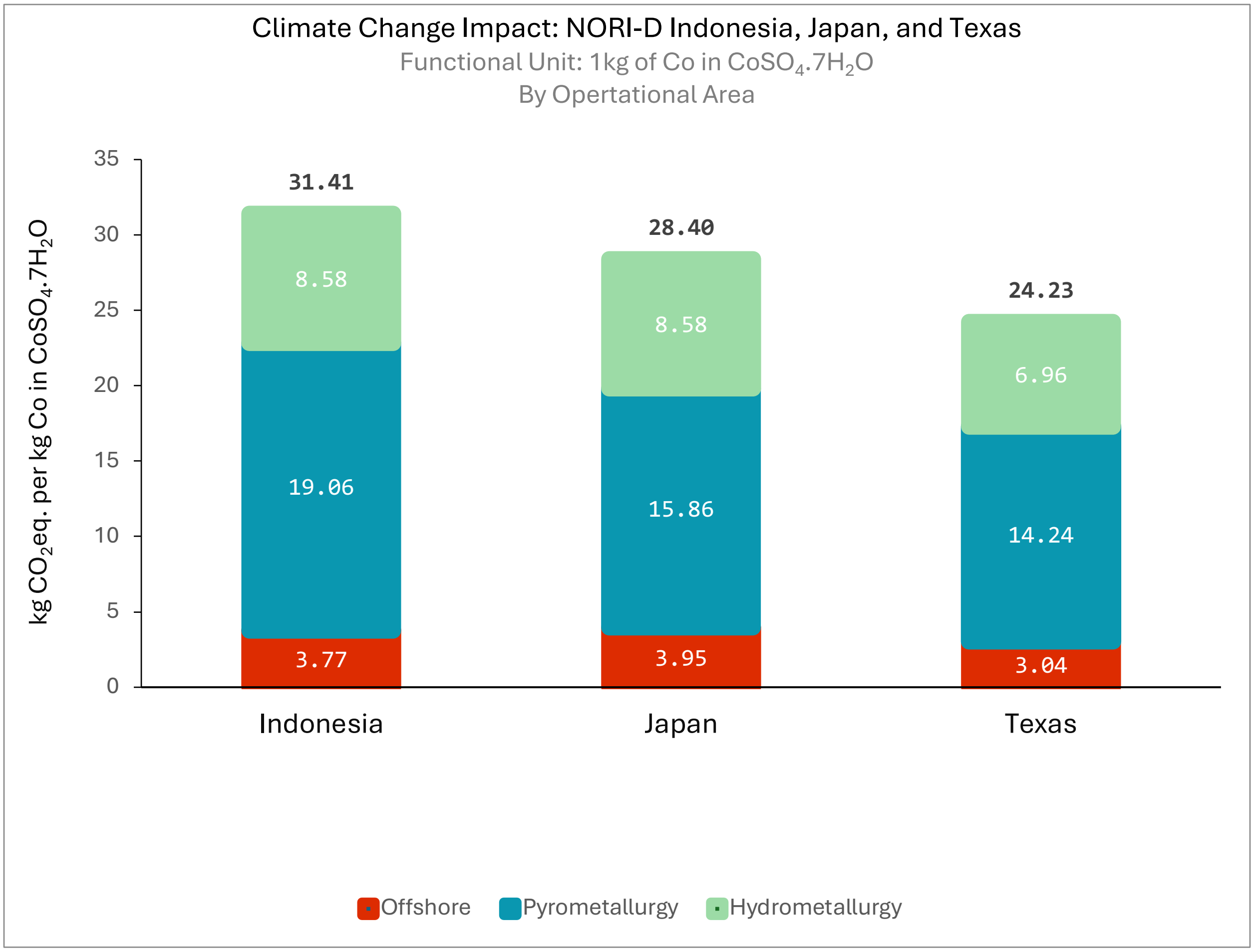


Figure 27: Climate Change Impact by Unit Operation: TMC NORI-D Indonesia, Japan, and Texas – 1 kg of Co in $CoSO_4.7H_2O$

5.1.7.1 Contribution Analysis - 1kg of Co in $CoSO_4.7H_2O$

The results of the contribution analysis can be seen in Figures 28 to 30. For all processing locations, the main contributors remain the same. They are:

- The use of reductant coal in TMC's pyrometallurgical processes, including both direct and indirect emissions, contributing approximately **11.53 kg CO_2eq**. for each location, representing 37%, 41%, and 48% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's pyrometallurgical operations contributing approximately **7.44 kg CO_2eq.** (24% of the total impact), **4.26 kg CO_2eq.** (15% of the total impact) and **3.06 kg CO_2eq.** (13% of the total impact), for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- Electricity usage during TMC's hydrometallurgical operations, contributing approximately **5.00 kg CO_2eq.,** for the TMC NORI-D Indonesia and Japan route (16% and 18% of total impact respectively) and **3.38 kg CO_2eq.** for the Texas route (14% of the total impact).

- The production and combustion of natural gas used in the hydrometallurgy process to provide heat and steam, contributing **3.62 kgCO_2eq.** for each location, representing 12%, 13%, and 15% of the total climate change impact respectively.

- The production and combustion of marine fuel burned by vessels during offshore operations contributing approximately **3.77 kg CO_2eq.** (12% of the total impact), **3.95, kg CO_2eq**. (14% of the total impact) and **3.04 kg CO_2eq**. (13% of the total impact) for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- The indirect emissions from the production of liquid ammonia used in the iron removal stage prior to solvent extraction, contributing **2.25 kg CO_2eq.** for each location, representing 7%, 8%, and 9% of the total climate change impact for the TMC NORI-D Indonesia, Japan, and Texas routes respectively.

- There is a significant environmental credit of **-4.55 kg CO_2eq**. received for the ammonium sulphate generated during hydrometallurgy at each processing location. The magnitude of the credit is due to the volume of ammonium sulphate generated, coupled with its embodied emissions

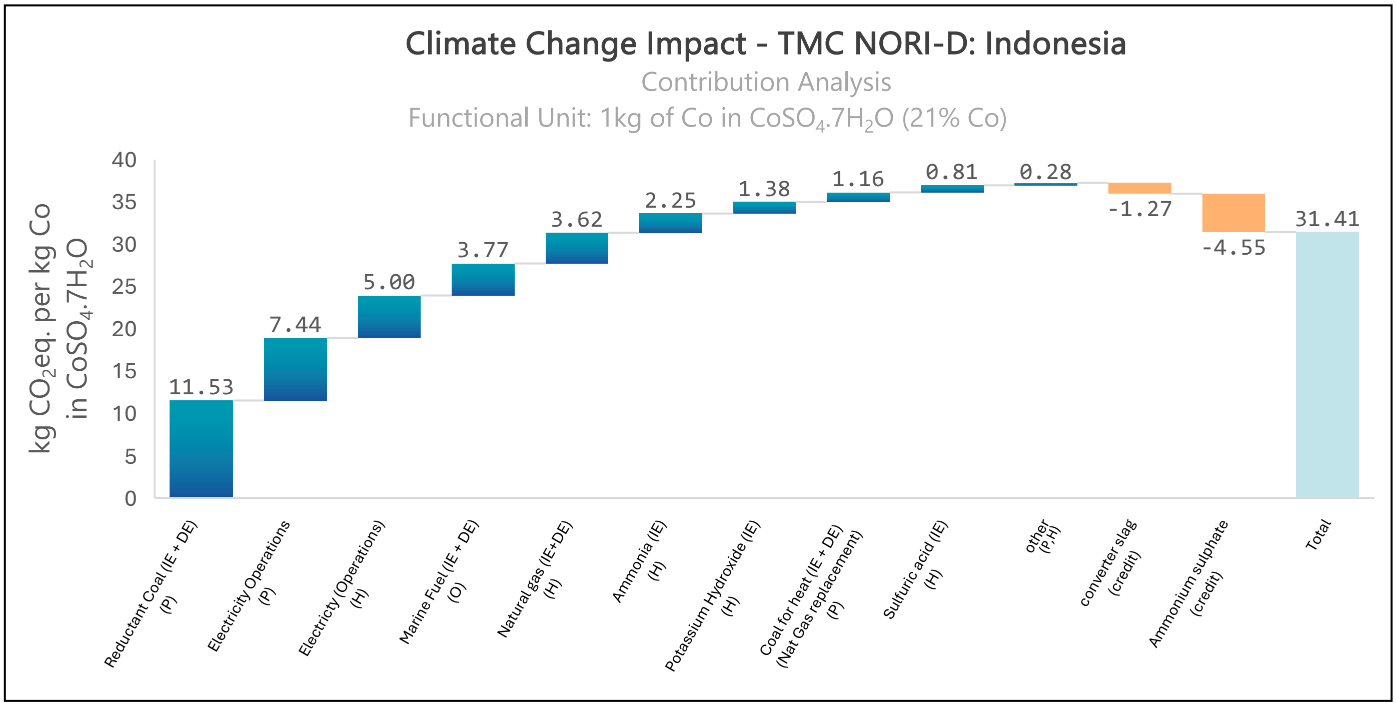


Figure 28: Climate Change Impact – Contribution Analysis: TMC NORI-D Indonesia – 1kg of Co in $CoSO_4.7H_2O$

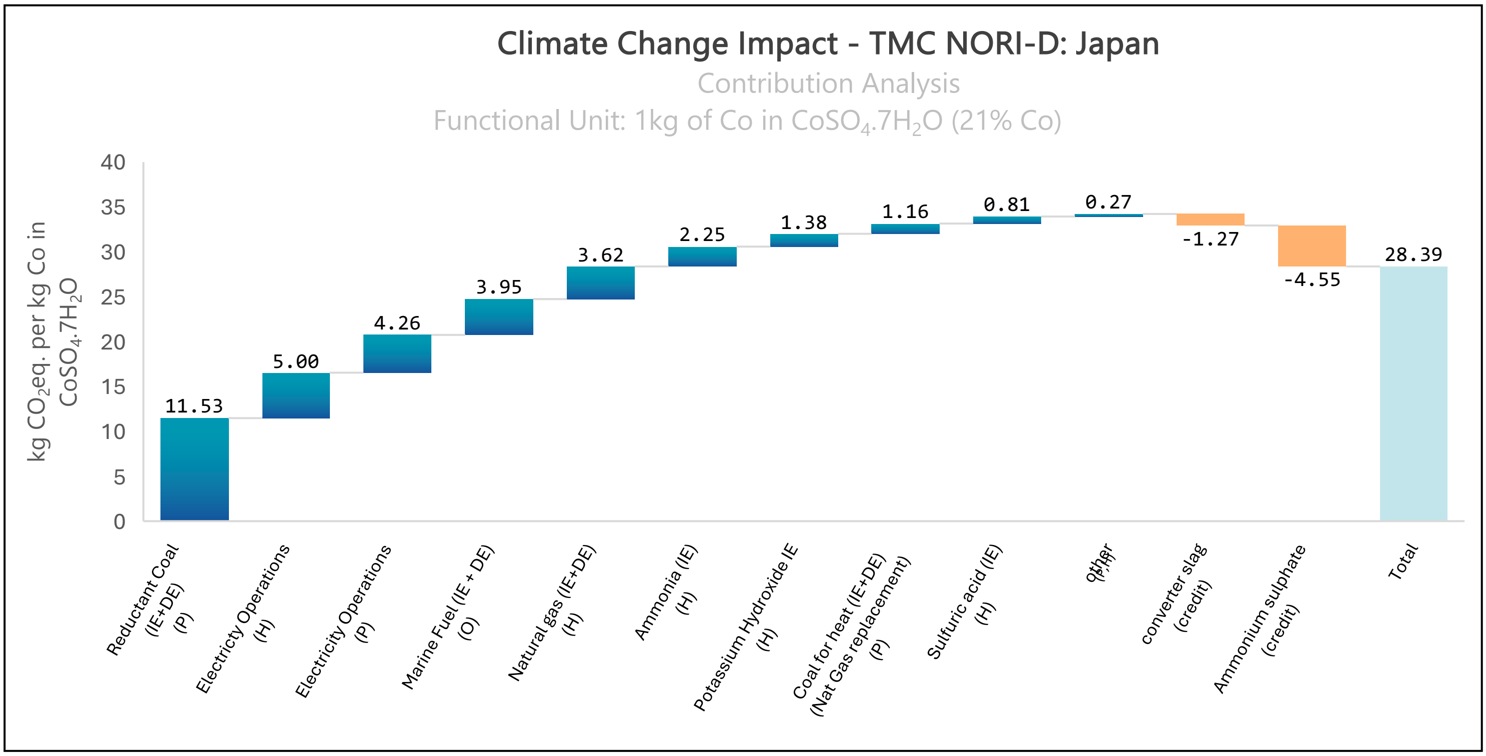


Figure 29: Climate Change Impact – Contribution Analysis: TMC NORI-D Japan – 1kg of Co in $CoSO_4.7H_2O$

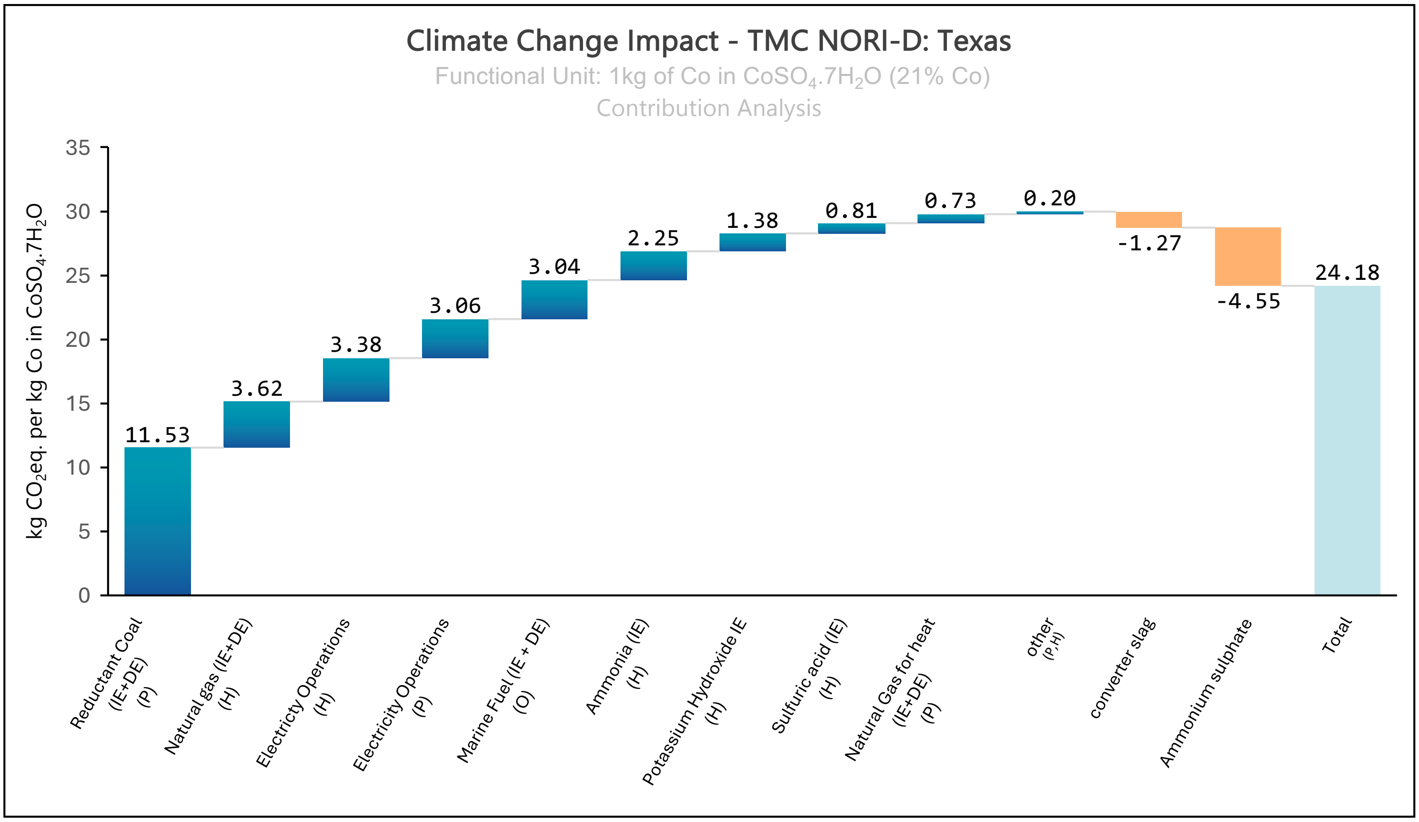


Figure 30: Climate Change Impact – Contribution Analysis: TMC NORI-D Texas – 1kg of Co in $CoSO_4.7H_2O$

6. Scenario, Sensitivity, and Uncertainty Analysis

Scenario, sensitivity, and uncertainty analyses were conducted. A sensitivity analysis was conducted to explore scenarios involving low-carbon and renewable electricity sources. TMC may be able to source these alternatives via market-based instruments in the future and was interested in analysis of how their climate change impact would vary. For the downstream processing of $MnSiO_3$ to SiMn, the electricity grid-mix for China was always chosen since TMC does not have control over a customer's electricity generation sources. A scenario analysis was also conducted to explore the differences in climate change impact when natural gas replaced coal for heat in the NORI-D Indonesia and Japan scenario.

A sensitivity analysis was conducted on allocation method to determine how the climate change impact results would vary depending on the allocation method employed. As TMC is not currently in operation various analyses were conducted on key parameters and major attributable processed to analyze how the climate change impact may vary. These include production volume, marine fuel use, pyro and hydrometallurgical electricity, reductant usage, and ammonia usage.

6.1 Sources of low carbon and renewable electricity

For this scenario analysis, various permutations of the following scenarios were evaluated:

- Indonesia: 25% solar and 75% coal fired
- Indonesia: 100% Hydroelectricity
- Texas: 100% Wind
- Japan: 100% Nuclear
- South Korea: 100% Nuclear

6.1.1 Dry nodules collected and processed

The results for the sensitivity analysis for 1 kg of dry nodules collected and processed is shown in Figure 31. The results range from **0.59 kg CO2eq.** in the best case (100% wind in Texas) to **1.32 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea).

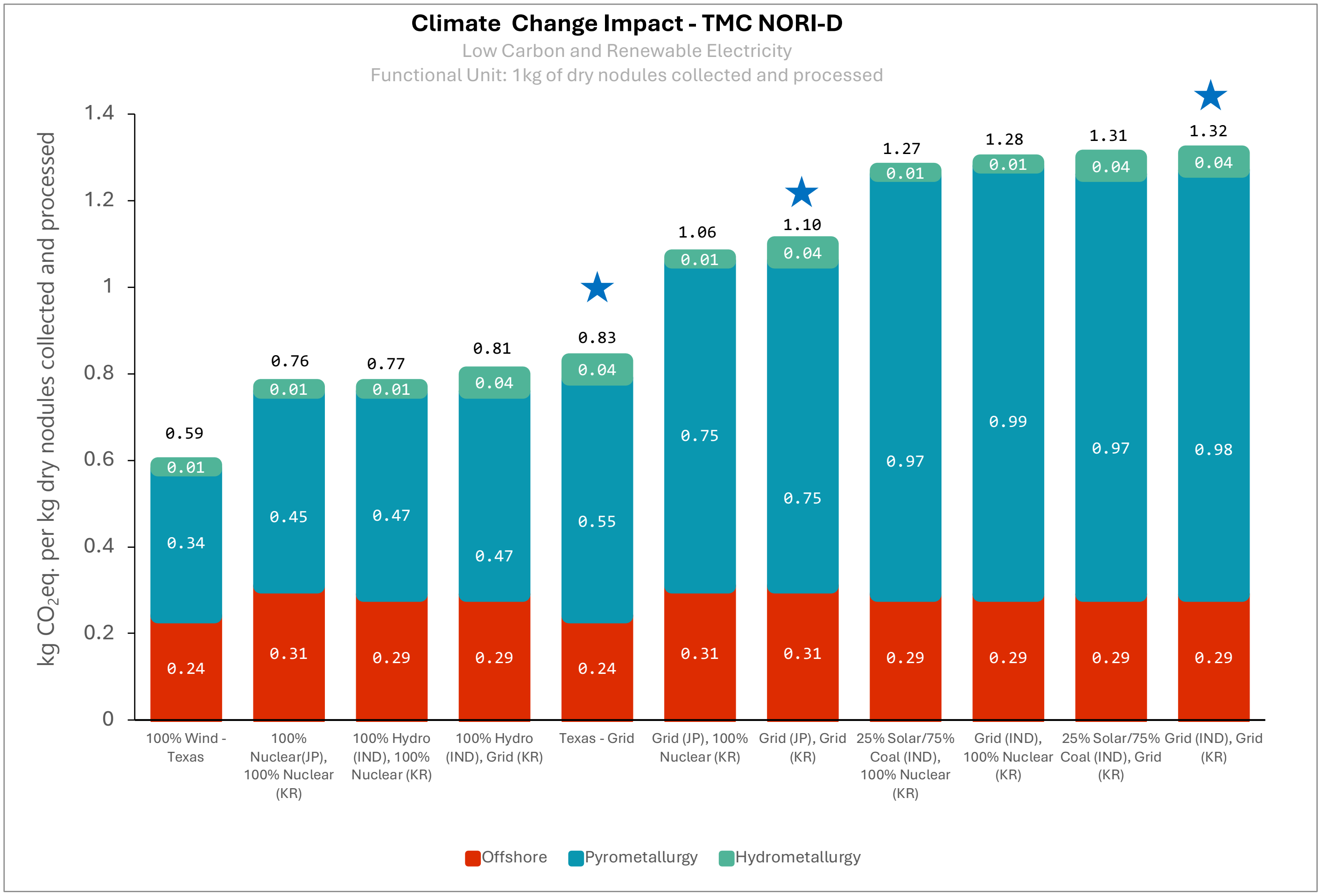


Figure 31: Variations in climate change impact when using low carbon and renewable electricity generation sources 1kg of dry nodules collected and processed. ★ = base case

6.1.2 Mn in $MnSiO_3$ (40% Mn)

The results for the scenario analysis for 1 kg of Mn in $MnSiO_3$ is shown in Figure 32. The results range from **1.56 kg CO2eq.** in the best case (100% wind in Texas) to **3.41 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea).

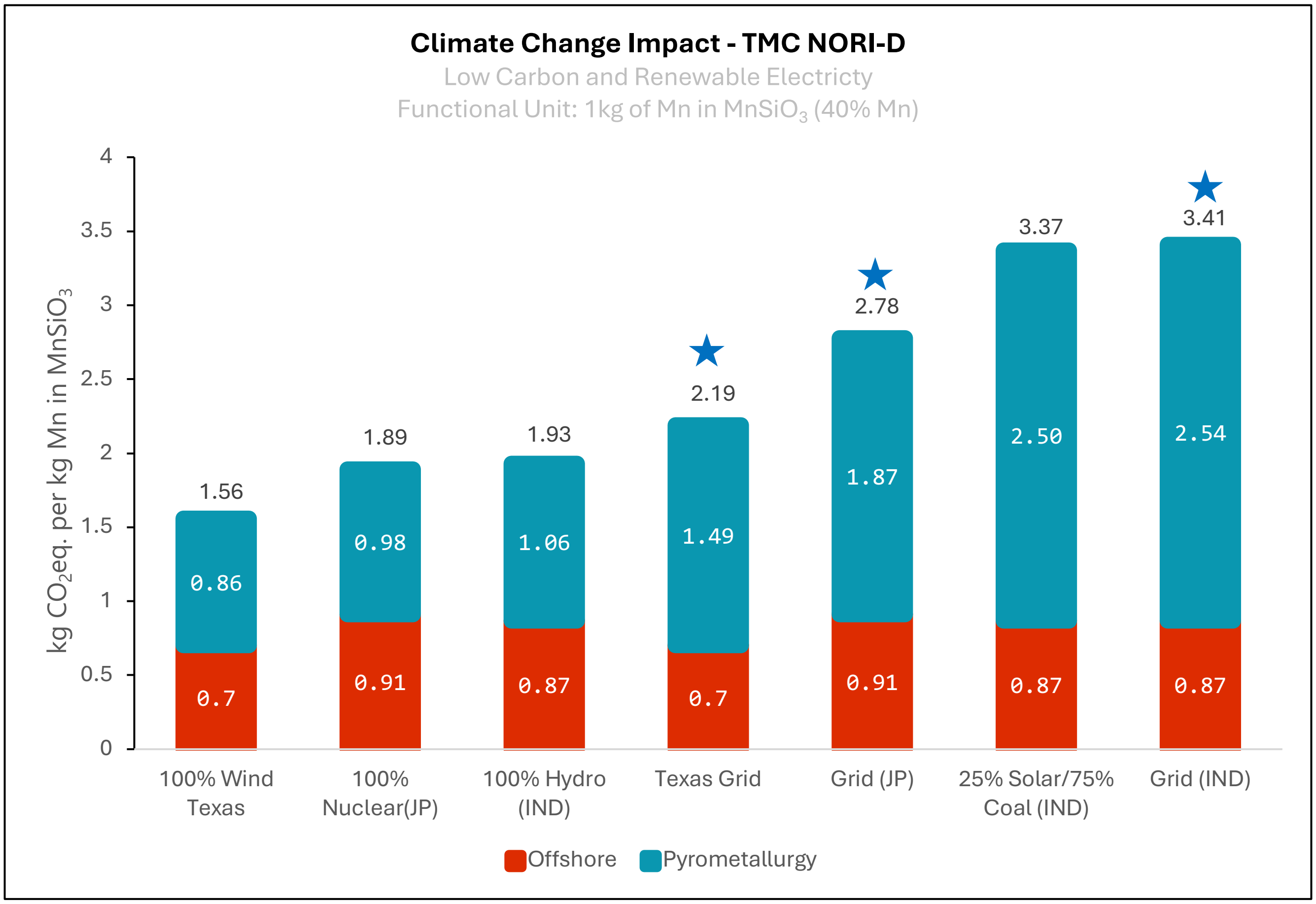


Figure 32: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Mn in $MnSiO_3$.
★ *= base case*

6.1.3 Ni-Cu-Co Matte (40.7% Ni, 30.5% Cu, 3.4% Co)

The results for the scenario analysis for 1 kg of Ni-Cu-Co matte is shown in Figure 33. The results range from **3.71 kg CO2eq.** in the best case (100% wind in Texas) to **5.52 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea).

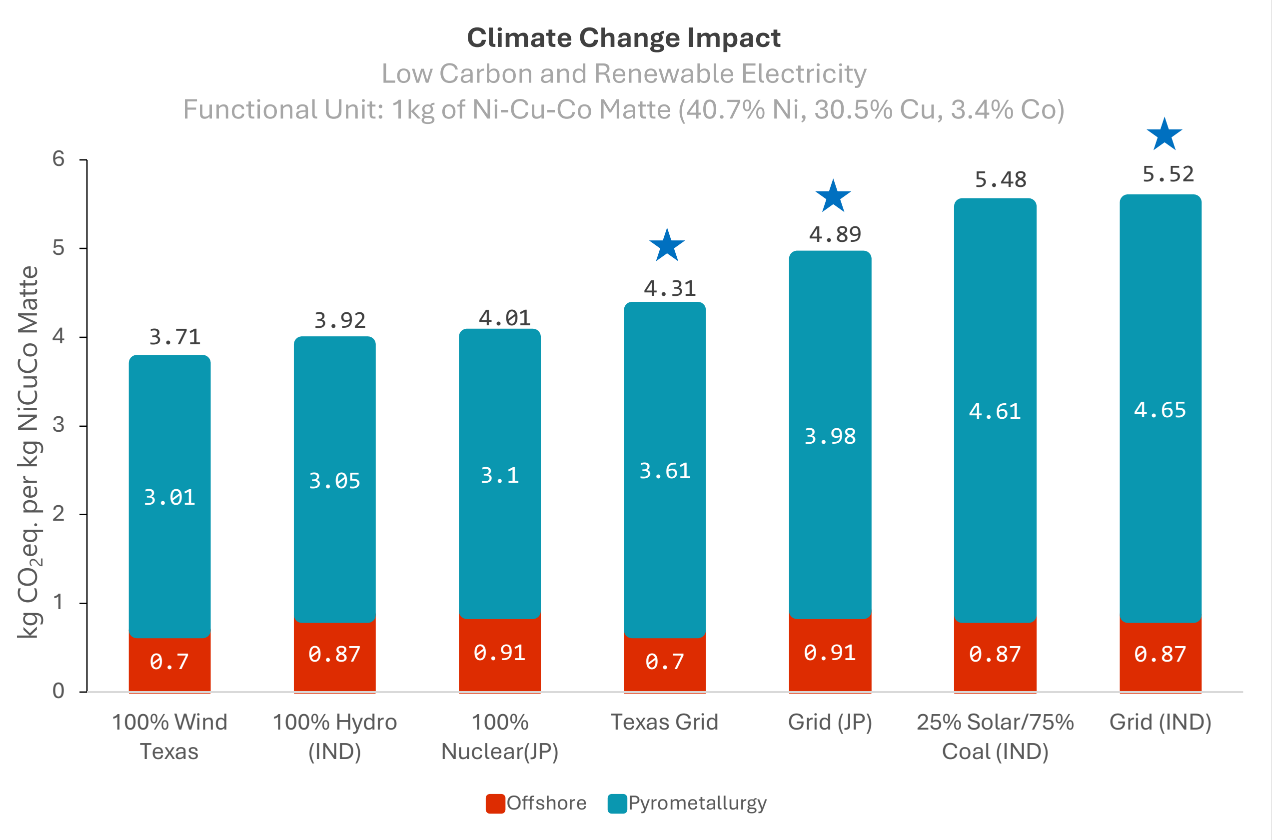


Figure 33: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Ni-Cu-Co matte ★ = base case

6.1.4 Silicomanganese

The results for the scenario analysis for 1 kg of Mn in SiMn is shown in Figure 34. The results range from **9.72 kg CO2eq.** in the best case (100% nuclear in Japan) to **11.27 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea).

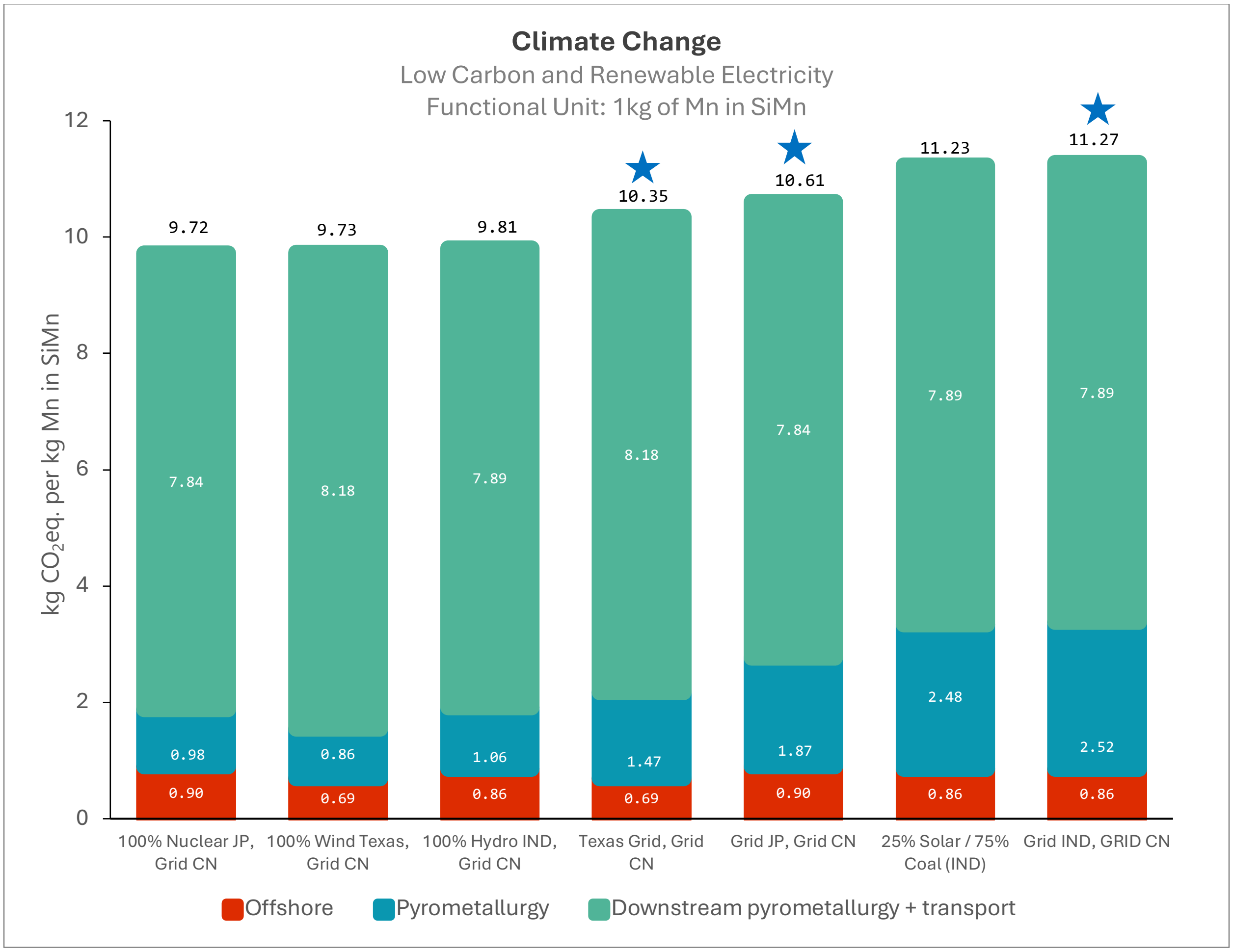


Figure 34: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Mn in SiMn. ★= base case

6.1.5 Ni in $NiSO_4.6H_2O$

The results for the scenario analysis for 1 kg of Ni in $NiSO_4.6H_2O$ is shown in Figure 35. The results range from **7.77 kg CO2eq.** in the best case (100% wind in Texas) to **12.56 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea).

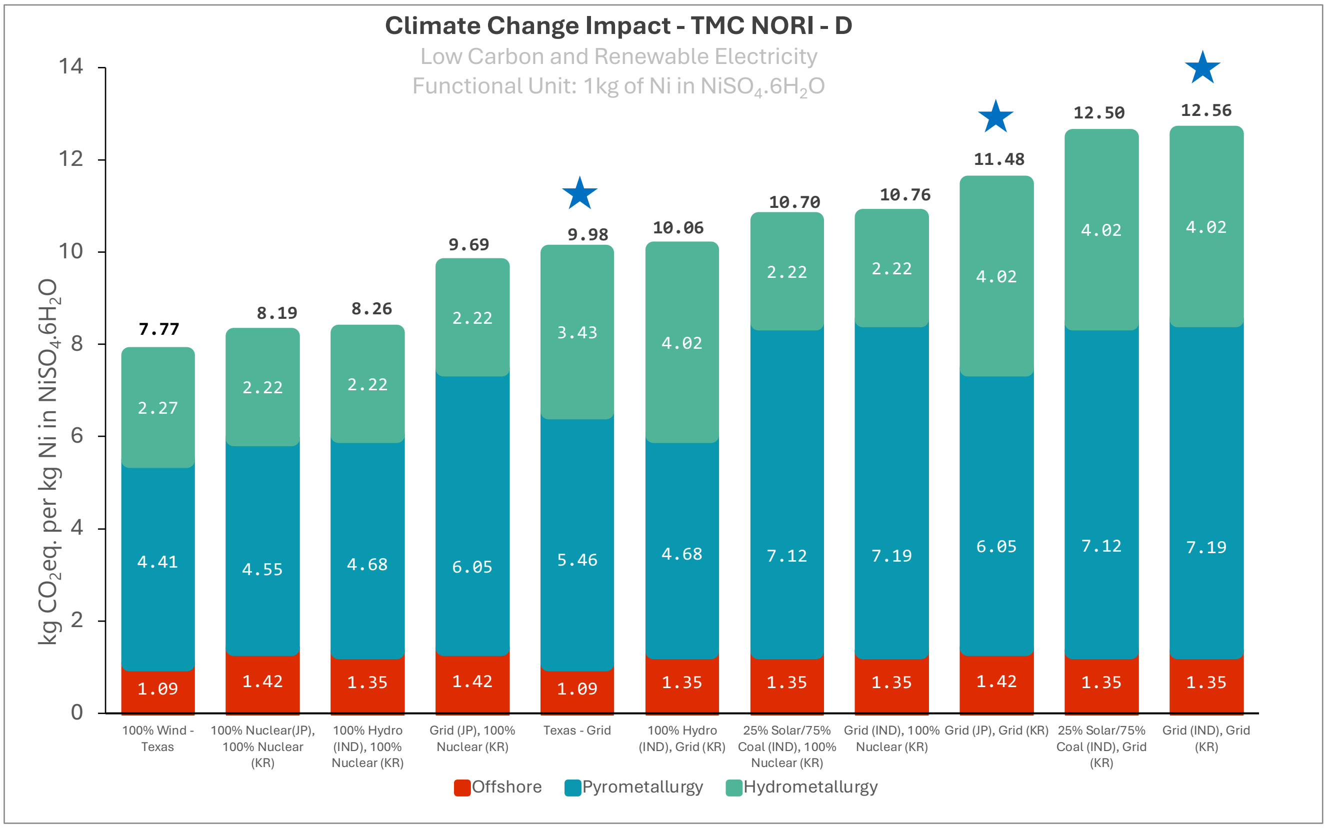


Figure 35: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg Ni in $NiSO_4.6H_2O$ ★ = base case

6.1.6 Copper cathode

The results for the scenario analysis for 1 kg of copper cathode is shown in Figure 36. The results range from **2.43 kg CO2eq.** in the best case (100% wind in Texas) to **4.63 kg CO2eq.** in the worst case (grid-mix in Indonesia and South Korea). In a few of the scenarios, the impact from the hydrometallurgy stage goes to zero due the low impact from renewable energy usage and the credit received from the ammonium sulfate.

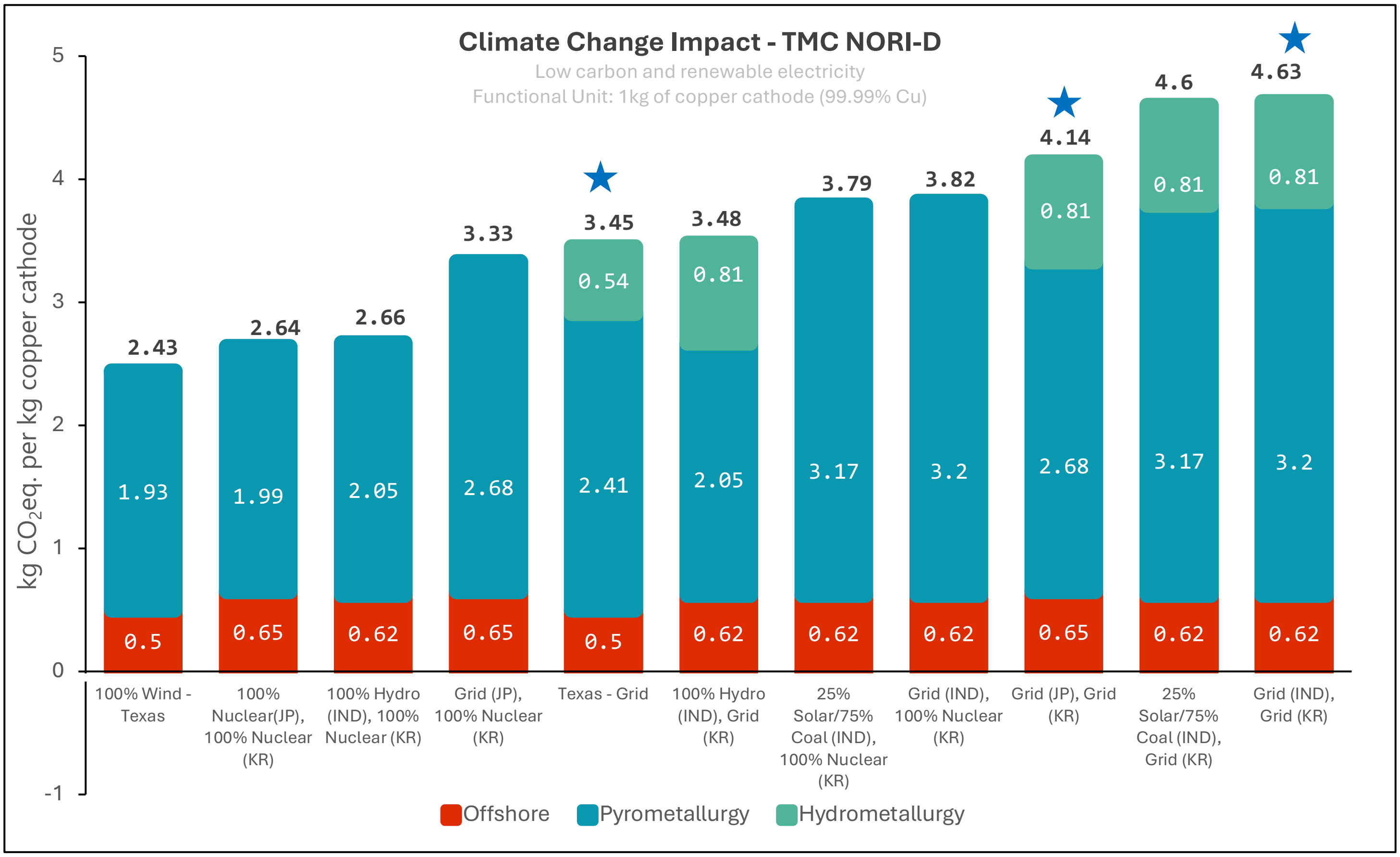


Figure 36: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of copper cathode. ★ = base case

6.1.7 Co in $CoSO_4.7H_2O$

The results for the scenario analysis for 1 kg of Co in $CoSO_4$.7H2O is shown in Figure 37. The results range from **18.04 kg CO$_2$eq.** in the best case (100% wind in Texas) to **31.41 kg CO$_2$eq.** in the worst case (grid-mix in Indonesia and South Korea).

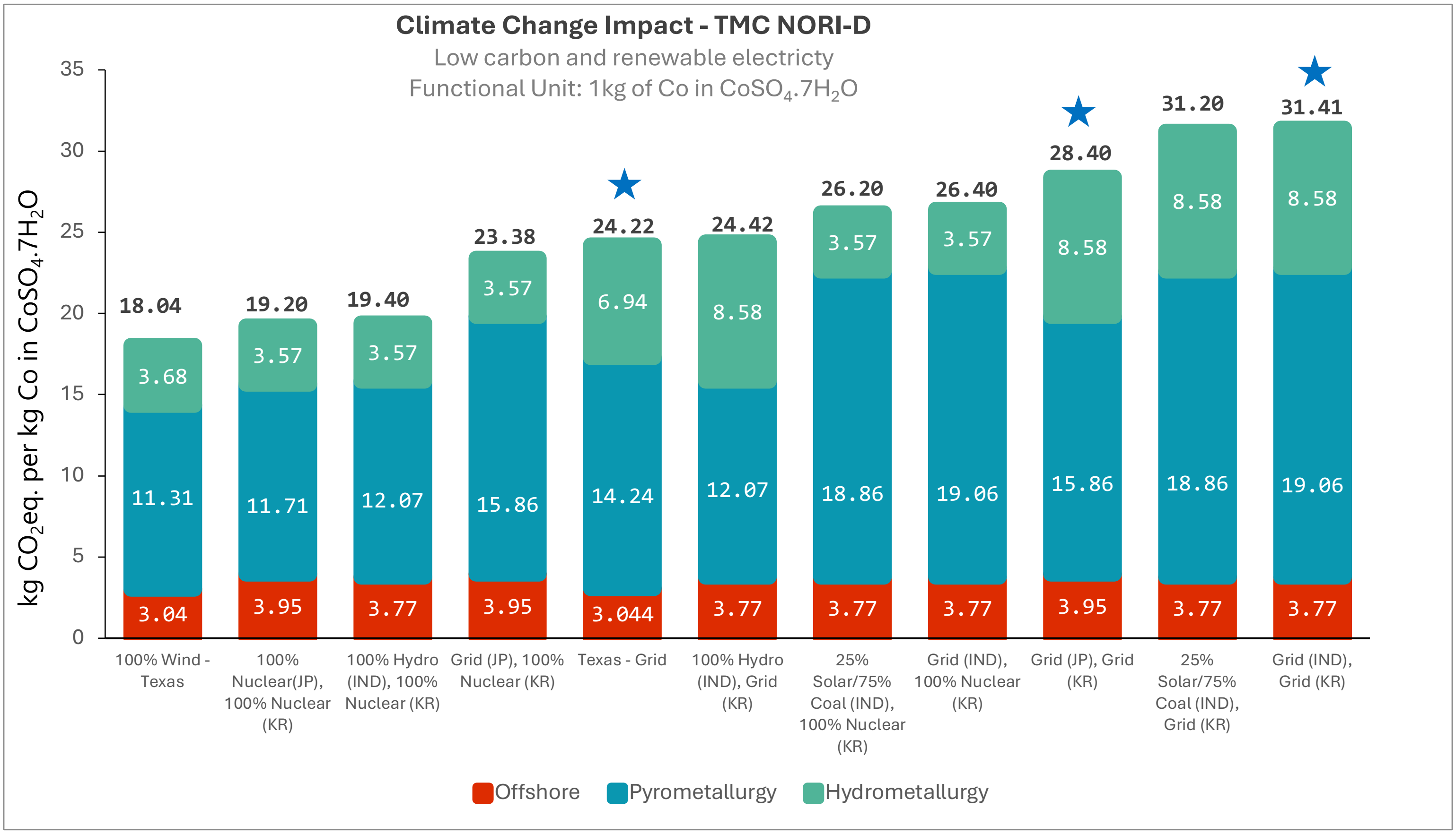


Figure 37: Variations in climate change impact when using low carbon and renewable electricity generation sources: 1kg of Co in $CoSO_4.7H_2O$.
★ *= Base case*

6.2 Natural Gas Replaces Coal for Heating

When natural gas is used to replace coal for heat in pyrometallurgy in the TMC NORI-D Indonesia and Japan scenarios, the climate change impact varies by 0.07 – 0.37 kg CO_2eq. depending on the functional unit (Figure 38). The climate change impact for the NORI-D Texas scenario remains the same as natural gas is used for heat in the base case scenario.

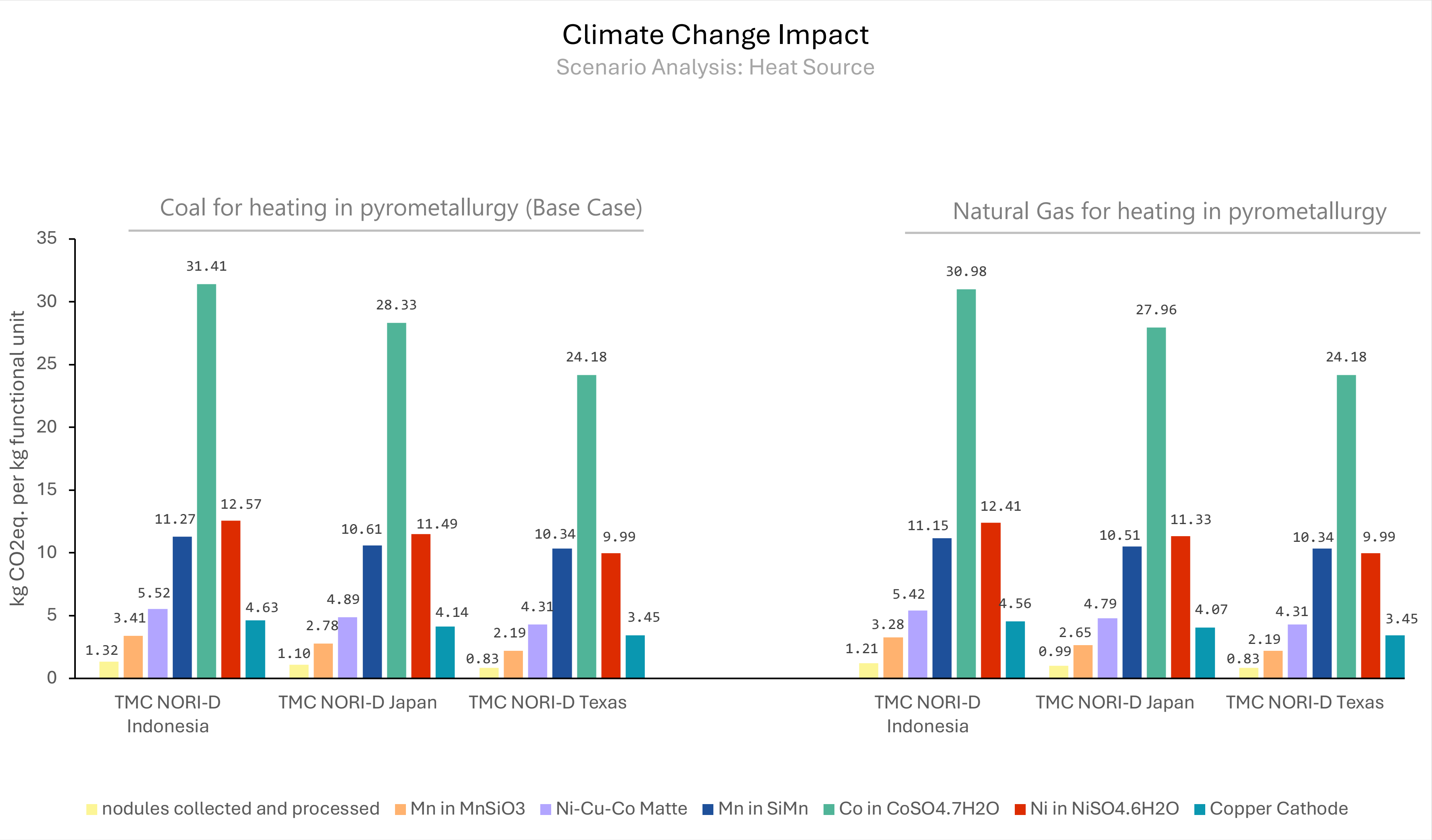


Figure 38: Scenario Analysis: Natural Gas Replacing Coal for Heat in the TMC NORI-D Indonesia and Texas Scenario

6.3 Metal Mass Allocation

As the price of the refined co-product mix varies by a factor greater than 5 (when considering copper and cobalt), economic allocation, as employed in the base case, is the recommended allocation approach as discussed in section 3.6.2. However, an argument can be made for the use of metal mass allocation as the price of nickel vs copper, and nickel vs cobalt varies by a factor less than 5. Therefore, allocation by metal mass was employed to analyze the difference in climate change impact when this allocation methodology is considered (Figure 39).

There is a vast difference in the climate change impact of TMC's co-products when economic or metal mass allocation is considered, specifically for copper cathode and Co in $CoSO_4.7H_2O$. The climate change impact for copper cathode increases by approximately 90% from the base case when metal mass allocation considered. The climate change impact of Co in $CoSO_4.7H_2O$ decreases by approximately 64% from the base case when metal mass allocation is considered. The climate change impact of Ni in $NiSO_4.6H_2O$ decreases by approximately 12% from the base case when metal mass allocation is considered.

This vast difference in climate change impact between the allocation approaches arises due to the prices and production volume of the metals. Though the production volume of cobalt is low relative to copper and nickel, its relatively higher price leads to an increased impact when economic allocation is considered. When metal mass allocation is considered, this impact shifts, leading to a much higher impact for copper with the higher production volume, and a much lower impact for cobalt, with the lower production volume. The climate change impact of nickel does not vary much as its production volume is the highest between the co-products, and its price is between that of copper and cobalt.

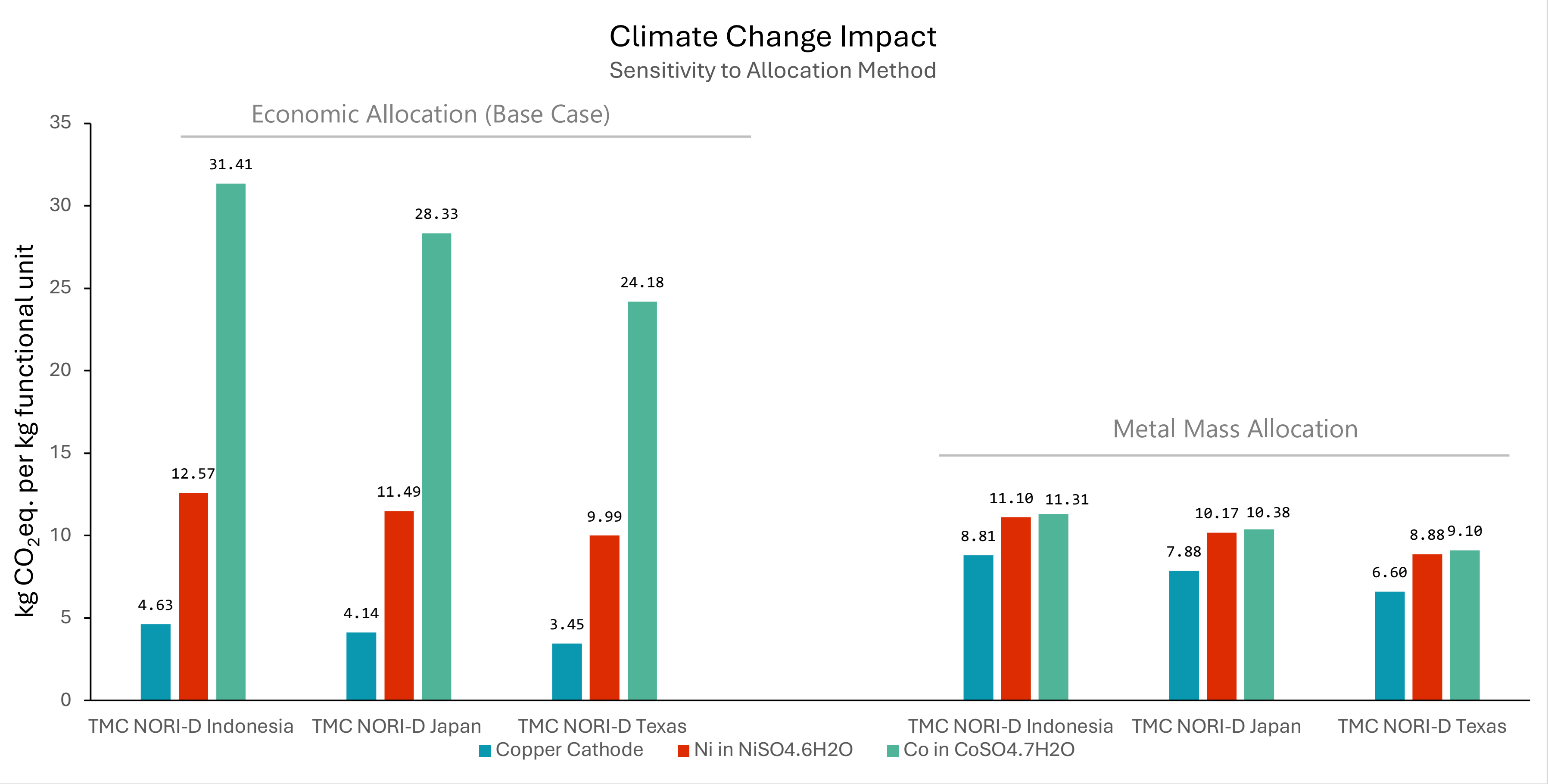


Figure 39: Sensitivity Analysis - Metal Mass Allocation

6.4 Production volume and main attributable flows

As TMC's process is not currently in the operational phase, uncertainty analyses was conducted on key parameters and main attributable inputs to examine their influence on the climate change impact results. This was done by lowering the parameter or input by 10% or increasing it by 10% of the original value. Considering that the data was generated using sound engineering principles with a design basis based on commercial operations, as well as test-work, it is unlikely that any of the inputs or parameters will exceed these variations.

Shown in Figure 40, increasing or decreasing the production volume of the functional units by 10% has an influence on the overall climate change impact of 6 -7 % for the nodules (min – max respectively), 3 - 4 % for Mn in SiMn (min – max respectively) 9 – 11% for all other functional units (min – max respectively).

Shown in Figure 41, increasing or decreasing the marine fuel usage by 10% has an influence on the overall climate change impact of 2% for the nodules, 3% for Mn in $MnSiO_3$, 2% for the Matte, and 1% for the remaining functional units.

Shown in Figure 42, increasing or decreasing the reductant coal usage by 10% has an influence on the overall climate change impact of 2% for Mn in $MnSiO_3$, 5% for the matte, 2% for the nodules, 1% for Mn in SiMn, 4% for copper cathode, and 3% for Co in $CoSO_4.7H_2O$ and Ni in $NiSO_4.6H_2O$.

Shown in Figure 43, increasing or decreasing pyrometallurgical electricity usage by 10% has an influence on the overall climate change impact of 5% for Mn in $MnSiO_3$, 3% for the matte, 4% for the nodules, 1% for Mn in SiMn, 3% for copper cathode, and 2% for for Co in $CoSO_4.7H_2O$ and Ni in $NiSO_4.6H_2O$.

Shown in Figure 44, increasing or decreasing hydrometallurgical electricity usage by 10% has an influence on the overall climate change impact of 0.5% for the nodules, 1% nickel, and 2% for copper and cobalt. Note that SiMn, Matte, and MnSiO3 exits the product system before hydrometallurgy.

Shown in Figure 45, increasing or decreasing Ammonia consumption has an influence on the overall climate change impact of 0.2% for the nodules, 1.8% for the nickel, and 0.7% for the cobalt. Note that SiMn, MnSiO3, Matte, and copper cathode exits the product system before ammonia is consumed.

Shown in Figure 46, increasing or decreasing electricity consumption in downstream processing of $MnSiO_3$ to produce SiMn has an influence on the overall climate change impact of 5% for Mn in SiMn.

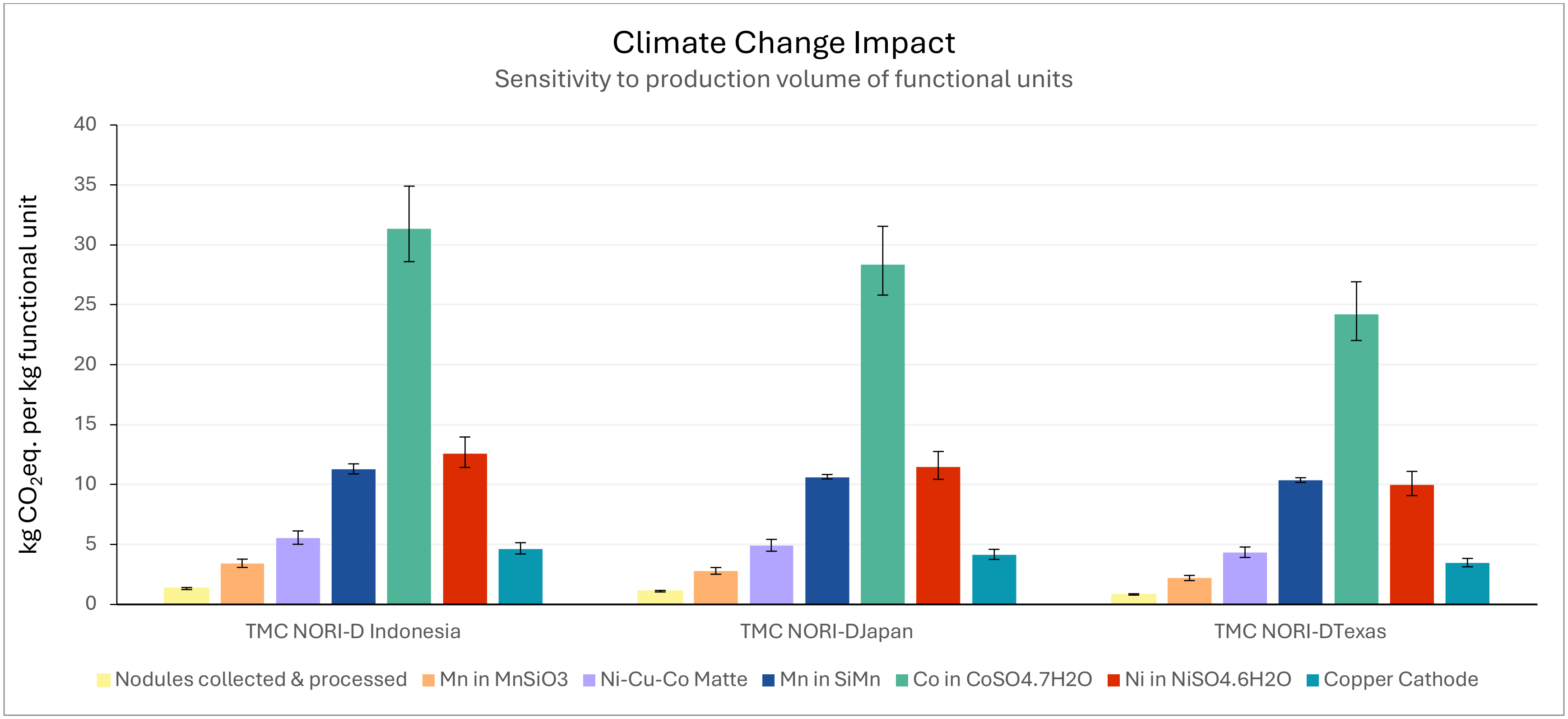


Figure 40: Uncertainty Analysis: Production Volume

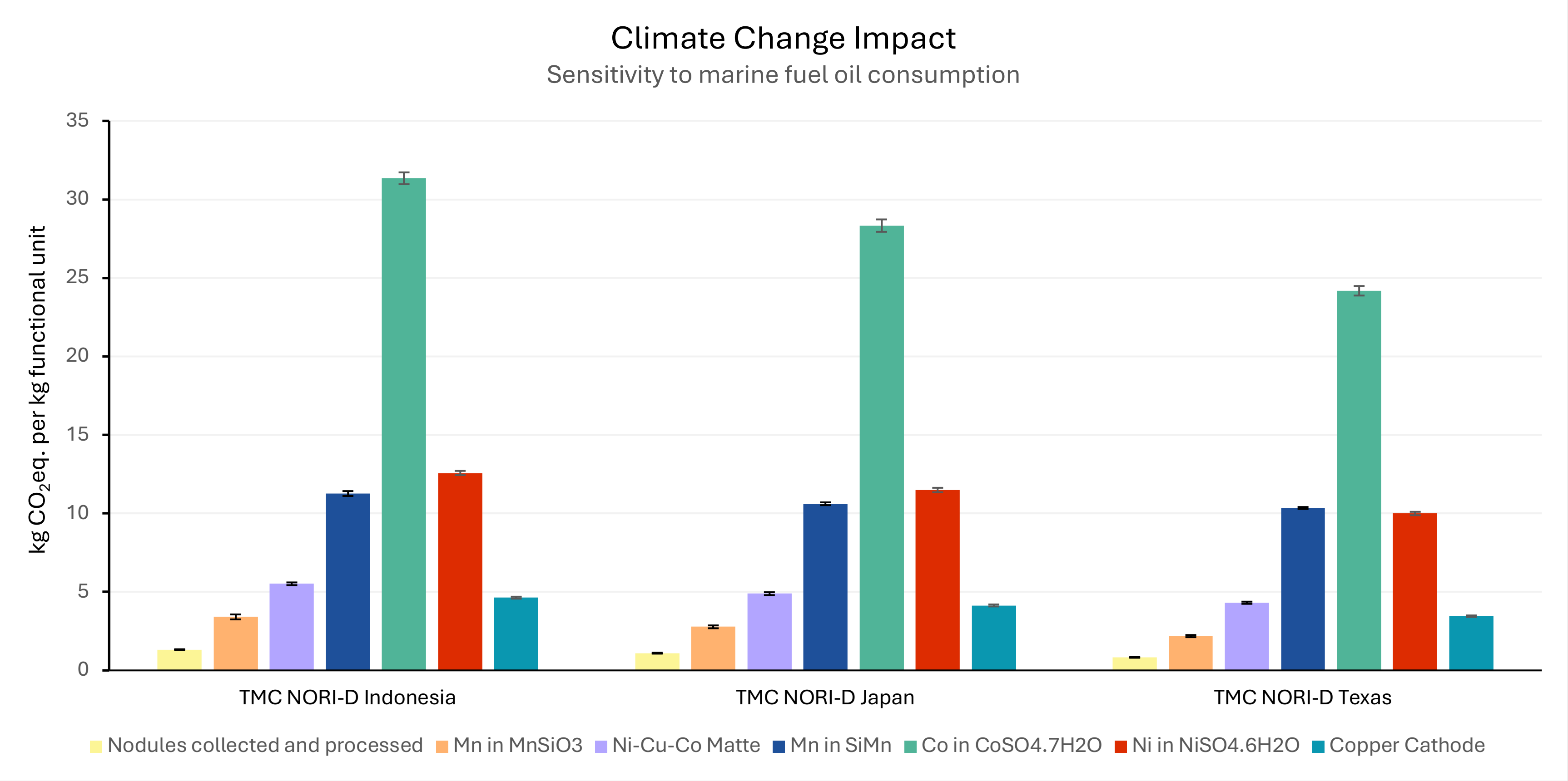


Figure 41: Uncertainty Analysis - Marine Fuel Oil Consumption

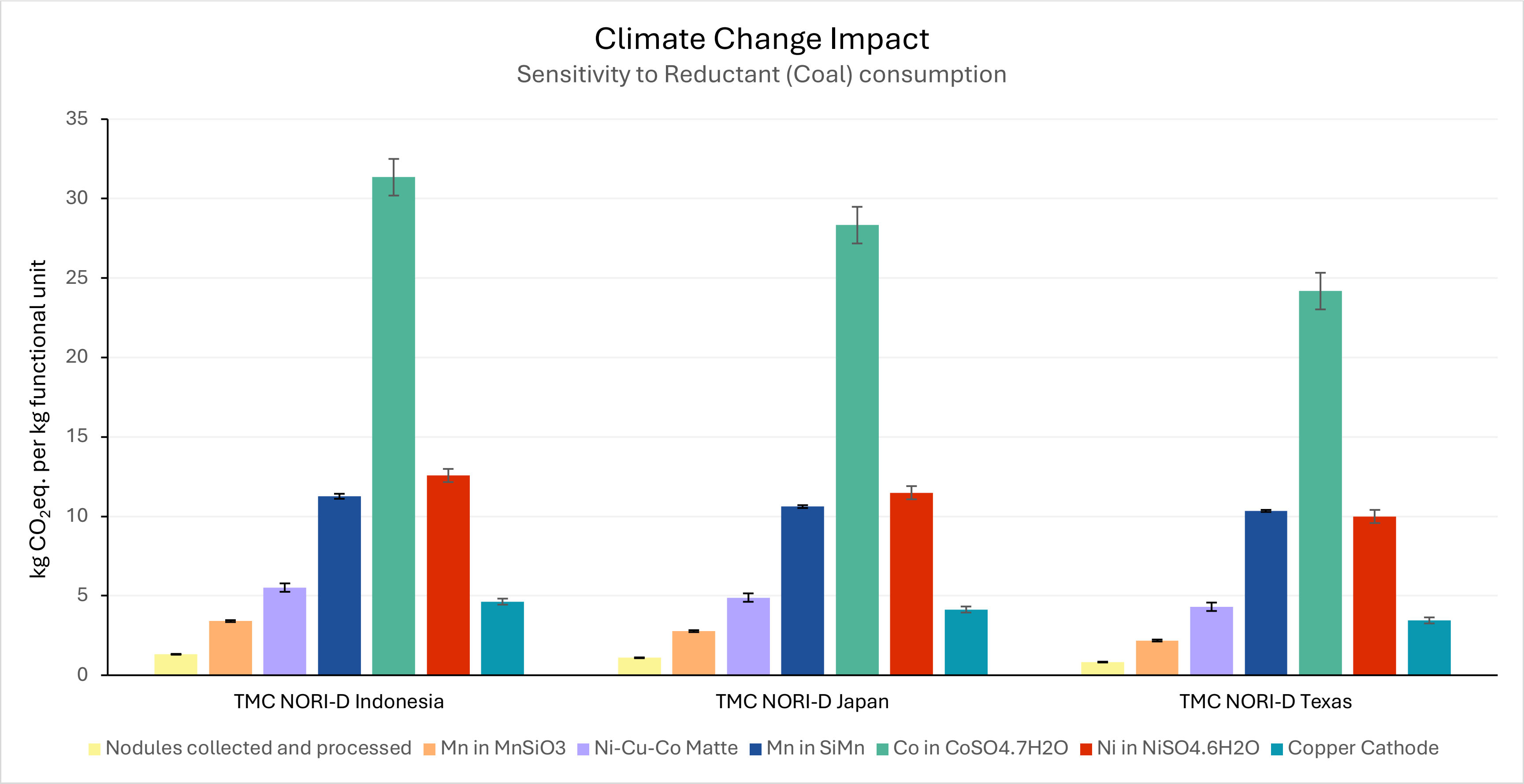


Figure 42: Uncertainty Analysis - Reductant Coal Usage

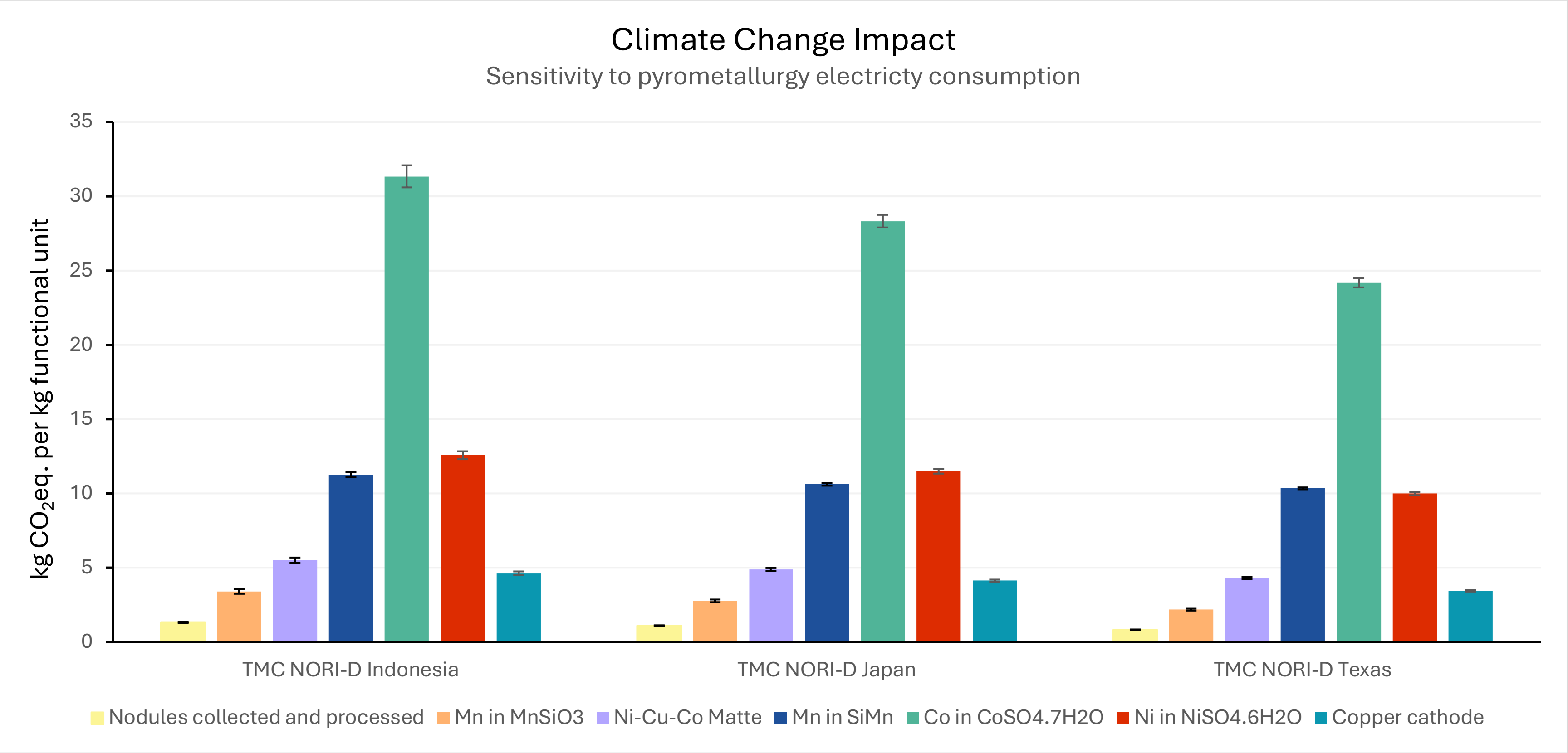


Figure 43: Uncertainty Analysis - Pyrometallurgical Electricity Consumption

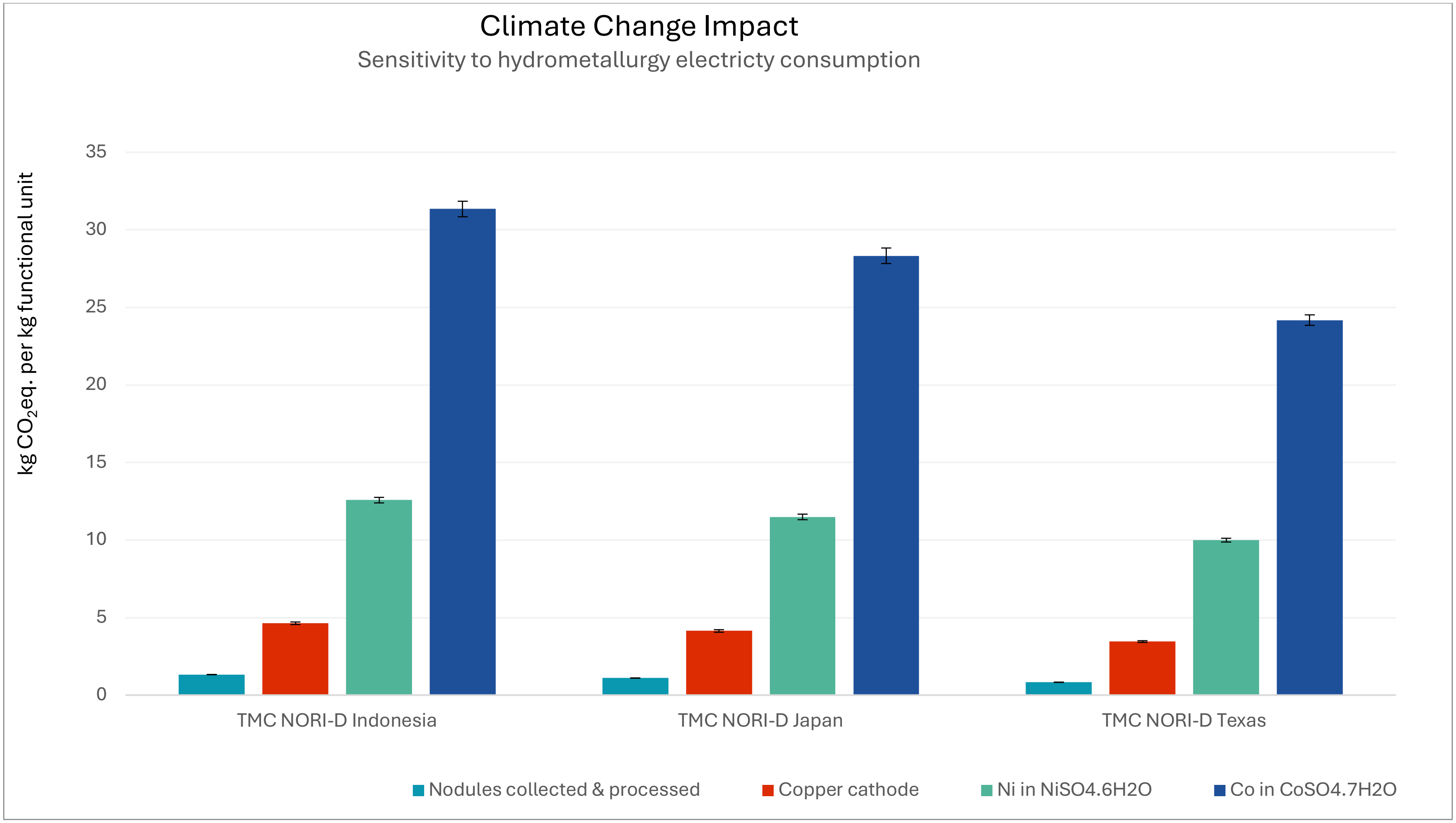


Figure 44: Uncertainty Analysis - Hydrometallurgical Electricity Consumption

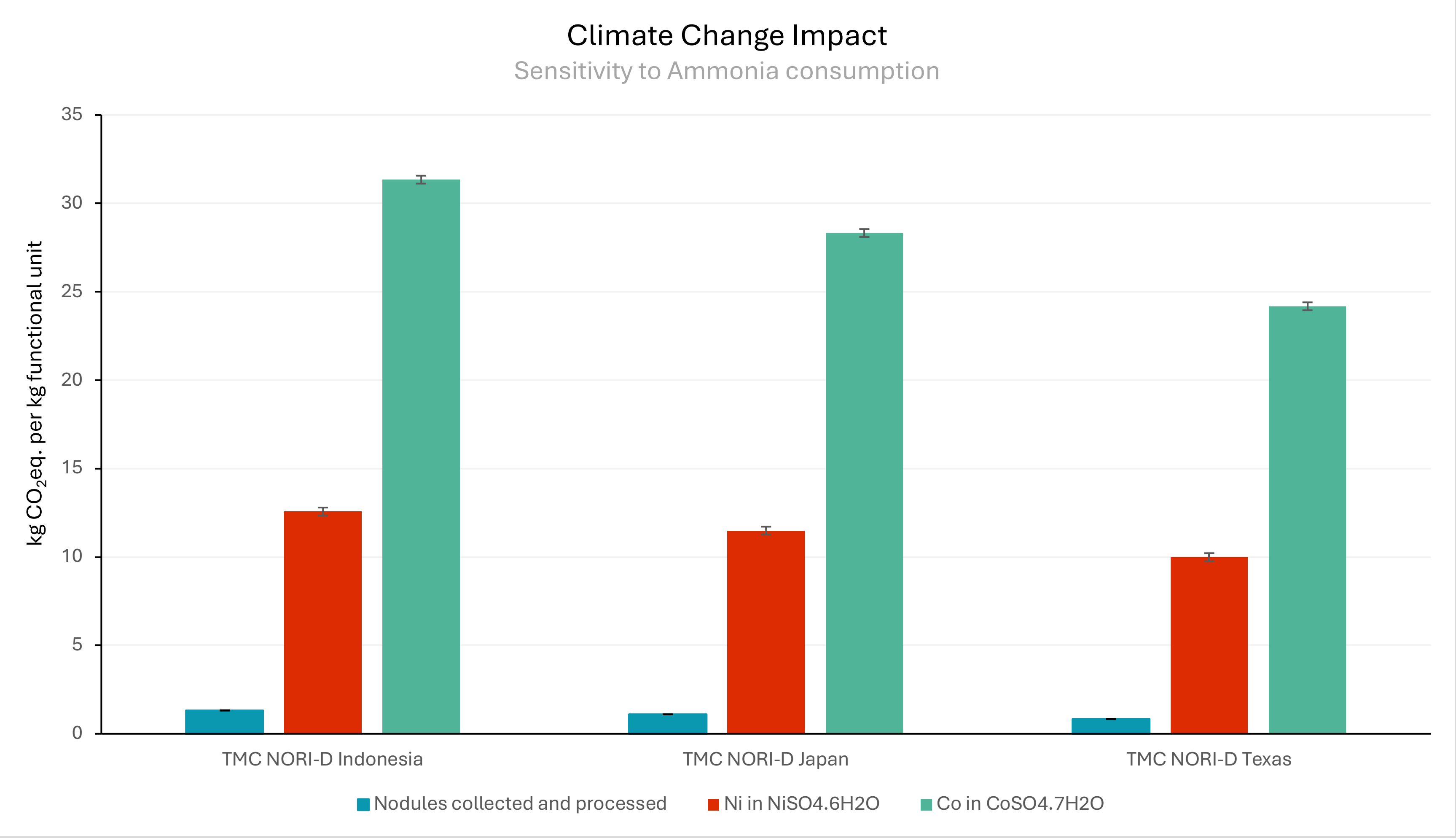


Figure 45: Uncertainty Analysis - Ammonia Consumption

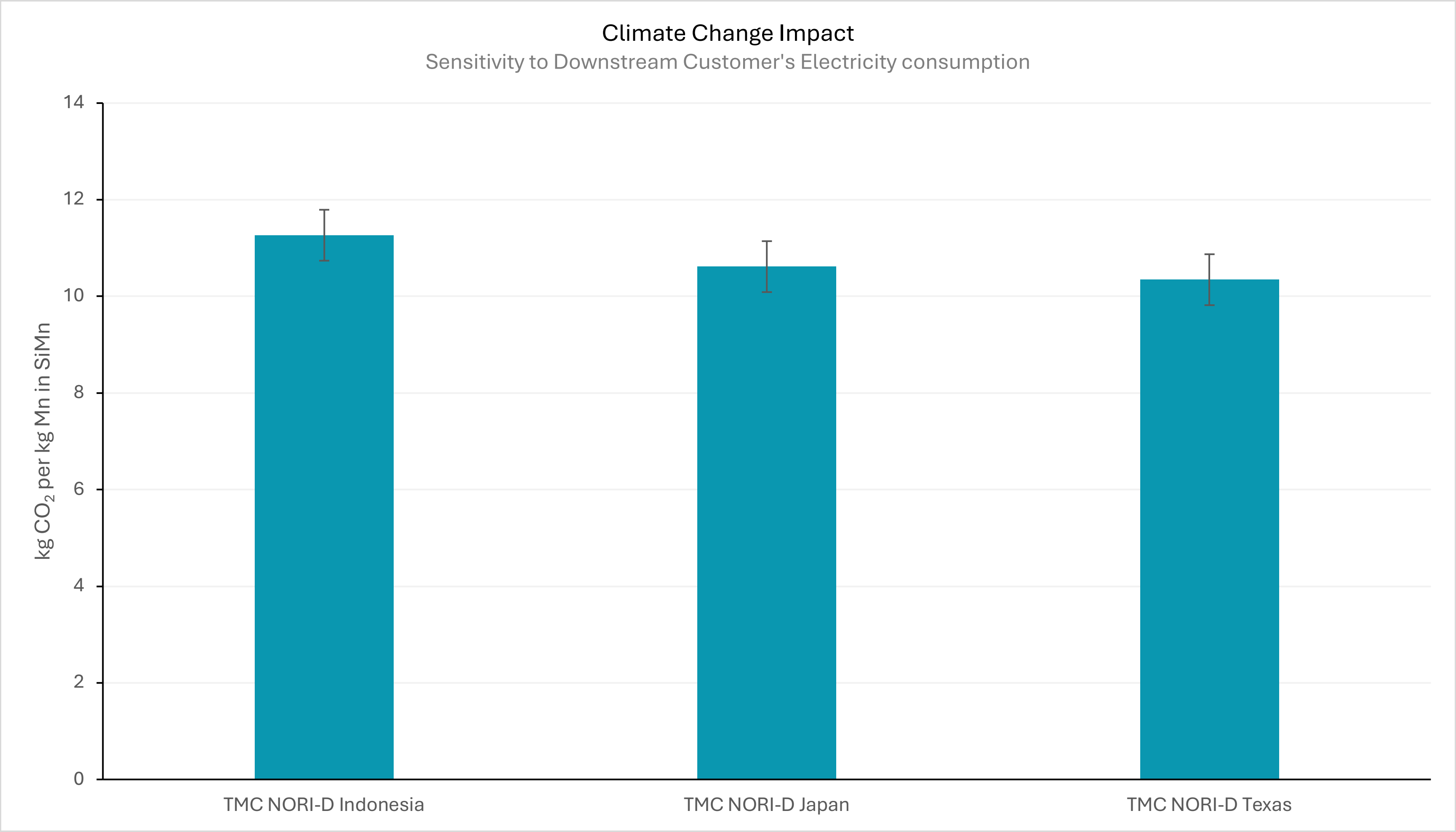


Figure 46: Uncertainty Analysis: Downstream Customers Electricity Usage for SiMn production

7. Terrestrial Comparisons

This section presents an analysis of the products SiMn, $NiSO_4.6H_2O$, Copper cathode, and $CoSO_4.7H_2O$ produced via traditional land-based routes. Each route is based on the best publicly available data from company sustainability reports, ESG databooks, literature, and third party databases.[19-31]Where data was not available, mass and energy balances, or proxy data was used. The data was extracted from these sources and modelled consistently with the methodology described in this report. The values presented in this report do not reflect the official disclosures or positions of the companies mentioned, as the system boundaries, assumptions, and emission factors used in the modeling may differ from those employed by the respective companies. The data was validated by cross examinations against systems that produce similar products to deduce if there were any major inconsistencies. None were found. A description of each route is given prior to an analysis of the results.

The chosen routes are used to display the environmental impacts for producing the respective product using the stated technologies. The selection of the routes were strategic as they reflect the most common current pathways for sourcing these metals, while also including a few lower-impact routes for comparison, providing a broader and more balanced perspective. However, the impacts of the same product produced using the same technologies may vary depending on parameters such as technological efficiencies, geographies, power sources, ore grades, and other local conditions. For pathways with lower data quality, variations in results can be partially attributed to the limitations of the underlying data.

7.1 Functional Equivalence

As the products being produced from TMC’s product system and the terrestrial systems are similar, the functional units, performance, and reference flows for the analyzed products are all the same as those laid out in section 3.3. The terrestrial comparisons were modelled using the same methodological considerations such as allocation procedure, and impact assessment method laid out in section 3.6 and 3.9 respectively.

Like TMC’s product system, the system boundary for each terrestrial route is cradle-to-gate. As most of the data for the terrestrial comparisons are based on real operational data, some aspects of the data quality are higher for the comparisons than for TMC. The system boundary diagram and data quality assessment will be laid out for each route. The data quality assessment follows the same methodology discussed in section 3.84. Table 14 provided key details on each route that is analyzed.

Table 14: Processing technologies and location of each product produced via land-based routes used for the terrestrial comparisons.

Route	Ore Type	Ore Grade	Ore Processing Technology	Mine & Processing Facility Location	Intermediate product	Refining Method	Refining Location	Final Product
Indonesia to China	Ni Laterite	<1.4% Ni <0.15% Co	HPAL	Indonesia	MHP	LX-SX	China	**$NiSO_4.6H_2O$ (22% Ni)**
Indonesia to Japan	Ni Saprolite	1.8% Ni	RKEF	Indonesia	Matte	LX-SX	Japan [1]	**$NiSO_4.6H_2O$ (22% Ni)**
Indonesia to China	Ni Saprolite	1.8%	RKEF	Indonesia	Matte	LX-SX	China	**$NiSO_4.6H_2O$ (22% Ni)**
Canada to Norway	Ni-Cu-Co sulfide	3.3% Ni	Smelting	Canada [2]	Matte	MCLE	Norway [3]	**$NiSO_4.6H_2O$ (22% Ni)**
Chile	Copper oxide	0.32%	Crushing, Heap Leaching	Chile	PLS	SX-EW	Chile	**Copper Cathode (99.99% Cu)**
Chile to China	Copper Sulfide	0.82%	Crushing, concentration	Chile	Copper concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
Peru to China	Copper Sulfide	0.36%	Crushing, concentration	Peru	Copper Concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
USA	Copper Sulfide	0.32%	Crushing, concentration	New Mexico & Arizona.	Copper Concentrate	Smelting, Refining	Texas, USA	**Copper Cathode (99% Cu)**
USA heap leaching	Copper oxide	0.23	Crushing, Heap Leaching	Arizona	PLS	SX-EW	Arizona, USA	**Copper Cathode (99% Cu)**
DRC to China	Cu-Co	2.44% Cu, 0.47% Co	Hydrometallurgy, Co Synthesis	DRC	Crude Cobalt Hydroxide	Refining (SX-EW)	China	**$CoSO_4.7H_2O$ (21% Co)**
Indonesia to China	Ni Laterite	<1.4% Ni <0.15% Co	HPAL	Indonesia	MHP	LX-SX	China	**$CoSO_4.7H_2O$ (21% Co)**
China	Copper Sulfide	0.36%	Crushing & concentration	China [5]	Copper Concentrate	Smelting, Refining	China [4]	**Copper Cathode (99% Cu)**
China	Mn ore	35.7%	Mining & beneficiation	China	Mn concentrate	Pyrometallurgy	China	SiMn (68.9% Mn)

1. For the nickel matte refined in Japan, due to the absence of disaggregated data for the actual refinery, an alternative dataset representing a similar refining process from another operation in China was used. This proxy was scaled to match the production volume and adjusted using the Japanese electricity grid emission factor to improve geographical relevance
2. Data for matte production was sourced from industry-level publications assessing similar ore types. The Canadian (Ontario) grid factor was used to partially account for geographical representativeness.
3. The ecoinvent dataset was used for the production of NiSO4.6H2O from first class Ni. Primary operational data on energy use, emissions, and output streams were used for the refining stage.
4. For copper production, smelting and refining data were extracted from peer-reviewed literature reflecting typical operations in China. Mining and concentration data were based on a South American operation with similar processing technologies; the average Chinese grid emission factor was applied to reflect regional conditions.
5. The operational data and material inputs for the mining and concentration phases were based on a representative site with similar processing methods in Peru. To improve the geographical relevance of the dataset, the average electricity grid emission factor for China was applied.

   The dataset is considered to have high technological representativeness, as the mining and concentration techniques in both the reference region and China are comparable, although differences in ore grade may exist.

7.2 LCIA Results & Interpretation: Silicomanganese

7.2.1 China

The silicomanganese is produced via the carbothermic reduction of manganese ores and silica in a submerged electric arc furnace (Figure 47). After the manganese ore is extracted, crushed, and screened, it is blended with raw materials such as silica, dolomite, and iron ore in a furnace at temperatures exceeding 1500°C. These raw materials are added to achieve the desired slag chemistry and alloy composition. Coke is also added in the furnace which reduces the manganese and silicon oxides to metallic manganese and silica. An EAF slag is generated from the pyrometallurgy process which can be used as aggregate for the construction industry. System expansion was used on this co-product. The total data quality score for this route is approximately 2 (good). The ranking of each data indicator is shown in Table 15.

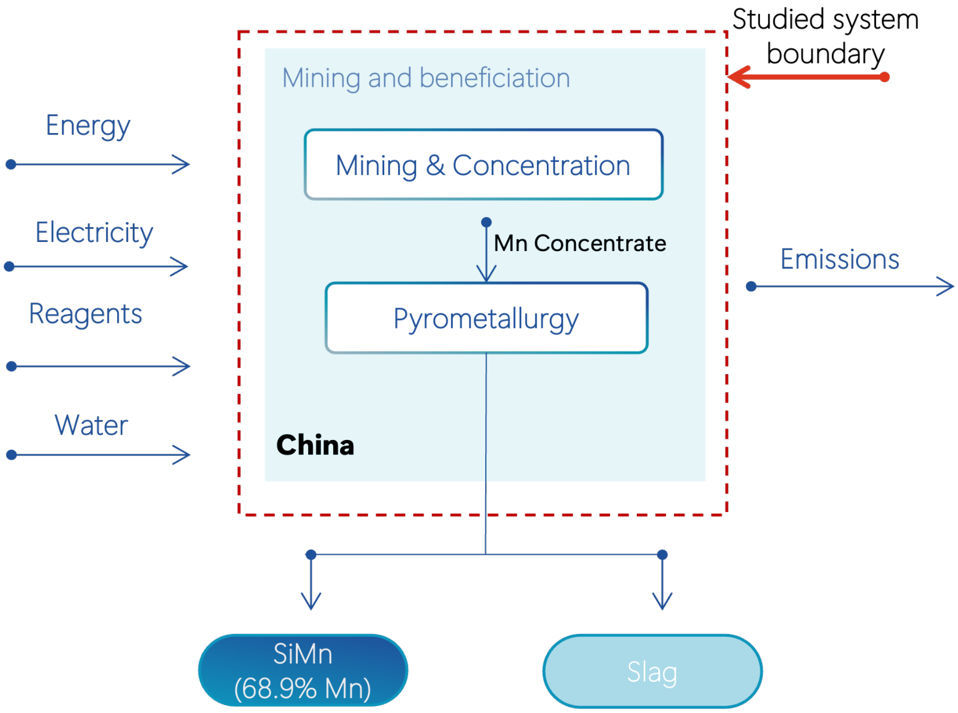
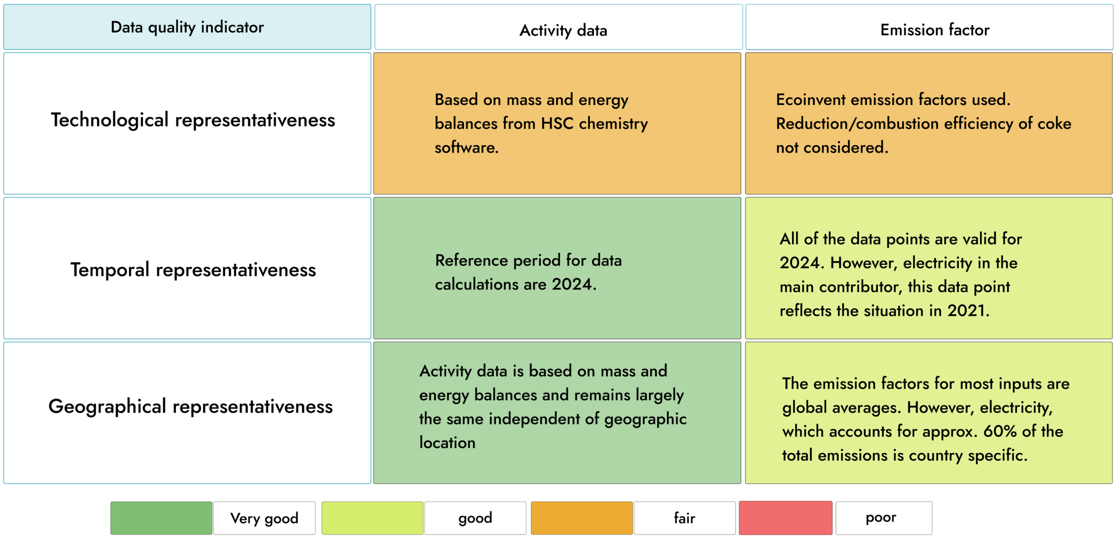


Figure 47: System Boundary for the Production of SiMn from Land Based Ores

Table 15: Data Quality Rating for the Production of Silicomanganese from Land Based Ores



Data quality indicator	Activity data	Emission factor
Technological representativeness	🟧 Based on mass and energy balances from HSC chemistry software.	🟧 Ecoinvent emission factors used. Reduction/combustion efficiency of coke not considered.
Temporal representativeness	🟩 Reference period for data calculations are 2024.	🟨 All of the data points are valid for 2024. However, electricity in the main contributor, this data point reflects the situation in 2021.
Geographical representativeness	🟩 Activity data is based on mass and energy balances and remains largely the same independent of geographic location	🟨 The emission factors for most inputs are global averages. However, electricity, which accounts for approx. 60% of the total emissions is country specific.

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.2.1.1 Climate Change Impact Results

The SiMn produced via the traditional land-based route performs better in the climate change impact category than SiMn produced from $MnSiO_3$ at each of TMC's NORI-D locations (Figure 48). The impact is 10.3% lower than TMC NORI-D Texas, 13.7% lower than TMC NORI-D Japan, and 18.3% lower than TMC NORI-D Indonesia.

This is because the source of manganese for the production of SiMn from TMC's NORI-D operations is $MnSiO_3$. This product has a relatively high embodied carbon due to the use of reductant coal and electricity in TMC's pyrometallurgical operations. However, TMC's $MnSiO_3$ is pre-reduced from the coal, thus decreasing the amount of reductant needed in downstream processing. The source of manganese via the land-based route is the manganese concentrate, whose mining and beneficiation has minimal climate change impact due to the high grade of the manganese ores, simple beneficiation methods, and relatively shallow open pit mining.[32]

The climate change impact of downstream pyrometallurgical processing when TMC $MnSiO_3$ is used as the source of manganese input is **7.82 kg CO_2.eq (NORI-D Texas)**, **versus 8.92 kg**

CO_2eq. when traditional based manganese ores are used as the manganese sources, a 14% increase. As this is the only route that has downstream processing of one of TMC's products, a contribution analysis of the climate change impact category was also included (Figure 49)

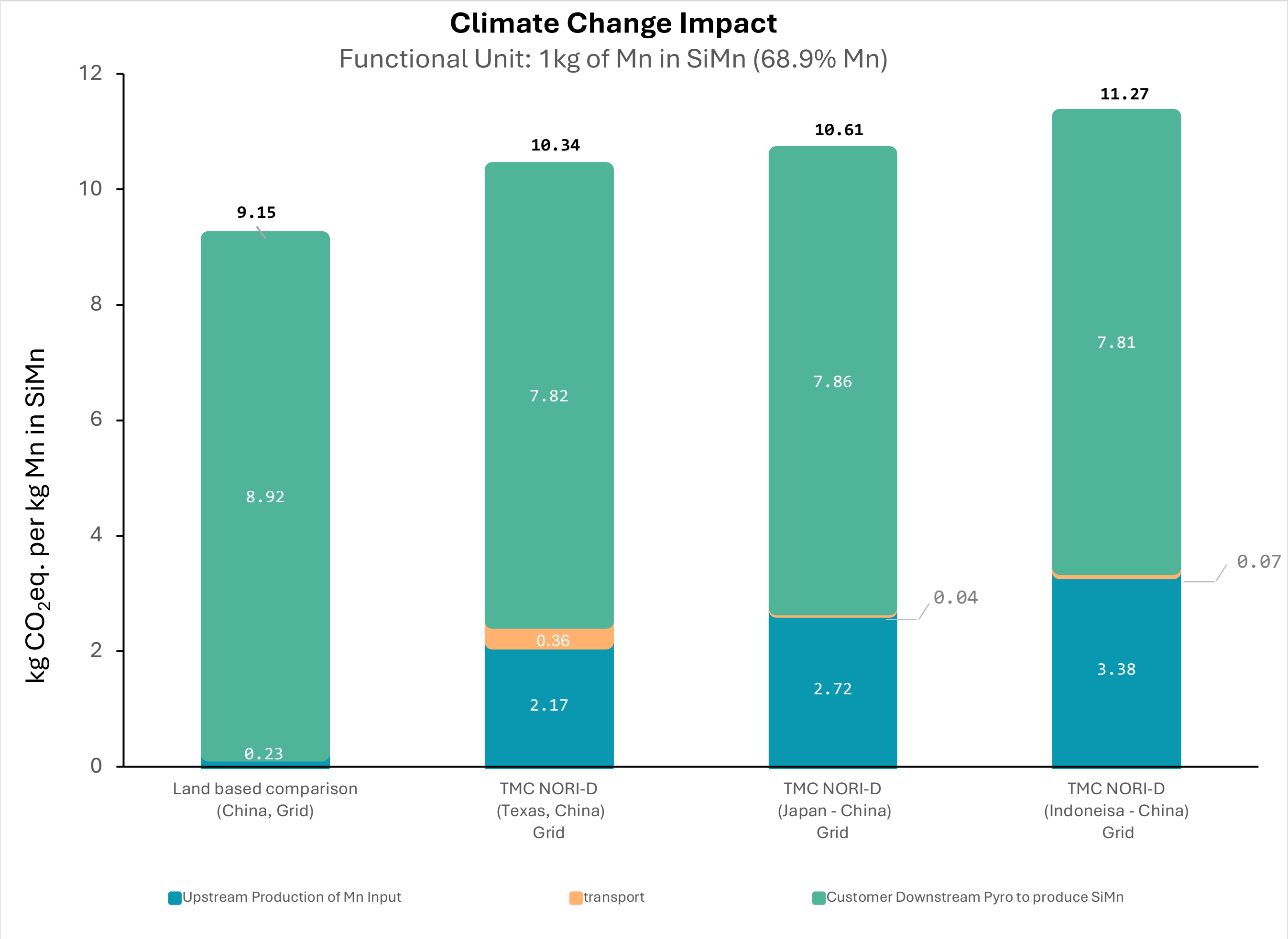


Figure 48:Climate Change Impact – Comparison of the climate change impact from the production of 1kg of Mn in SiMn produced using traditional manganese ores vs TMC's $MnSiO_3$

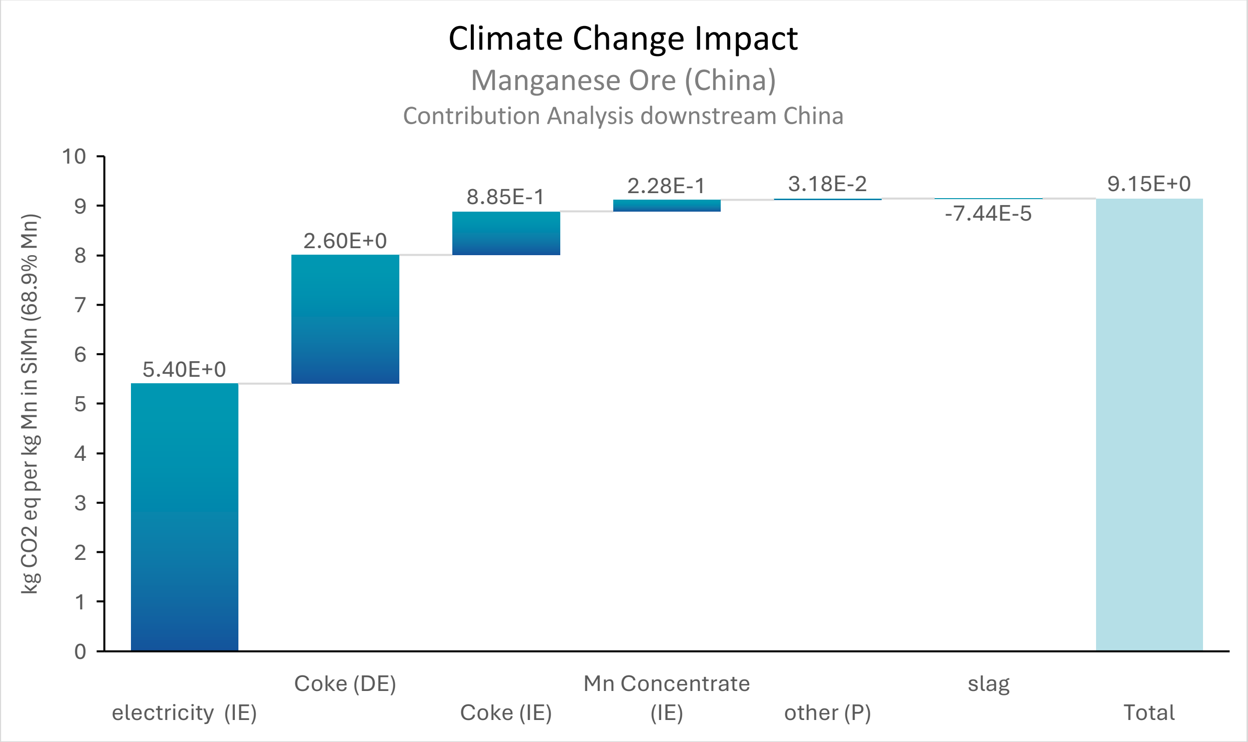


Figure 49: Climate Change Impact – Contribution Analysis: 1 kg of Mn in SiMn from land-based Mn ore (China)

7.2.1.2 Acidification Results

The SiMn produced via the traditional land-based route performs better in the acidification category than SiMn produced from $MnSiO_3$ at each of TMC's NORI-D locations (Figure 50). The impact is 88% lower than TMC NORI-D Japan and Texas Route, and 89% lower than TMC NORI-D Indonesia route.

The higher acidification impact in the TMC NORI-D routes is attributed to the usage of marine gas oil in offshore operations. Further acidification impacts from the NORI-D operations are attributed to the transport of $MnSiO_3$ to China for processing, as well as the usage of reductant coal in pyrometallurgical operations. These inputs are not a part of the production of SiMn from the land-based route.

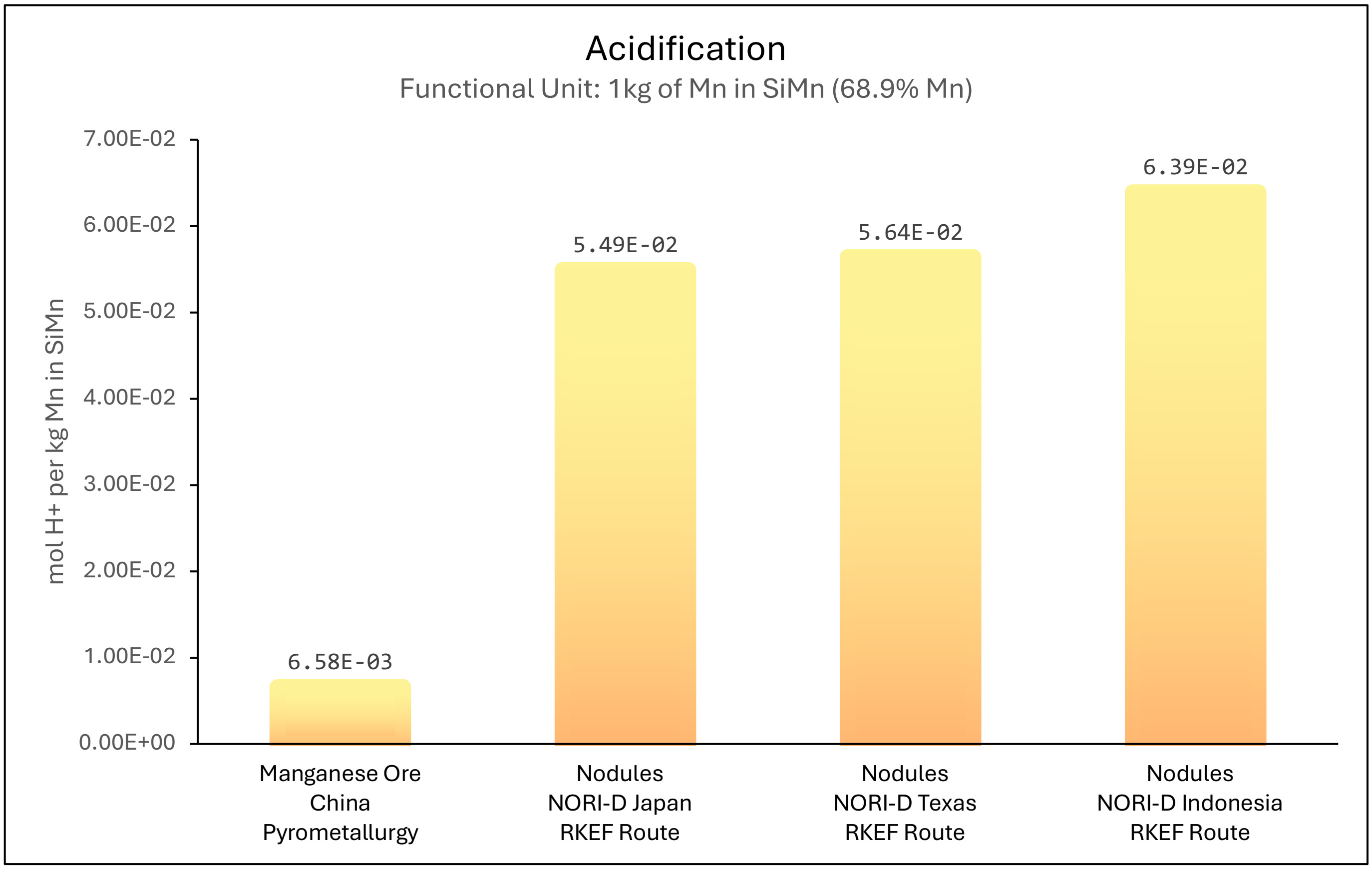


Figure 50: Comparison of the Acidification Impact from the production of 1kg of Mn in SiMn produced using traditional manganese ores vs TMC's $MnSiO_3$

7.2.1.3 Freshwater Eutrophication Results

The SiMn produced via the traditional land-based route performs better in the freshwater eutrophication category than SiMn produced from $MnSiO_3$ at each of TMC's NORI-D locations. The impact is 88% lower than TMC NORI-D Japan and Texas route, and 96% lower than the NORI-D Japan route, 98% lower than the Indonesia route, and 99% lower than the NORI-D Texas route (Figure 51).

The higher impact from the NORI-D routes is attributed to the transport of the $MnSiO_3$ from onshore processing locations to the downstream customer in China. The impact is highest for the NORI-D Texas route since the transport distance by sea freight to China is the greatest between the NORI-D routes. The terrestrial comparison does not have this transport as the ore is mined and processed in China.

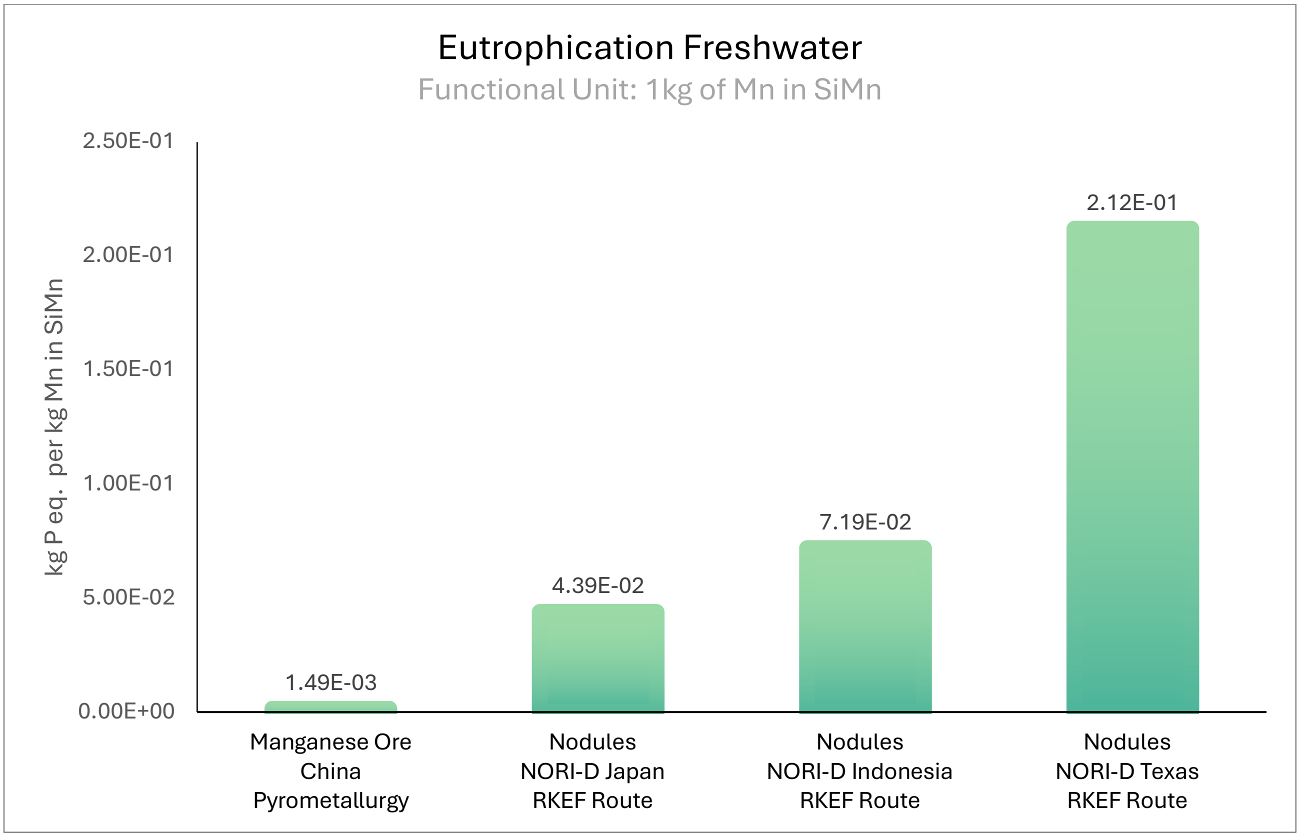


Figure 51: Comparison of the Freshwater Eutrophication Impact from the production of 1kg of Mn in SiMn produced using traditional manganese ores vs TMC's $MnSiO_3$.

7.2.1.4 Energy Use Results

The SiMn produced via the traditional land-based route performs better in the Energy use impact category than SiMn produced from $MnSiO_3$ at each of TMC's NORI-D locations (Figure 52). The impact of 88 MJ from the land based route increases by approximately 19% for the TMC NORI-D Texas Route, and 28% for the TMC NORI-D Indonesia route and Japan routes.

The higher energy use impact in the TMC NORI-D routes is attributed to the usage of marine gas oil in offshore operations, as well as coal and electricity usage in TMC's pyrometallurgy.

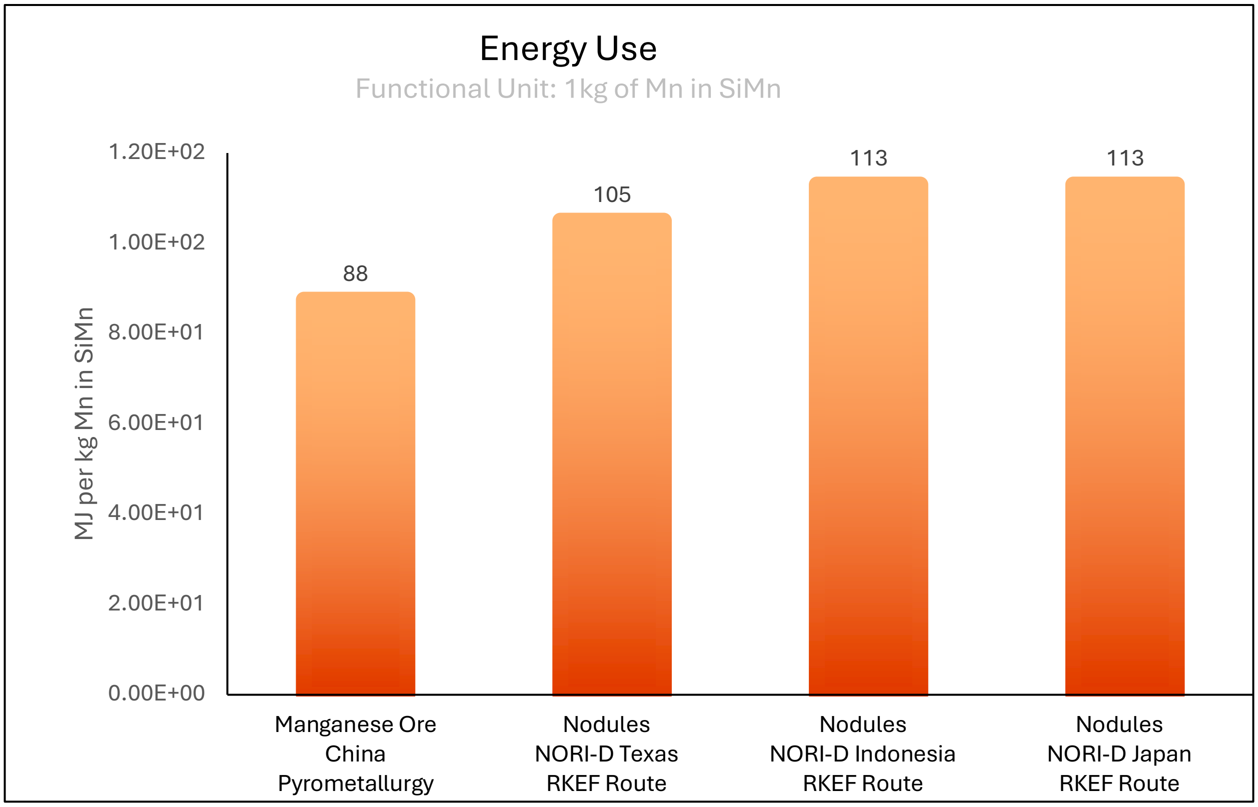


Figure 52: Comparison of Energy Use from the production of 1kg of Mn in SiMn produced using traditional manganese ores vs TMC's $MnSiO_3$

7.3 LCIA Results & Interpretation: $NiSO_4.6H_2O$

7.3.1 Indonesia to China (HPAL)

Indonesia is the world's largest producer of mined nickel and the leading global exporter of mixed hydroxide precipitate (MHP), the majority of which is shipped to China—positioning this route as a critical pathway for the production of $NiSO_4·6H_2O$.[33]The production of MHP is forecasted to grow further in subsequent years as ore grades decline.

Limonite ores typically contain lower grades of nickel than other nickel ores such as saprolite and often contain small amounts of cobalt as well.[20]They are characterized by a high iron content and low MgO content. Their composition makes them suitable for leaching under high pressure and temperature conditions using a technology known as HPAL (high pressure acid leaching).[34]

Limonite ore that has been slurried with water is fed to an autoclave, then heated with steam to about 200°C. Sulfuric acid is added to the solution. After leaving the autoclave, the product slurry is sent to flash cooling, before passing two neutralization stages (using a base such as limestone). The neutralization stage leads to precipitation of compounds such as Fe an Al, forming a residue that is washed and deposited as tailings. The Ni/Co bearing solution is then precipitated into a mixed nickel-cobalt hydroxide, simply known as mixed hydroxide precipitate (MHP).

MHP is then shipped to China, where it is re-leached and further refined through solvent extraction and crystallization to a $NiSO_4.6H_2O$ and $CoSO_4.7H_2O$ product (Figure 53). This method generally has a lower climate change impact when compared to other nickel extraction processes, however, it generates substantial amounts of process residues that negatively impacts the environment. The total data quality score for this route is approximately 2 (good). The ranking of the data indicators are shown in table 16 and the allocation factor for the co-products is shown in table 17.

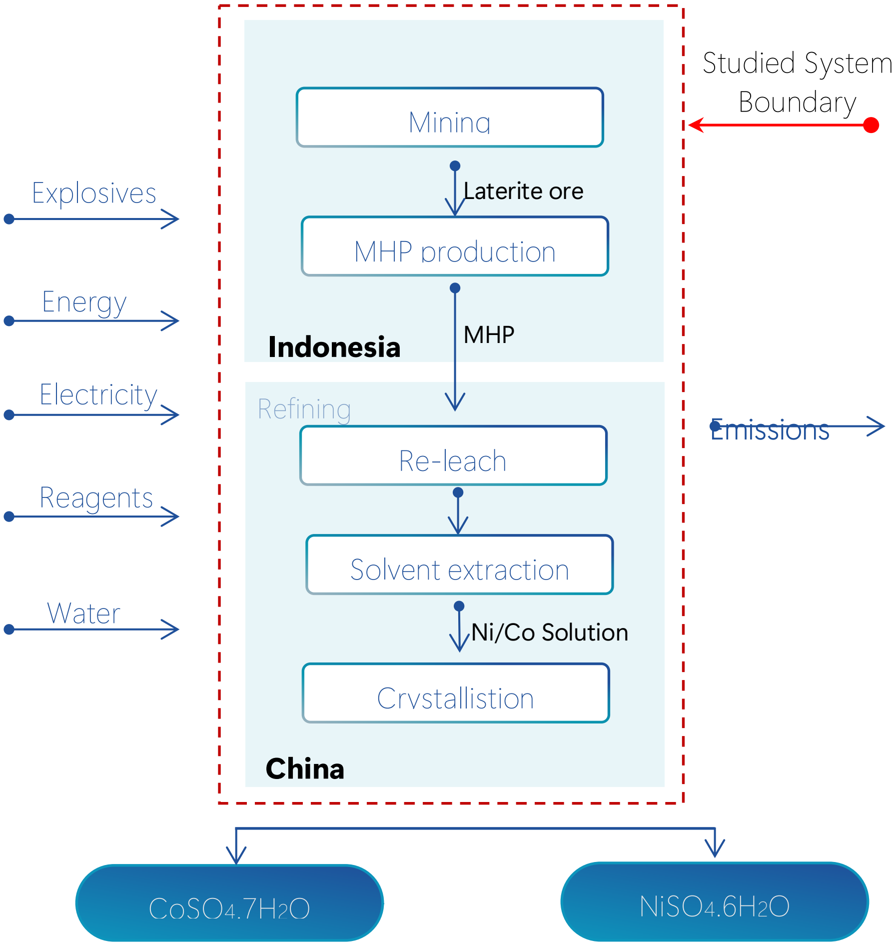


Figure 53: System Boundary for the production of $NiSO_4.6H_2O$ from limonite ores via the HPAL route.

Table 16: Data Quality Rating for the Indonesia-China HPAL route analyzed

Data quality indicator	Activity data	Emission factor
Technological representativeness	🟨 The data for the production of matte, which represents the majority of the impact, is from primary sources. Secondary data is used for the refining of the matte.	🟧 Ecoinvent emission factors used. Reduction/combustion efficiency of coal not considered.
Temporal representativeness	🟩 Reference period for data calculations are from 2023	🟩 All of the data points are valid for 2023.
Geographical representativeness	🟩 Activity data is largely from site-specific primary sources. Secondary data used is independent of geography.	🟨 The emission factors for most inputs are global averages.

🟩	Very good	🟨	good	🟧	fair	🟥	poor

Table 17: Price and Allocation factors of the generated co-products from the Indonesia-China HPAL route.

Product	Price ($/ton)	Economic allocation factor
Ni in $NiSO_4.6H_2O$	15536	0.76
Co in $CoSO_4.6H_2O$	43,280	0.24

7.3.2 Indonesia to Japan (RKEF)

Though significant, this route accounts for only a small portion of global $NiSO_4{\cdot}6H_2O$ production. The data from this specific site analyzed is considered a low impact route as the matte is produced in Indonesia on a site that has access to a significant share of renewables. Unlike limonite ores, saprolite ores are characterized by low iron and high MgO content.[34] These ores typically are processed via smelting. The ore is first dewatered and calcined in coal fired hot rotating kilns. Liquid sulfur is sprayed into the kiln to sulfidize the metallic nickel and iron in the calcine. The sulfided calcine is fed to electric arc furnaces where it reacts to form molten matte, and molten slag. The matte and slag are immiscible and are tapped separately. In this analyzed route, the matte is shipped to Japan where it undergoes further refining via acid leaching, purification, and solvent extraction to produce $NiSO_4.6H_2O$ (Figure 54). The slag is used as aggregate in construction of roads, thus a system expansion was used on this co-product. The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in table 18.

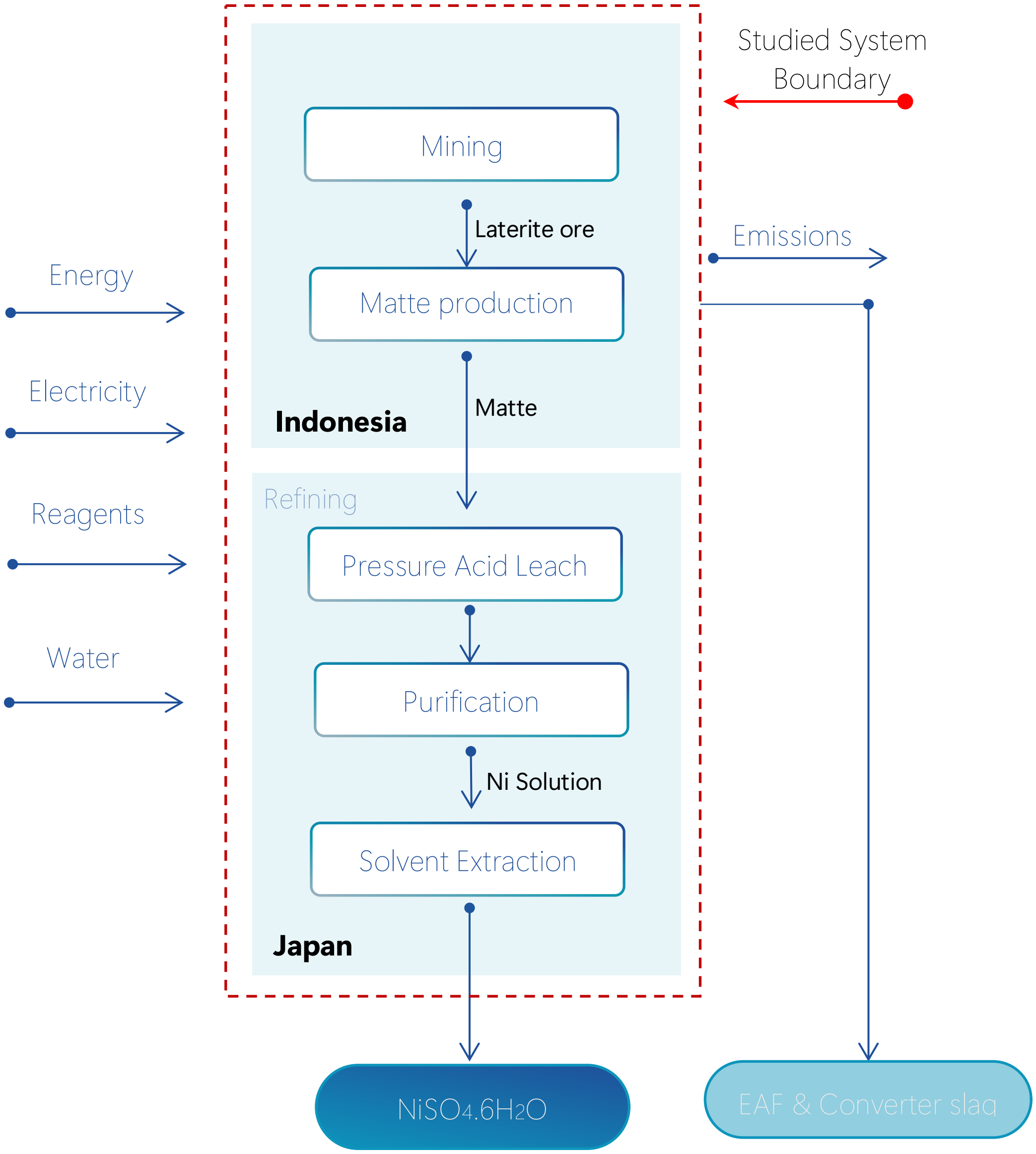


Figure 54: System Boundary for the production of $NiSO_4.6H_2O$ from saprolite ores via the Indonesia - Japan RKEF route.

Table 18: Data Quality Rating for the Indonesia-Japan RKEF route analyzed

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of matte, which represents the majority of the impact, is from primary sources. Secondary data is used for the refining of the matte.	Ecoinvent emission factors used. Reduction/combustion efficiency of coal not considered.
Temporal representativeness	Reference period for data calculations are from 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages.

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.3.3 Indonesia to China (RKEF)

Similar to with MHP, Indonesia is the leading global exporter of nickel matte, accounting for 48% of global exports, the majority of which is shipped to China—positioning this route as a critical pathway for the production of $NiSO_4 \cdot 6H_2O$.[33]

The $NiSO_4.6H_2O$ produced here follows a similar production pathway as described in section 7.2.2. However, the produced matte is shipped to China for re-leach, solvent extraction, and crystallization to form the $NiSO_4.6H_2O$ (Figure 55). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 19.

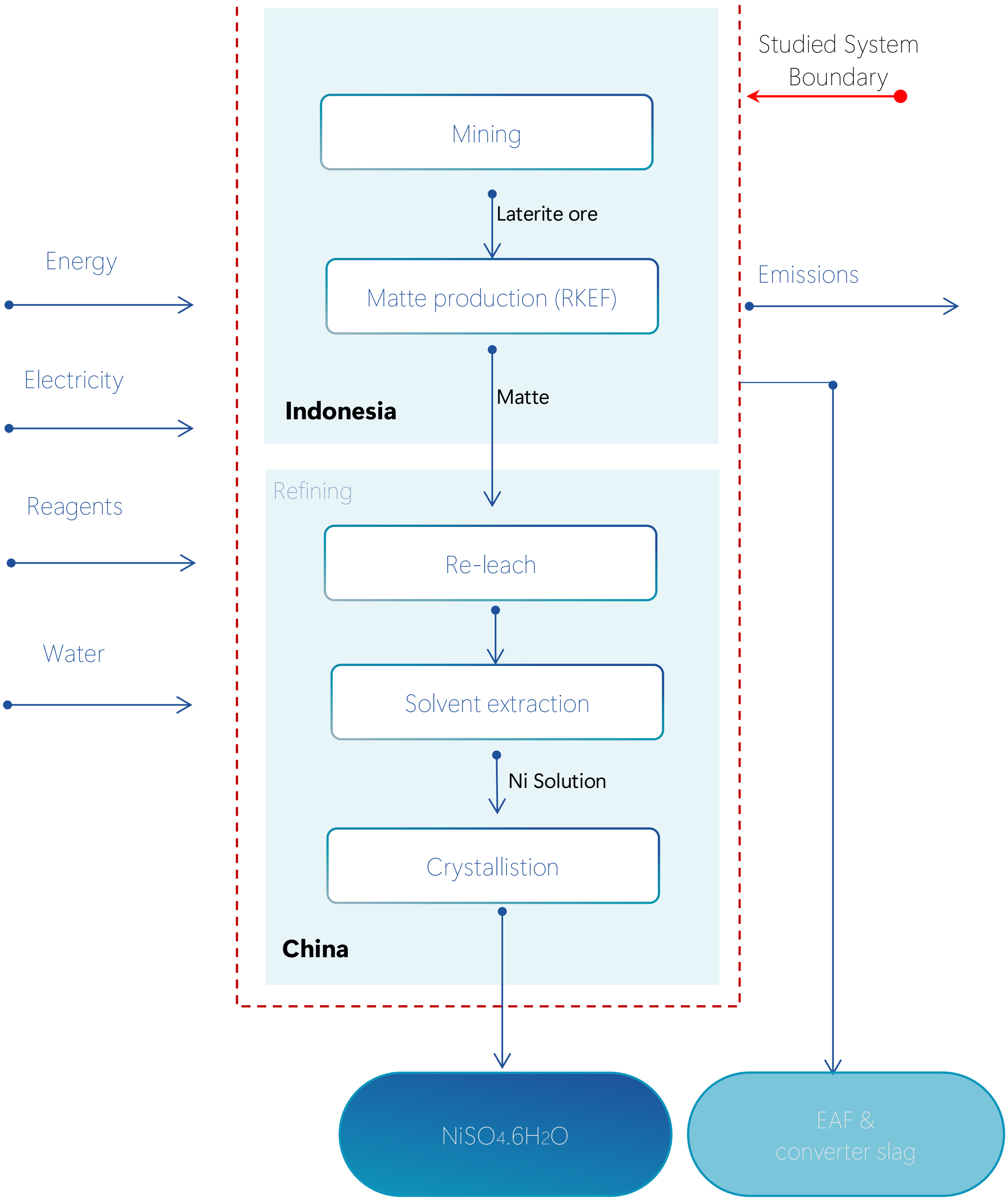
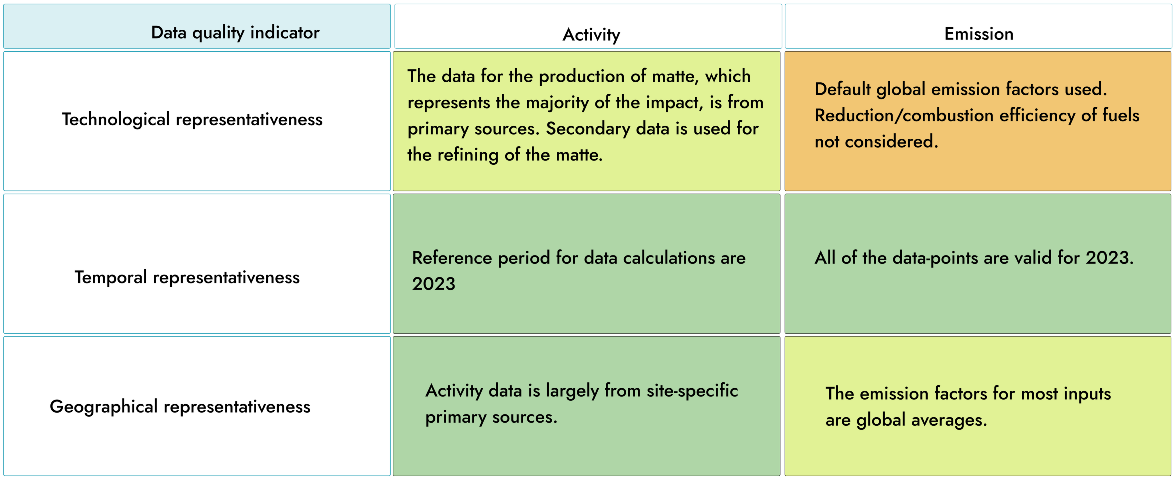


Figure 55: System Boundary for the production of $NiSO_4.6H_2O$ from saprolite ores via the Indonesia - China RKEF route.

Table 19: Data Quality Rating for the Indonesia-China RKEF route analyzed



Data quality indicator	Activity	Emission
Technological representativeness	The data for the production of matte, which represents the majority of the impact, is from primary sources. Secondary data is used for the refining of the matte.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are 2023	All of the data-points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages.

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.3.4 Canada to Norway (Smelting)

Canada is the world's second-largest exporter of nickel matte, accounting for 11% of global exports, with the majority shipped to Norway. This route is considered a low impact route for the production of $NiSO_4.6H_2O$ due to the large share of renewables on the Canadian and Norwegian grid. Nickel sulfide ores are treated through pyrometallurgy. In this analyzed route, sulfide ores are mined, crushed and grinded, concentrated, and processed to a matte in Canada. The grinding and crushing stages liberate the valuable minerals from the ore prior to froth flotation which separates the nickel, cobalt, and copper bearing minerals from the gangue material. The product is a concentrate that is fed to a smelter. The concentrate is smelted and converted to form a matte. The matte is then transported to Norway where it is further refined to a class I nickel via electrolysis, which is then converted to battery grade $NiSO_4.6H_2O$ (Figure 56). The total data quality rating for this route is approximately 3 (fair). The ratings of the individual data indicators are shown in Table 20 and the allocation factors for the co-products are shown in Table 21.

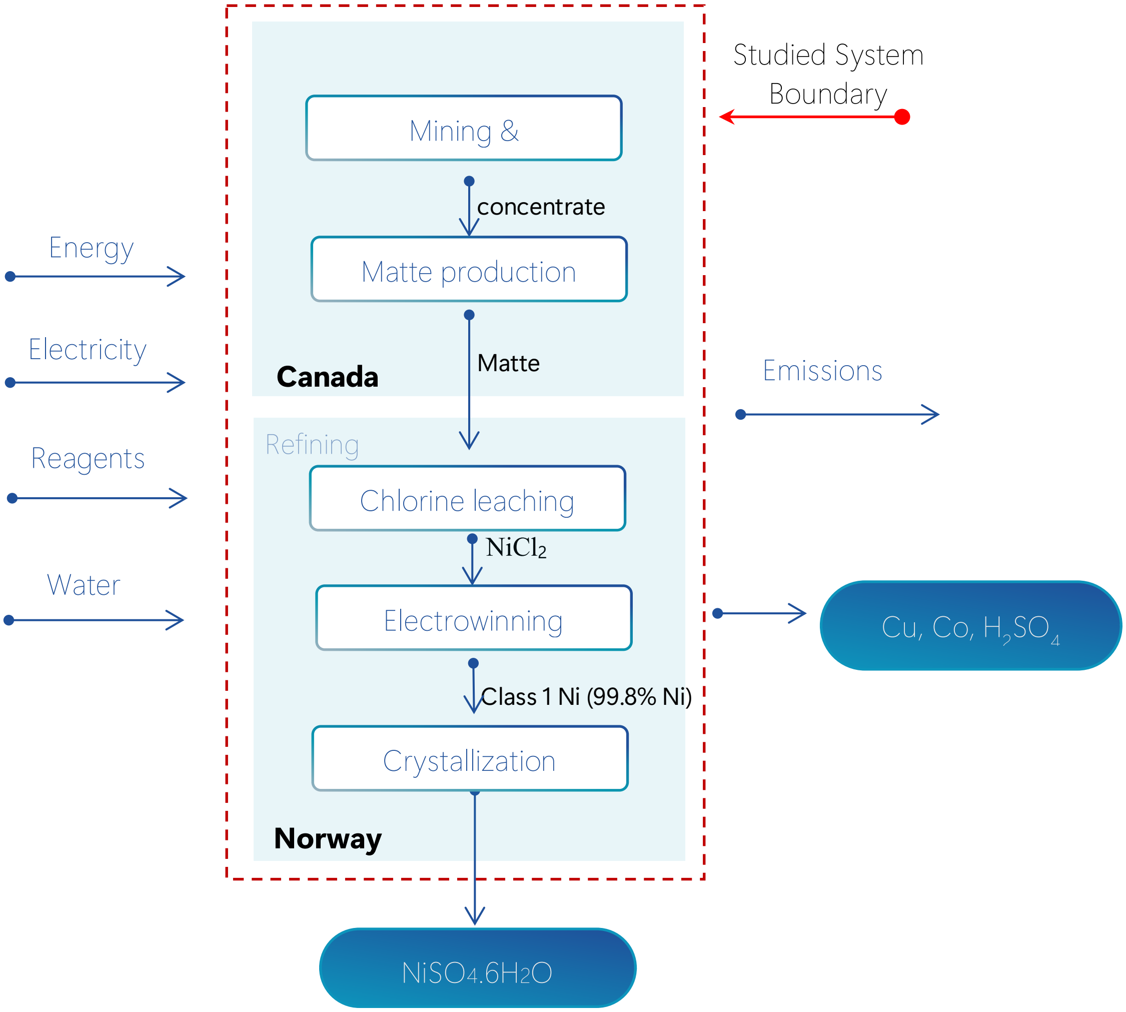


Figure 56: System Boundary for the production of $NiSO_4.6H_2O$ from sulfide ores via the Canada - Norway Smelting route.

Table 20: Data Quality Rating for the Canada-Norway Smelting route analyzed

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of the matte was from secondary sources. Primary data was used for energy consumption and direct emissions for the matte refining. Secondary data was used for the conversion of Class I Nickel.	Default global emission factors used.
Temporal representativeness	Reference year for the data ranges from 2017 to 2022.	All of the datapoints are valid for 2023.
Geographical representativeness	Activity data are largely based on averages.	The emission factors for most inputs are global averages, Canada specific emission factors were used where possible to account for geographical representativeness.

🟩	Very good	🟨	good	🟧	fair	🟥	poor

Table 21: Price and Allocation factors of the generated co-products from the Canada-Norway route.

Product	Price ($/ton)	Economic allocation factor
Ni in $NiSO_4.6H_2O$	15536	0.81
Co in $CoSO_4.6H_2O$	43,280	0.1
Copper Cathode	6670	0.09
Sulfuric Acid	-	System Expansion

7.3.5 Climate Change impact Results

The climate change impact associated with the production of 1kg of Ni in $NiSO_4.6H_2O$ is lower at TMC's NORI-D Texas and Japan routes than all land-based production routes evaluated (Figure 57). The impact of TMC NORI-D Texas is lowest at **9.98 kg CO2eq** . It increases by 15% for the NORI-D Japan route, 23% for the Canada – Norway route, 26% for the NORI-D Indonesia route, 109% for the Indonesia-China (HPAL) route, 228% for the Indonesia – Japan (RKEF) route, and 586% for the Indonesia-China (RKEF) route.

The performance of the NORI-D TMC routes can be attributed to a few factors. Firstly, the relatively high grade of nickel in the nodules leading to less material use per ton of extracted nickel as opposed to a lower grade land-based ore. Secondly, the relatively small climate change impact from offshore operations, and finally, the unique processing pathway which produces multiple co-products that share the environmental load.

The Canada-Norway production route demonstrates a comparable climate change to the TMC NORI-D routes, performing slightly better than the TMC NORI-D Indonesia route. This performance is attributable to the high nickel grade of the Canadian ore, the generation of multiple co-products in the process, and the predominance of renewable energy sources in the electrical grid mixes of both Canada and Norway.

The Indonesia-China route (limonite) performs relatively well as HPAL processing is not characterized by high temperature like those seen in smelting, nor does it use carbon-based reductants. However, this processing pathway does generate a significant amount of toxic waste that negatively affects the environment and society.[35]This can be seen when looking at the impacts of the additional impact categories for this route versus other routes.

The Indonesia – Japan and Indonesia-China (saprolite) routes shows the largest climate change impact. These routes use high temperature for smelting and fossil-based fuels such as coal, coke, and high sulfur diesel oil to power the kiln and furnaces and to act as reductants. The Indonesia-Japan route analyzed uses hydropower in the pyrometallurgy stage, accounting for approximately 30% of the total energy use. This makes for a matte with a significantly lower impact than that of the Indonesia-China route. This shows that the introduction of renewables in the electricity generation sources can greatly affect the carbon intensity of the produced matte.

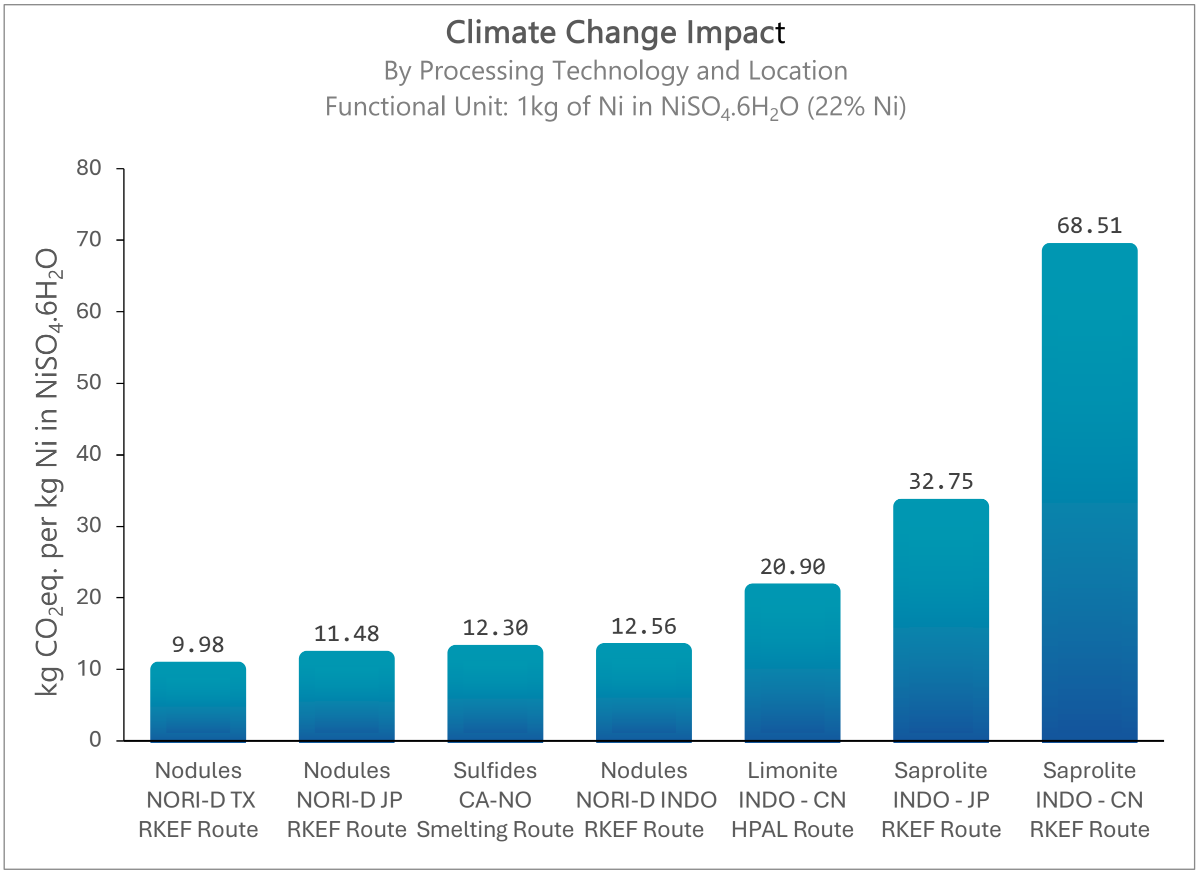


Figure 57: Comparison of the climate change impact of 1 kg of Ni in $NiSO_4.6H_2O$ produced via various land-based routes vs TMC's NORI-D processing routes.

7.3.6 Acidification Results

The acidification impact associated with the production of 1kg of Ni in $NiSO_4.6H_2O$ is lower at TMC's NORI-D Texas route than all land-based production routes evaluated (Figure 58). The impact of TMC NORI-D Texas is lowest at **6.64E-02 mol H+eq** . It increases by approximately 8% for the Canada-Norway route, 23% for the TMC NORI-D Japan route, 32% for the NORI-D Indonesia route, 600% for the Indonesia-China (HPAL) route, 1341% for the Indonesia – China (RKEF) route, and 1406% for the Indonesia-Japan (RKEF) route.

The acidification impact of the Canada-Norway route is comparable to that of the TMC NORI-D routes. This is due to the relatively low usage of coal, the predominance of renewable energy sources in the electrical grid mixes of both Canada and Norway, and the production of co-products which share the environmental burden.

The relatively large acidification impact from the Indonesia– China (HPAL) route is predominately attributed to the release of SO_2 gas during the production of sulfuric acid (both from the production of sulfur and its conversion to sulfuric acid). Coupling the release of SO_2 gas from the production of sulfuric acid with the large quantities of the acid consumed in this process leads to the relatively high impact.

The acidification impact of the Indonesia-China (RKEF) and Indonesia-Japan routes are due to the use of coke, coal, and sulfur during the matte production process. The Indonesia-Japan route also uses high sulfur diesel oil in the matte production process, leading to a further increase in the acidification impact.

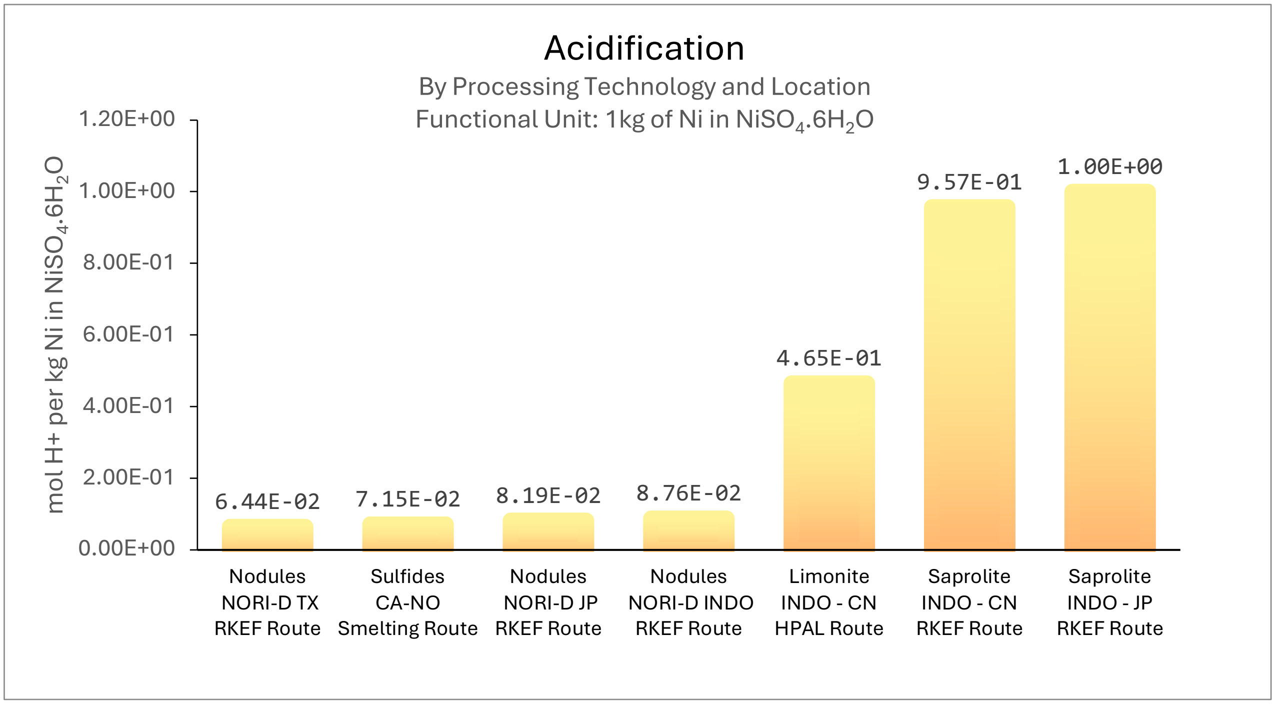


Figure 58: Comparison of the Acidification Impact from the production of 1kg of Ni in $NiSO_4.6H_2O$ produced using traditional land-based ores vs NORI-D Nodules

7.3.7 Freshwater Eutrophication Results

The impact on freshwater eutrophication associated with the production of 1kg of Ni in $NiSO_4.6H2_O$ is lower across all TMC's NORI-D project locations compared to the traditional land-based production route evaluated. The impact of TMC NORI-D Texas is lowest at 9.97 and increases by approximately 56% for TMC NORI-D Indonesia route, 78% for the TMC NORI-D Japan route, and 215% for the Indonesia-Japan (RKEF) route, 246% for the Canada-Norway route, 836% for the Indonesia-China (HPAL) route, and 1094% for the Indonesia-China (RKEF) route (Figure 59).

The impact on freshwater eutrophication from TMC's operation is predominately associated with the usage of electricity. The production of the fossils used in electricity generation produce phosphorous containing compounds, leading to impacts on eutrophication. This impact is highest for the NORI-D Indonesia route due to the grid mix being dominated by coal in the form of lignite. Spoil from lignite mining is high in phosphates.

The Indonesia-Japan route performs comparably to the NORI-D routes. This is because the energy intensive pyrometallurgy stage occurs on a plant who has significant renewable energy in their grid-mix.

The Canada–Norway route is among those with the highest impact on freshwater eutrophication of the routes analyzed. This impact predominantly stems from the generation of tailings during the mining and beneficiation of ore in Canada.

The Indonesia-China (HPAL) route has the second highest impact on this freshwater eutrophication of the routes analyzed. The impact primarily comes from the tailings, especially due to the large volume of tailings generated during the production of MHP.

The Indonesia-China (RKEF) route has the highest impact on freshwater eutrophication of the analyzed routes. For this route, the energy intensive pyrometallurgy stage uses grid electricity for energy. The electric grid in Indonesia is dominated by lignite coal. The production of this coal results in spoil from the mining process, which is high in phosphates, leading freshwater eutrophication impacts.

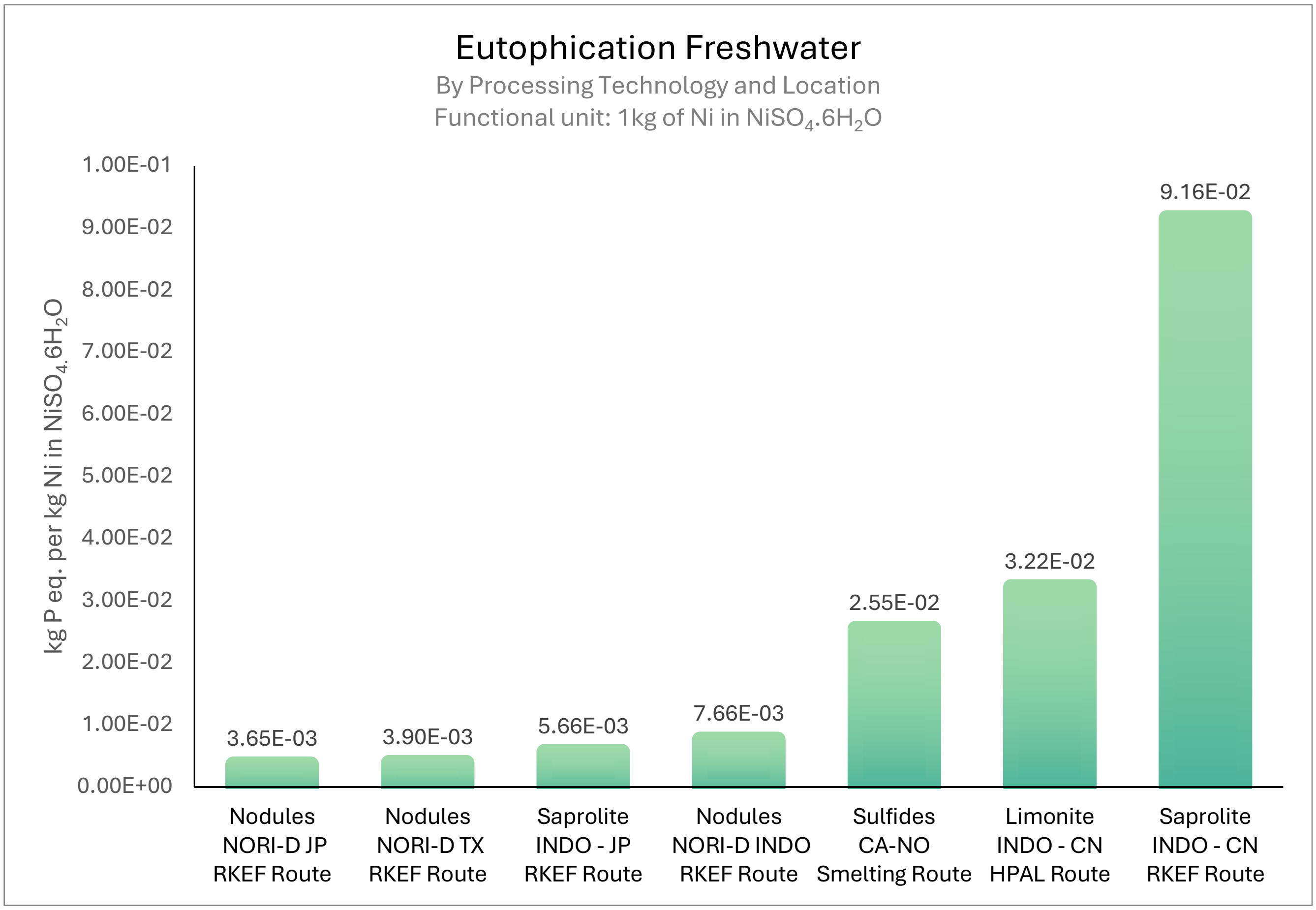


Figure 59: Comparison of the Freshwater Eutrophication Impact from the production of 1kg of Ni in $NiSO_4.6H_2O$ produced using traditional land-based ores vs NORI-D Nodules.

7.3.8 Energy Use

The energy use associated with the production of 1kg of Ni in $NiSO_4.6H_2O$ is lower across all TMC's NORI-D project locations compared to the land-based production route evaluated. The impact of TMC NORI-D Texas is lowest at 114 MJ and increases by approximately 25% for TMC NORI-D Japan route, 30% for the TMC NORI-D Indonesia route, 81% for the Indonesia-China (HPAL) route, 201% for the Indonesia-Japan route, 232% for the Canada-Norway route, and 628% for the Indonesia-China (RKEF) route (Figure 60).

The energy use at TMC's operations is predominately associated with marine fuel usage during offshore operations, and coal and electric usage during pyrometallurgical operations.

The energy use from the Indonesia-China (HPAL) route is predominately associated with the production of sulfuric acid, whose feedstock is sulfur which is mainly produced from petroleum refinery operations, as well as the production of coal.

The energy use from the Indonesia-Japan (RKEF) route and the Indonesia-Chinese (RKEF) is predominately from the use of coal, coke, and diesel in the RKEF lines.

The energy use from the Canada-Norway route is predominately from electricity usage. The electricity generation source in the region of Canada where this route was modelled has a significant share of nuclear power which uses uranium as the source of energy.

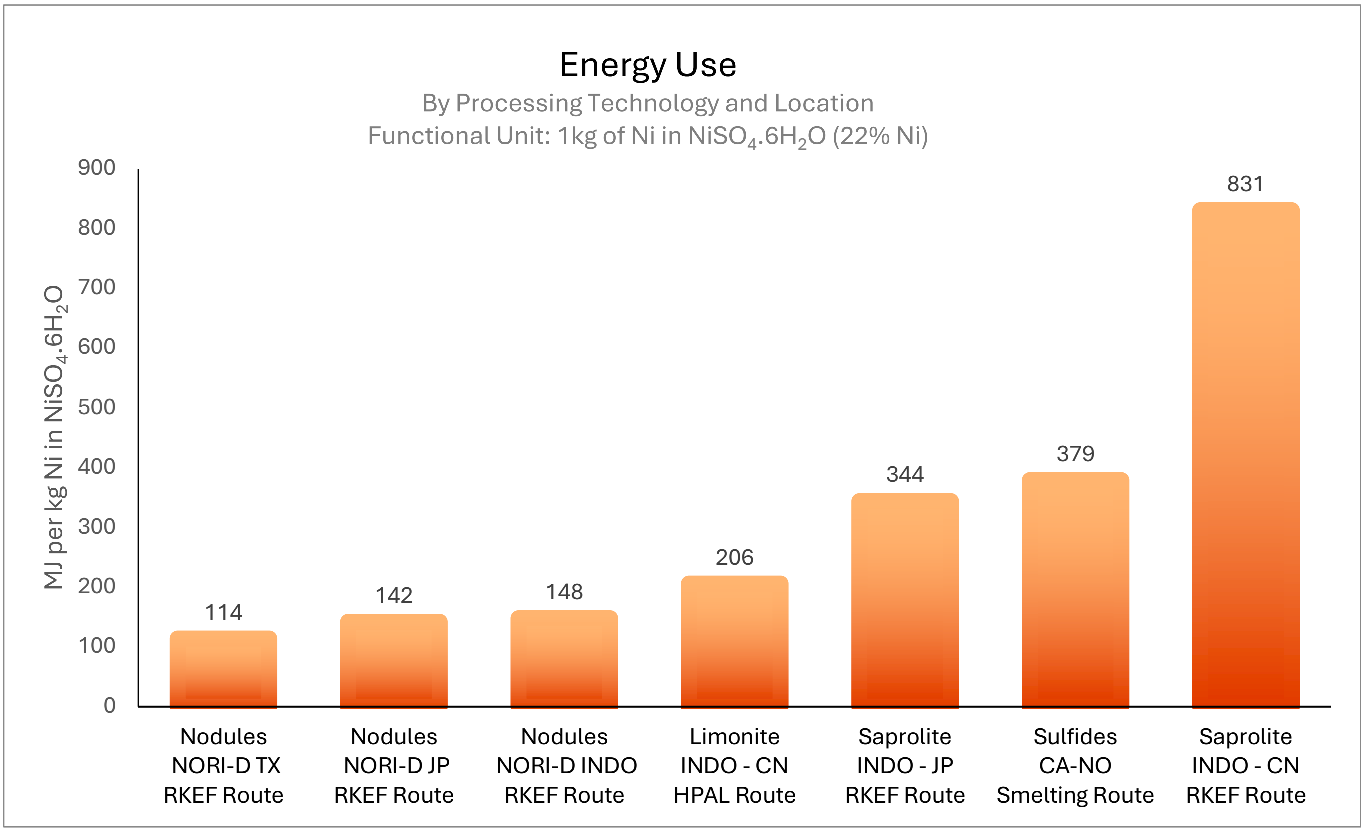


Figure 60: Comparison of Energy Use from the production of 1kg of Ni in $NiSO_4.6H_2O$ produced using traditional land-based ores vs NORI-D Nodules

7.4 LCIA Results & Interpretation: Copper Cathode

7.4.1 DRC: Cu-Co

Historically, copper concentrates produced in the Democratic Republic of Congo (DRC) were largely exported for further processing. However, currently the copper concentrates are now processed within the DRC who now rank top 3 in the world for refined copper production.[36,37]

Cu-Co ores are mined and then milled to liberate the valuable minerals from the ore. The liberated minerals are then enriched to a concentrate through flotation. Concentrates containing sulfides are roasted, blended with the concentrates containing oxides, and sent to leaching. Sulfuric acid is added to the leaching tank, along with SO_2 gas which facilitates the leaching process. The leached slurry goes through solvent extraction and stripping which increases the concentrations of copper and cobalt and separates them as a copper and cobalt rich solution. The copper rich solution is sent to electrowinning where the coper cathode is produced (Figure 61).[38]The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 22 and the allocation factors for the co-products are shown in Table 23.

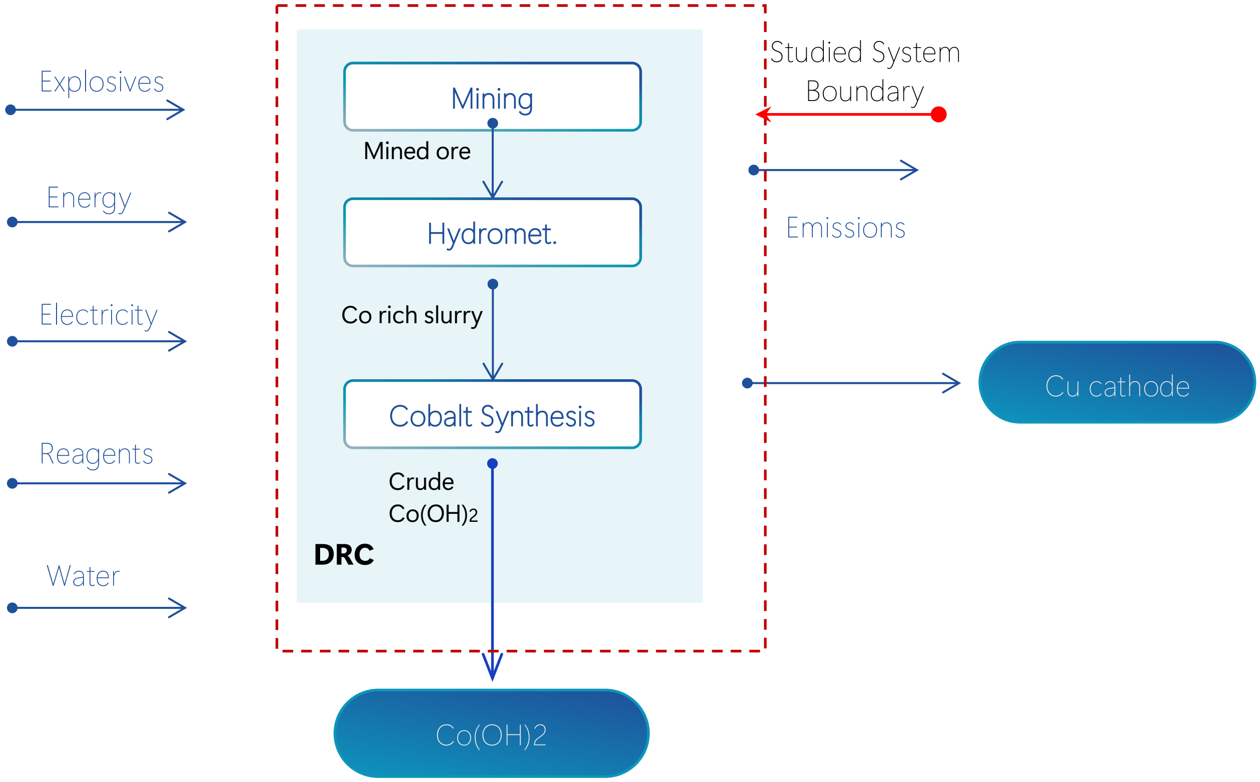


Table 22: Data Quality Rating for the DRC hydrometallurgy route analyzed

Figure 61: System Boundary for the production of Copper Cathode from copper-cobalt ores in the DRC.

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production copper cathode is based on primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are 2018.	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. DRC specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

Table 23: Price and Allocation factors of the generated co-products from the DRC Route

Product	Price ($/ton)	Economic allocation factor
Copper Cathode	6970	0.59
$Co(OH)_2$	21652	0.41

7.4.2 Chile: (Heap Leach)

Chile is the largest producer of mined copper in the world and ranks top 3 in refined copper production.[37] Heap leaching accounts for approximately 30-40% of annual copper production in Chile, making this route a key route for the production of copper cathode.[39] In this route, the Cu-oxide ore is mined at a large open pit mine in Chile. The mined ore undergoes a 3-stage crushing circuit. The crushed ore is then agglomerated and prepped before being stacked into a heap. Concentrated sulfuric acid is then applied to the heap under atmospheric conditions to leach copper into solution. The pregnant leach solution then goes through solvent extraction and electrowinning to form a 99.99% pure copper cathode (Figure 62). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 24.

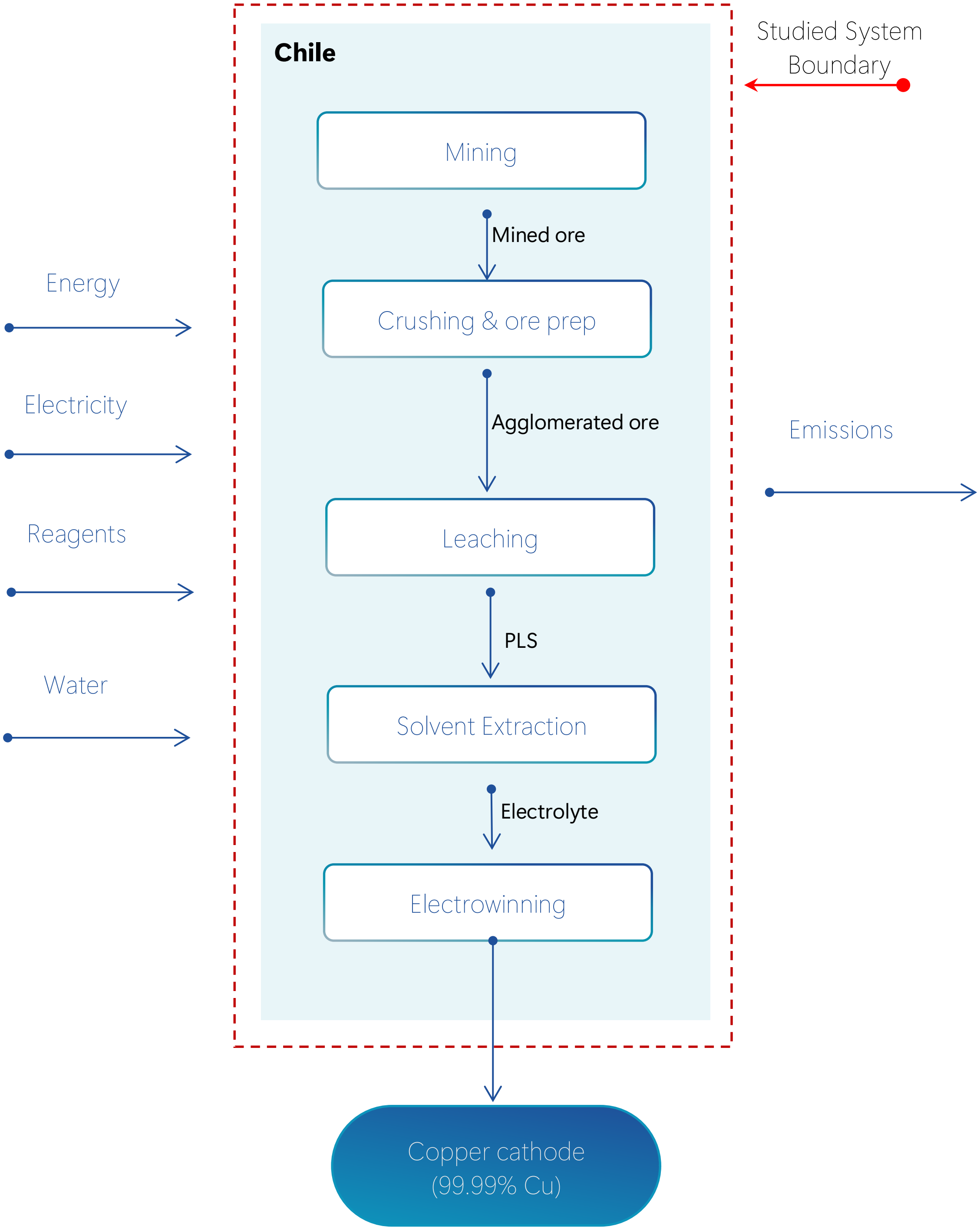
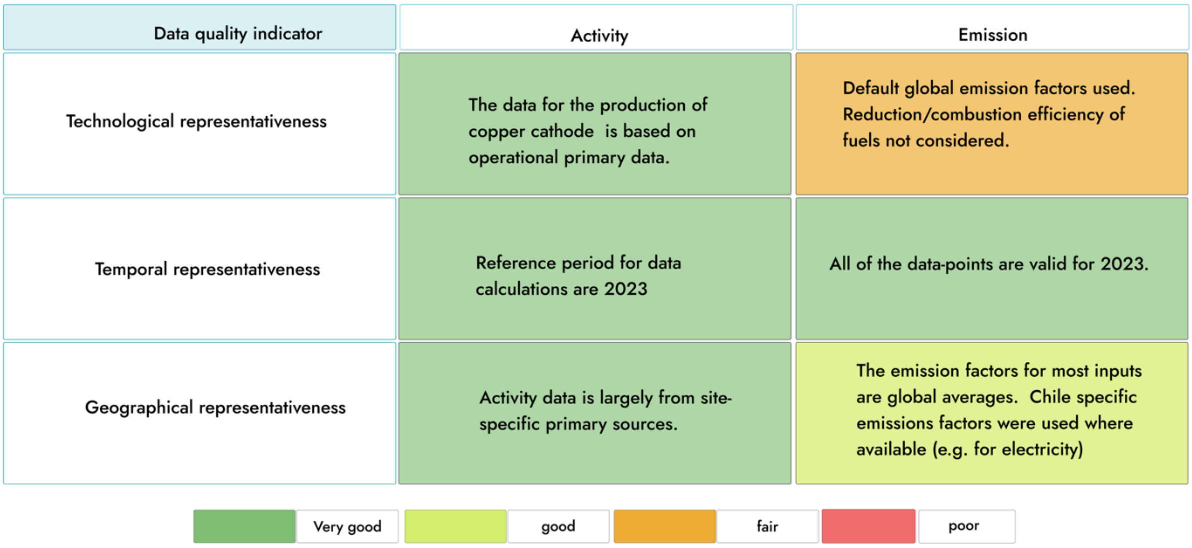


Figure 62: System Boundary for the production of copper cathode from copper oxide ores via the Chile Heap Leach route.

Table 24: Data Quality Rating for the Chile Heap Leach route analyzed



Data quality indicator	Activity	Emission
Technological representativeness	The data for the production of copper cathode is based on operational primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are 2023	All of the data-points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. Chile specific emissions factors were used where available (e.g. for electricity)

🟩 Very good 🟨 good 🟧 fair 🟥 poor

7.4.3 Chile to China: (Smelting)

Chile is the largest producer of mined copper in the world, however, they currently lack the refining facilities to match their mined output. Therefore, the majority of their copper concentrate is exported mostly to China. Consequently, this route represents a major route to produce copper cathode.

The mined copper sulphide ores go through a series of crushers before being milled and concentrated through flotation. The concentrate is then prepped for shipment to China from a port in Chile. In China, the concentrate is smelted and converted to a blister copper which is then electrolytically refined to copper cathode (Figure 63). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 25.

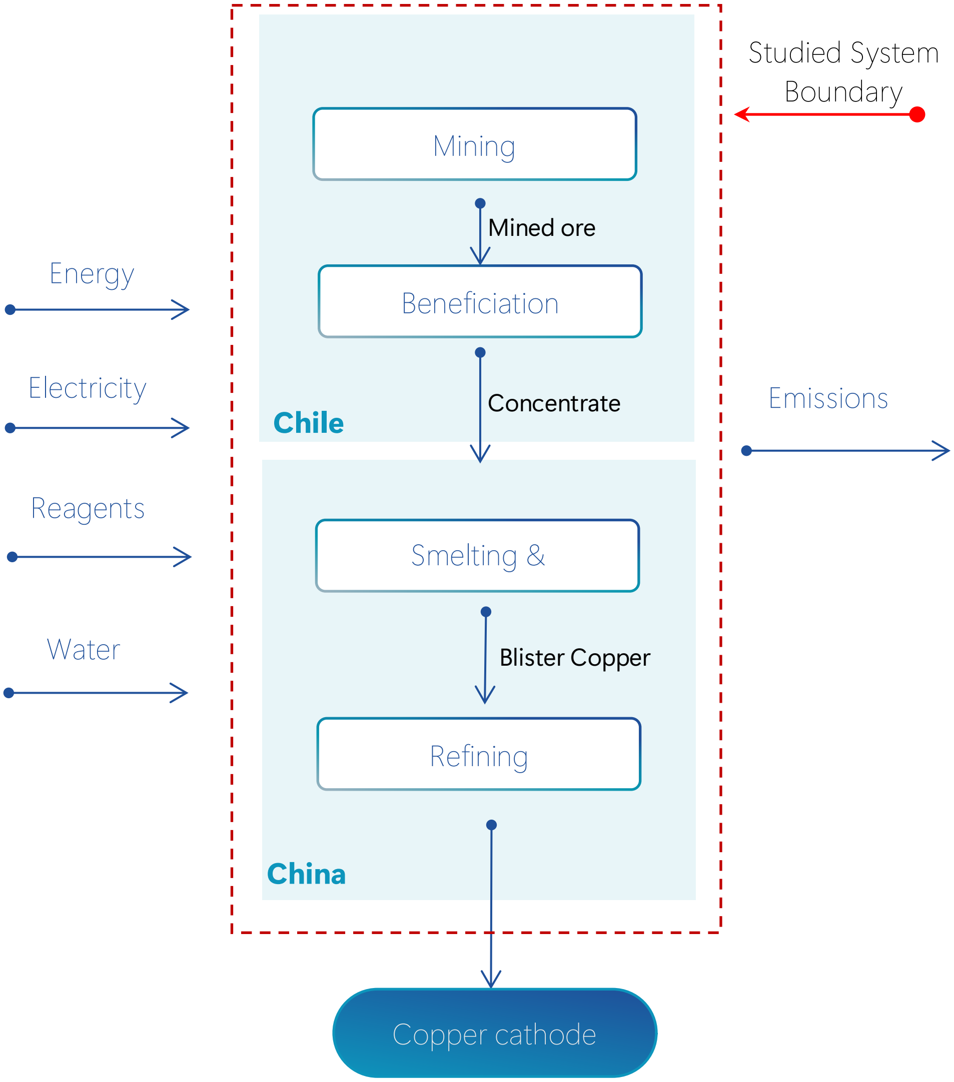


Figure 63: System Boundary for the production of copper cathode from copper sulfide ores via the Chile-China Smelting route.

Table 25: Data Quality Rating for the Chile-China Smelting route analyzed.

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of copper cathode is based on operational primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are from 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. Chile and China specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.4.4 Peru to China: (Smelting)

Peru ranks 2nd or 3rd in terms of global copper mine production.[37] However, they also lack the facilities to refine their mined copper output, and thus exports the majority of their copper, mostly to China.

The mined copper sulphide ores are crushed, milled, and then sent to flotation to form a concentrate. A molybdenum concentrate is also formed as a co-product. The copper concentrate is then prepped for shipment to China from a port in Peru. In China, the concentrate is smelted and converted to a blister copper which is then electrolytically refined to copper cathode (Figure 64). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 26 and the allocation factors are shown in Table 27.

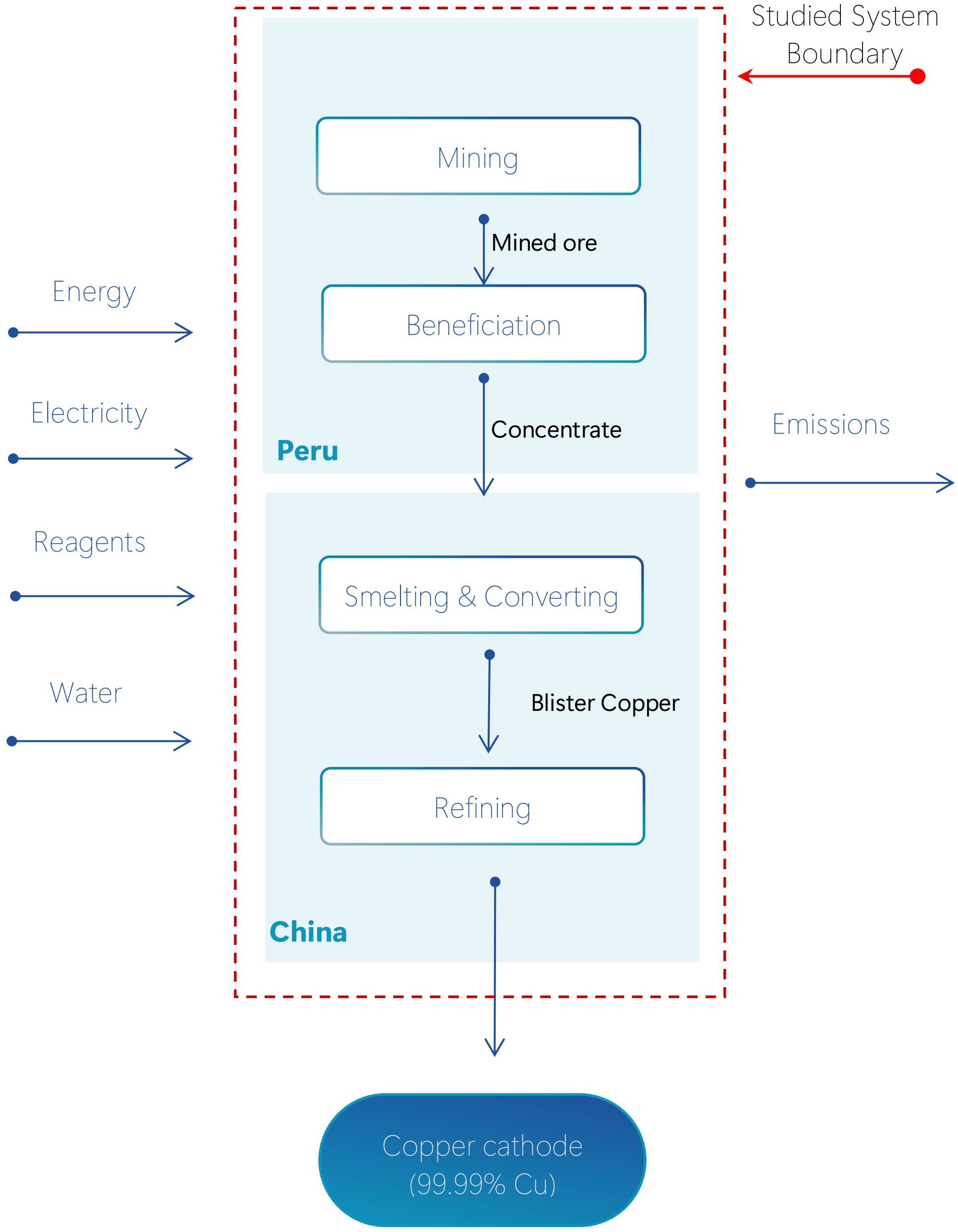


Figure 64: System Boundary for the production of copper cathode from copper sulfide ores via the Peru-China Smelting route.

Table 26: Data Quality Rating for the Peru-China Smelting route analyzed

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of copper cathode is based on operational primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are from 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. Peru and China specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

Table 27: Allocation factors of the generated co-products from the Peru-China Route analyzed.

Product intermediate	Production Volume	Mass allocation factor
Copper Cathode	396,464	0.974
Molybdeum Concentrate	10,558	0.026

7.4.5 USA: (Smelting)

The United States is a major producer of copper, ranking 5th in terms of mine production and 6th in terms of refinery production. Therefore this route represent a major route for the production of copper cathode. In this route, the copper ores are mined and concentrated at open pit copper mines. The concentrates are then transported for smelting where a blister copper is produced. The blister copper is then refined to a copper cathode (Figure 65). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 28.

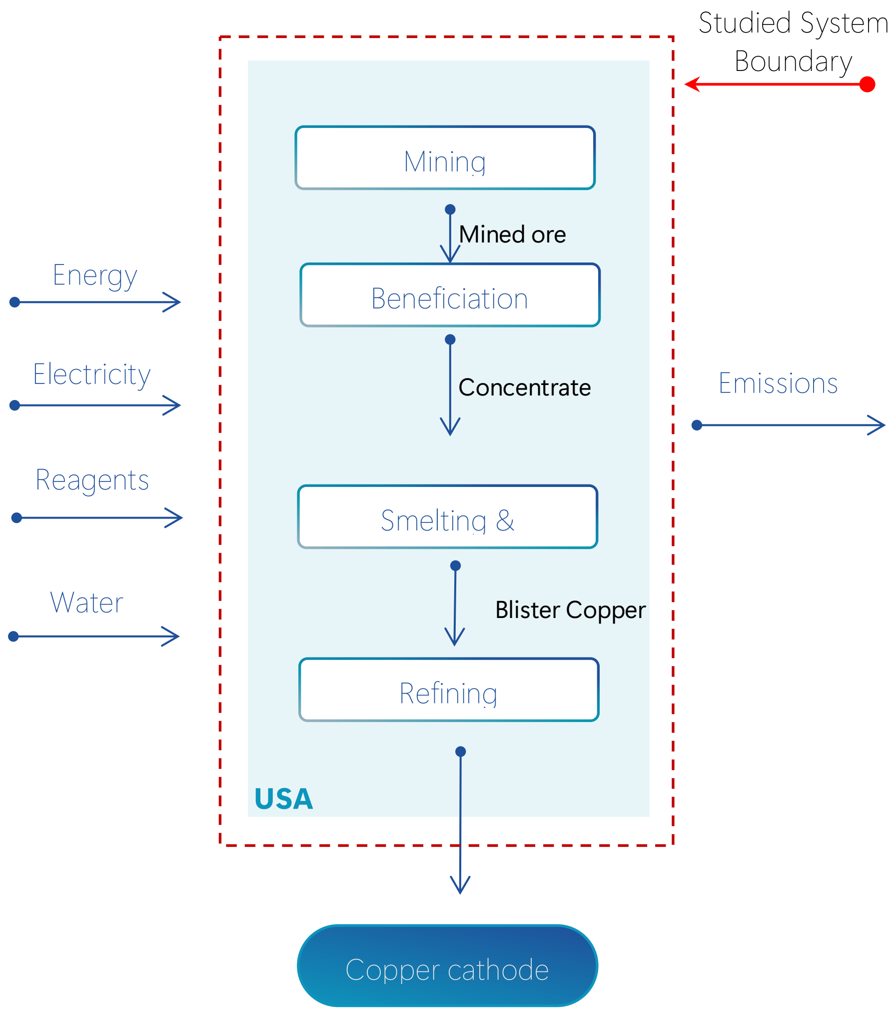
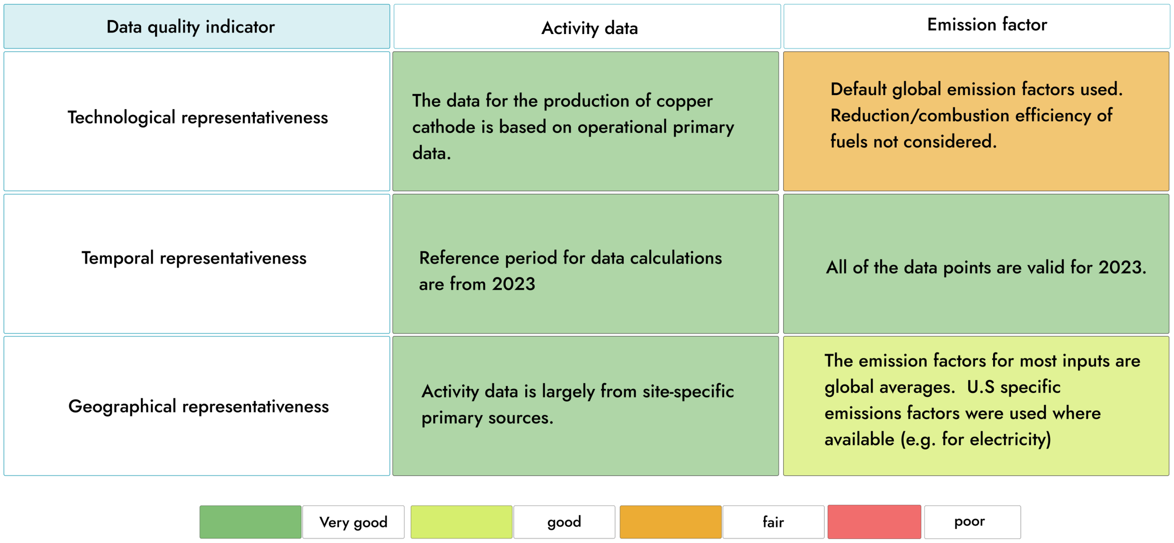


Figure 65: System Boundary for the production of copper cathode from copper sulfide ores via the USA Smelting route.

Table 28: Data Quality Rating for the USA Smelting route analyzed.



Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of copper cathode is based on operational primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are from 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. U.S specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.4.6 USA (Heap Leaching)

In this route, run-of-mine (ROM) is crushed and stacked ore is leached with concentrated sulfuric acid which is applied under atmospheric conditions to leach copper into solution. The pregnant leach solution then goes through solvent extraction and electrowinning to form a 99.99% pure copper cathode (Figure 66). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 29.

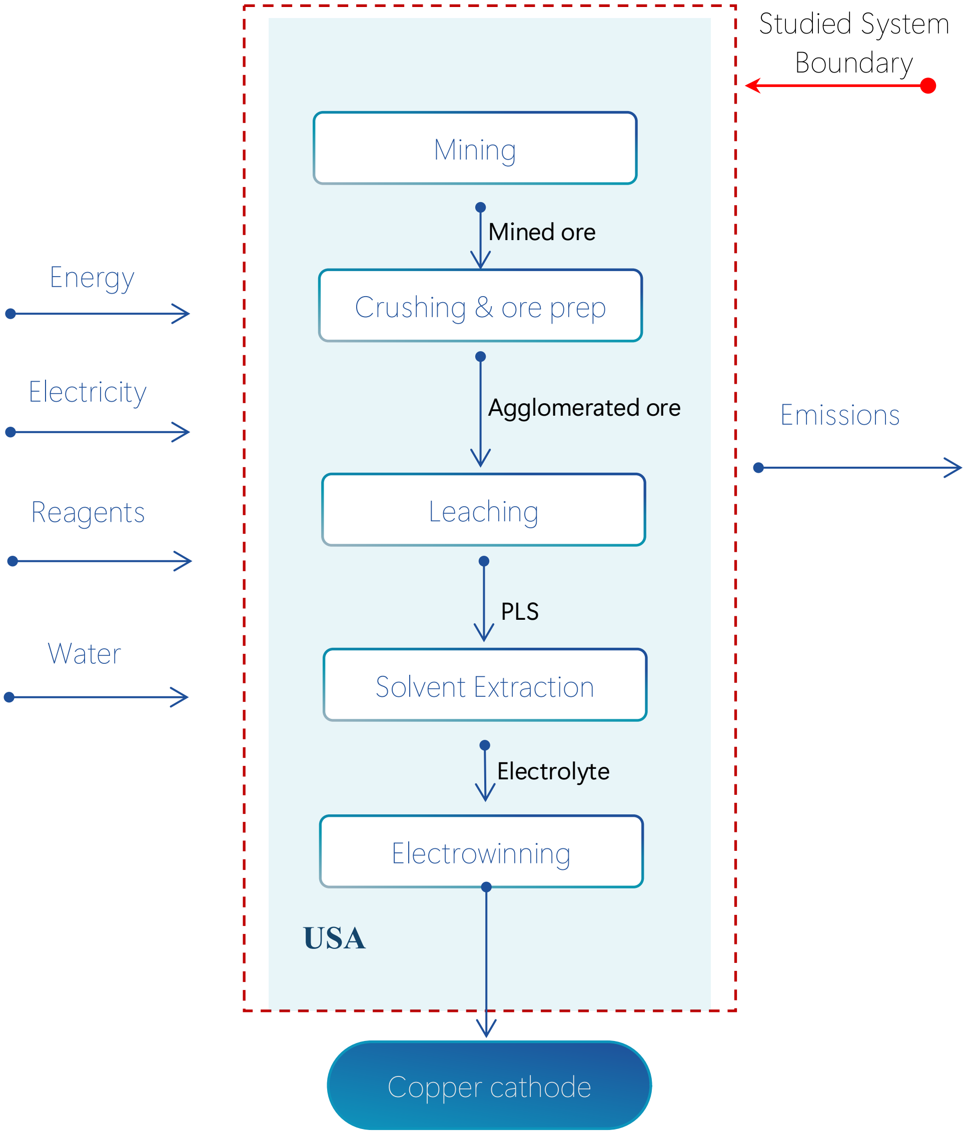
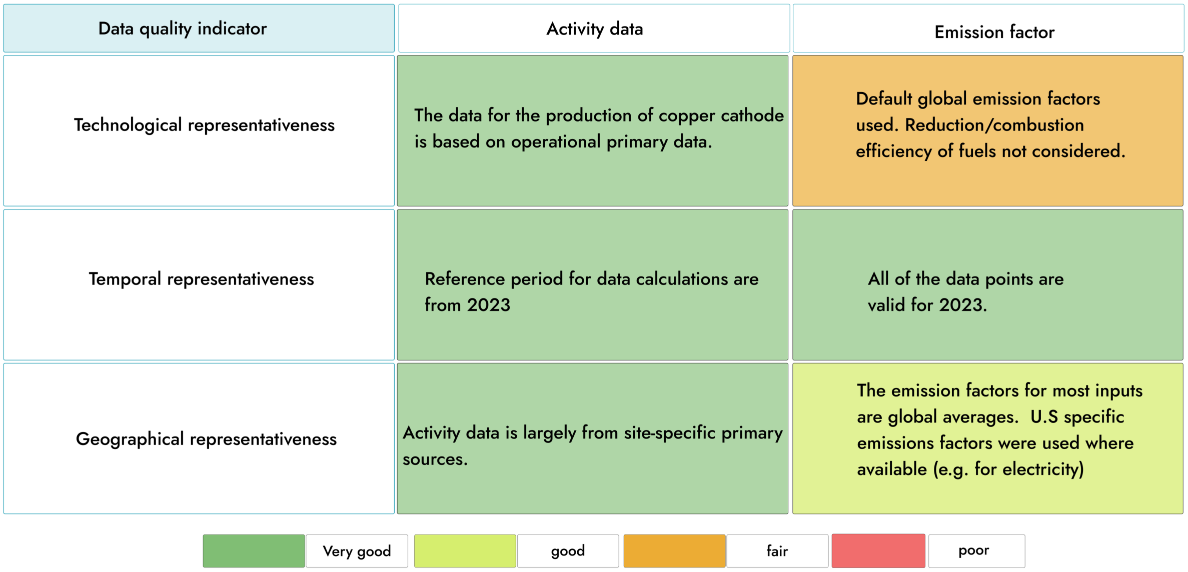


Figure 66: System Boundary for the production of copper cathode from copper oxide ores via the USA Heap Leach route.

Table 29: Data Quality Rating for USA Heap Leach Route Analyzed



Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of copper cathode is based on operational primary data.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are from 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. U.S specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.4.7: China: (Smelting)

China ranks 4th in terms of global copper mine production, but 1st in terms of refined copper production due to the sheer volume of copper concentrates that are shipped to China for refining.

In this route, the copper sulfide ores are crushed, milled, and then sent to flotation to form a concentrate. The concentrate is smelted and converted to a blister copper which is then electrolytically refined to copper cathode (Figure 67). The entire process occurs in China. The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 30.

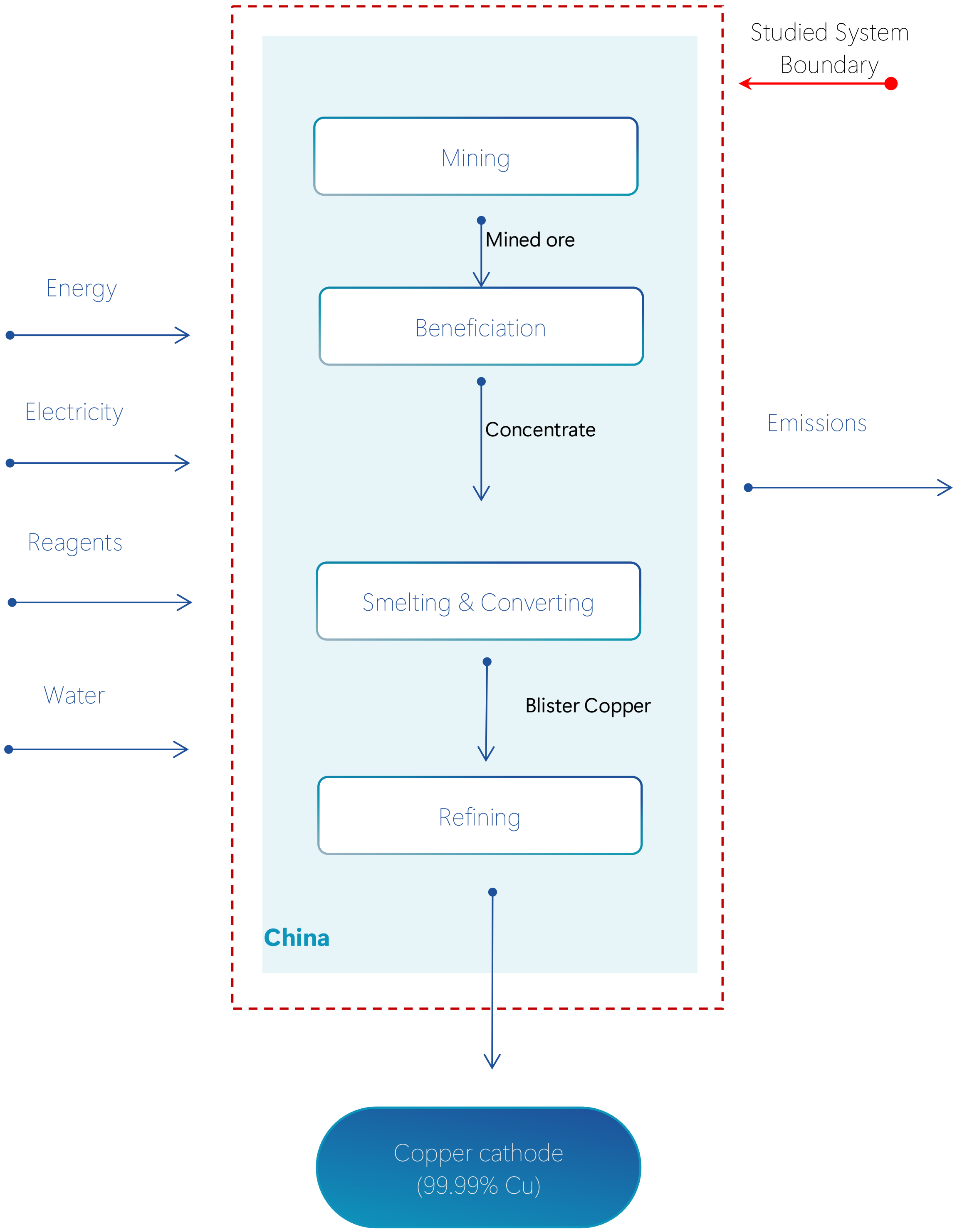


Figure 67: System Boundary for the production of copper cathode from copper sulfide ores via the China Smelting route.

Table 30: Data Quality Rating for the China smelting route analyzed.

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of copper cathode is based on operational primary data. However, activity data for a mine in Peru was used as a proxy.	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are 2023	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources, however Peru is used as a proxy. Ore grades and other parameter affecting the activity data may vary.	The emission factors for most inputs are global averages. Peru and China specific emissions factors were used where available (e.g. for electricity)

🟩 Very good 🟨 good 🟧 fair 🟥 poor

7.4.8 Climate Change Impact Results

The climate change impact associated with the production of 1kg of copper cathode via the TMC NORI-D Texas route is lower for all evaluated routes except the DRC route (Figure 68). The TMC NORI-D Indonesia and Japan routes also performs better than most evaluated. The TMC NORI-D Texas route has a climate change impact of **3.45 kg CO_2eq.,** this is 92% greater than the DRC route, 25% less than the Chile (heap leach) route, 41% less than the USA (heap leach) route, 42% less than the USA (smelting) route, 47% less than the Peru-China route, 53% less than the Chile-China route, and 61% less than the China route.

The low climate change impact of the DRC route is partly due to the large degree of hydropower used in their production processes, but also because of the relatively high grade of copper ores and cobalt forming as a co-product which share the environmental load.

The Chile (heap leach) route also has a relatively low environmental impact, as heap leaching is not associated with high energy use and fossil-based reductant as seen in copper smelting pathways. The main impact here comes from diesel used in the mining stage to remove and transport overburden, as well as from lime used for neutralization. The production of lime from limestone is associated with a significant release of carbon dioxide.

The USA heap leach route has an impact that is roughly average compared to all the routes analyzed. The impact is primarily due to the use of diesel in mining operations. Lower grade ores tend to require more diesel use in mining as an more material is required to be moved as opposed to higher grade ores.

The USA smelting and heap leach routes has an impact that is roughly average compared to all the routes analyzed. For the smelting route, the impact is primarily from the concentration stage (which can be very energy intensive), as well as diesel used in the mining stage. For the heap leach route, the impact is primarily from diesel used in the mining stage as well as from the electricity used in solvent extraction and electrowinning. Lime used for neutralization also carries a significant climate change impact.

The Peru-China and Chile-China routes are towards the higher end of climate change impact between the evaluated routes. This is mostly due to the processing of concentrate in China who has a relatively carbon-intensive grid mix, but also because there are emissions associated with the shipment of the concentrate to China from Peru and Chile.

The China route shows the highest climate change impact for the production of copper cathode, mostly due to the carbon intensity of the electrical grid mix.

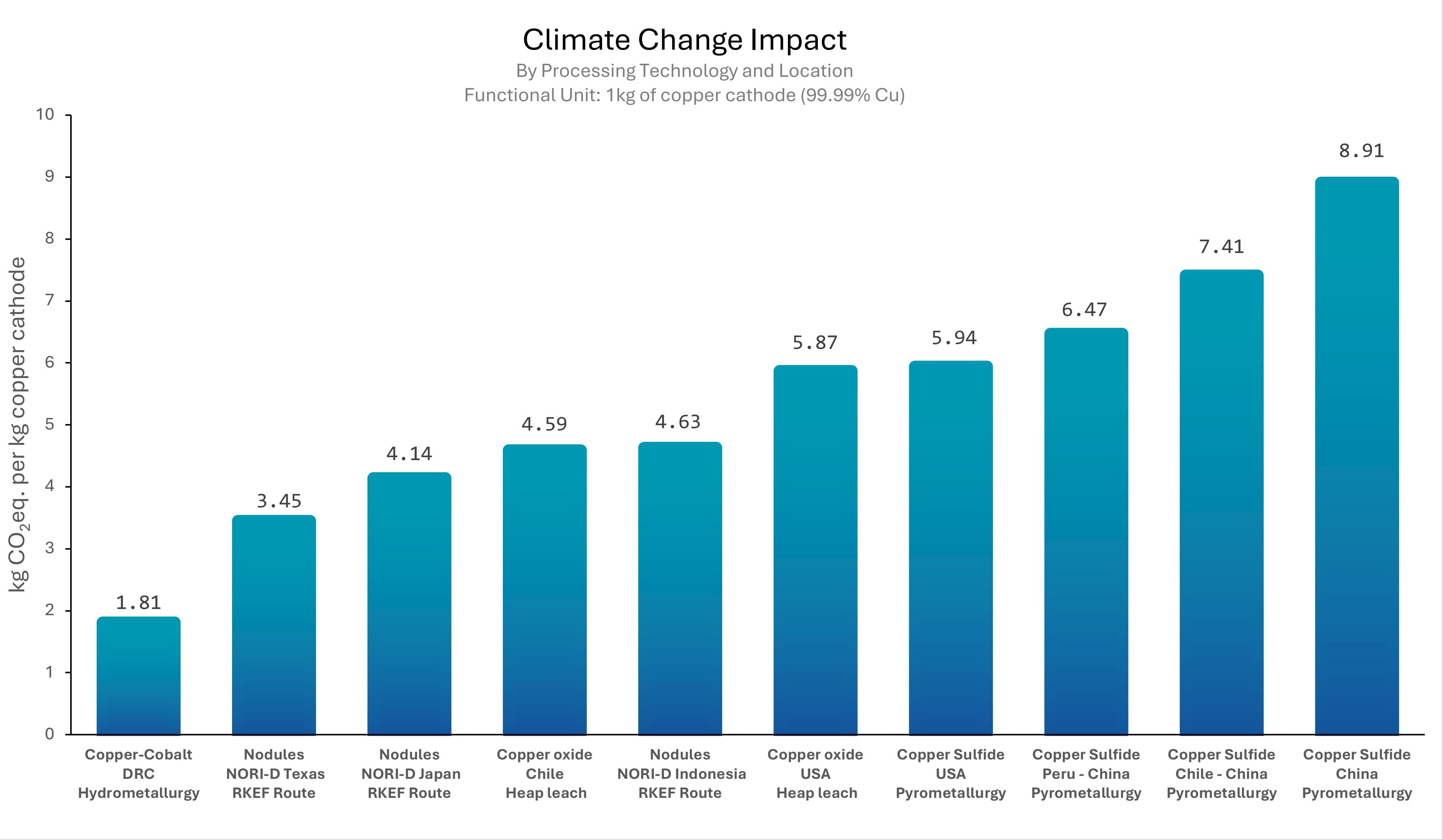


Figure 68: Comparison of the climate change impact of 1 kg of copper cathode produced via various land-based routes vs TMC's NORI-D processing routes.

7.4.9 Acidification Results

The acidification impact associated with the production of copper cathode is lower across all TMC's NORI-D routes than all of the land-based production routes evaluated (Figure 69). The impact of TMC NORI-D Texas is lowest at **2.70 E-02 mol H+eq** . It increases by approximately 27% for the TMC NORI-D Japan route, 36% for the TMC NORI-D Indonesia route and USA (smelting) route, 107% for the DRC route, 124% for the Peru-China route, 159% for the Chile (heap leach) route, 168% for the China route, and 179% for the USA (heap leach route).

The acidification impact from the TMC NORI-D routes are primarily associated with the use of marine fuel oil in offshore operations, and coal used in pyrometallurgy operations.

The acidification impact from the DRC route is associated with diesel and sulfur use (the sulfur is used to generate sulfuric acid onsite).

The acidification impact associated with the USA, Chile, China, and Peru smelting routes arises primarily from diesel use in mining operations. Additional contributions come from the use of coal and coke in their pyrometallurgical processes. For the Peru–China and Chile–China routes specifically, the long-distance transport of concentrate to China also results in a significant acidification burden.

The acidification impacts from the USA and Chile heap leach routes are primarily linked to the use of diesel and sulfuric acid. Sulfuric acid production from elemental sulfur results in the release of sulfur dioxide (SO_2), a key contributor to acidification. Additionally, the combustion of diesel—like other fossil fuels—emits SO_2, further adding to the acidification potential.

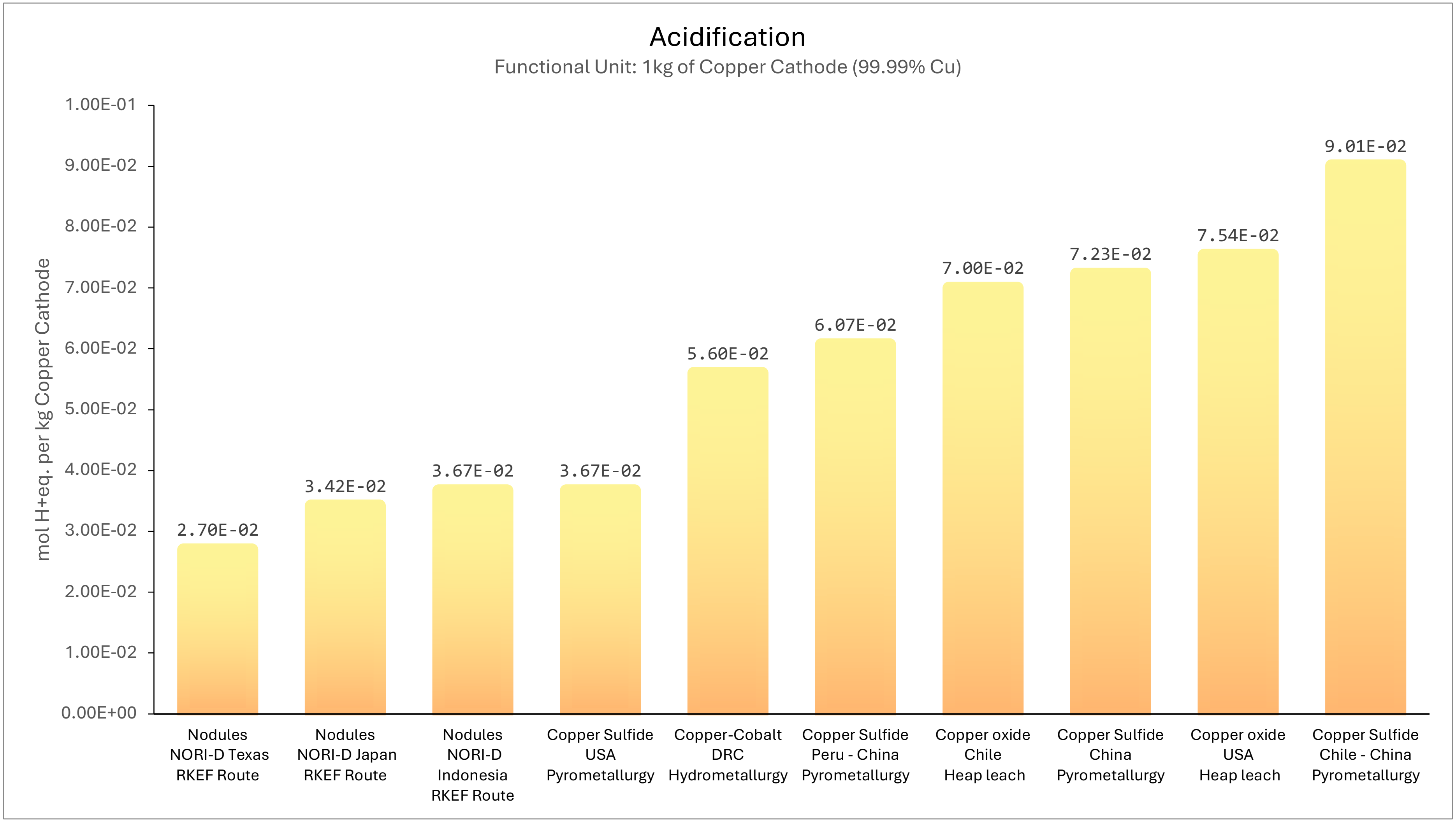


Figure 69: Comparison of the Acidification Impact from the production of 1kg of copper cathode produced via various land-based routes vs TMC's NORI-D processing routes.

7.4.10 Freshwater Eutrophication Results

In general, the impacts on freshwater eutrophication associated with the production of 1kg of copper cathode are lower for the NORI-D and hydrometallurgy routes compared to the pyrometallurgy routes. This is due to the larger volume of tailings generated during the concentration stages of the pyrometallurgy routes (U.S, Peru, Chile, and China).

The impact of TMC NORI-D Japan is lowest at 1.41E-03 kg Peq. and increases by 13% for the TMC NORI-D Texas route, 115% for the Chile (Heap Leach) route, 130% for TMC NORI-D Indonesia route, 286% for the DRC route, 291% for the USA (heap leach) route, 1304% for the China route, 2552% for the Chile-China route, 4205% for the USA (smelting route) and 5708% for the Peru-China route (Figure 70).

The impact on freshwater eutrophication from the TMC NORI-D routes, the Chile (heap leach) route, and the USA (heap leach) route, is primarily associated with the usage of electricity.

The impact on freshwater eutrophication from the DRC, China, USA (smelting), Chile-China, and Peru-China are all primarily associated with the generation of tailings during the concentration stages.

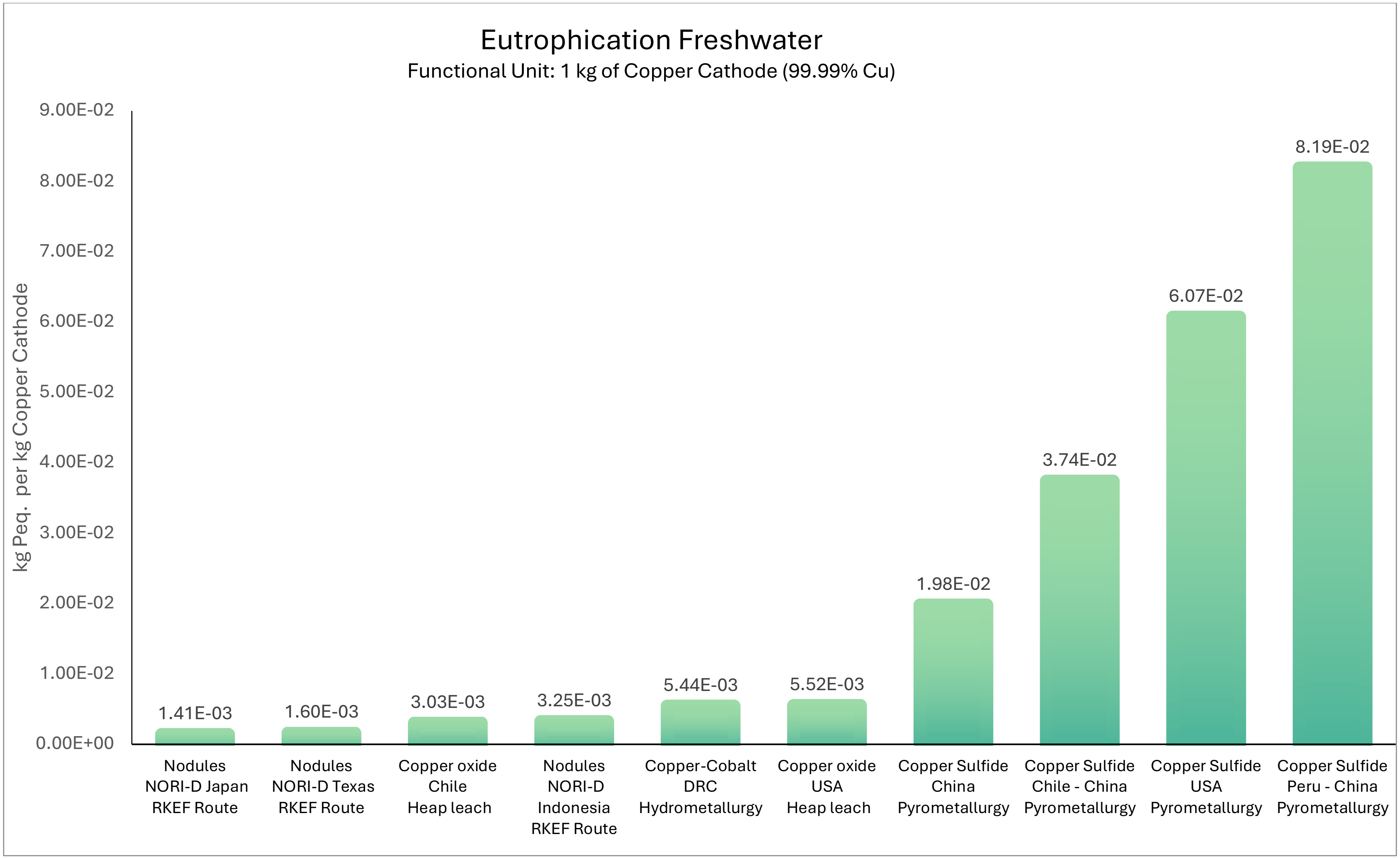


Figure 70: Comparison of the Freshwater Eutrophication Impact from the production of 1kg of copper cathode produced via various land-based routes vs TMC's NORI-D processing routes.

7.4.11 Energy Use Results

The energy use associated with the production of 1kg of copper cathode is lowest at the DRC route. Among the NORI-D TMC routes, the Texas route performs the best at 19.30 MJ. This is 122% greater than the DRC route, 18% less than the NORI-D Japan route, 21% less than the NOR-D Indonesia route, 44% less than the Chile (heap leach) route, 49% less than the Peru-China route, 51% less than the USA (smelting) route, 59% less than the Chile-China route, 62% less than the USA (heap leach) and China routes (Figure 71).

Energy use at the DRC route is predominately from diesel use during mining operations. This route performs the best in terms of energy intensity because of the relatively high copper ore grade, which reduces the volume of material that needs to be mined. Additionally, the hydro-powered grid does not use non-renewable fossil energy resources. The energy intensity is further mitigated by the co-production of cobalt hydroxide that shares the environmental burden.

Energy use for all the remaining routes are predominately from diesel and electricity use from mining and concentration.

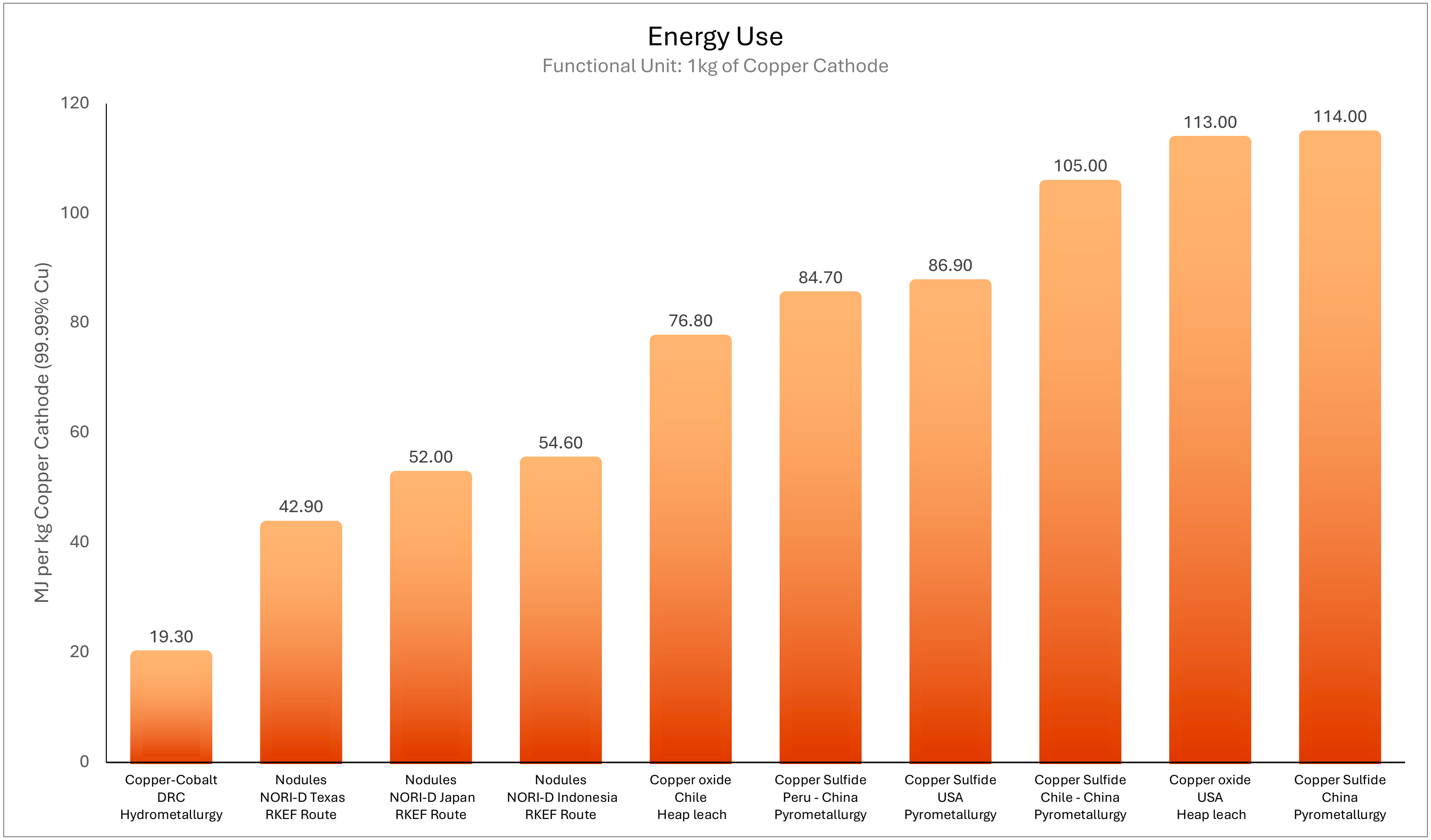


Figure 71: Comparison of Energy Use from the production of 1kg of copper cathode produced via various land-based routes vs TMC's NORI-D processing routes.

7.5 LCIA Results & Interpretation: $CoSO_4.7H_2O$

7.5.1 DRC to China

The DRC is the world's largest producer of cobalt, accounting for 70-80% of global mine production. Historically, the DRC exported most of their cobalt ores and concentrates to China, making this route the major route for the production of $CoSO_4.7H_2O$.

At the time this report was written, the DRC authorities placed a 4-month embargo on the export of their cobalt ores and concentrates with the aim of balancing the market and creating local value. The ban was again extended for another 3 months until September 21st where the next steps of the ban (whether it will be extended, modified, or terminate) is expected to be addressed.

The production of the cobalt-rich solution was described in section 7.4.1. This solution is first neutralized, then goes through a few precipitation steps to remove iron, aluminum, and manganese impurities. The resultant slurry (after impurity removal) is precipitated out as $Co(OH)_2$ using magnesium oxide. The $Co(OH)_2$ is then shipped to China for further processing. Once in China, the $Co(OH)_2$ is treated with sulfuric acid to leach out cobalt as $CoSO_4$. The leached solution then undergoes a few precipitation and solvent extraction steps to remove impurities, and stripping with sulfuric acid, and finally evaporation and crystallization to form refined $CoSO_4$.7H2O (Figure 72). The total data quality score for this route is approximately 2 (good). The ratings of the individual data indicators are shown in Table 31. The co-product allocation is the same as shown in Table 23.

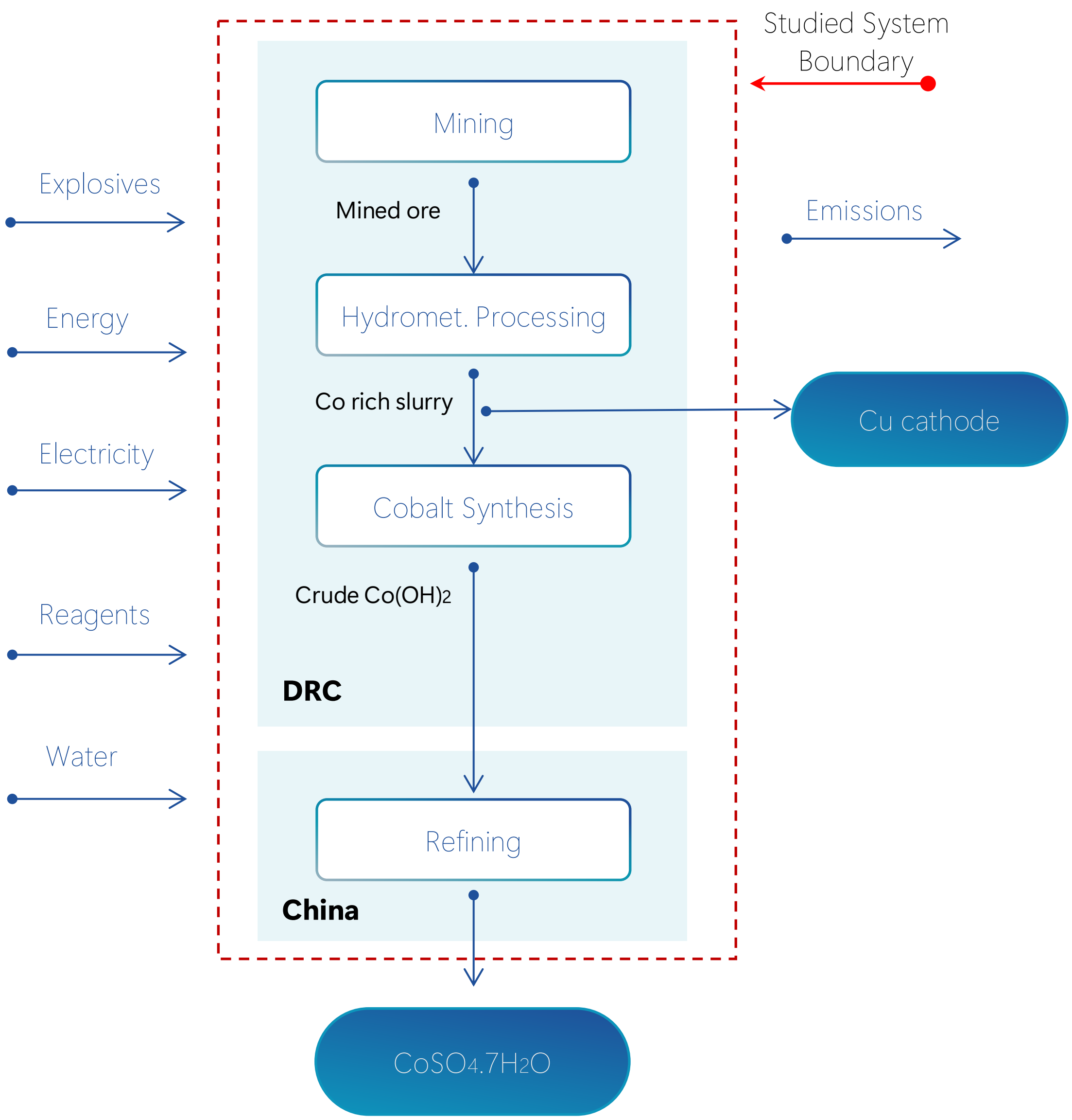


Figure 72: System Boundary for the production of $CoSO_4.7H_2O$ from copper-cobalt ores via the DRC route.

Table 31: Data Quality Rating for the DRC-China Route analyzed.

Data quality indicator	Activity data	Emission factor
Technological representativeness	The data for the production of cobalt hydroxide is based on primary data. Primary data is also used for the conversion of the crude Co(OH)2 to CoSO4.7H2O	Default global emission factors used. Reduction/combustion efficiency of fuels not considered.
Temporal representativeness	Reference period for data calculations are 2018.	All of the data points are valid for 2023.
Geographical representativeness	Activity data is largely from site-specific primary sources.	The emission factors for most inputs are global averages. DRC and China specific emissions factors were used where available (e.g. for electricity)

🟩	Very good	🟨	good	🟧	fair	🟥	poor

7.5.2 Indonesia to China (HPAL)

The production of $CoSO_4.7H_2O$ via this route is described in section 7.3.1. The system boundary and data quality is the same as shown in Figure 53 and Table 16. Because of the sheer volume of MHP produced in Indonesia, this route has emerged as a dominant route for the production of $CoSO_4.7H_2O$.

7.5.3 Climate Change Impact Results

The climate change impact associated with the production of 1kg of Co in $CoSO_4.7H_2O$ is lower across all TMC's NORI-D project locations compared to the land-based production routes evaluated (Figure 73). The impact of TMC NORI-D Texas is lowest at **24.23 kg CO2eq.** It increases by approximately 17% for the TMC NORI-D Japan route, 30% for the TMC NORI-D Indonesia route, 64% for the DRC-China route and by 154% for the Indonesia-China route.

As previously stated, the performance of the NORI-D TMC routes can be attributed to the relatively small climate change impact from offshore operations, the high grade of the matte, and the unique processing pathway which produces multiple co-products that shares the environmental load.

For the DRC-China route, most of the impact occurs during the refining stage in China, largely attributed to the embodied emissions of the NaOH used in refining and the emissions associated with the production of steam. Diesel used in the mining stage in the DRC also contributes a significant impact.

Production of $CoSO_4.7H_2O$ is highest via the Indonesia-China (HPAL) route between all the routes analyzed. This is attributed to the coal-based electricity used, the embodied emissions of the sulfuric acid used, and the direct or process emissions from limestone use during MHP production.

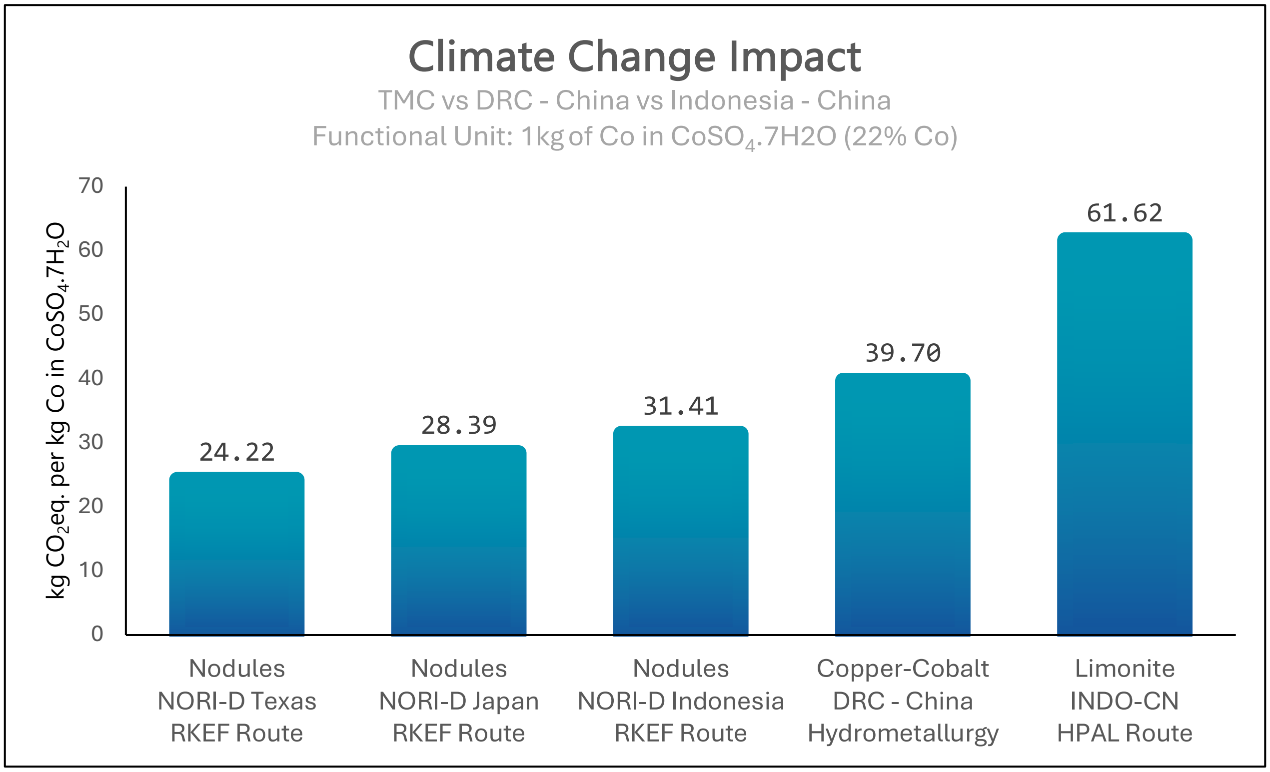


Figure 73: Comparison of the climate change impact of 1 kg of Co in $CoSO_4.7H_2O$ produced via various land-based routes vs TMC's NORI-D processing routes.

7.5.4 Acidification Results

The acidification impact associated with the production of 1kg of Co in $CoSO_4.7H_2O$ is lower across all TMC's NORI-D routes than all land-based production routes evaluated (Figure 74). The impact of TMC NORI-D Texas is lowest at **8.29E-02 mol H+eq** . It increases by approximately 30% for the TMC NORI-D Indonesia route, 50% for the TMC NORI-D Japan route, 675% for the DRC-China route, and 1565% for the Indonesia-China route.

The acidification impact from the TMC NORI-D routes are primarily associated with the use of marine fuel oil in offshore operations, and coal used in pyrometallurgy operations.
The acidification impact from the DRC-China route is predominately due to diesel, sulfur, and use of explosives.

The acidification impact from the Indonesia– China route , which is the largest of the analyzed routes, is predominately attributed to the release of SO_2 gas during the production of sulfuric acid (both from the production of sulfur and its conversion to sulfuric acid). Coupling the release of SO_2 gas from the production of sulfuric acid with the large quantities of the acid consumed in this process leads to the relatively high impact.

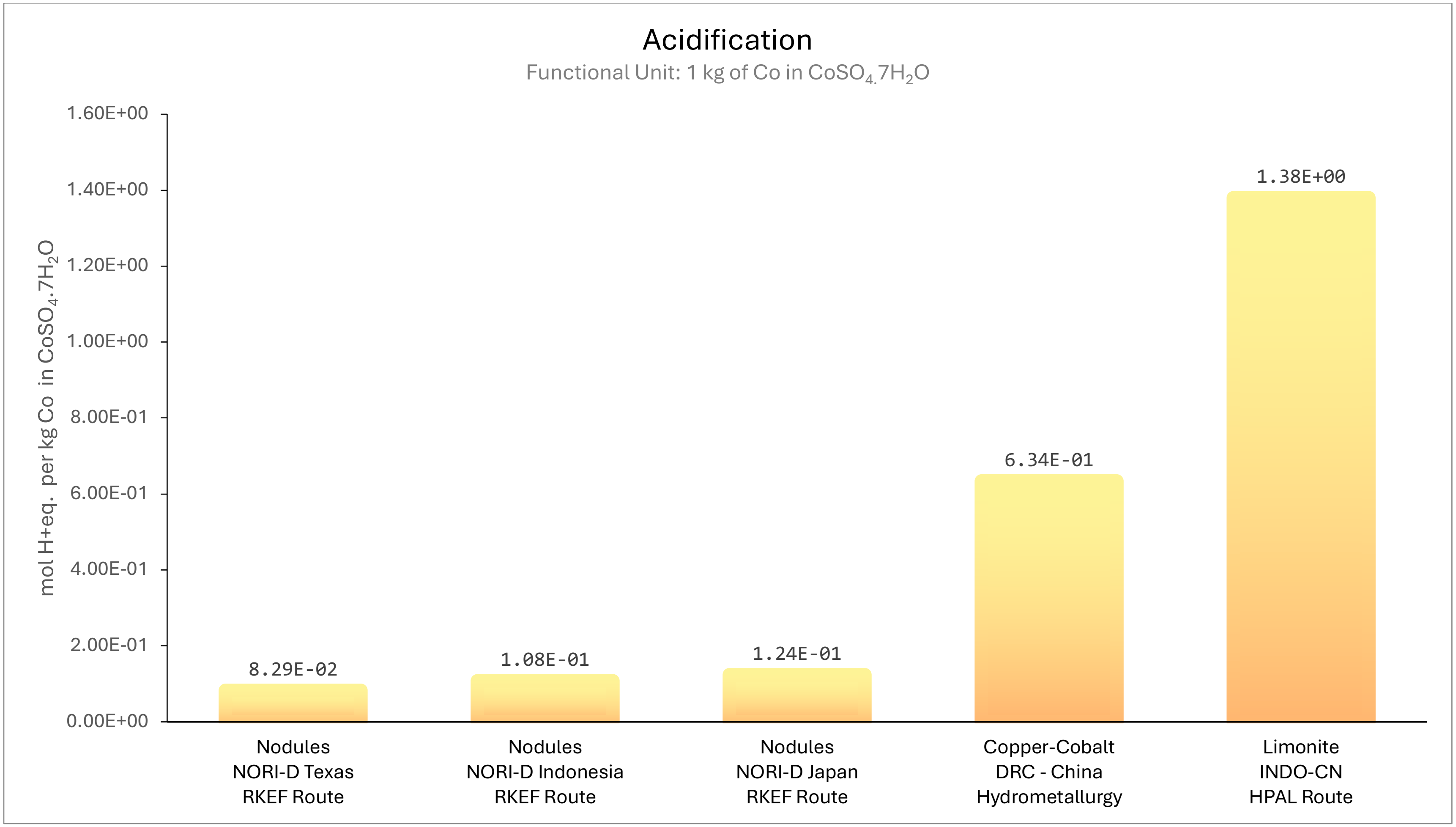


Figure 74: Comparison of the Acidification Impact from the production of 1kg of Co in $CoSO_4.7H_2O$ produced via various land-based routes vs TMC's NORI-D processing routes

7.5.5 Freshwater Eutrophication Results

The impact on freshwater eutrophication associated with the production of 1kg of Co in $COSO_4.7H_2O$ is lower across all TMC's NORI-D project locations compared to the traditional land-based production route evaluated. The impact of TMC NORI-D Indonesia is lowest at 6.39 E-03 kg P eq. and increases by approximately 1% for TMC NORI-D Japan route, 21% for the Indonesia-China route, 1389% for the Indonesia-Japan route, and 4907% for the DRC-China route (Figure 75).

The impact on freshwater eutrophication from TMC's operation is predominately associated with the usage of electricity. The production of the fossils used in electricity generation produce phosphorous containing compounds, leading to impacts on eutrophication. This impact is highest for the NORI-D Indonesia route due to the grid mix being dominated by coal in the form of lignite. Spoil from lignite mining is high in phosphates.

The Indonesia-China (HPAL) route and the DRC-China route's impact on freshwater eutrophication are primarily due to the generation of tailings

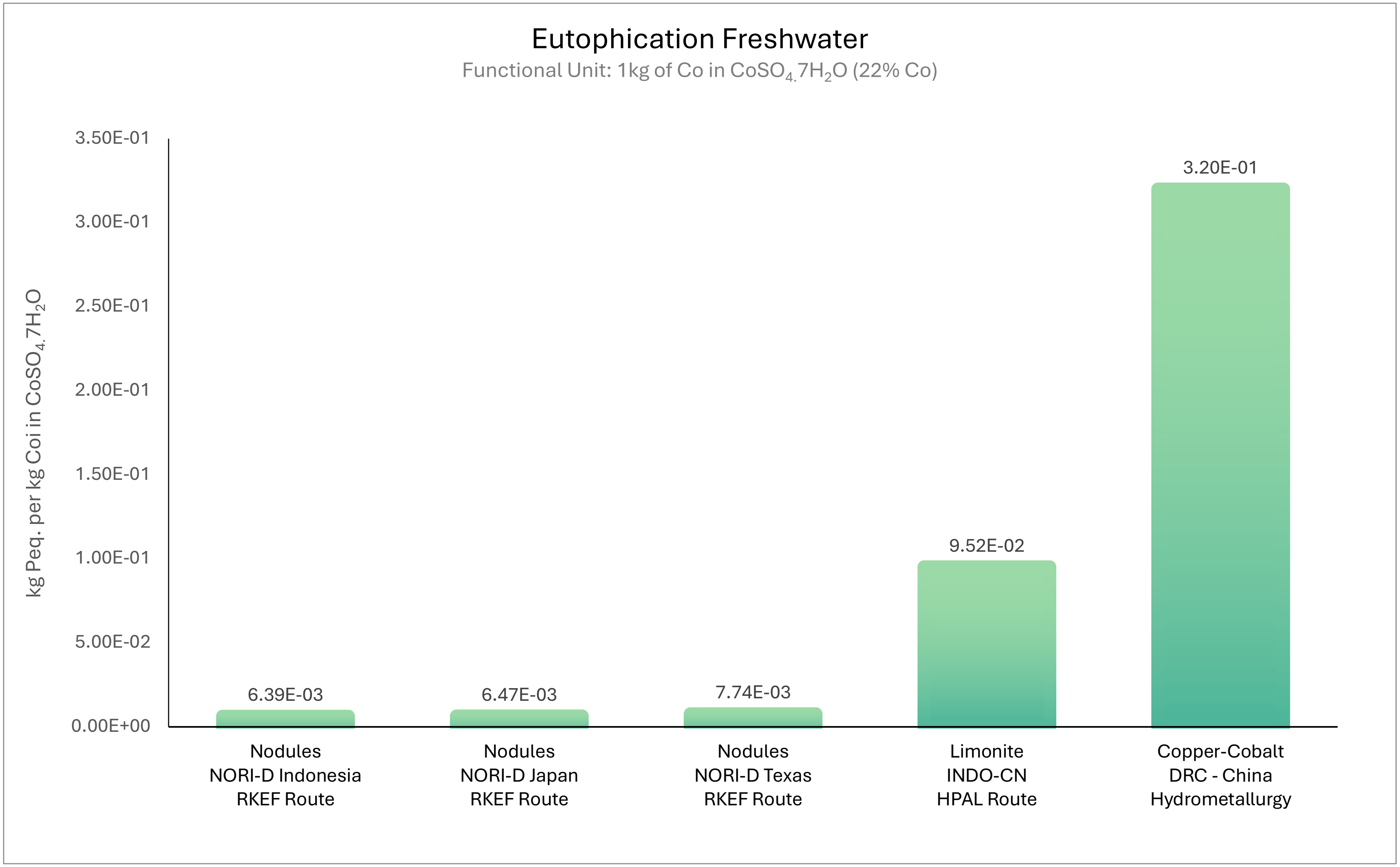


Figure 75: Comparison of the Freshwater Eutrophication Impact from the production of 1kg of Co in $CoSO_4.7H_2O$ produced via various land-based routes vs TMC's NORI-D processing routes.

7.5.6 Energy Use Results

The energy use associated with the production of 1kg of Co in $CoSO_4.7H_2O$ is lower across all TMC's NORI-D project locations compared to the traditional land-based production routes evaluated (Figure 76). Among the NORI-D TMC routes, the Texas route performs the best at 19.30 MJ. This increases by 1.3% for the TMC NORI-D Indonesia route, 23.7% for the TMC NORI-D Japan route, 101.8% for the DRC-China route, and 172.3% for the Indonesia-China route.

The energy use at TMC's operations is predominately associated with marine fuel usage during offshore operations, and coal and electric usage during pyrometallurgical operations.

The energy use from the DRC-China route is predominately from the use of diesel in the mining stage and the use of sodium hydroxide in the refining stage in China. The production of sodium hydroxide occurs mainly through the chlor-alkali electrolysis process which used a relatively high amount of electricity. For globally produced sodium hydroxide, the generation of this electricity is mostly from fossil sources, leading to the impact on energy use.

The energy use from the Indonesia-China (HPAL) route is predominately associated with the production of sulfuric acid, whose feedstock is sulfur which is mainly produced from petroleum refinery operations, as well as the production of coal.

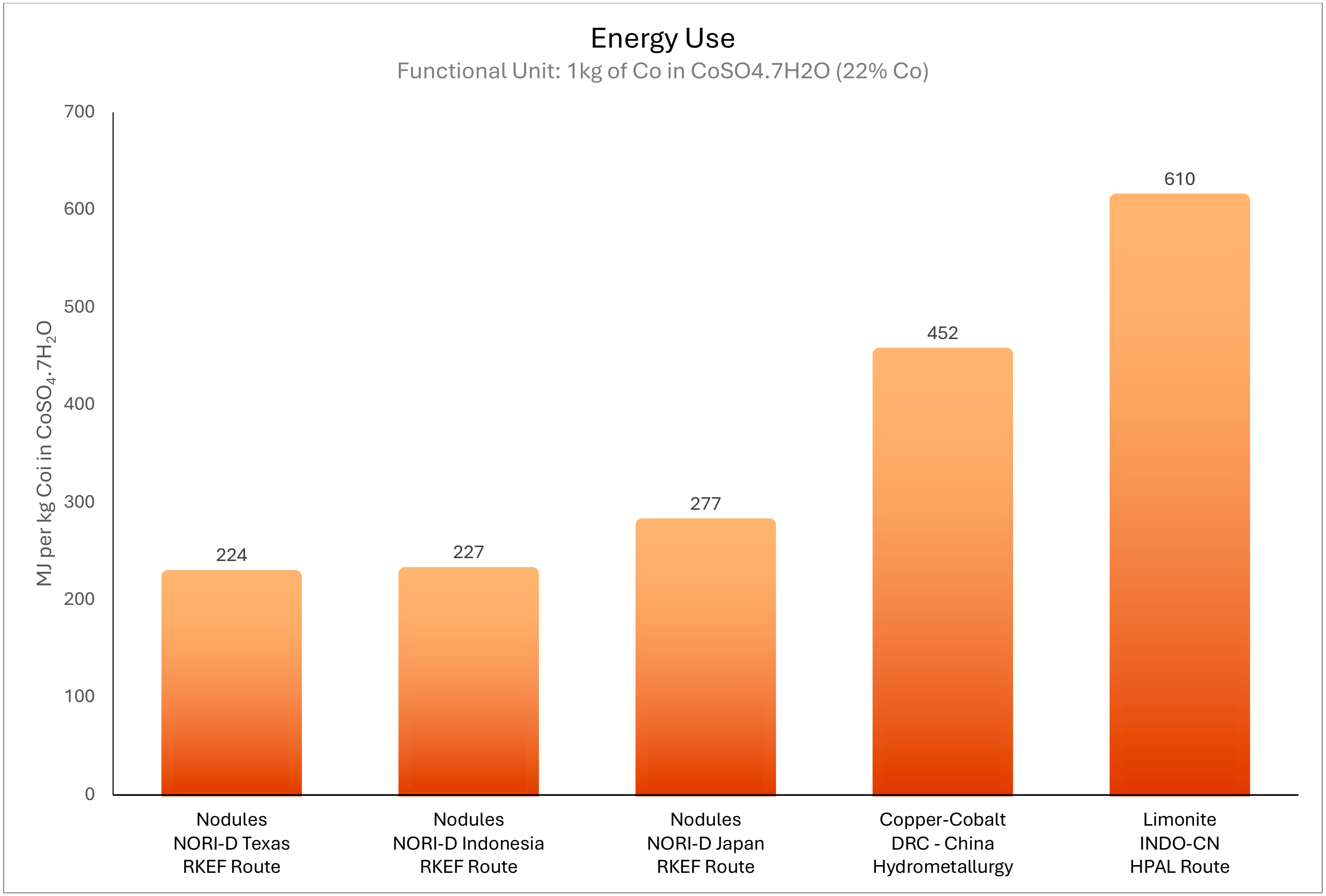


Figure 76: Comparison of Energy Use from the production of 1kg of Co in $CoSO_4.7H_2O$ *produced via various land-based routes vs TMC's NORI-D processing routes.*

8. Conclusions & Recommendations

Aspects of the environmental impacts associated with the production of 1kg of $MnSiO_3$, 1kg of SiMn Ni-Cu-Co Matte, $NiSO_4.6H_2O$, copper cathode, $CoSO_4.7H_2O$, and the impact associated with the collection and processing of 1kg of dry nodules from the NORI-D Polymetallic Nodules Project were quantified. The aspects quantified were the LCIA categories available in the EF 3.1 method. The LCIA categories that were assessed and interpreted in detail included those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories were summarised in annex A.

Only certain aspects of the environmental impact were quantified, as current life cycle assessment methodologies lack a robust and consistent framework for assessing impacts on biodiversity, the seabed, forest ecosystems, and temporally related ecological effects. However, TMC has an environmental research program that assesses the impacts of their operations on the ecosystem in NORI-D.

The TMC NORI-D Texas route consistently performs better than the TMC NORI-D Indonesia and Japan Route's for each functional unit in all impact categories evaluated. This is due to the shorter transport distance from the CCZ to onshore processing, the use of natural gas for heating instead of coal, and the relatively cleaner electricity grid of Texas opposed to Indonesia and Japan.

The pyrometallurgy processing stage contributes the most to climate change impact. Contribution analysis reveal that this is primarily due to the use of reductant coal. Other major contributors, depending on the functional unit, include electricity use during pyrometallurgical and hydrometallurgical operations, marine fuel use during offshore operations, and natural gas and ammonia used during hydrometallurgical operations. There is also a significant environmental credit received from the production of ammonium sulfate during the hydrometallurgy stage, which is assumed to substitute globally produced ammonium sulfate for the chemicals and agriculture industry.

Since electricity is a main contributor to the climate change impact, if TMC has access to market instruments or onsite generation of electricity from low carbon or renewable sources, their climate change impact for the NORI-D project can decrease significantly. This was revealed from the sensitivity analysis on low carbon and renewable electricity sources.

The method of allocation has a substantial impact on the results, particularly for copper cathode and $CoSO_4.7H_2O$. This was revealed from the sensitivity analysis using metal mass allocation where the climate change impact increased by 90%, and decreased by 64% and 12% for copper, cobalt, and nickel respectively. This was mainly due to the impact being shifted from cobalt, with the lower production volume and higher price, to copper with the higher production volume and lower price.

Differences in certain environmental impacts of producing TMC's products from the NORI-D Polymetallic Nodules Project versus the same products produced via key terrestrial routes were also quantified using the EF method. The chosen routes were strategically selected as they represent major production pathways that dominate the global supply of these products, while also incorporating several lower impact alternatives to provide a well-rounded perspective.

For the production of silico-manganese, the land-based route performs better than all TMC NORI-D routes for the impact categories evaluated. This is because the source of input manganese for the land-based route is manganese concentrate from a typical mining and beneficiation operation which has a relatively low environmental impact. The source of input manganese for TMC's NORI-D route is their $MnSiO_3$ intermediate product which has a relatively high embodied impact due to the use of reductant coal and electricity during its production from pyrometallurgy. However, this use of reductant coal pre-reduces the

$MnSiO_3$, leading to the use of less coke and a lower downstream climate change impact compared to SiMn produced via manganese ore.

For the production of $NiSO_4.6H_2O$, TMC NORI-D (particularly NORI-D Texas) consistently shows the lowest environmental burdens among the impact categories evaluated compared to all evaluated routes. This is due to the high grade of nickel in the nodules, the relatively low environmental burdens from offshore operations, and the unique processing pathway which produces multiple co-products that shares the environmental load.

The Canada-Norway route performs comparably to the TMC routes along the climate change and acidification impact category, performing better than the NORI-D Indonesia route in terms of climate change impact, and better than NORI-D Japan and Indonesia in terms of acidification Impact. This route however performs poorly (2nd to last) in the energy use category due to the use of uranium to generate electricity. This route also performs relatively poorly in the freshwater eutrophication category due to the tailings generated during processing. The Indonesia-Japan route however performs well among the evaluated routes, and better than TMC NORI-D Indonesia, due to the renewables present in the electricity mix used at the processing facility.

For the production of copper cathode, the TMC NORI-D routes generally perform better than all evaluated routes across the assessed impact categories, except for the DRC route in the climate change and energy use categories. The DRC route performs better than all evaluated routes in the climate change and energy use categories partly due to the predominance of hydropower on the electrical grid, but also because of the high grade of copper ores. This route however performs poorly in acidification due to diesel and sulfur use.

For the production of $CoSO_4.7H_2O$, all TMC NORI-D routes perform better than all the evaluated routes across the assessed impact categories. The Indonesia-China (HPAL) route performed the worse in the climate change, acidification, and energy use categories, and the DRC-China route performed the worst in the freshwater eutrophication category.

8.1 Recommendations

After quantifying aspects of TMC's environmental impact from a life cycle perspective using the EF 3.1 method, Ecoquant has several recommendations for TMC that may improve the quality of the life cycle assessment of their products.

As the project advances toward commercial-scale operations, it is anticipated that certain data inputs and operational processes may evolve. Consequently, it is essential to periodically review, refine, and update the LCA of their products to reflect these potential changes. This iterative approach aims to enhance the accuracy and relevance of the assessment, while acknowledging that uncertainties and assumptions may continue to influence the results.

Although this study does not address the certain environmental impacts associated with TMC's offshore operations, (i.e. impacts on deep-sea ecosystems) Ecoquant recommends that TMC considers integrating the findings from this assessment with prior and forthcoming assessments of TMC's offshore activities. Such an integrated approach may contribute to a more comprehensive understanding of the overall environmental footprint related to the production of their products, while acknowledging that the completeness and accuracy of the quantification remain subject to the scope and limitations of the combined studies.

Ecoquant acknowledges that TMC does not currently exert direct control over the emission factors associated with key upstream consumables. Nonetheless, it is recommended that, as the project advances toward commercial-scale operations, efforts be undertaken to acquire supplier-specific or regionally representative emission factors for critical inputs such as marine fuel oil, coal, ammonia, and electricity. Incorporating such primary supplier-specific data would significantly enhance the precision, transparency, and overall quality of the LCA results. Moreover, it would support alignment with best practices in environmental accounting and may facilitate improved comparability of the results.

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Annex A - EF 3.1 Impact Category Results

Table A 1: LCIA Results for 1 kg of dry nodules collected and processed.

Impact Category	**Unit**	**Per kg Dry Nodules collected and processed**		
		TMC IND	**TMC JP**	**TMC TX**
Climate Change	**kg CO2-Eq**	1.32E+00	1.10E+00	8.34E-01
Freshwater + Terrestrial Acidification	**mol H+-Eq**	2.14E-04	9.57E-03	3.35E-03
Freshwater Eutrophication	**kg P-Eq**	2.36E-05	3.39E-04	2.59E-05
Terrestrial Eutrophication	**mol N-Eq**	8.83E-05	1.03E-02	1.78E-03
Freshwater Ecotoxicity	**CTU**	-5.64E+00	-4.13E+00	-5.49E+00
Marine Eutrophication	**kg N-Eq**	-2.70E-05	9.54E-04	1.29E-04
Ionising Radiation	**kg U235-Eq**	1.16E-02	5.55E-02	1.21E-02
Photochemical Ozone	**kg NMVOC-.**	9.93E-05	3.58E-03	1.02E-03
Carcinogenic	**CTUh**	-1.91E-11	8.06E-11	-1.91E-11
Non-Carcinogenic	**CTUh**	1.32E-09	4.21E-09	1.32E-09
Respiratory	**disease i.**	8.04E-10	6.96E-08	4.15E-08
Ozone Depletion	**kg CFC-11.**	5.87E-10	9.52E-09	3.35E-09
Minerals + Metals	**kg Sb-Eq**	-5.01E-07	-2.75E-07	-4.75E-07
Fossils	**MJ**	6.75E-01	1.30E+01	3.62E+00
Water	**m3 world eq.**	2.84E-02	1.13E-01	3.14E-02
Land	**points**	6.51E-02	2.01E+00	2.20E-01

Table A2: LCIA Results for 1 kg of Mn in $MnSiO_3$

Impact Category	Unit	Per kg Mn in $MnSiO_3$		
		TMC ID	**TMC JP**	**TMC TX**
Climate Change	**kg CO2-Eq**	3.40E+00	2.78E+00	2.18E+00
Freshwater + Terrestrial Acidification	**mol H+-Eq**	2.77E-02	2.41E-02	2.41E-02
Freshwater Eutrophication	**kg P-Eq**	3.17E-03	7.62E-04	7.62E-04
Terrestrial Eutrophication	**mol N-Eq**	3.57E-02	2.53E-02	2.53E-02
Freshwater Ecotoxicity	**CTU**	7.53E+00	3.61E+00	3.61E+00
Marine Eutrophication	**kg N-Eq**	3.89E-03	2.43E-03	2.43E-03
Ionising Radiation	**kg U235-Eq**	7.17E-03	1.17E-01	1.17E-01
Photochemical Ozone	**kg NMVOC-.**	1.16E-02	8.93E-03	8.93E-03
Carcinogenic	**CTUh**	6.20E-10	2.64E-10	2.64E-10
Non-Carcinogenic	**CTUh**	3.05E-08	7.62E-09	7.62E-09
Respiratory	**disease i.**	2.95E-07	1.92E-07	1.92E-07
Ozone Depletion	**kg CFC-11.**	1.80E-08	2.49E-08	2.49E-08
Minerals + Metals	**kg Sb-Eq**	5.33E-07	6.11E-07	6.11E-07
Fossils	**MJ**	3.64E+01	3.19E+01	3.19E+01
Water	**m3 world eq.**	3.63E-01	2.21E-01	2.21E-01
Land	**points**	3.84E+00	4.83E+00	4.83E+00

Table A3: LCIA Results for 1kg of NiCuCo Matte.

Impact Category	Unit	Per kg Matte		
		TMC ID	TMC JP	TMC TX
Climate Change	kg CO2-Eq	5.52E+00	4.89E+00	4.31E+00
Freshwater + Terrestrial Acidification	mol H+-Eq	3.01E-01	4.21E-02	3.68E-02
Freshwater Eutrophication	kg P-Eq	4.06E-03	1.16E-03	1.63E-03
Terrestrial Eutrophication	mol N-Eq	6.12E-02	4.58E-02	3.99E-02
Freshwater Ecotoxicity	CTU	1.24E+01	7.81E+00	8.13E+00
Marine Eutrophication	kg N-Eq	6.36E-03	4.35E-03	3.92E-03
Ionising Radiation	kg U235-Eq	1.19E-02	5.43E-02	1.44E-01
Photochemical Ozone	kg NMVOC-.	1.87E-02	1.47E-02	1.33E-02
Carcinogenic	CTUh	7.16E-10	2.29E-10	2.95E-10
Non-Carcinogenic	CTUh	3.37E-08	6.68E-09	1.23E-08
Respiratory	disease i.	3.74E-07	2.65E-07	2.21E-07
Ozone Depletion	kg CFC-11.	1.99E-08	2.64E-08	2.29E-08
Minerals + Metals	kg Sb-Eq	8.04E-07	8.52E-07	1.03E-06
Fossils	MJ	5.68E+01	4.53E+01	4.90E+01
Water	m3 world eq.	6.14E-01	2.71E-01	2.20E-01
Land	points	8.47E+00	9.45E+00	6.74E+00

Table A4: LCIA Results for 1kg of Mn in SiMn

Impact Category	Unit	Per kg Mn in SiMn			
		TMC JP	TMC ID	TMC TX	Per kg Mn in SiMn Land based comparison - China
Climate Change	kg CO2-Eq	1.06E+01	1.13E+01	1.02E+01	9.15E+00
Acidification	mol H+-Eq	5.49E-02	6.39E-02	5.64E-02	6.58E-03
Freshwater Eutrophication	kg P-Eq	4.39E-02	7.19E-02	2.12E-01	1.49E-03
Terrestrial Eutrophication	mol N-Eq	5.90E-01	9.13E-01	2.74E+00	9.08E-02
Freshwater Ecotoxicity	CTU	2.09E+01	2.87E+01	2.45E+01	2.43E+01
Marine Eutrophication	kg N-Eq	7.34E-03	4.96E-03	3.54E-03	8.20E-03
Ionising Radiation	kg U235-Eq	1.45E-01	1.74E-02	1.47E-01	1.57E-01
Photochemical Ozone	kg NMVOC-.	2.21E-02	1.35E-02	8.34E-03	1.38E-02
Carcinogenic	CTUh	7.97E-09	7.89E-09	7.49E-09	4.98E-09
Non-Carcinogenic	CTUh	5.74E-08	6.29E-08	4.19E-08	-7.25E-04
Respiratory	disease i.	4.36E-07	9.03E-07	7.58E-07	-7.22E-05
Ozone Depletion	kg CFC-11.	1.15E-07	2.89E-08	2.55E-08	1.37E-08
Minerals + Metals	kg Sb-Eq	2.79E-06	2.45E-06	2.60E-06	7.73E-06
Fossils	MJ	1.13E+02	1.13E+02	1.05E+02	8.75E+01
Water	m3 world eq.	2.32E+00	1.18E+00	1.13E+00	9.30E-01
Land	points	1.70E+01	1.95E+01	1.80E+01	2.61E+01

Table A5. LCIA Results for 1kg of Ni in $NiSO_4.6H_2O$

Impact Category	**Unit**	**Per kg Ni in NiSO4.6H2O**						
		TMC IND	**TMC JP**	**TMC TX**	**Indonesia to China (MHP)**	**Indonesia to China (RKEF)**	**Indonesia to Japan**	**Canada to Norway**
Climate Change	kg CO2-Eq	1.26E+01	1.15E+01	9.99E+00	2.09E+01	6.85E+01	3.27E+01	1.23E+01
Freshwater + Terrestrial Acidification	mol H+-Eq	8.76E-02	8.19E-02	6.44E-02	4.65E-01	5.77E-01	1.00E+00	7.15E-02
Freshwater Eutrophication	kg P-Eq	7.66E-03	3.65E-03	3.90E-03	3.22E-02	9.16E-02	5.66E-03	2.55E-02
Terrestrial Eutrophication	mol N-Eq	1.04E-01	8.76E-02	5.09E-02	3.81E-01	9.66E-01	4.33E-01	5.51E-02
Freshwater Ecotoxicity	CTU	-2.52E+02	-2.59E+02	-2.60E+02	3.83E+02	2.42E+02	5.78E+01	5.39E+02
Marine Eutrophication	kg N-Eq	9.01E-03	6.68E-03	3.48E-03	3.41E-02	1.06E-01	4.15E-02	6.34E-03
Ionising Radiation	kg U235-Eq	5.83E-01	7.88E-01	4.17E-01	7.43E-01	4.10E-01	4.31E-01	1.99E+01
Photochemical Ozone	kg NMVOC-.	3.72E-02	3.31E-02	2.37E-02	1.25E-01	2.74E-01	1.56E-01	3.09E-02
Carcinogenic	CTUh	7.96E-10	2.35E-10	-3.11E-10	2.63E-08	3.65E-08	9.26E-09	6.69E-09
Non-Carcinogenic	CTUh	1.32E-07	9.45E-08	9.18E-08	1.50E-06	7.10E-07	5.83E-04	1.39E-07
Respiratory	disease i.	6.34E-07	4.60E-07	3.67E-07	2.58E-06	6.94E-06	1.44E-03	1.83E-06
Ozone Depletion	kg CFC-11.	8.76E-08	1.01E-07	5.15E-08	1.34E-07	2.67E-07	3.77E-07	9.43E-08
Minerals + Metals	kg Sb-Eq	-2.11E-05	-2.09E-05	-2.34E-05	1.93E-03	1.34E-04	1.30E-04	2.72E-04
Fossils	MJ	1.48E+02	1.42E+02	1.14E+02	2.06E+02	8.31E+02	3.44E+02	3.79E+02
Water	m3 world eq.	2.33E+00	2.11E+00	1.23E+00	2.02E+01	1.14E+01	4.54E+01	4.60E+01
Land	points	1.56E+01	1.77E+01	9.97E+00	9.33E+01	1.19E+02	3.14E+01	3.45E+01

Table A6. LCIA Results for 1kg of copper cathode

Impact Category	Unit	Per kg Copper Cathode									
		TMC JP	TMC IND	TMC TX	DRC	Chile (heap leach)	Peru to China	Chile to China	USA Sulphide	USA Oxide	China
Climate Change	kg CO2-Eq	4.14E+00	4.63E+00	3.45E+00	1.81E+00	4.59E+00	6.47E+00	7.43E+00	5.94E+00	5.87E+00	8.92E+00
Freshwater + Terrestrial Acidification	mol H+-Eq	3.42E-02	3.67E-02	2.70E-02	5.60E-02	7.00E-02	6.07E-02	9.01E-02	3.67E-02	7.54E-02	7.23E-02
Freshwater Eutrophication	kg P-Eq	1.41E-03	3.25E-03	1.60E-03	5.44E-03	3.03E-03	8.19E-02	3.74E-02	6.07E-02	5.52E-03	1.98E-02
Terrestrial Eutrophication	mol N-Eq	3.25E-02	3.98E-02	1.73E-02	2.16E-01	1.94E-01	2.07E-01	2.91E-01	1.60E-01	1.90E-01	2.19E-01
Freshwater Ecotoxicity	CTU	-1.20E+02	-1.17E+02	-1.20E+02	1.75E+02	1.54E+01	1.25E+03	1.32E+02	6.58E+02	3.10E+01	2.32E+02
Marine Eutrophication	kg N-Eq	2.33E-03	3.40E-03	1.03E-03	1.51E-02	1.80E-02	2.08E-02	2.77E-02	1.66E-02	1.82E-02	2.07E-02
Ionising Radiation	kg U235-Eq	3.51E-01	2.57E-01	1.83E-01	2.13E-02	4.43E-02	1.18E-01	1.30E-01	6.67E-01	9.16E-01	7.93E-01
Photochemical Ozone	kg NMVOC-.	1.23E-02	1.42E-02	8.65E-03	4.60E-02	5.54E-02	5.92E-02	8.16E-02	4.71E-02	5.79E-02	6.10E-02
Carcinogenic	CTUh	-1.89E-10	6.83E-11	-3.71E-10	6.52E-10	1.48E-09	2.32E-09	2.85E-09	1.39E-09	2.64E-09	1.78E-09
Non-Carcinogenic	CTUh	3.48E-08	5.20E-08	3.57E-08	1.16E-08	9.26E-08	4.17E-08	4.11E-08	4.53E-08	1.77E-07	4.87E-08
Respiratory	disease i.	1.67E-07	2.47E-07	1.35E-07	3.46E-07	3.12E-07	2.61E-07	4.76E-07	1.31E-07	3.37E-07	6.23E-07
Ozone Depletion	kg CFC-11.	3.38E-08	2.74E-08	1.45E-08	2.70E-08	6.60E-08	6.23E-08	8.42E-08	1.04E-07	1.01E-07	5.50E-08
Minerals + Metals	kg Sb-Eq	-1.31E-05	-1.32E-05	-1.33E-05	7.51E-06	9.97E-05	1.18E-05	1.50E-05	1.22E-05	1.87E-04	1.15E-05
Fossils	MJ	5.20E+01	5.46E+01	4.29E+01	1.93E+01	7.68E+01	8.47E+01	1.05E+02	8.69E+01	1.13E+02	1.14E+02
Water	m3 world eq.	-2.68E-01	-1.66E-01	-4.24E-01	2.15E-01	1.28E+00	3.74E+01	6.19E-01	1.05E+00	3.24E+00	1.03E+00
Land	points	5.08E+00	4.13E+00	2.17E+00	6.64E+00	3.38E+02	5.51E+01	3.03E+01	4.01E+01	2.38E+02	2.61E+01

Table A7. LCIA Results for 1kg of Co in CoSO4.7H_2

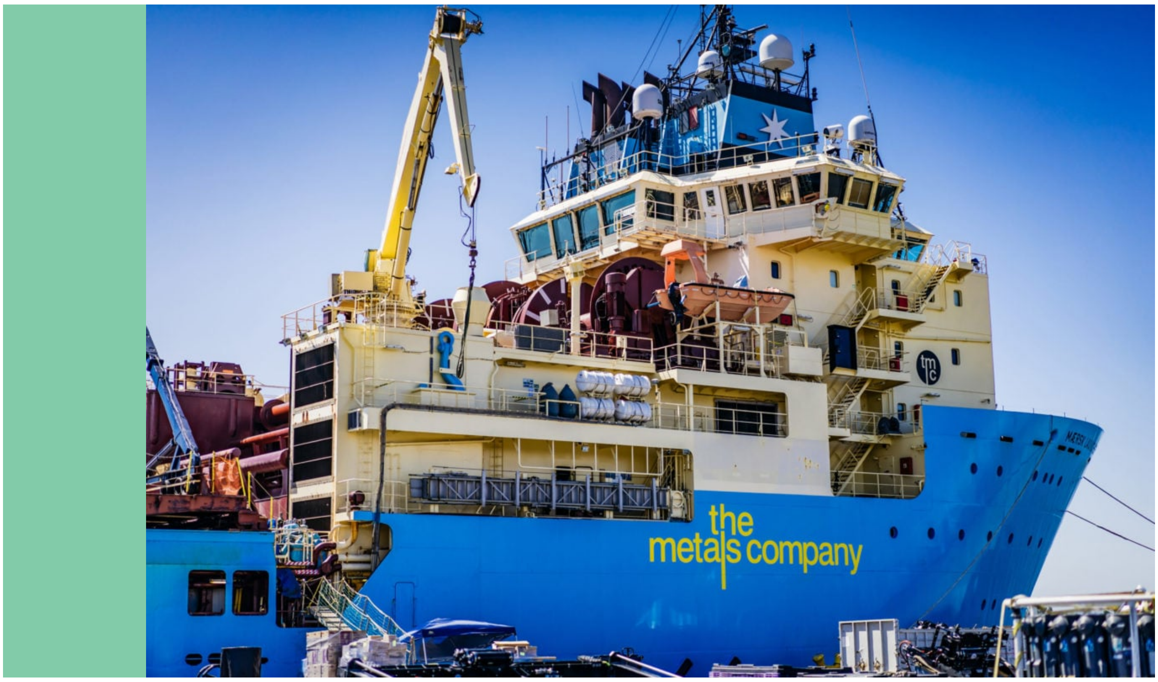
Impact Category	Unit	Per kg Co in CoSO4.7H2O				
		TMC IND	**TMC JP**	**TMC TX**	**DRC to China**	**Indonesia to China**
Climate Change	kg CO2-Eq	3.14E+01	2.84E+01	2.42E+01	3.97E+01	6.16E+01
Freshwater + Terrestrial Acidification	mol H+-Eq	1.08E-01	1.24E-01	8.29E-02	6.34E-01	1.38E+00
Freshwater Eutrophication	kg P-Eq	6.39E-03	6.47E-03	7.74E-03	3.20E-01	9.52E-02
Terrestrial Eutrophication	mol N-Eq	8.59E-02	1.12E-01	2.40E-01	2.19E+00	1.13E+00
Freshwater Ecotoxicity	CTU	-7.44E+02	-7.43E+02	-7.44E+02	9.26E+03	1.81E+03
Marine Eutrophication	kg N-Eq	3.72E-03	6.01E-03	-1.51E-03	1.67E-01	1.02E-01
Ionising Radiation	kg U235-Eq	1.60E+00	2.18E+00	1.16E+00	1.68E+00	2.20E+00
Photochemical Ozone	kg NMVOC-.	4.58E-02	5.44E-02	3.33E-02	4.95E-01	1.20E-01
Carcinogenic	CTUh	2.43E-10	1.08E-09	-4.55E-12	9.32E-08	7.80E-08
Non-Carcinogenic	CTUh	2.18E-07	2.32E-07	2.34E-07	5.16E-07	4.43E-06
Respiratory	disease i.	9.26E-07	9.21E-07	7.33E-07	4.79E-06	1.37E-06
Ozone Depletion	kg CFC-11.	1.92E-07	2.56E-07	1.39E-07	4.62E-07	3.97E-07
Minerals + Metals	kg Sb-Eq	-6.23E-05	-6.04E-05	2.16E-01	4.09E-04	6.87E-04
Fossils	MJ	2.27E+02	2.28E+02	-6.16E-05	4.52E+02	6.10E+02
Water	m3 world eq.	3.79E+00	4.11E+00	3.19E+00	7.75E+00	8.04E+00
Land	points	1.64E+01	2.75E+01	1.04E+01	2.84E+02	2.76E+02

Annex 2 – Critical Review Documents

The following pages contain the critical review documents.

Life Cycle Assessment of Products from the NORI-D Polymetallic Nodules Project and Terrestrial Comparisons – critical review statement and report

The Metals Company



August 2025

Private and Confidential

1. Introduction

The Metals Company (TMC) is a mining company engaged in deep-sea exploration. It aims to extract base metals from polymetallic nodules located in the Clarion-Clipperton Zone (CCZ) of the Pacific Ocean. These nodules are rich in nickel, copper, cobalt, and manganese, which are key materials for infrastructure, energy systems, and batteries. TMC is interested in understanding and reducing the environmental impact of their products. To this end, TMC commissioned sustainability consulting firm Ecoquant to carry out an ISO-conformant life cycle assessment (LCA) of metal production from seabed nodules in comparison to incumbent scenarios of terrestrial mining. To add additional credibility, TMC also commissioned a team of reviewers to perform a critical review of this LCA.

2. Scope of critical review

This critical review examined the life cycle assessment of the full process from seabed collection of nodules to the production of $MnSiO_3$, Ni-Cu-Co matte, copper cathode, nickel sulfate hexahydrate ($NiSO_4 \cdot 6H_2O$), cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$), and the production of silicomanganese (SiMn) from TMC's $MnSiO_3$, in comparison equivalent products obtained from terrestrial mining. The LCA was prepared by Ecoquant for TMC in accordance with the international standards on LCA: ISO 14040:2020 and ISO 14044:2020.

Details of this LCA study are provided below:

- **Title of study**: "Life Cycle Assessment of Products from the NORI-D Polymetallic Nodules Project and Terrestrial Comparisons".
- **Commissioner of the study**: The Metals Company.
- **Practitioner of the study**: Keno Ignace and Aytan Seyidova (Ecoquant).
- **Version of the report which the review statement belongs**: "TMC LCA Report Version 1.2_Latest.pdf".
- **Assurance type**: third party assurance via critical review.
- **Modelling principle**: attributional.
- **Functional units**: 1kg of dry nodules collected and processed, 1kg of Mn in MnSiO3 (40% Mn), 1kg of Ni-Cu-Co Matte (40.7% Ni, 30.5% Cu, 3.4% Co), 1kg of Mn in SiMn (68.9% Mn), 1kg of Ni in NiSO4.6H2O (22% Ni), 1kg of copper cathode (99.99% Cu), and 1kg of Co in CoSO4.7H2O (21% Co).
- **System boundary**: cradle-to-gate.
- **Background database**: ecoinvent v3.11 (cut-off).
- **Impact method and impact category focus**: EF3.1, with a focus on climate change, with additional focus on acidification, energy use, and freshwater eutrophication.

As the commissioner of this LCA may provide comparative assertions to external parties, it is required that a critical peer review is carried out by a panel of LCA experts. The reviewers were external and independent of the LCA project, had knowledge of LCA and relevant industry experience, and comprised:

- Dr Matthew Fishwick (chair and panel member)
- Dr Cynthia Adu (panel member)
- Elke Breitmayer (panel member)

The reviewers were commissioned independently to review the LCA study against ISO 14040/44 acting as an external independent verification body with no vested interest in the outcomes of the review. A critical review is a process used to verify whether LCA studies meet the requirements for methodology, data, interpretation, and reporting and whether they conform with the standards. Thus, it should be made clear that this critical review statement and report should not be taken as an approval or endorsement of deep-sea mining in general.

3. Level of assurance

For this critical review, a “limited” assurance level was sought. For a limited assurance engagement, the reviewers reduce risk to a level that is acceptable. The reviewers collect less evidence than for a “reasonable” assurance engagement, but sufficient for a negative form of expression of the critical review.

4. Procedural aspects of the critical review

The critical review process involved a detailed review of the LCA report for conformance with ISO 14040/44. The review was undertaken at the end of the study. The reviewers used a peer review template to log their comments, based on the example given in ISO-TS 14071. These comments were discussed with Ecoquant. Responses to these comments were sent back to the reviewers along with an updated version of the LCA report to check. The reviewers proceeded to check that they were satisfied with the responses or requested final changes. The reviewers were provided with a detailed LCA report and sight of the model, but not source data. Therefore, the review cannot be said to include an assessment of individual data sets, rather a sampling of these as much as practicable from the report. Details of the review are provided in this critical review statement, which has been prepared in accordance with ISO-TS 14071:2016 and ISO 14044:2020.

The critical review process ensured that:

- The methods used to carry out the LCA are consistent with ISO 14040/44;
- The methods used to carry out the LCA are scientifically and technically valid;
- The data used are appropriate and reasonable in relation to the goal of the study;
- The interpretations reflect the limitations identified and the goal of the study; and

- The study report is transparent and consistent.

Comments and responses from the review process are documented in Table 1 (ISO 14044 conformity comments) and Table 2 (general comments), which form the critical review report.

5. Reviewers competence

Dr Matthew Fishwick: Matthew is an environmental chemist and specialist consultant offering deep technical expertise in LCA, EPD, and product, organisational, and supply chain environmental footprinting. His project experience of over 18 years spans a wide range of sectors including, chemicals, oil and gas, construction, and food and drink. Past clients include 3M, Saint-Gobain, BP, PepsiCo, ArcelorMittal, and Johnson & Johnson. He has PhD, MRes, MSc and BSc degrees in environmental chemistry and is a member of the Royal Society of Chemistry (MRSC).

Dr Cynthia Adu: Cynthia is a Sustainability professional with up to 10 years' experience. She has worked as a sustainability consultant delivering projects in LCA, GHG reporting, decarbonisation strategy and circular economy for FTSE companies and multinationals operating in FMCG, textiles, automotives, chemicals, telecoms, mining and offshore energy. She has an Engineering Doctorate (EngD) in Sustainable Materials and Manufacturing and MSC in Manufacturing systems. She is also a member of the Institute of Materials Minerals and Mining and a Chartered Environmentalist (CEnv).

Elke Breitmayer: Elke has 15 years of experience in Life Cycle Assessment (LCA) and strategic sustainability consulting across sectors such as chemicals, pharmaceuticals, FMCG, and manufacturing. She has solid methodological expertise and is well-versed in sector-specific guidance documents. Over the years, she has focused on emerging technologies, applying prospective LCA to assess solutions that are not yet commercially available. Her sector-agnostic perspective enables her to interpret LCA results strategically and place them in a broader context where necessary, ensuring that findings are both meaningful and actionable and a solid base for decision-making.

6. Conflict of interest

A review of potential conflict of interest was carried out by the review team and it was established that the potential for conflict of interest between reviewers and participants is low.

7. Critical review statement

Having re-read the final report and responses to final comments, the reviewers are all confident that there is no reason to suggest that this study is not in conformance with ISO 14040:2006 and ISO 14044:2006. Furthermore, the reviewers feel that the study is very thorough and well thought through, with a large amount of data collection and analysis. However, the next sections document qualification statements, limitations, and recommendations.

8. Qualification statements and limitations

Whilst the majority of comments were addressed to the reviewers' satisfaction, the following qualification statements and limitations are noted:

- There is a general limitation regarding the lack of suitable methods in LCA to cover key relevant impacts of deep-sea mining, e.g. seafloor disturbance and sediment releases and associated ecological impacts.
- The LCA focuses on a limited number of impact categories: climate change, acidification, energy use, and freshwater eutrophication. Whilst it is noted that some other impact categories may not have been relevant or well developed enough to include in detail, usually LCA provides a detailed assessment across many impact categories.
- Given the early stage of production, there are inherent limitations regarding projections/simulations/assumptions required in the absence of full-scale production data. This will improve over time as more data become available.
- As the report will be made publicly available, a limitation of the report is that it may not be accessible to a general audience without mining and LCA experience.
- The reviewers note that there could have been more transparency in referencing. This is of particular relevance for the terrestrial routes where some transparency about the translation of public available data into the specific LCA model (such as cut-off rules, allocation, transports etc). Providing this information would help the reader understand the assumptions, limitations and choices made in modelling.
- The reviewers note that there could have been more discussion included for the reader to understand the uncertainties of the work consequently, to assess whether differences in the values are significant and sufficiently robust.
- It is noted that a summary presentation will be produced from this LCA by TMC, the summary presentation was not in scope of the critical review.

9. Recommendations

The following recommendations are also noted:

- It is recommended that the outputs of the LCA are considered with other environmental assessments and alternative environmental assessments to LCA are considered in the future.
- A recommendation for future LCAs critical reviews would be to specifically select interested parties from terrestrial mining, NGOs, etc.
- The reader should bear in mind that the boundary of the LCA is cradle-to-gate, and there may be advantages or disadvantages of the various routes further downstream, e.g. the advantage of reduced transport distances could be offset once downstream transport and processing are included.
- Should the results of the study be communicated externally, the reviewer recommends that access to this review statement be made available, for instance, by including it as an annex to the LCA report or future third party LCA report (summary of main report).

10. Disclaimer

The review team have prepared this critical review statement for the sole use of the client and for the intended purposes as stated in the agreement between the review team and the client under which this statement was completed. The review team have exercised due and customary care in preparing this statement, but has not, save as specifically stated, independently verified information provided by others. No other warranty, express or implied, is made in relation to the contents of this statement. The use of this statement, or reliance on its content, by unauthorised third parties without written permission from the review team shall be at their own risk, and the review team accepts no duty of care to such third parties. Any recommendations, opinions or findings stated in this statement are based on facts and circumstances as they existed at the time the statement was prepared. Any changes in such facts and circumstances may adversely affect the recommendations, opinions or findings contained in this statement. The review team accepts no responsibility for any environmental claims that are released based on this study.

Yours sincerely,

Dr Matthew Fishwick
24.08.2025

Dr Cynthia Adu
24.08.2025

Elke Breitmayer
24.08.2025

Table 1 – Log of ISO 14044 conformance review comments and responses

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
Goal and scope	LCA studies shall include the goal and scope definition, inventory analysis, impact assessment and interpretation of results.	4.1	MF, EB, CA	Yes	-	-	-	Yes
	LCI studies shall include definition of the goal and scope, inventory analysis and interpretation of results. The requirements and recommendations of this International Standard, with the exception of those provisions regarding impact assessment, also apply to life cycle inventory studies.	4.1	MF, EB, CA	n/a	-	-	-	n/a
	An LCI study alone shall not be used for comparisons intended to be used in comparative assertions intended to be disclosed to the public.	4.1	CA	No	CA: Although the work will be disclosed to the public through TMC website, the study is not going to be used alone as comparison; it's unclear what other methods of comparison would be used.	This study alone will be used for the comparative assertions made within the document. Claims of overall environmental superiority or equivalence were not made, as the LCA methodology has its limitations.	CA: comment closed.	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	Goal and scope shall be clearly defined and shall be consistent with the intended application.	4.2.1	EB	Yes	EB: I suggest to be more specific in the goal and scope definition. In particular, to release the results to the general public and to use it as one perspective to contribute to the ongoing debate about DSM And could you please confirm my understanding, that the permit application requires Climate Change only?	The goal of this study is not to contribute to the ongoing debate about deep sea mining, however, since it is public that may very well happen. Yes that is correct. One of many of the requirements of the permit application is the climate change data, which can be used from this report. Aspects now defined as. The following paragraph has been added to the goal: "The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A".	EB: Starting from your own statement you KNOW who the "interested parties" are namely the players firing the public debate plus SMEs. You cannot take your own ideas as the likely scenario, but need to accept reality. I recommend to address this as a risk to the publication of the study. Plus I suggest to explicitly exclude this as a goal to demonstrate that the commissioner of the study is aware of the controverse discussion Plus I noticed that the word "aspects" was added. This is too vague for a goal definition. Please describe what aspects mean, e.g. exclusions of process steps, selection (and deselection) of impact categories etc. CA: Okay, the intended audience added, which also has been included to state "possible investors, customers, and anyone interested in deep-sea mining".	Yes
	In defining the goal of the study, items listed in 4.2.2 shall be stated: – the intended application; – the reasons for carrying out the study; – the intended audience, i.e. to whom the results of the	4.2.2	MF, EB, CA	No	MF: More could be included to make clear what the results will be used for and the limitations in regards to projections/simulations/assumptions required in absence of full-scale production data and the lack of suitable methods in LCA to cover	The results will be used exactly as is written in the goal definition. That is, the results will provide TMC with additional environmental impact insights of their production process and highlight emission reduction pathways through scenario/sensitivity analyses. The GHG emissions data from this study may also be used as a part of TMC's application for a	MF: Comment closed. Although we should add this as a note to the critical review report. EB: Given this answer, along with the response to question 2.1, I wonder whether the commissioner of this study is aware of the	Yes. Although, I understand the intention is to prevent misinterpretation of the findings.

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	study are intended to be communicated; – whether the results are intended to be used in comparative assertions intended to be disclosed to the public.				key relevant impacts of deep sea mining e.g. seafloor disturbance and sediment releases. EB: Will it also be used for Lobbying and/or as a response to sceptic parties? If so, please mention it. This should also result in a specification of the target audience: NGOs, Science, Politicians and Decision makers, Journalists... The mentioned goal of creating an in-depth (internal) understanding of the technology, would require to address potential trade-offs in more depth. CA: "The goal of the study is missing the intended audience as shown in 4.2.2 Goal of the study In defining the goal of an LCA, the following items shall be unambiguously stated: — the intended audience, i.e. to whom the results of the study are intended to be communicated: Although the intended audience is mentioned on page 36, this should be brought out a lot earlier, where the goal was discussed. ""The target audience of this includes possible investors, customers, and anyone interested in deep-sea mining"	commercial recovery/permit license. This report will not be used for lobbying nor to deter those away from deep sea mining. However, as it will be made public, it is out of anyone control to how it will ultimately used. The goal section as well as section 3.10 lays out limitations of the LCA methodology, and thus limitations of this report. It also makes it clear that the goal of this study is to measure aspects of the environmental impacts according to the EF method. Anything beyond that scope should not be considered a limitation. The intended audience is now mentioned in the executive summary well. "Statement now added to expand on the target audience and the possibility for the selective use of results to support claims. The paragraphs is as follows: Ecoquant recognizes the debate on the technology that is studied in this report and the possibility of selective use of individual data to support claims. As the target audience includes anyone interested in deep-sea mining, it should be noted that the authors and commissioning party do not assume responsibility for the interpretations made by parties who lack the necessary technical background. Misinterpretation or selective use of individual findings outside the context of the complete study may lead to inaccurate conclusions.	controversial nature of the debate and the role they are playing in it. The possibility that this LCA will be used by unspecified interested parties—including individuals without expertise in LCA or mining—should be explicitly addressed. It is the commissioners role to overtake responsibility of disclosed information and this includes 1) avoid vague language like ""aspects"" 2) clearly specify the target audience and if you think, that only mining experts will be able to understand is, you need to limit the target audience to experts in this field and 3) address likely misuse and misunderstanding which includes clear conclusions that are supported by data. CA: Okay, the intended audience added, which also has been included to state "possible investors, customers, and anyone interested in deep-sea mining".	However, the current wording could be read as dismissive toward non-technical readers, which may be counterproductive given that the target audience explicitly includes "anyone interested in deep-sea mining.
	The definition of the scope shall consider and clearly define a list of items detailed in section 4.2.3.1 of ISO 14044: – the product system to be studied;	4.2.3.1	MF	No	MF: 'There are a few sections for this requirement missing: data quality requirements, method for interpretation, cut-off criteria and detailed exclusions, communication of results, type and format of report, type of critical review.	All of these sections are included in the report. The list of exclusions has been extended to make it clear what is in the system boundary. See additional paragraph in section 3.2 as well.	MF: as mentioned in other comments, whilst there are sections for data quality requirements and cut-off criteria, these things are no defined in these sections. For the others, there is some mention of these in the report, even if not in	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	– the functions of the product system or, in the case of comparative studies, the systems; – the functional unit; – the system boundary; – allocation procedures; – LCIA methodology and types of impacts; – interpretation to be used; – data requirements; – assumptions; – value choices and optional elements; – limitations; – data quality requirements; – type of critical review, if any; – type and format of the report required for the study.						their own section. Comment closed in the interest of moving the review forward. EB: Note: data quality requirements are not specified.	
	The scope shall define whether a critical review is necessary and if so what type of review and who would conduct it, and their level of expertise.	4.2.3.8	MF	No	MF: Please add more details on the review e.g. what it covered, at what stage in the LCA it was conducted, what type of review and who would conduct it, and their level of expertise etc. Also good to mention here the process for selecting the panel. We can provide text on this if needed.	Details added on who conducted the review (expertise provided in the CVs of the reviewers as required by the standards), how the reviewers were selected, and the version of the report that was reviewed. "Wording in chapter 3.11 changed to reflect that products are being compared. Sentence changed to: his will include highlighting the variation in the measured environmental impacts of TMC's products in comparison to the same products produced from each of the terrestrial production pathways. Parameters, processes, and flows in the production systems that leads to one product performing better than another within an environmental impact category will be underlined.	MF: comment closed. EB: Clear, I would suggest adding this perspective into the comparisons to have a comprehensive view on the technology as such. Based on the metals as FU, an overall benchmark on technology level taking ist multifunctionality into account is not possible based on Chapter 7. Chapter 3.11 remains here unnecessarily generic and the sentence "This will include highlighting the variation in the measured environmental impacts of TMC's product system in comparison to each of the terrestrial production pathways. "is not adequately addressing that. You are evaluating and comparing PRODUCTS, not the "PRODUCT SYSTEM" in Chapter 7. I still put yes as the technology benchmarking as	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
							the goal definition is here more precise and relates to "products"". Suggest to change the wording o to capture this finding in the review statement.	
Functional unit	The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied.	4.2.3.2	MF, EB, CA	Yes	-	-	-	Yes
	The functional unit shall be consistent with the goal and scope of the study.	4.2.3.2	EB	No	EB: In parts. To understand the technology a more systemic approach is recommended. To evaluate per kg of Output (distinct) requires a careful interpretation of results as the study partitions a system that is in fact a system. Partially. To fully understand the technology, a more systemic approach is recommended. Evaluating impacts per kilogram of distinct output requires careful interpretation, as the study separates elements of a system that inherently functions as an integrated whole.	When the functional unit is 1kg of dry nodules collected and processed, the entire system without portioning is considered. The impacts per each valuable output are measured when the other 6 functional units are considered.	EB: ok noted. For goal 1 and 2 ok and goal 3 focusses on products, not the technology.	Yes
	The functional unit shall be clearly defined and measurable and clearly specify the functions of the system being studied and reference flow shall be defined.	4.2.3.2	MF, EB, CA	Yes	-	-	-	Yes
	Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s) in the form of their reference flows. If additional functions of any of the systems are not taken into account in the comparison of functional units, then these omissions	4.2.3.2	MF, EB, CA	Yes	-	-	-	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	shall be explained and documented. As an alternative, systems associated with the delivery of this function may be added to the boundary of the other system to make the systems more comparable. In these cases, the processes selected shall be explained and documented.							
System boundary	The system boundary determines which unit processes shall be included in the LCA. The system boundary shall be consistent with the goal of the study and criteria used to establish it shall be explained.	4.2.3.3.1	EB	No	EB: Sediments excluded: what does this mean in particular for the study? Are there any consumables besides the fuel for the machines? I am also wondering about emissions. I understand emissions are solely due to fuel combustion?	This means that any potential impacts from the sediments which are lifted during the nodule collection process are not considered. LCA cannot measure this. Yes you are correct, the offshore emissions are solely due to the combustion of marine fuel oil which is the only consumable for offshore operations.	EB: comment closed.	Yes
	Decisions shall be made regarding which unit processes to include in the study and the level of detail to which these unit processes shall be studied.	4.2.3.3.1	MF, EB, CA	Yes	-	-	-	Yes
	Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained.	4.2.3.3.1	MF, EB	No	MF: As per general comments, a full list of exclusions is not provided in the report. EB: "sediments and other impacts""...please specify what these other impacts are. As this is one of the main criticisms of the technology, I would like to have this part somewhere discussed in more depth incl. What this means in the interpretation. Please confirm there are no	List of exclusions is provided in table 5. This list has been extended. When the nodules are dislodged and lifted from the seafloor, there is sediment that is released. Perhaps this can be thought of as waste. The sediments settle back to the ocean floor. Any potential impacts associated with the lifting of this sediment is not included in this LCA report as it cannot be measured by any of the 16 environmental impact categories within the EF 3.11 method.	MF: comment closed. EB: comment closed.	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
					consumables, wastewater, emissions apart from fuel combustion etc. There are also some inconsistencies between the LCI in the report and the excel file, Please check again.	The only consumable from offshore operation is the marine fuel oil. The LCI in the excel file and the LCI in table 12-13 match. The liquid oxygen input in the MAIN Tab of the excel file is included in the electricity consumption.		
	Decisions shall also be made regarding which inputs and outputs shall be included and the level of detail of the LCA shall be clearly stated.	4.2.3.3.1	MF, EB	No	MF: As per general comments, a full list of exclusions is not provided in the report. EB: Given the data sources, I would consider LCA due to the lack of actual data.	The list of exclusions has been extended (see table 5) The data is not based on operational data, therefore it is a prospective LCA. The data was generated by Hatch (engineering consultancy firm) who used mass and energy balances utilising the Metsim industry standard software package and qualified process engineers. The operational technology will be that of well known existing processing technologies, therefore the design basis and test work followed actual operating plants.	MF: comment closed. EB: comment closed.	Yes
	Energy inputs and outputs shall be treated as any other input or output to an LCA. The various types of energy inputs and outputs shall include inputs and outputs relevant for the production and delivery of fuels, feedstock energy and process energy used within the system being modelled.	4.2.3.3.2	MF, EB, CA	Yes	-	-	-	Yes
	Where study intended for comparative assertions is disclosed to a third party a sensitivity analysis shall be performed.	4.2.3.3.3	MF, EB, CA	Yes	-	-	-	Yes
	The cut-off criteria for initial inclusion of inputs and outputs and the assumptions on which the cut-off criteria are established shall be clearly described. The effect on the outcome of the study of the cut-off criteria	4.2.3.3.3	MF	No	MF: Cut-off criteria have not been defined.	There were no cut-offs used, all known flows were considered. Section 3.7 covers the cut-off criteria.	MF: there are exclusions based on materiality listed in Table 5. How was it decided these were excluded? Cut-off criteria are needed for this and need to be defined in the report. Even if there are no exclusions the reader needs to know on what basis it was	Yes

Category	**ISO 14044 Requirement**	**ISO 14044 clause number**	**Reviewer initials**	**Conforms to ISO requirement (Yes or No) at beginning of review**	**Reviewer comment**	**Practitioner of the LCA study response**	**Reviewer response**	**Conforms to ISO requirement (Yes or No) at end of review**
	selected shall also be assessed and described in the final report. Where the study is intended to be used in comparative assertions intended to be disclosed to the public, the final sensitivity analysis of the inputs and outputs data shall include the mass, energy and environmental significance criteria so that all inputs that cumulatively contribute more than a defined amount (e.g. percentage) to the total are included in the study.						decided not to make exclusions. Comment closed in the interest of moving the review forward.	
Methodology and impact categories	Impact categories, category indicators and characterisation models shall be defined and shall be in line with the goal.	4.2.3.4	EB, CA	No	EB: Suggest to specify that it is a carbon footprint study plus additional impact categories. For the comparison Review Panel: any knowledge of a relevant category that is not considered? CA: Although impact category indicators are defined the characterisation models have not been, see general comment on pg 58-59 (CA)	It is true that this study goes into the most detail (providing contribution analyses and sensitivity analyses) for the climate change impact category. This is because it is a well characterised method that benefits from global frameworks and guidance and has the lowest level of uncertainties among the 16 EF 3.11 impact categories. Though not to the same level of detail, all other impact categories were also evaluated (appendix), with visualisations and interpretations for Acidification, Energy Use, and Land Use. Acidification is usually a recommended impact category for mining LCA's as sulfuric acid, sulfur, and fossil fuels are commonly used. Energy Use and GWP are usually closely correlated, however it can also provide additional insights. Land Use is debatable since mining supply chains are global, however the main impacts of land use come from the overburden or tailings deposition in the comparison scenarios. The characterisation models are intrinsic to the EF 3.11 method which is defined throughout the report.	EB: Are you sure that this is the robustness of the method is the reason and not its global urgency, universal relevance, and strong policy and public focus? You may at least want to add that this is the relevant one for the permit application? In general, it is not the method that determines what is important. Instead, what is important determines which method should be used. CA: comment closed.	Yes

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						Yes this makes sense. Paragraph in the goal section now updated as follows: "While all impact categories assessed in this report are valuable, climate change is one that LCA methodologies do particularly well. In addition to its global urgency, universal relevance, and public focus, it is widely recognized as the most established impact category and benefits from global frameworks and guidance's such as the greenhouse gas (GHG) protocol and ISO 14067. As a result, the GHG emission data generated in this this study can be used as a part of TMC's application for an exploration and commercial recovery/permit license Accordingly, the climate change impact category will receive the most detailed interpretation in this report, including contribution, sensitivity, and scenario analyses"		
	It shall be determined which impact categories, category indicators and characterization models are included within the LCA study. The selection of impact categories, category indicators and characterization models used in the LCIA methodology shall be consistent with the goal of the study and considered as described in 4.4.2.2.	4.2.3.4	MF	No	MF: As below for 4.4.2.1.	All impact categories are included in the LCA as the appendix contains the full list of 16 impact categories for each pathway. The report mentions why the focus is on climate change, and an additional paragraph has been added on why acidification, energy use, and land use were looked at in more detail than the remaining methods.	MF: comment closed. Although this focus of impact categories should be added to the critical review report.	Yes
	Impact categories, category indicators and characterisation models shall be referenced.	4.4.2.2.1	CA	No	CA: No reference to characterisation model.	The characterisation models are intrinsic to the EF 3.11 method which is defined throughout the report. Table now visible and characterization models have been added.	CA: Table 11: EF 3.1 Environmental Impact Categories did not show table after the latest version of the PDF please update. There are no references of the characterisation model used for each please update	Yes

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							the table if possible as this may be useful context for the readers.	
Data quality	Data quality requirements shall be specified to enable the goal and scope of LCA to be met and shall be characterized by both quantitative and qualitative aspects. Where a study is intended to be used in comparative assertions intended to be disclosed to the public, the data quality requirements stated in a) to j) in 4.2.3.6.2 shall be addressed.	4.2.3.6.1 and 4.2.3.6.2	MF, EB, CA	No	MF: Data quality requirements have not been specified. EB: I would label the study as a Screening LCA and adjust the DQR requirements accordingly. The inventory includes mainly modelled and calculated Data of a product system that is still under development (prospective). The specification of data quality requirements includes also the reference system, where I would prefer an industry average over site specific data. CA: There is no discussion on if the data quality requirement has been met for this comparative assertion or what is the intended DQR.	The data quality requirements are specified in section 3.8.2 of the report. Though the ISO standards (or other sector specific standards) does not mention a minimum data quality score, tables 9 and 10 indicate the data quality rating of each material input. The ghg guidance calculation for nickel products refers to the iso standards and the ghg protocol. The data quality rating from thee GHG protocol product standard was used in this report (Table 8). According to the GBA GHG rulebook, primary data can be from stoichiometric calculations, engineering models, or product balances (all methods for which these data were generated by Hatch for TMC's product system). However, as the data is not for current operational processes, technological representativeness does not receive the highest score. For the comparisons, industry averages were specifically not used as we could not control the method in which they were modelled (allocation methods, emission factor databases etc.), therefore comparisons would be unfair. Furthermore, industry averages do not reflect the main production pathways for most metals. For example, the industry average value of NiSO4.6H2O poorly represents Indonesia, who is the leading producer of nickel. The data quality section has now been revamped to include minimum data quality requirements, calculation logic, and an overall quantitative assessment (including a DQR score) of the data quality.	MF: I still cannot see the data quality requirements in section 3.8.2. These are the minimum requirements for data to be accepted into the study e.g. for temporal coverage this could be something like: "primary data shall be < 5 years old and secondary data shall be < 10 years old". EB: Not defined. CA: As per the 4.2.3.6.1 and 4.2.3.6.2 data quality still requires a quantitative assessment to meet the ISO standard and requirements for comparative assertions intended to be disclosed to the public.	Yes

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	Where data is missing it shall be documented and explained.	4.2.3.6.3	MF, EB	No	MF: As per general comments, a full list of exclusions is not provided in the report. EB: some contradictions between the excel "Main", "LCA" and the report. See general comment #5	Full list of exclusions now extended. Additional text also added in section 3.2 for clarity. The "LCI" tab is mapped to the LCI table in the report.	MF: comment closed. EB: comment closed.	Yes
	In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Consequently, the scope of the study shall be defined in such a way that the systems can be compared. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures, decision rules on evaluating inputs, and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported. If the study is intended to be used for a comparative assertion intended to be disclosed to the public, interested parties shall conduct this evaluation as a critical review.	4.2.3.7	EB, CA	No	EB: see general comments. CA: Results are interpreted and discussed even with a sensitivity analysis discussed for the Nori-D before the comparative study is brought in	This study has 3 goals, to first quantify aspects of the environmental impact for the production of TMC's products, secondly to quantify aspects of the environmental impact for the production of SiMn, and thirdly to compare the results to the same products produced terrestrially. Since TMC's product. system is the novel system, it first had to be described in detail before comparing to the terrestrial system to avoid confusion to the reader. This is why TMC's system and all methodological consideration were first described in detail. It was mentioned that the comparison followed the same methodological considerations (section 7.1)	CA: comment closed.	Yes
Methodological framework	A life cycle impact assessment shall be performed for studies intended to be used in comparative assertions		MF, EB, CA	Yes	-	-	-	Yes

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	intended to be disclosed to the public.							
Data collection	Qualitative and quantitative data shall be collected for each unit process included in the boundary.	4.3.2.1	EB	No	EB: We cannot evaluate if the data collection is complete.	To the best of my knowledge, all data are included in the report for TMC's product system. The onshore data was compiled by Hatch, and the offshore data was compiled by AllSeas. All data was also cross reference to similar production pathways (i.e. companies that produce nickel, copper, and cobalt) and the data matches. The data quality section has now been revamped to include minimum data quality requirements, calculation logic, and an overall quantitative assessment (including a DQR score) of the data quality.		Yes
	When data have been collected from public sources, the source shall be referenced. For those data that may be significant for the conclusions of the study, details about the relevant data collection process, the time when data have been collected, and further information about data quality indicators shall be referenced. If such data do not meet the data quality requirements, this shall be stated.	4.3.2.1	MF, EB, CA	No	MF: As per general comments, the LCI is limited for both TMC and comparative product systems and could do with expanding on to make it as transparent as possible. EB: For the comparative part, the references are not clear to me (Chapter 7). CA: There isn't proper references of all inventory data sources	The LCI is complete for TMC's product system. Inputs such as lubricants for machinery, parts that are replaced during regular maintenance, and other inputs not material to the production of the products are not included in TMC's nor the comparisons product system. The inventory data for the comparisons are available for your review, however they will not be included in the report. They may be made available upon request. The technical report summary that contains all of the foreground data for TMC's system has now been referenced and is included in annex B. The data sources for the comparisons have also been referenced.	MF: At the very least the sources used for the comparative products need to be referenced in the report for transparency. EB: Clarification: the references are not clear. It mentions ""primary data"" but the report does not specify where they were collected, which site, how many sites. Please check also the Chapter references as the citation is not always correct. For web-based sources add the link and when it was retrieved. E.g. source 19 was not accessible anymore in the library I am in general not sure if the terms "Primary data" and "secondary data" are used in a correct, scientific manner. If primary data were collected, could you please include how it was sampled and from how many mines and the coverage/representativeness?	Yes

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							CA: comment closed.	
	Individual data shall be further detailed to satisfy the goal of the study.	4.3.2.3	MF, EB, CA	No	MF: As above for 4.3.2.3. EB: disclosed in the excel file, please address general comments CA: as above.	See above response. The sources used for the comparisons have now been referenced in text and in the references.	MF: At the very least the sources used for the comparative products need to be referenced in the report for transparency. CA: comment closed.	Yes
	A description of each unit process shall be recorded.	4.3.2.1	MF, EB, CA	Yes	-	-	-	Yes
	A validity check shall be performed during collection to check it meets data quality requirements.	4.3.3.2	MF, EB	No	MF: It is not clear that this has been done. EB: Validation procedure is not mentioned in the report.	A validity check was conducted on the data. A paragraph has been added to the report about this in the data collection section (see section 3.8.1.2)	MF: comment closed. EB: ok, if done by ecoquandt. If done by Hatch this needs to be described.	Yes
Calculating data	All calculation procedures shall be explicitly documented and assumptions made clearly stated and explained.	4.3.3.1	MF, EB, CA	No	MF: As per general comments, the LCI is limited for both TMC and comparative product systems. For example, how were the quantities of coal, marine diesel, electricity derived? Do these match the quantities of product produced? How were the quantities of product produced derived e.g. assumptions on yield, amount extracted per day	The full LCI for TMC's product system is included. The quantities of marine diesel were derived by Allseas, an offshore contractor, as described in section 3.8.1.1. Allseas provided average daily marine fuel use rate for the production vessel, the compressor, spread, and the transfer vessel. This data was used along with the production schedule to calculate annual fuel use. Bulk carriers fuel usage was calculated	MF: At the very least the sources used for the comparative products need to be referenced in the report for transparency. EB: We are not able to differentiate between calculated data, assumptions and measurements (except fuel) and I suggest to capture this finding in the review	Yes. Not exactly the scientific way, but at least it is in the report

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				🟥	etc.? Bulk carrier stages seem to be missing from the inventory - what assumptions were made here e.g. utilisation, loading etc? EB: A chapter assumptions is missing in the report. For the comparatives the calculation is not clear. CA: Assumptions made in the document could still be aggregated together and shown in the limitations.	using cycle durations and by splitting the time into steaming, port, and idle to attribute accordingly different fuel usage rates. For onshore data (coal, electricity, natural gas etc.) it is described in section 3.8.1.2. The data was generated by Hatch (engineering consultancy firm) who used mass and energy balances utilising the Metsim industry standard software package and qualified process engineers. The operational technology will be that of well known existing processing technologies, therefore the design basis and test work followed actual operating plants. The inventory data for the comparisons are available for your review, however they will not be included in the report. They may be made available upon request. The data for TMC's system has now been referenced. The data for the comparisons have also now been referenced with a description on how they were gathered. i.e.: ". Each route is based on the best publicly available data from company sustainability reports, ESG databooks, literature, and third party databases.18-29 Where data was not available, mass and energy balances, or proxy data was used. The data was extracted from these sources and modelled consistently with the methodology described in this report. The values presented in this report do not reflect the official disclosures or positions of the companies mentioned, as the system boundaries, assumptions, and emission factors used in the modelling may differ from those employed by the respective companies. "	statement. I note that we will capture this point in the review statement that this was information not disclosed to the reviewer panel and thus cannot be evaluated as a potential source of uncertainty. Could you at least add a correct scientific reference how you obtained the data? Sampling, name of the site, how many sites, literature (which ones) etc .. LCA is a scientific method and follows scientific standards which includes references. CA: Please aggregate these in one section to help the reader.	🟩

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						Please note that the footnotes of table 14 provides additional detail. Decided to not make a separate section of assumptions as the report is already at 200 pages and the assumptions are laid out in tables 2, 14 (footnotes), and brought up in the relevant sections. However this can be included in the summary report. " There is no specific chapter on assumptions, however there are very detailed tables within relevant chapters that form the basis of the assumptions. For example, on production processes and electricity sources (e.g. grid electricity assumed, see table 1, 2 and 3). The entire basis for the comparisons are shown in great detail in table 14. Additional footnotes have also been added for key assumptions that have been made as per your recommendation.		
	When determining the elementary flows associated with production, the actual production mix should be used whenever possible, in order to reflect the various types of resources that are consumed. As an example, for the production and delivery of electricity, account shall be taken of the electricity mix, the efficiencies of fuel combustion, conversion, transmission and distribution losses.	4.3.3.1	MF, EB, CA	Yes	-	-	-	Yes

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	Where energy from combustible fuels is calculated, it shall be reported whether the higher heating value or lower heating value was used.	4.3.3.1	MF, CA	No	MF: This is not explicitly stated in the report. CA: No much insight on which data point is used if HHV or LHV.	LHV was used for consumption amounts as well as emission factors. I have added a sentence about this in the data collection section (section 3.8.1.2)	MF: comment closed. CA: comment closed.	Yes
	An appropriate flow shall be determined for each unit process and quantitative input and output data shall be calculated for each.	4.3.3.3	MF, EB, CA	Yes	-	-	-	Yes
	Where inputs and outputs of the system need to be aggregated, the level of aggregation shall be consistent with the study.	4.3.3.3	MF, EB, CA	Yes	-	-	-	Yes
Refining the system boundary	Decisions regarding the refining of the system boundary shall be based on results of a sensitivity analysis to determine significance of data to be included/excluded. The initial system boundary shall be revised, as appropriate, in accordance with the cut-off criteria established in the definition of the scope. The results of this refining process and the sensitivity analysis shall be documented.	4.3.3.4	MF, EB, CA	Yes	-	-	-	Yes
Allocation	The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure.	4.3.4.1	MF, EB, CA	Yes	-	-	-	Yes
	The sum of the allocated inputs and outputs of a unit process shall be equal to	4.3.4.1	MF, EB, CA	Yes	-	-	-	Yes

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	inputs and outputs of unit process before allocation.							
	Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted.	4.3.4.1	MF, EB, CA	Yes	-	-	-	Yes
	Allocation shall be dealt with by using the following methods, in order of preference: - By dividing the process into sub-processes and collecting data on each of these - System expansion - Allocation according to physical properties - Economic allocation	4.3.4.2	MF, EB, CA	Yes	-	-	-	Yes
	Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products part only.	4.3.4.2	MF, EB, CA	Yes	-	-	-	Yes
	Allocation procedures shall apply uniformly to similar inputs and outputs. For example, if allocation is made to usable products (e.g. intermediate or discarded products) leaving the system, then the allocation procedure shall be similar to the allocation procedure used for such products entering the system.	4.3.4.2	MF, EB, CA	Yes	-	-	-	Yes
	Changes in the inherent properties of materials shall be taken into account. In addition, particularly for the recovery processes between	4.3.4.3	MF, EB, CA	Yes	-	-	-	Yes

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	the original and subsequent product system, the system boundary shall be identified and explained, ensuring that the allocation principles are observed as described in 4.3.4.2. However, in these situations, additional elaboration is needed for the following reasons: – reuse and recycling (as well as composting, energy recovery and other processes that can be assimilated to reuse/recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system; – reuse and recycling may change the inherent properties of materials in subsequent use; – specific care should be taken when defining system boundary with regard to recovery processes.							
Impact Assessment	The LCIA phase shall be coordinated with other phases of the LCA to take into account the following possible omissions and sources of uncertainty: - Whether the quality of the LCI data and results is sufficient to conduct the LCIA in accordance with the study goal and scope	4.4.1	MF, EB	No	MF: It is not clear that this has been done. EB: We need to be clear that some of the selected impact categories are insufficient to assess the environmental impacts esp. Land use	Yes, the LCI is complete and the quality of the data is sufficient to calculate the LCIA as all significant input and attributable processes are included. Therefore, the goal of calculating aspects of the environmental impacts for the production of the products studied using the EF methodology was sufficiently met. The LCI functional unit calculation did not decrease the environmental relevance of any	MF: comment closed. EB: The use of the term "aspects" in this context is misleading, as it is too vague and can imply either everything or nothing. Please specify what the word aspects is referring to: impact assessment methods, exclusions, etc. It will also provide clarity to clearly name the impacts that are identified to be	Yes

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	definition; - Whether the system boundary and data cut-off decisions have been sufficiently reviewed to ensure the availability of LCI results necessary to calculate indicator results for the LCIA; - Whether the environmental relevance of the LCIA results is decreased due to the LCI functional unit calculation, system wide averaging, aggregation and allocation.					of the 16 impact categories quantified as no aggregation was used and allocation was transparent and followed industry standards. Yes you are correct that the impact categories offered by EF (though the most complete) are insufficient to assess the total environmental impacts of the system. However, the goal of this study is the assess aspects of the environmental impact using the EF methodology. LCA alone cannot measure total environmental impacts. As per your recommendation, I have made this clear throughput the report and in the conclusion. Aspects have now been defined and it was clarified that only climate change, acidification, energy use, and freshwater eutrophication has been analysed. Other impact categories are included in the annex. The statements in the goal section is as follows: "The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A"".	of particular relevance. While it is a generally recommended to include the complete set of impact category results in the Annex, the Annex should serve only as supplementary information. The core findings of the study - particularly those relevant to the goal and scope - must be addressed and interpreted directly in the main report. A table in the Annex, without corresponding interpretation and conclusion, is insufficient to fulfil the requirements of ISO 14044. Furthermore, I noted that land use is substituted.	
	LCIA shall include selection of impact categories, category indicators and characterization models; assignment of LCI results to the selected impact categories (classification); and calculation of category indicator results (characterization).	4.4.2.1	MF, CA	No	MF: As per general comments, the focus TMC product systems is carbon and only four impact categories has been considered for the comparison. CA: The impact category and characterisation models used are standard however, for a new technology no further assessment on impact categories and characterisation models have been	Yes, the focus is climate change. See section 3.9.1 for the selection of the other impact categories that have been examined in detail, and please note that the full spectrum of impact categories offered by the EF 3.1 method is included in the appendix. EF 3.1 is the most up-to-date and robust LCIA method as described in the report. TMC's technology is not new, they are only processing collected nodules using existing technologies who also conduct LCA's using	MF: comment closed. Although this focus of impact categories should be added to the critical review report. EB: Just providing the numbers is not the same like an in-depth discussion. It is ok to select relevant impact categories with a justification. CA: Okay, if the full selection of	Yes

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					conducted to show that they are the most applicable in the context of this LCA.	the EF method. Added to the goal is: "The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A".	impact categories is only compared in the appendix what is the intention and justification for not having this in the report if its a comparative assertion, what are the findings from the full impact category comparison, can this be discussed?	
	Whenever impact categories, category indicators and characterization models are selected in an LCA, the related information and sources shall be referenced.	4.4.2.2.1	CA	No	CA: As above in line 28.	See response.	CA: comment closed.	Yes
	Accurate and descriptive names shall be provided for the impact categories and category indicators.	4.4.2.2.1	MF, EB, CA	Yes	-	-	-	Yes
	The selection of impact categories, category indicators and characterization models shall be both justified and consistent with the goal and scope of the LCA.	4.4.2.2.1	MF, CA	No	MF: As above for 4.4.2.1. CA: This is justified in Chapter 3.9 however this justification is generic, the work could discuss the context of the impact categories for the scope of the work. E.g. are these typical impact categories used for mining.	The selection criteria of the impact categories have now been detailed as per your recommendation. See section 3.9.1.	MF: comment closed. Although this focus of impact categories should be added to the critical review report. EB: I understand that the selection is base on the relevance for mining CA: comment closed.	Yes
	The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration	4.4.2.2.1	MF, CA	No	MF: As above for 4.4.2.1. CA: Though there are 16 impact categories applied it doesn't cover other environmental issues adequately such as biodiversity, land use.	It is acknowledged that the impact categories offered by LCA are insufficient to cover all of the environmental impacts (for this, or any other product system for that matter). However, the goal and scope of this LCA is to	MF: comment closed. Although this focus of impact categories should be added to the critical review report. CA: comment closed.	Yes

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						quantify **aspects** of the environmental impact of TMC's product system and the comparisons. Therefore, a comprehensive (not total, this is impossible) set of issues has been studied.		
	The environmental mechanism and characterization model that relate the LCI results to the category indicator and provide a basis for characterization factors shall be described.	4.4.2.2.1	CA	No	CA: As above in line 20.	See response. The table is now visible and the characterisation models have been added.	CA: Table 11: EF 3.1 Environmental Impact Categories did not show table after the latest version of the PDF please update. There are no references of the characterisation model used for each please update the table if possible as this may be useful context for the readers.	Yes
	The appropriateness of the characterization model used for deriving the category indicator in the context of the goal and scope of the study shall be described.	4.4.2.2.1	CA	No	CA: As above in line 20.	See response.	CA: comment closed.	Yes
	LCI results other than mass and energy flow data included in an LCA (e.g. land use) shall be identified and their relationship to corresponding category indicators shall be determined.	4.4.2.2.1	MF, EB, CA	Yes	-	-	-	Yes

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Comparative LCAs	An LCIA that is intended to be used in comparative assertions intended to be disclosed to the public shall employ a sufficiently comprehensive set of category indicators. Comparison shall be conducted category indicator by category indicator.	4.4.5	MF, CA	No	MF: As above for 4.4.2.1. CA: Although indicators are comprehensive i.e. 16 impact categories their characterisation models may not always be applicable to this case	See previous responses. Added to the goal is: "The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A". According to the standards, only a sufficient amount of impact categories need to be quantified/discussed. Sufficient for this report are those that are relevant for mining LCA's. However, the raw values for all impact categories has still been included in the appendix as the client finds this useful. "	MF: comment closed. Although this focus of impact categories should be added to the critical review report. CA: Okay, if the full selection of impact categories is only compared in the appendix what is the intention and justification for not having this in the report if its a comparative assertion, what are the findings from the full impact category comparison, can this be discussed?	Yes
	The method of calculating indicator results shall be identified and documented, including the value-choices and assumptions used.	4.4.2.4	MF, EB, CA	Yes	-	-	-	Yes
	The application and use of normalization, grouping and weighting methods shall be consistent with the goal and scope of the LCA and it shall be fully transparent. All methods and calculations used shall be documented to provide transparency.	4.4.3.1	MF, EB, CA	Yes	-	-	-	Yes
	The LCA shall not provide the sole basis of comparative assertion.	4.4.5	MF, EB, CA	Yes	-	-	-	Yes
	Category indicators, as a minimum shall be scientifically and technically valid and environmentally relevant.	4.4.5	EB	No	EB: Could you please add a justification of the relevance of the selected impact assessment methods?	This has now been added (see section 3.9.1)	EB: comment closed.	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	An analysis of results for sensitivity and uncertainty shall be conducted for studies intended to be used in comparative assertions intended to be disclosed to the public.	4.4.5	EB	No	EB: not integrated in the comparative part.	To perform an "apples-to-apples" comparison of TMC's product system and the alternatives, everything was kept the same and compared along the base case. As the data quality is higher (based on operational data) for the comparisons, they would not benefit from sensitivity analysis in the same way that TMC's product system did. However, sensitivity analysis was conducted to a great extent on TMC's product system. Those values that are a result of the sensitivity analysis could be compared to the base case comparisons. (Note* - A sensitivity on allocation method is unjustifiable for the terrestrial comparisons that produce co-products since there is no large discrepancies in the price of co-products formed, unlike in TMC's product system). Both the footprint of cobalt and copper are dependant on the allocation method while the footprint of nickel remains consistent. The allocation method (economic allocation for the base case) was chosen from the harmonization of methodologies for Metals. However a metal mass allocation was done as well for a sensitivity analysis as this argument could be made. This variation was discussed in section 6.3 and brought up again in the conclusion. Figure 39 shows the comparison of the allocation methods for each metal in each NORI-D scenario. In summary, the report says: This vast difference in climate change impact between the allocation approaches arises due to the prices and production volume of the metals. Though the production volume of cobalt is low relative to copper and nickel, its	EB: The explanation provided is not sufficient, particularly given the demonstrated relevance of the allocation method to the study outcomes. This study applies a mixed allocation approach, which inherently carries the risk of selective application - or “cherry-picking” that may compromise the robustness and transparency of the conclusions. The influence of the chosen allocation method is especially significant when comparing copper cathode and cobalt. In the case of copper cathode, the study’s conclusions are sensitive to the allocation method used, and therefore not robust. In contrast, the conclusions for cobalt remain consistent regardless of the allocation method applied. This distinction should be clearly acknowledged and reflected in the interpretation of results, as it directly impacts the credibility and reproducibility of the findings. I hope this helps to understand the requirements of section 4.5.4 last paragraph for sensitivity and how you need to address the analysis results in your conclusions.	Yes. Although, it is not the most thorough interpretation with the highest scientific standard and leaves room for interpretation to the reader. Especially for the comparison part, the uncertainty is not sufficiently addressed in all cases.

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
						relatively higher price leads to an increased impact when economic allocation is considered. When metal mass allocation is considered, this impact shifts, leading to a much higher impact for copper with the higher production volume, and a much lower impact for cobalt, with the lower production volume. The climate change impact of nickel does not vary much as its production volume is the highest between the co-products, and its price is between that of copper and cobalt.		
	Weighting, shall not be used in comparative LCAs intended to be disclosed to the public.	4.4.5	MF, EB, CA	Yes	-	-	-	Yes
Interpretation	The results shall be interpreted according to the goal and scope of the study and interpretation shall include a sensitivity check.	4.5.1.1	MF, EB, CA	Yes	-	-	-	Yes
	Appropriateness of the definitions of system functions, system boundary and functional unit as well as limitations identified by data quality assessment and sensitivity analysis shall also be considered in the interpretation.	4.5.1.2	MF, EB, CA	Yes	-	-	-	Yes
	Documentation of data quality assessment and sensitivity analysis, conclusions and any recommendations shall be checked.	4.5.1.2	MF, EB, CA	Yes	-	-	-	Yes
Evaluation	An evaluation shall be undertaken in accordance with the goal and scope of the study. The following techniques shall be considered: - Completeness check	4.5.3.1	MF	No	MF: It is not clear that a completeness and consistency check has been done.	This has been carried out. See earlier responses about validity checks, and data collection. Additional sections have been added to support. Additionally, for the consistency check, data source, accuracy, age, and technological,	MF: comment closed.	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	- Sensitivity check - Consistency check					geographical, and temporal coverage has been analysed for TMC's product system and the comparisons. See table B.13 in the ISO 14044.		
	The findings from the preceding phases (LCI, LCIA) shall be assembled and structured together with information on data quality.	4.5.2.3	MF, CA	No	MF: It is not clear that this has been done. CA: No overall data quality score	No overall data-quality score has been given as this is not mandated by the ISO-standards or sector specific guidelines. All relevant results (and their significance) have been interpreted considering data quality as well, in the results section (section 6 and 7) as part of the goal of this study included interpreting the results. These were again discussed in the conclusions. The data quality section has now been revamped and included quotative assessments of the data quality.	MF: comment closed. CA: As per the 4.2.3.6.1 and 4.2.3.6.2 data quality still requires a quantitative assessment to meet the ISO standard and requirements for comparative assertions intended to be disclosed to the public.	Yes
	When an LCA is intended to be used in comparative assertions intended to be disclosed to the public, the evaluation element shall include interpretative statements based on detailed sensitivity analyses. When the results from the preceding phases (LCI, LCIA) have been found to meet the demands of the goal and scope of the study, the significance of these results shall then be determined. All relevant results available at the time shall be gathered and consolidated for further analysis, including information on data quality.	4.5.2.3 and 4.5.3.3	EB	No	EB: Please state the used sources clearly.	TMC's system and the comparison system has been detailed and interpreted in the results section if the report. Detailed sensitivity analysis has been conducted on TMC's system Sources of data for the reference system as well as TMC's has now been cited.	EB: In the text I could not find the references/sources for data.	Yes

Category	ISO 14044 Requirement	ISO 14044 clause number	Reviewer initials	Conforms to ISO requirement (Yes or No) at beginning of review	Reviewer comment	Practitioner of the LCA study response	Reviewer response	Conforms to ISO requirement (Yes or No) at end of review
	The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete. If any relevant information is missing or incomplete, the necessity of such information for satisfying the goal and scope of the LCA shall be considered. This finding and its justification shall be recorded.	4.5.3.2	MF	No	MF: It is not clear that this has been done.	As all relevant life cycle stages and flows are included in the system boundary, the completeness check has been intrinsically completed. Nothing was left out. The list of exclusions of the system boundary has been extend, with an additional paragraph in section 3.2 (system boundary).	MF: comment closed.	Yes
	The sensitivity check shall include the results of the sensitivity analysis and uncertainty analysis, if performed in the preceding phases (LCI, LCIA). In a sensitivity check, consideration shall be given to – the issues predetermined by the goal and scope of the study, – the results from all other phases of the study, and – expert judgements and previous experiences. When an LCA is intended to be used in comparative assertions intended to be disclosed to the public, the evaluation element shall include interpretative statements based on detailed sensitivity analyses.	4.5.3.3	EB	No	EB: Yes for the core system The reference system requires more transparency on data sources and LCI to determine the need for sensitivity analysis. It shall be noted, that the sensitivity analysis revealed that the allocation method matters. This was not repeated for the comparative assertion allocation method	See response in cell G59. It should be noted that TMC's system is the only system in this study that produces 4 metal containing co-products (Mn, Ni, Cu, and Co). The Canada Norway route also produces Ni, Cu, Co as co-products, but the dataset was pre allocated, also using economic allocation as with the base case. This is shown in the system boundary diagram of figure 56 and the allocation table in table 21. All other system only produced a single metal, or one co-product. Allocation always followed the methodology recommended by the harmonization of LCA methodologies for metals For TMC's system: Both the footprint of cobalt and copper are dependant on the allocation method while the footprint of nickel remains consistent. The allocation method (economic allocation for the base case) was chosen from the harmonization of methodologies for Metals. However a metal mass allocation was done as well for a sensitivity analysis as this argument could be made. This variation was discussed in section 6.3 and brought up	EB: see H59	Yes

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						again in the conclusion. Figure 39 shows the comparison of the allocation methods for each metal in each NORI-D scenario. In summary, the report says: "This vast difference in climate change impact between the allocation approaches arises due to the prices and production volume of the metals. Though the production volume of cobalt is low relative to copper and nickel, its relatively higher price leads to an increased impact when economic allocation is considered. When metal mass allocation is considered, this impact shifts, leading to a much higher impact for copper with the higher production volume, and a much lower impact for cobalt, with the lower production volume. The climate change impact of nickel does not vary much as its production volume is the highest between the co-products, and its price is between that of copper and cobalt"		
	If relevant to the LCA or LCI study the following questions shall be addressed. - Are differences in data quality along a product system life cycle and between different product systems consistent with the goal and scope of the study - Have regional and/or temporal differences, if any, been consistently applied? - Have allocation rules and the system boundary been consistently applied to all product systems? - Have the elements of impact assessment been consistently applied?	4.5.3.4	MF, EB	No	MF: It is not clear that this has been done. EB: Regional and temporal differences are sufficiently covered and the general data quality of the core system is consistent with the goal and scope of a prospective LCA Allocation ruled: see comment #12 and 13	Yes this has been done. Additionally, see comment in cell G59.	MF: comment closed.	Yes
Conclusions	Conclusions shall be drawn from the study.	4.5.4	MF, EB, CA	Yes	-	-	-	Yes

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	Recommendations shall be based on the final conclusions of the study, and shall reflect a logical and reasonable consequence of the conclusions.							
Reporting	The results and conclusions of the LCA shall be completely and accurately reported without bias to the intended audience.	5.1.1	EB	No	EB: While the results are very elaborated, the reader is a bit lost in the interpretation of the results. The comparative assessment requires more support to the reader to understand when a difference in the results is really significant or within the expected uncertainty.	There is not bias to the intended audience here. The results are completely and accurately reported. However, since this is a mining LCA, it is acknowledged that those without knowledge in this particular industry may struggle to understand the significance of the results. A statement has been added to the report for the possibility of misinterpretation or selective use of results. It is as follows: "Ecoquant recognizes the debate on the technology that is studied in this report and the possibility of selective use of individual data to support claims. As the target audience includes anyone interested in deep-sea mining, it should be noted that the authors and commissioning party do not assume responsibility for the interpretations made by parties who lack the necessary technical background. Misinterpretation or selective use of individual findings outside the context of the complete study may lead to inaccurate conclusions". All sources for the comparisons have now been cited. The paragraph is section 7 has now been expanded and reads as flows: The chosen routes are used to display the environmental impacts for producing the respective product using the stated technologies. The selection of the routes reflects the most common current pathways for sourcing these metals, while also including a few lower-impact routes for	EB: The reasoning presented in the comment is, diplomatically stated, questionable and not in accordance with ISO 14044, section 4.5.4. It is the responsibility of the LCA practitioner to present results as clearly and unambiguously as possible, particularly when key information, such as data sources used for comparative assertions, is not disclosed. It is not the audience's task to interpret or resolve such ambiguities, especially when the audience may include parties such as journalists, NGOs, or investors. The reviewer acknowledges that the practitioner is aware of the risk of misinterpretation when the study is disclosed to the public, particularly given the anticipated interest from stakeholders with varying levels of technical expertise. Moreover, the term "significance" is commonly used in statistical analysis and LCA methodology. In general, the fact that one numerical result is lower than another does not automatically imply statistical or methodological significance. A defined significance level is necessary to determine whether observed differences fall within the same range or are meaningfully different. As such, the argument made in the comment lacks	Yes

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						comparison, providing a broader and more balanced perspective. However, the impacts of the same product produced using the same technologies may vary depending on parameters such as technological efficiencies, geographies, power sources, ore grades, and other local conditions. For pathways with lower data quality, variations in results can be partially attributed to the limitations of the underlying data.	methodological soundness in this regard. Should further clarification on the concept of significance level be needed, I am available for consultation.	
	The type and format of the report shall be defined in the scope phase of the study.	5.1.1	MF, EB, CA	Yes	-	-	-	Yes
	The results, data, methods, assumptions and limitations shall be transparent and presented in sufficient detail to allow the reader to comprehend the complexities and trade-offs inherent in the LCA. The report shall also allow the results and interpretation to be used in a manner consistent with the goals of the study.	5.1.1	MF, EB	No	MF: As per general comments, the LCI is limited for both TMC and comparative product systems and could do with expanding on to make it as transparent as possible. EB: The results would benefit from greater transparency, particularly regarding the comparative products, which were not included in the accompanying Excel file. Given the controversial nature of the mining process examined in this study, it's important to acknowledge that some potential trade-offs may fall outside the scope of a traditional LCA. To support a comprehensive understanding, readers should be informed that this environmental assessment is complemented by other ongoing company initiatives aimed at evaluating broader ecosystem impacts.	The LCI is complete for TMC and the comparisons (which are available to the reviewers). The trade-offs falling outside the scope of the LCA and the fact that ongoing company initiatives on broader ecosystem impacts are taking place has been discussed in the goal. It has also now been added to the conclusion for greater transparency. All sources for the comparison system has now been cited, all known flows (including waste) was included for the comparisons. The methodological choices, and database for emissions factors for the comparison system follows the same methodological choices of the reference system. The choice of allocation method is stipulated by the document "Harmonization of LCA Methodologies for Metals"	MF: At the very least the sources used for the comparative products need to be referenced in the report for transparency. EB: Let me be more specific, for the comparisons, only the LCI and the total result is provided. Missing is: - Uncertainties and sensitivity to methodological choices is not provided in the report. - datasets/proxies used - Exclusions and Assumptions e.g. I am not seeing waste and waste management. No waste in mining? - sources/references are unclear. Although the study states ""site-specific primary sources"", no info about the sampling procedure and processing of the data is given.	Yes
	When results of the LCA are to be communicated to any third party (i.e. interested party other than the commissioner or the practitioner of the study), regardless of the form of	5.2	MF, EB	No	MF: Third-party report not discussed in the main technical report. This can be the full report with any confidential information removed. EB: The executive summary may	The client will create a summary report for communication to third parties. We will ensure that the third party report contains all relevant information stipulated in clause 5.2. Now added to the final paragraph of the goal section in the report.	MF: can this be added to the report i.e. that a summarise version of the full technical report will be made as serve as the third-party report.	Yes

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	communication, a third-party report shall be prepared. The third-party report can be based on study documentation that contains confidential information that may not be included in the third-party report.				serve this function, however, it requires a more in-depth evaluation and interpretation given the maturity of the process and the controversial nature. Especially the comparative parts benefits from a higher transparency as mentioned			
	The third-party report constitutes a reference document, and shall be made available to any third party to whom the communication is made.	5.2	MF	No	MF: As above.	Now added to the final paragraph of the goal section in the report.	MF: can this be added to the report i.e. that a summarise version of the full technical report will be made as serve as the third-party report.	Yes
	The third-party report shall cover the aspects listed in 5.2 and 5.3.	5.2 and 5.3	MF	No	MF: As above.	Now added to the final paragraph of the goal section in the report.	MF: can this be added to the report i.e. that a summarise version of the full technical report will be made as serve as the third-party report.	Yes
Critical Review	The critical review shall ensure that the methods used to carry out the LCA are consistent with the ISO14044 standard, scientifically and technically valid, data is appropriate and reasonable, interpretations reflect limitations and study is transparent and consistent.	6.1	MF, EB, CA	Yes	-	-	-	Yes
	The scope and type of critical review desired shall be defined in the scope phase of an LCA, and the decision on the type of critical review shall be recorded.	6.1	MF, EB, CA	Yes	-	-	-	Yes

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	A panel of interested parties shall conduct critical reviews of LCAs being disclosed to the public.	6.1	MF, EB, CA	No	MF: earlier discussion was had on the inclusion of an NGO, terrestrial mining expert or other interested parties. Please add commentary on in the report as to how the panel were selected. EB: see comments shared via email earlier in the process. The inclusion of a Mining expert is recommended. CA: The panel doesn't consider interested parties from terrestrial mining nor deep sea explorations.	Section 3.12 now talks about the selection process. "interested parties" may be LCA practitioners. There are those on this panel who have reviewed other mining LCA's.	MF: comment closed. EB: comment closed. CA: comment closed.	Yes
	A critical review may be carried out by an internal or external expert. In such a case, an expert independent of the LCA shall perform the review.	6.1	MF, EB, CA	Yes	-	-	-	Yes
	For LCIA, the expertise of reviewers in the scientific disciplines relevant to the important impact categories of the study, in addition to other expertise and interest, shall be considered.	6.3	EB	No	EB: To my knowledge the review panel does not include a mining and metals specialist.	The expertise of each panellist was considered during the selection process. See section 3.12 which has now been expanded to talk about the selection process.	EB: comment closed.	Yes
	A review statement and review panel report, as well as comments of the expert and any responses to recommendations made by the reviewer or by the panel, shall be included in the LCA report.	6.3	MF, EB, CA	Yes	-	-	-	Yes
	Additional requirements of ISO 14071 shall be followed for the review panel report.	ISO 14071	MF, EB, CA	Yes	-	-	-	Yes
2017 and 2020 amendments	All footprint methodologies and footprint studies shall be prepared in accordance with Annex C.	4.1	MF, EB, CA	n/a	-	-	-	n/a

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	If any footprint information is not communicated to third parties, the requirements of 5.1.1 shall apply.	(5) Annex C.2	MF, EB, CA	n/a	-	-	-	n/a
	If any footprint information is intended to be communicated to third parties, a third-party report in accordance with 5.1.2 and 5.2 c) shall be prepared and shall become the footprint study report, regardless of the chosen footprint communication. This third-party report shall serve as an input for the development of any footprint communication formats that might have to fulfil additional requirements in accordance with the relevant International Standards on environmental labels and declarations developed by ISO/TC 207/SC 3.	(5) Annex C.2	MF, EB, CA	n/a	-	-	-	n/a
	Footprints shall be named in a way that accurately reflects the area of concern or reflects the potential environmental impacts assessed. Where an area of concern has only been partially assessed, an alternative name descriptive of the narrower scope shall be applied.	(5) Annex C.2	MF, EB, CA	n/a	-	-	-	n/a
	The report of the footprint quantification shall document the limitations with regard to selected environmental impact categories in a transparent manner.	(5) Annex C.2	MF, EB, CA	n/a	-	-	-	n/a

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	Footprints shall not be used in comparative assertions intended to be disclosed to the public.	(5) Annex C.2	MF, EB, CA	n/a	-	-	-	n/a
	When an organization decides to use a footprint study report as a basis of a footprint communication, this footprint study report shall be publicly available in accordance with 5.2.	(6) Annex C.3	MF, EB, CA	n/a	-	-	-	n/a
	When a critical review is performed, it shall be in accordance with Clause 6 or ISO/TS 14071.	(6) Annex C.3	MF, EB, CA	n/a	-	-	-	n/a

Table 2 – Log of general review comments and responses

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
General	MF	High	The focus of the study is carbon for the TMC product systems, and limited to four impact categories for the comparisons with terrestrial systems. A (perhaps "the") key requirement of the ISO 14044 and LCAs in general is that multiple impact categories are considered e.g. requirement 4.4.2.2.1 "The selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking the goal and scope into consideration" and requirement 4.4.5 "An LCIA that is intended to be used in comparative assertions intended to be disclosed to the public shall employ a sufficiently comprehensive set of category indicators.". Therefore, results for other impact categories should be presented in detail and comparisons made between product systems one impact category at a time. This could all be done in one figure for each product system using 100% stacked charts.	See sheet "ISO 14044 Requirements", cell G20.	Comment closed. Although this focus of impact categories should be added to the critical review report.
General	MF	High	The key limitation of the LCA is the exclusion of impacts associated with nodule and seafloor disturbance and associated (potential) habitat destruction and the discharge of sediment. These are "the" key issues being discussed in the media and LCA cannot currently adequately access these. At the very least there should be more discussion of these limitations in the report, and it should form a key part of the critical review statement. Ideally, however, an attempt should be made to integrate these issues into the LCA e.g. you could potentially analyse the mining area through the lens of indirect land use change to gain a comparative understanding of area productivity. In this context, obtaining more detailed information about the total operational damage area could serve as an indicator for a potential biodiversity loss. With conventional mining, land use changes can be assessed using LCA (albeit with limitations), but obviously this is much more difficult with deep sea mining. The waste in terms of sediment discharge would likely be more straightforward for both systems. If it is too difficult to integrate these two issues into LCA though then more discussion of these limitations could be added to the report with reference to the other studies TMC have conducted on nodule and seafloor disturbance and discharge of sediment.	This LCA is conducted using the EF 3.1 methodology considering all impact categories offered as stated in the goal. Unfortunately, EF 3.1 (or any other life cycle impact assessment method) does not have an indicator that measures impacts on the seafloor. I want to make it clear, as I've mentioned in the report, that impacts from land-based mining leading to land changes (except soil quality), potential harm on forest ecosystems, other potential habitat destruction, and temporal impacts are also not measured. This is not only a limitation of this LCA, it is a limitation of all mining LCA's. I only explicitly mentioned that seafloor impacts are not measured as I know some readers will likely not remain impartial. We are not conducting a full environmental assessment of TMC's operations, we are simply conducting an LCA using what is thought to be the most robust LCA methodology. TMC has conducted their own studies for impacts on the sea-bed that can be found on their website. With that being said, limitations have been discussed in depth within the report.	Comment closed. Although we should add this as a note to the critical review report.
General	MF	High	In general the LCI is limited for both TMC and comparative product systems. For example, how were the quantities of coal, marine diesel, electricity derived? Do these directly relate to the quantities of product produced? How were the quantities of product produced derived e.g. assumptions on yield, amount extracted per day etc.? Bulk carrier stages seem to be missing from the inventory - what assumptions were made here e.g. utilisation, loading etc? There is very little detail on the activity data and secondary data and assumptions used for the terrestrial systems. As a general rule the LCA report should provide enough detail to allow someone to replicate results well.	See sheet "ISO 14044 Requirements", cell G32. Sources for the comparisons have now been added.	At the very least the sources used for the comparative products need to be referenced in the report for transparency. Comment closed.
Page 40. Table 5	MF	High	Also excluded from the study is the transportation of crew to and from the production ship (likely by helicopter) - this transportation should really be	Not included in the product system as these are not material for the production of TMC's products. See section 3.2 (system boundary) and table 5.	Comment closed.

Page number of comment	**Reviewer initials**	**Priority**	**Reviewer comment**	**Practitioner of the LCA study response**	**Reviewer response**
			included in the study. Likewise, do they need guard vessels, support vessels to bring supplies?		
Page 50. Section 4.7	MF	High	More information about cut-off criteria and exclusions is needed i.e. what are the criteria for considering an exclusions and a list of all the exclusions and justification.	List of exclusions expanded (table 5). No cut-off criteria was used. See section 3.11.	Comment closed.
Table 5	MF	High	As above in relation to exclusions, please add justification to exclusions in Table 5 and add in any exclusions that have been missing (e.g. discharge of sediments).	Table expanded, also justifications now added in new paragraph in section 3.2.	Comment closed.
Page 50. Section 4.8	MF	High	Make it clear in the data section that production has not started yet and that all data are theoretical based on pilot studies, modelling, similar processes and input from industry experts.	This has been added.	Comment closed.
Table 9	MF	High	Related to the comment above, activity data are scored as good or very good despite being largely theoretical. I think it needs to be acknowledged that the data are at best fair given that production has not yet started.	The data is ranked on various indicators (technological, temporal, geographical) using the GHG protocol product standard data quality ranking system. Additionally, according to the GBA GHG rulebook, primary data can be from stoichiometric calculations, engineering models, or product balances (all methods for which these data were generated by Hatch for TMC's product system). However, as the data is not for current operational processes, technological representativeness does not receive the highest score.	Comment closed.
Page 51. Section 3.8.2	MF	High	Also related to the comment above, there is a sentence on data quality that reads "12-month averages representing the year 2024 to compensate for seasonal influence and variability of data" - is this correct? Were data taken from 12 months of operation?	Yes this is correct. See section 3.8.1 of the report or see response in sheet "ISO 14044 Requirements", cell G32.	Comment closed.
Page 50. Section 3.8.1	MF	High	Please add a data section to include where terrestrial mining data have come from for the comparison.	See the first paragraph of section 7. The data is available to the reviewers but will not be included in the LCA report. However, it can be made available upon request. Sources for the comparisons have now been added.	The sources need to be referenced in the report for transparency. Comment closed.
Page 91. Section 5	MF	High	Before moving onto further analysis in section 6, base case results for other impact categories should be presented and interpreted.	This study has 3 goals, to first quantify aspects of the environmental impact for the production of TMC's products, secondly to quantify aspects of the environmental impact for the production of SiMn, and thirdly to compare the results to the same products produced terrestrially. Since TMC's product system is the novel system, it first had to be described in detail before comparing to the terrestrial system to avoid confusion to the reader. This is why TMC's system and all methodological consideration were first described in detail. It was mentioned that the comparison followed the same methodological considerations (section 7.1).	Comment closed.
Page 117. Section 7.2.1.3	MF	High	For TMC' operations, sediment resuspension is a waste stream, and sea bed disturbance should really be seen as a land use change, but these issues are not captured by LCA. These issues should be noted here in section 7.2.1.3	It is noted throughout the report that these issues are not captured by LCA. Sediments and impacts to seafloor ecosystems is in the list of exclusions in table 5.	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
Page 164. Figure 74 and throughout	MF	High	While land use change is an important factor to consider in mining operations, I feel it is misleading to highlight the land use results in this report. The waste generated and land use change created by deep sea mining is not 'absent', it is just not captured by the LCA. I think at the very least, as caution should be added to the land use results to explain that the key impacts are not considered for deep sea mining.	Land use results have been removed and replaced with freshwater eutrophication, a recommended impact category for mining LCA's.	Comment closed.
Page 168. Section 8	MF	High	As mentioned previously, the deep sea mining does produce it's own version of tailings - sediment that is discharge, transported with the nodules (as well as sediment disturbance on the seafloor). However, it is not captured by LCA methodologies. I don't think you can write 'absent' with regards to the tailings. It would be better to discuss the likely amounts of deep sea sediment vs terrestrial waste and how the impact is not captured for the deep sea mining. On a similar note, there are references to deep sea mining not producing waste (e.g. pg 35) - it does, it is just not captured.	This is a great point, Though I believe it is debatable. I am not sure if the sediment should be considered waste since it only becomes suspended and then re-settles without any chemical change. Now added. Section 3.5.1 reads "Within the vehicle, more than 90% of the sediment is filtered out and discharged from the collector back to the seafloor without any chemical change".	Can this be mentioned in brief in the report. Just the response you have given here would be good. They are also still references to the TMC nodule collected having "no waste". Comment closed.
Pge 42. Section 3.5.1	MF	High	It is worth considering and mentioning the potential for CO2 release from sediment resuspended at the ocean surface, which would not be captured well by LCA. Perhaps you will receive questions about this. Many deep-sea sediments are rich in calcium carbonate from the shells of planktonic micro and nano-organisms that rain down onto the seafloor (depending on depth and acidity of ocean waters in an area). If large quantities of sediments are taken from the deep-sea and resuspended at the ocean surface the carbonate content is likely to neutralise any ocean acidity, and thus release CO2 back to the atmosphere. However, the CCZ is generally an abyssal zone ~4.5 to 5 km deep, which is around and below the carbonate compensation depth (CCD at ~4.5 km in the pacific ocean). The CCD is the depth at which calcium carbonate is totally dissolved into the ocean. So in theory the sediments below the CCD should be free of calcium carbonate and therefore not an issue. It is mentioned that the collection area is up to 4.5 km deep - so there may be some carbonate content in the sediment. Even with 90% of the sediment removed at the seafloor, the remaining 10% could release CO2 at the surface, is there an estimate of sediment discharge at the ocean surface? Of course there will be other biogeochemical issues around re-suspension of sediments (e.g. introducing metal-rich materials into the ocean surface could lead to algal blooms), but this is more of an ecological issue and not for the LCA, but should be highlighted.	Great point. This topic is covered by analyses covered by TMC. At the depth, there is no/very minimal amounts of CO2 that would be released to the surface. Added	Can this be mentioned in brief in the report. Just the response you have given here would be good. Comment closed. Comment closed,
Excel model	EB	High	I think, the model could have been made simpler. It was not possible to check for completeness or the mass balance.	The main data tab is from the client. The LCI tab normalises these data to the relevant functional units.	Comment closed. The response does not address the comment, but ok and to exclude the task in the review statement.

Page number of comment	**Reviewer initials**	**Priority**	**Reviewer comment**	**Practitioner of the LCA study response**	**Reviewer response**
Excel model / Cut-off criteria	EB	High	In the model there are several Inputs unconsidered. Comparing "MAIN" and the results, I am missing some reported Inputs e.g. for Hydro: liquid oxygen, activated carbon. Could you please check? I was also not able to check the mass balance properly. How do emissions reported in "MAIN "correspond to the calculated footprints? Are there no consumables, lubricants, wastes, wastewater etc in the off-shore part?	See comment in cell G32 in "ISO 14044 requirements" sheet. The "LCI" tab has the data that was used to conduct the LCI. Liquid oxygen is assumed to be produced onsite and is included in the electricity usage. No other waste from the offshore part. The only consumable is the marine fuel oil that powers the generators. Yes this is correct.	Confirmation needed. My understanding is, that the liquid oxygen is included in the 266200 MWh process electricity. Could you please confirm? Comment closed.
Introduction	EB	High	The study provides many data and graphs, however, an interpretation and conclusion needs to be added to help the reader understand what we see.. The introduction of a significance level (taking the robustness of the method into account) plus considering the overall uncertainty will help the reader to understand whether a difference is significant. Please note, just because there is not a written statement claiming superiority does not mean that the study does not suggest it. (1) The way graphs are clustered suggest superiority which requires more context and interpretation esp when differences are insignificant. (2) Maybe you can add the TRL to the Processes to help understand the variance.	Interpretations are included in the results section to help readers understand what drives the impacts for each route. For example, copper production in the DRC route has the lowest climate change impact among all evaluated routes. "This is partly due to the large degree of hydropower used in their production processes, but also because of the relatively high grade of copper ores and cobalt forming as a co-product which share the environmental load". Uncertainties are not driving the differences that we see in the results, (note that the comparisons which are largely based on real operational data have very low uncertainty levels, but the results for each route vary) rather, the difference are driven by the production methods, grade of the ores, the specific electricity-grid ,whether co-products form or not, etc. Therefore, within an impact category (such as climate change), the results for one pathway may very well be superior to another.	Comment closed. See the new specific comments on the interpretation.
General / LCI	EB	High	Please elaborate more on the data sources used and the LCIs, both core and comparative system.	See comment in cell G32 in "ISO 14044 requirements" sheet.	Comment closed. redundant.
LCI	EB	High	Could you please describe validation procedures for the inventories, both the core system and the comparisons	See comment in cell G31 in "ISO 14044 requirements" sheet. For the comparisons, see section 7 where I added a sentence on the validation procedure as per your recommendation.	Comment closed.
General	EB	High	sources shall be referenced in a scientific way, this is of particular importance of the reference system.	I am not sure which sources are meant here, however the report now mentions Hatch for the onshore data collection, and AllSeas for the offshore data collection. Data for TMC's reference system, as well as the comparisons have now been cited. The data from Allseas on marine fuel usage is not yet publicly available.	Comment closed.
42	EB	High	"These vehicles use water jets to gently lift the nodules from the seabed. " I would prefer a more neutral language. Can you elaborate what "gently" means, esp. as this suggest to the reader that there is no real harm on the seabed. Could you please elaborate a bit more the process of sediment release e.g. the volume it pollutes as this is a major criticism of the technology.	The word gently has been removed. I am not sure if pollute is the right term here. This report does not go into detail about the sediment as this is not something that we measure. I understand that there are criticisms around that point, however answers to those can be found in other studies conducted by TMC.	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
Allocation	EB	High	Could you please provide a justification of the mix of allocation methods, esp. The system expansion of ammonium sulphate.	As ammonium sulfate is a non-metal co-product generated in a product mix with metals, avoiding allocation by system expansion is the recommended approach (sector specific guidance - harmonization of metals, santero and hendry). See section 3.6.3.2 and the allocation section for more details. (Also, please note that due to the share volume of non-metallic by-products that form in some metal refining processes, allocation would severely decrease the environmental impacts of the metals.	Comment closed.
Allocation	EB	High	Please reference correctly "Santero and Hendry". I would not recommend to adopt this without an evaluation of the tendencies. If in 10 years the price is constantly raising, I would not recommend to use a 10yr average, but to go to the upper end instead (see Copper). Economic allocation requires some market research.	It is not only santero and hendry, most guidance (PACT, GBA, Catena-X etc.) recommends a 5-10 yr average on the price of metals for an economic allocation. Though I can understand the application to an extent, it won't be fair to choose the highest price for copper, cobalt, and nickel. This will be different years for each metal. It would be hard to justify for example, using the 2018 price of cobalt, 2022 price of copper, and 2015 price of nickel for an economic allocation.	Comment closed. Shared a reference with you.
49	EB	High	"All other inputs" should be 14.6% for Co. Typo?	Yes this is a typo in the text, good catch. This has been adjusted.	Comment closed.
52 /54	EB	High	The section describes that the data are mainly calculated or estimated (not measured). This puts a limitation on precision (footnote p 54). For transparency it is easier if this is directly linked to the processes	Correct, as we discussed in previous comments, the data was generated by Hatch. The fact that TMC's processes are not yet operational, are reflected in the data quality ratings.	Comment closed. But you need to take this into consideration when interpreting the data. See other comments
58	EB	High	"Interpretation": Please elaborate also the use and interpretation of the comparative part especially if conclusions about the superiority shall be made or not.	As per your recommendation, a paragraph has now been added in section 3.11 to discuss how the comparative part was interpreted.	Comment closed.
58	EB	High	One further limitation is that some aspects seem to be excluded (see comment above). To help fully understand, could you indicate how mature processes are e.g. by indicating the TRL level and the respective robustness.	Mining is very mature and the processing technologies (e.g. TMC uses RKEF, solvent extraction, electrowinning) have existed for a long time and are very established. These are not novel. The collected nodules are being processed using existing technologies. Therefore, TRL's are not so relevant for mining projects. Instead, the mining industry focuses on studies. There is first a preliminary economic assessment (PEA), followed by a Pre-Feasibility Study (PFS), followed by a feasibility study which is used for detailed engineering, commissioning and construction. "A paragraph on this has now been added to section 3.8.1.1 in the report. It is as follows: ""The process data employed as input to the LCA was from TMC's pre-feasibility study (2025). In mining project development, pre-feasibility studies are more detailed than initial assessment and scoping studies as they contain preliminary engineering, metallurgical tests, and environmental baseline studies. However, they are less detailed than feasibility studies which entail detail engineering, final CAPEX and OPEX estimates, and execution plans."" Fuel usage is from Allseas who has been in operations for >40 years.	Why don't you just add this in the report and we can close the comment? Do I understand correct: the fuel consumption is modelled data, not measured data Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
				They estimated the fuel usage for each vessel individually for TMC's entire operation based on annual fuel usage per vessel."	
60	EB	High	Inventory does not correspond to "LCI" in Excel e.g. the fuel consumption, silica. There are also two columns in the excel. I did not check each value, but there are several differences.	The LCI table in the report corresponds to the LCI tab in the excel. The silica value appears twice in the excel because it is used in two distinct prices during pyrometallurgy, however they have been summed together in the LCI table.	Comment closed.
63 and general	EB	High	Figure 3 and all similar. I understand that there is a small credit involved for system expansion of by-products (converter sludge, Ammonium Sulphate). It is not in the Legend and the reader needs to know, if the presented values are netted.	I have added, "net results" to all figures in the executive summary to make it clear that everything (including the system expansion) is included in the results. In text I have made mentioned that all impacts, including the credits, are including in the total graphs. In order to make this more transparent i would need to go into the model of >15 different datasets to change the graphs. As the credit has been mentioned in text, I do not think the effort of remodelling to visibly show the credit are warranted.	It is best practice and in some standards mandatory to make this impact transparent.
Multiple Chapters on results	EB	High	The text remains mainly descriptive and would benefit from context and interpretation: what do we learn; how can we improve; what are the low or high hanging fruits; what matters, what not; how robust it the result etc. Please also add the key conclusions	The insights are sufficient for the client. The conclusions has been extended. The target audience in the goal has now been expanded and it is mentioned that those lacking expertise may cherry pick or come to inaccurate conclusions. It is stated that: "As the target audience includes anyone interested in deep-sea mining, it should be noted that the authors and commissioning party do not assume responsibility for the interpretations made by parties who lack the necessary technical background. Misinterpretation or selective use of individual findings outside the context of the complete study may lead to inaccurate conclusions."	The insights need to be sufficient for your entire target audience. I understand the intention is to prevent misinterpretation of the findings. However, the current wording could be read as dismissive toward non-technical readers, which may be counterproductive given that the target audience explicitly includes "anyone interested in deep-sea mining.
Sensitivity and anything that places results next to each other suggesting a comparison.	EB	High	Please mention, if a difference is significant to help the reader to understand if a difference is significant or not.	See response in cell G71 "ISO 14044 requirements" sheet. The paragraph is section 7 has now been expanded and reads as flows: "The chosen routes are used to display the environmental impacts for producing the respective product using the stated technologies. The selection of the routes reflects the most common current pathways for sourcing these metals, while also including a few lower-impact routes for comparison, providing a broader and more balanced perspective. However, the impacts of the same product produced using the same technologies may vary depending on parameters such as technological efficiencies, geographies, power sources, ore grades, and other local conditions. For pathways with lower data quality, variations in results can be partially attributed to the limitations of the underlying data"	See H71 n cell G71 "ISO 14044 requirements" sheet. Comment closed.

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Chapter 6	EB	High	I am missing a bit conclusions and a real interpretation/link to the processes. Plus, I would compare FU per FU because this is what you want to show. (see previous comments)	Functional unit per functional units have been compared. See table 14 in section 7.1 for the functional unit of each terrestrial comparison, and the following sections for the results. The conclusions have been extended.	Comment closed.
Figure 39	EB	High	What is the key for the metal mass allocation incl. copper? Because it is missing in the excel file	Everything remains the same but the instead of economic allocation (base case), metal mass allocation was employed. This is in a separate file and is available for your review.	Comment closed.
Figure 41 and ff	EB	High	I needed quite a bit to understand the graph and I find it a bit misleading. 10% variation for the nodules will be lower than 5% for Cobalt.	Yes you are correct that it would be lower than 5% for cobalt. The 10% variation in marine fuel usage had an influence of 1% for the Co, Ni and Cu. Please refer to the accompanying text for the figure.	I close this comment as the section is not too relevant. Comment closed.
Chapter 7	EB	High	see above: the LCI, the validation procedure of the LCI of the comparisons is missing. We would also need more details for the reference system to compare the values and get a feeling how realistic the calculations are.	See response in cell F21.	Comment closed.
Chapter 7	EB	High	The LCI of the comparatives seem to be selected site specific, can an industry average be added? Plus how representative, complete, are the data for an average value.	See response in cell G23 "ISO 14044 requirements" sheet.	Comment closed.
Chapter 7	EB	High	Please provide more details how the Impact assessment methods for the comparative assessment were selected. Please also provide info that the Categories are the most relevant for the systems under study. Does it follow a sector guidance? Which one?	This has now been detailed in its own section (section 3.9.1)	Comment closed.
Table 1021	EB	High	Table 1021: Allocation factor (6670 $/ton) for Copper Cathode is different than in the Excel. Typo: please check and in case it is not a typo could you elaborate this more?	This dataset is from a comparison scenario. It is from a published source and has been previously allocated, the dataset could not be disaggregated. The 10 year average price of copper used here (6670) does not reflect the latest 10 year average (7114), though the values are very close. Note that the data quality ranking for this route is low. Sources have now all been cited. Table 21 shows the allocation table for this mentioned comparison route.	In general ok, but the documentation could be improved. A data quality rating is a different aspect than a proper documentation. Comment closed.
128 ff	EB	High	The transparency, data quality and completeness does not provide enough evidence for the statements.	I am not sure what you mean. All data has now been cited with explanation on how the data was taken from those sources. For the comparisons. Each route is based on the best publicly available data from company sustainability reports, ESG databooks, literature, and third party databases.18-29 Where data was not available, mass and energy balances, or proxy data was used. The data was extracted from these sources and modelled consistently with the methodology described in this report. The values presented in this report do not reflect the official disclosures or positions of the companies mentioned, as the system boundaries, assumptions, and emission factors used in the modelling may differ from those employed by the	It is not described how data were obtained. You mention you collected primary data. This alone does not make it representative. 2 options: (1) It is site specific and conclusions can be made only comparing the DSM metal and the particular site. (2) you evaluate how representative your selected site is as a representative of an industry average. See also comment G45

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				respective companies. No industry averages were used. Stated in section 7: "The selection of the routes reflects the most common current pathways for sourcing these metals, while also including a few lower-impact routes for comparison, providing a broader and more balanced perspective" For TMC's system: The process data employed as input to the LCA was from TMC's pre-feasibility study (2025). This data is contained in the technical report summary available in annex B.	Comment closed.
General	EB	High	Ecoinvent value for Cobalt sulfate is between 29 and 30 kg CO2e/kg. Can you explain the difference? As mentioned before here it is particularly important to reference well the primary data source and the data used and to ensure its representativeness. FYI I also checked other values	The first difference is that the reference product in ecoinvent is cobalt sulfate, the reference product throughout this report is Co in cobalt sulfate. Additionally, the production pathways to produce cobalt sulfate are different. It is produced via rkef, leaching, and solvent extraction for TMC product system, it is produced via MHP for the Indonesian route, and it is produced from the DRC using hydrometallurgy for the DRC-China route.	Comment closed.
153	EB	High	The interpretation of land use should clearly address the limitations of the method and the significance level	This has now been spoken about in detail. See response. Note that the caption of every land use results also mention that land-use impacts on the sea-bed are not captured.	Comment closed.
To add	EB	High	Please add an overview of the Proxies used. This can also be an attachment.	See comment in cell G32 in "ISO 14044 requirements" sheet. Data on the comparisons can be made available upon request. Report now contains all sources.	Comment closed.
Chapter 7 DQRs	EB	High	Site specific data for a comparative system may or may not be representative for an industry average. Here we do not benchmark how accurate a specific inventory is, but how suitable it is as a benchmark.	See response in cell G23 "ISO 14044 requirements" sheet. Report now contains all sources. Section 7 states: "The selection of the routes reflects the most common current pathways for sourcing these metals, while also including a few lower-impact routes for comparison, providing a broader and more balanced perspective"	Please describe the sampling method in the report for the reader. Which site did you pick and why and how representative is it. Comment closed.
Pg 2-29 Executive summary	CA	High	The entire executive summary could be improved and made more concise. For executive-level readers, the key findings should be provided in bullet points. Some of the figures are repetitive and do not provide any key information, some figures could be combined into 1(e.g. figure E2,E3,E4) and (E5,E6,E7,E8)	In some cases yes. The client is okay with this executive summary, they prefer this level of detail. A third party report will be prepared by the client for communication purposes that will be more digestible. This has now been mentioned in the goal section of the report.	Executive summary has been updated. My recommendation is to consider the other readers as the client is not the only intended audience. Others may benefit from some bullet points summarising what the key results are the graphs are mostly left without interpretation. Comment closed.
Pg. 2, Goal and pg35	CA	High	Although the work will be disclosed to the public through TMC website, the study is not going to be used alone as comparison, it's unclear what other	See comment in cell G4 in "ISO 14044 requirements" sheet.	Comment closed.

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			methods of comparison would be used. There should still be a disclaimer considering that a comparative analysis has limitations due to potential differences in the methodology, data and data quality thresholds etc. Add a disclaimer that considers the ISO 4.1 "An LCI study alone shall not be used for comparisons intended to be used in comparative assertions intended to be disclosed to the public."		
Pg. 2, Goal and pg36	CA	High	"The goal of the study is missing the intended audience as shown in 4.2.2 Goal of the study In defining the goal of an LCA, the following items shall be unambiguously stated: — the intended audience, i.e. to whom the results of the study are intended to be communicated: Although the intended audience is mentioned on page 36, this should be brought out a lot earlier, where the goal was discussed. "The target audience of this includes possible investors, customers, and anyone interested in deep-sea mining"	As per your recommendation, the intended audience has now been mentioned in the executive summary as well.	Comment closed. seen on page 4, 41 and 44 of the report
Pg 23	CA	High	The key findings from the terrestrial comparison is not discussed instead graphs are presented expecting the reader to deduce the information.	Discussed in section 7. Key findings for the terrestrial comparison for climate change, acidification, freshwater eutrophication, and energy use have all been discussed.	Same as row 46 Comment closed.
Pg. 35	CA	High	This statement should be brought earlier on "This study does not measure the environmental impacts on the seabed from nodule collection, nor does it adequately capture the full scope of impacts on forest and other ecosystems from terrestrial mining activities such as deforestation and large-scale impoundment. The life cycle assessment methodology currently lacks a methodologically sound framework for adequately quantifying these impacts; thus, this should be considered a limitation of this study."	This statement has now been added to the executive summary.	Comment closed.
Pg. 2, Goal and pg36	CA	High	The goal of the report states that "This assessment can be used in their application for a commercial recovery/permit license" See ISO 14044 6.1 In order to decrease the likelihood of misunderstandings or negative effects on external interested parties, a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public. In addition, the selection of the critical review panel may not meet requirements of 6.3 "Critical review by panel of interested parties" - In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. As this has not been done, consider adding in the limitations that the review panel did not specifically select interested parties for example expert from terrestrial mining	See comment in cell G79 in "ISO 14044 requirements" sheet. Also, note that the climate change results **can (not will)** be used. This does not mean that TMC will use the results of this study as a part of their application, nor does them receiving an exploration and future mining license depend on the results of this report.	Comment closed. this will be raised in the critical review statement as a recommendation
pg.36 (3.1)	CA	High	Unlike terrestrial mining, which produces large volumes of waste, deep-sea nodules lie unattached on the seafloor; thus their collection is not associated with the generation of waste and overburden. Please can you share the article that this information is from, I am unable to find it online.	See response F15 and F23 in this sheet, and cell G15 in "ISO 14044 requirements" sheet. land use impacts (volumes of waste generated) has been and	Whilst freshwater eutrophication has replaced terrestrial land-use in the comparison, it is still discussed throughout the report. Is the

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
			This statement may be drawing conclusions without further explanations on why this particular process avoids any waste, provide more information on the claims and how the wastewater from the nodules are avoided or managed. Moreover if the volumes of waste generated by terrestrial methods are raised as a point of comparison why has waste been omitted from the system boundary of the NORI-D study?	replaced with freshwater eutrophication, a recommended impact category for mining LCA's. The land use impact category is not discussed in the report. However, as the topic may brought up, it is mentioned that LCA does not adequately capture land use (especially deep sea mining related land use) impacts.	intention that the reader will not make any comparisons with land use as only 4 impact categories (Climate change, energy, freshwater eutrophication and acidification) is compared in the graphs for the terrestrial comparison. Also Table 11: EF 3.1 Environmental Impact Categories is not showing Comment closed.
Page 39 (3.2)	CA	High	In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results See 4.2.3.7 on comparative assertions between systems. Whilst this has been improved from the previous version, there are still some areas that could help the reader like adding a diagram of the system boundary for the terrestrial method. The system boundary section should also have a subsection on the terrestrial method. Example of a comparative report where both systems are introduced and discussed equally throughout the report https://www.ball.com/get attachment/85d9e3af-e3aa-4b93-a687-5b34888b2bfc/Ball-Comparative-2020-LCA-full-report-FINAL.pdf	See comment in cell G25 in "ISO 14044 requirements" sheet.	Comment closed. understand the complexity of putting both systems side by side
pg.42 (3.5.1)	CA	High	The offshore operations are not described with enough technical depth, as this is the core technology that differentiates this from the terrestrial applications; there should be more description on the process. In addition, "these vehicles use water jets to gently lift the nodules from the seabed" suggests a benign process to the reader without much quantification on the force of the water jets, the size of the equipment used to lift them, no schematic of the process is provided. The processes mentioned needs to be explained in the report and illustrated for the reader.	the word "gently" has been removed to avoid confusion or bias language. The offshore portion was is detailed and was provided by the client.	Comment closed.
pg.42 (3.5.2)	CA	High	TMC's onshore processing consists of a pyrometallurgical circuit followed by a hydrometallurgical circuit which are conducted in separate locations depending on where the nodules are shipped. This study examines the environmental impact when the nodules are processed to produce refined products at each location. The processes mentioned needs to be explained in the report and illustrated for the reader.	See section 3.5.2 and section 3.5.3.	Comment closed.
pg. 41 Table 5	CA	High	As per ISO 14044 4.2.3.3.1 The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study. Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained. Table 5 does not provide any concrete justification on why the system boundary was omitted	Justification added and table 5 has been extended.	Comment closed.

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pg 53 - 3.8.3	CA	High	3.4.4 "Though Data quality is a requirement by ISO-14044, they do not provide data quality levels or scores. Therefore, the GHG protocol product standard data quality ratings are used in this report" - Whilst this a common and reasonable approach, have industry specific data quality requirements for mining been researched and considered for the study? See sector specific rules chapter 6 in GHG rulebook from Global battery alliance. https://www.carbon-transparency.org/resources/greenhouse-gas-rulebook This can be considered as industry relatable standard as it refers to similar critical minerals used in EVs	The GBA rulebook does not offer data quality levels. Quantitative assessment of data quality now included in the report.	Please see page 42 Table 5-2 of the GBA rule book where the scoring methodology of data quality is provided Comment closed.
pg 53 - 3.8.3	CA	High	Primary data is from a March 2021 study and its not clear if this is based on actual operational data collected for this study. The DQR does not include criteria on completeness and reliability. Data quality assessment for primary and secondary data should be separated	See comment in cell G32 in "ISO 14044 requirements" sheet. Also the data collection section of the report. Completeness and reliability are included in temporal and technological representativeness (see section 3.8.2.1 and 3.8.2.2. Activity data and emissions factors have been graded separately.	Comment closed.
pg 54	CA	High	see 4.2.3.6.2 Where a study is intended to be used in comparative assertions intended to be disclosed to the public, the data quality requirements stated in a) to j) above shall be addressed. DQR should also be both quantitative and qualitative, An overall data quality score should be included and commentary on the overall data quality of the report	See comment in cell G23 and G65 in "ISO 14044 requirements" sheet. Quantitative assessment on data quality has n0w been added.	It is a mandatory requirement due to comparisons being made Comment closed.
pg 54	CA	High	The data quality assessment needs improvement: - Data quality assessment should be done for each data point in the inventory, the reference to the data source, if primary/secondary data and quantitatively assessed against criteria in a table - the DQA needs interpretation. The matrix is not enough. Describe the most remarkable aspects that drive the quality of the study per indicator; explain where proxies have been used - can we talk about an overall DQ score? have the DQ requirements be met?	See previous responses. All data is from Hatch and Allseas (no secondary data has been used). All emission factors are from ecoinvent.	Comment closed.
Pg 58 - 59	CA	High	The selected environmental impact categories are standard; however, they have limitations on the assessment, which have been discussed. Further clarity could be made for the reader to understand which specific impact categories have limitations for this assessment. In addition, there should be a further comment on how this limitation affects comparisons against the terrestrial method by discussing the methodologies used and what aspects may not be considered in these methodologies. Impact categories such as water use, land use, resource use, and ecotoxicity freshwater (i.e. deep sea isn't freshwater) they do not specifically consider these deep-sea CCZ mining regions in their scope.	New section of the report added (see section 3.9.1)	Comment closed.
Pg 59	CA	High	The limitations section is very light touch, it should be structured with sub-heading to the key limitation areas identified which should be discussed with some technical depth. For example biodiversity measurement is a limitation to discuss further.	The goal section as well as section 3.10 lays out limitations of the LCA methodology, and thus limitations of this report. It also makes it clear that the goal of this study is to measure **aspects** of the environmental impacts according to the EF method. Anything beyond that scope should not be considered a limitation. However they can be considered future topics of research for TMC.	Comment closed. this may be mentioned in the review statement

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
				Biodiversity, dose-response, temporal related impacts, impacts on forest ecosystems, etc. are a limitation of the LCA methodology.	
Pg 91 Sensitivity analysis	CA	High	The sensitivity analysis doesn't take into consideration any changes in the process of the deep sea mining operations, highlighting again the lack of discussions in the actual technology for the mining operation. I would expect issue related to water jet speed, dept of the sea bed being discussed in the report and sensitivity. The focus is all on the energy source which understandably drives the impact but this keeps it generic and stays away from the actual technicalities of the mining operations	Hte offshore operation only used marine fuel, which and uncertainty analysis was conducted for. If the speed of the water jests increase/decrease, this would only affect the energy/marine fuel usage.	Comment closed.
Pg 23	CA	High	The key findings from the terrestrial comparison is not discussed instead graphs are presented expecting the reader to deduce the information.	See cell F49.	Comment closed.
Pg 132	CA	High	Comparing land use change results for the NORI-D and terrestrial route doesn't seem feasible if the methodology for land use doesn't consider land use impacts in deep sea mining	This is fair comment. Why land use was selected has been discussed in section 3.9.1. And it was made clear continuously throughout the report and in figures that the land use impacts from deep sea mining were not measured. The land use impact category has been replaced with freshwater eutrophication.	Not clear if this addresses the comment Comment closed.
pg 170	CA	High	A section on Uncertainty & limitation analysis is formally missing. This does not necessarily mean a quantitative uncertainty analysis but at least a description of the uncertainties and limitations with a focus on: - Uncertainty arising from data measurements (e.g. direct measurements, estimations...) - Uncertainty arising from data quality (use of proxies,...) - uncertainty from impact assessment (e.g. toxicity indicators are very uncertain in EF and therefore should be considered only with limitations)	The data collection section talked about how the data was generated and the data quality ratings graded each datapoint according to an international standard metric. The uncertainty of the data is captured here. No proxies used for TMC system. Where proxies are used or the comparisons, this is reflected in the data quality. Uncertainties on the impact assessment methods are included in the EF method.	Comment closed.
Pg 170	CA	High	The recommendation section requires more work and an in-depth recommendation. Recommendations should be grouped into subheadings: impact categories, data quality, land use, biodiversity assessment, consequential LCA approach, review panel and technology. consider some of the recommendations provided from the review panel as recommendations to TMC	As discussed, if the reviewers so wish you may make recommendations that can form a part of the critical reviewer statement.	Comment closed. this will be raised in the critical review statement as a recommendation
p137	EB	High	New comment: The statement that Japan route is lower than all land-based routes cannot be supported. More adequate is saying " it is in the same range" taking the recommended significance level and the additional uncertainty of a prospective LCA into account. This does not require Mining expertise, but LCA expertise.	You are correct that it is within the same range. Japan will continue to have a slightly lower impact that Indonesia, regardless of the uncertainty, because the distance from the nodule collection point (CCZ) to Japan is less than the collection point to Indonesia. Therefore less fuel is used. Japan also has a lower carbon intensity on their grid mix than Indonesia who is dominated by coal. These points will remain the same regardless of the uncertainty of datapoints.	While acknowledged in the excel file it is not included in the report. Why?
several	EB	High	New comment: The values across the reports do not always match and are outside of potential rounding errors. Please check again and keep in mind that this can have an influence on the significance level. -> reported already via email	Values that differ outside of rounding errors have now been checked for consistency and adjusted accordingly.	Not addressed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
p 28	EB	High	New comment: Copper Cathode: Please look up how robust your results are taking the results of the sensitivity analysis into account. (For the other products it is less relevant)	Both the footprint of cobalt and copper are dependant on the allocation. method. The allocation method (economic allocation for the base case was chosen from the harmonization of methodologies for Metals. However a metal mass allocation was done as well for a sensitivity analysis as this arguments could be made. This variation was discussed in section 6.3 and brought up again in the conclusion. In summary, the report says: "This vast difference in climate change impact between the allocation approaches arises due to the prices and production volume of the metals. Though the production volume of cobalt is low relative to copper and cobalt, its relatively higher price leads to an increased impact when economic allocation is considered. When metal mass allocation is considered, this impact shifts, leading to a much higher impact for copper with the higher production volume, and a much lower impact for cobalt, with the lower production volume. The climate change impact of nickel does not vary much as its production volume is the highest between the co-products, and its price is between that of copper and cobalt"	Although intensively discussed via phone it feels the comment was not understood and sufficiently addressed.
Executive summary	MF	Medium	The executive summary is extremely long. Ideally it should be 5 pages or so.	See response in cell F46.	Not addressed, but if this length of exec summary is preferred by the client then I'm happy to close. Comment closed.
Page 6, III.II	MF	Medium	It would be informative to add a brief interpretation of the results to the results section.	See results section. In section 5, the results for TMC's system is displayed along with an interpretation. The interpretation follows the logic as described in section 3.11. A contribution analysis was conducted to show each major contributor and hotspot for the climate change impact category of TMC's system and descriptions on why those contributors cause their impacts. Further interpretation are given by the sensitivity and scenario analyses.	Has not been addressed Comment closed.
Page 6, III.II	MF	Medium	TMC's process were modelled using data from their latest PFS (2025). Suggested edit: TMC's **offshore** process were modelled using data from their latest PFS (2025).	TMC process consists of offshore (nodule collections) and onshore (pyrometallurgical and hydrometallurgical processing) operations.	Comment closed.
Page 22. III.III	MF	Medium	It would informative to add a brief interpretation of the results to the terrestrial comparisons section.	see section 7. For section 7 the comparison, similar to section 5, the total results are shown for each system and an interpretation and description as to what are causing the impacts for each processing pathway and why one pathway has a lower impact in a particular impact category than another.	Has not been addressed Comment closed.
Page 35. Section 3.1	MF	Medium	How will the nodules be extracted? By suction / dredging, ROV? If sediment is coming up with the nodules then the sediment is generated waste. How does the volume of sediment waste compare to terrestrial mining?	The sediment is discharged to the seafloor. Nodules are hit with water jets and suctioned.	These details need including in the report.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
				Included in the report in section 3.5.1. It reads: "The offshore operations involve a combination of specialized machinery and vessels. Key components include tracked underwater collector vehicles, a riser system, and several types of vessels such as production, support, and transfer ships. The collection process begins with the remotely operated vehicles, which are powered by electricity supplied through umbilical cables from surface vessels. These vehicles use water jets to lift the nodules from the seabed. At the depths of the operations, there is no/very minimal amounts of CO2 that is released to the surface. The nodules, along with some water and sediment, form a slurry that is gathered by the collectors. Within the vehicle, more than 90% of the sediment is filtered out and discharged from the collector back to the seafloor without any chemical change. A dilute slurry is then pumped up through a steel riser pipe using an airlift system to bring it to the surface. Once topside, the nodules are dewatered, transferred to another ship and eventually loaded onto bulk carriers, which transport them to designated facilities for further processing. Offshore operations are fully fuelled with marine gas oil (MGO). The production vessel uses the ships power plant and diesel generator that provide electricity for vessel operations, the collector vehicles, and compressor".	Comment closed.
Page 36. Table 1 legend	MF	Medium	Typo: NORI-D Onshore details. Should this be offshore?	Yes, this was a typo, good catch. Adjusted.	Comment closed.
Page 58. Section 3.10	MF	Medium	Impacts on the sea-bed and also impacts on the wider water column from sediment released at the ocean surface.	Adjusted to "sea-bed and deep-sea ecosystems"	Comment closed.
Page 74. Section 5.1.4?	MF	Medium	This section on SiMn appears to be missing a heading 5.1.4	Adjusted.	Comment closed.
Page 98. Figure 3722	MF	Medium	Figure numbers appear to be random. Please check all figure numbers.	The numbering system malfunctioned with the table of contents. This has been adjusted.	Comment closed.
Page 99. Figure 38	MF	Medium	Key colour does not match chart. Nodules collected and processed should be yellow.	Corrected.	Comment closed.
Page 111. Section 7	MF	Medium	It would be informative to give a brief description of the terrestrial mining techniques.	See section 7, where the product systems of each terrestrial comparisons (outlined in table 14) are briefly described. "I suppose you are referring to whether it is open pit, underground, surface mining etc. This information can be inferred from the second column of table 14 ""ore type"". Since this is a mining LCA, the reader will need to have some knowledge of mining to catch these details. Nickel laterite and saprolite ores are typically mined through open pit methods. Copper oxides are also typically mined through open pit methods. Copper sulfides and Ni-Cu-Co sulphides are typically mined undergrounds.	Has not been addressed. Table 14 contains processing tech but no information about the general mining technique. Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
				However, all sources are now in the report and this can also be read there. "	
Page 112. Table 14	MF	Medium	If possible, please add citations to Table 14.	Footnotes have been added. Details of the data are available for review, but will not be added to the report. It can be made available upon request. All sources for the comparisons have now even added.	Has not been addressed. I see no citations or footnotes to literature sources for the comparisons. All sources for the comparisons have now even added. Comment closed.
Page 125. Table 198	MF	Medium	The table numbers are out of sync in some cases. Please check.	Adjusted.	Comment closed.
Page 169. Section 8.1	MF	Medium	In the sentence "this study does not address the environmental impacts associated with TMC's offshore operations" - LCA does address environmental impacts. Perhaps change to ecological impacts?	Sentence changed to "Although this study does not address the **certain** environmental impacts associated with TMC's offshore operations, (i.e. impacts on deep-sea ecosystems)..."	Comment closed.
Section 6 and elsewhere	MF	Medium	Please highlight the basecase/s in sensitivity/scenario analysis figures.	Base Case is grid electricity in the graphs (as mentioned in the table and body of the report). Base case highlighted on other graphs (heat source sensitivity, allocation sensitivity, etc.)	Comment closed.
Page 102. Section 6.4	MF	Medium	Currently the uncertainty analysis is based on a +/-10% of key inputs. Is there a better way of doing this? i.e. using plausible range of values providing in the activity data?	The values are very specific that were provided by HATCH and are based on mass balances, stoichiometry and conducted using Metsim software. There are not more plausible values that can be chosen. Therefore -10%/+10% was chosen to see how the impacts would value with this range (It is possible that the activity likely will not vary that much).	Comment closed.
Page 102. Section 6.4	MF	Medium	I think it is worth mentioning the various ways the uncertainty can be assessed e.g. Monte Carlo and where this was not used in this study.	This can be good,, but I do not think it will provide much additional insights.	Comment closed.
General	MF	Medium	To confirm, are they any local intermediate onshore facilities to transfer to bulk carrier (e.g. Hawaii)?	No The system boundary diagram shows the exact processing pathway.	Can it be made clear in the report that this is not included in the assessment. Comment closed.
General	MF	Medium	To confirm, have surveying and exploration been included - or is this excluded?	Not included, the impacts of producing the products are measured. Anything not related to that is not included. This is an LCA of TMC's products. Impacts related to exploration and surveying will not be included in the footprint of their products. This is described in action 3.2 where it says: "Table 5 summarizes inclusions and omissions from the system boundary. In general, only the inputs/outputs which are material to the production of the products are included in the system boundary. Other activities linked to company operations that are not specific to the production of products should be included in the corporate scope 3 inventories".	Comment closed.
Excel model	EB	Medium	I assume, the review panel did not receive the final model. I saw differing values between report and excel (right in the report, typo(?) in the excel)	The review panel did receive the final model. See comment F15 in "ISO 14044 requirements sheet" where commons on inconsistency of the excel file and report have been addressed.	Comment closed.

Page number of comment	**Reviewer initials**	**Priority**	**Reviewer comment**	**Practitioner of the LCA study response**	**Reviewer response**
General	EB	Medium	In this particular context, it is important to avoid the use of the generic term “environmental impacts.” This is because, firstly, a Life Cycle Assessment (LCA) does not fully capture several critical aspects of the technology, such as biodiversity, land-use-related impacts, and water pollution. Secondly, current assessment methods are not specifically designed for underwater processes, which may lead to the omission of significant environmental effects.	You are correct. It is now explicitly stated in the goal and throughout the report that "**aspects** of the environmental impacts from production using the indicators present in EF 3.1 are measured.**"** This has now been clarified. Aspects now defined as: "The aspects quantified are the LCIA categories available in the EF 3.1 method. The LCIA categories that are assessed and interpreted in detail includes those that are typically recommended for metals, namely, climate change, acidification, eutrophication, and energy use. The results from the remaining LCIA categories are summarised in annex A	instead of a generic "aspect", be specific like " aims to understand climate impact, acidification... etc" Comment closed.
Goal and Scope	EB	Medium	Will the study be shared also with other interested parties such as Journalists, NGOs. Will it be used for Lobbying activities?	No. The study however will be publicly available.	Comment closed. Noted that it will not be actively shared, but those are typically the interested parties.
Scope	EB	Medium	"Sediments excluded: what does this mean in particular for the study? Are there no consumables besides the fuel for the machines? "Please check also if completeness and cut-off rules are applied consistently	See response in cell G13 of "ISO 14044 requirements" sheet.	Comment closed. I will note down that fuel consumption is considered the only consumables and any other consumables like lubricants, wear parts etc are omitted.
21 / Sensitivity analysis	EB	Medium	Figure E16, consider grouping the results by FU (not locations) . It will help the reader to get a better idea of how allocation method influences.	Each location produces the 3 functional units (Ni, Cu, Co). Currently I believe that this figures is clear and lets the reader know hoe allocation influences the results.	Comment closed. This is not critical for the review, but the response is not satisfying. The purpose of a sensitivity analysis is to evaluate how robust results are per FU. It is not to compare geographies. It would have helped you in the interpretation as it was overlooked that some conclusions are not robust due to allocation. See comment E147.
Figure 12	EB	Medium	I wonder why there is "Transports" which is not separated in the other graphs	SiMn is the product that is being produced by TMC's customer from TMC's MnSiO3. TMC's MnSiO3 is transported from their onshore processing locations to the clients processing site. This does not occur for any of the other functional units.	Comment closed.
Chapter 7	EB	Medium	Suggest to include the significance level to evaluate superiority. Plus I am missing that the uncertainty is addressed in the interpretation The results of the sensitivity analysis is not integrated and expanded to the scope. Like this the robustness of the comparison cannot be thoroughly evaluated.	Since this is a mining LCA, it is acknowledged that those without knowledge in this particular industry may struggle to understand the significance of the results. For the comment on sensitivity analysis, see cell G59 in "ISO 14044 requirements" sheet.	I will close the comment here as it is described in the main sheet. Comment closed.
98	EB	Medium	Number of figure should be 37	Adjusted	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
Figure 38	EB	Medium	I find the inclusion of Texas a bit confusing. What is here the core message: How to improve the process or the situation at a specific location? What confuses me in general is the comparison of location which is not consistent with the functional units. For the reader, grouping for the most important aspect is helpful.	You are correct that Texas does not need to be included in this graph since Texas already uses Natural gas for heating in the base case, therefore the results do. to change. I included it for transparency, but it does not need to be included. Indonesia and Japan has a lot of coal naturally, hence this will be the assumed heating source. However, it is possible that natural gas can be sourced. The core message here shows how the climate change impact changes when natural gas would be used instead of coal. Texas included for transparency. Some readers that miss the fact that Texas uses natural gas may ask the question "Why is Texas not included"	See comment G 93. It would help the reader that the difference is insignificant and in the range of <5%. Again a misunderstanding although discussed. The replacement of coal by gas has a very minor impact and does not even exceed the overall uncertainty of an LCA study. Comment closed.
127 / General	EB	Medium	Please check table and figure numbering. On this page it is table 920 and 1021	Adjusted	Comment closed.
160	EB	Medium	I compared with the ecoinvent value which is significantly lower (29,3) Given the uncertainty, the difference would then not be significant.	The reference product in ecoinvent is **cobalt sulfate**. The functional unit in this study is **Co in cobalt sulfate (21% Co)**. See comment in cell 42. Some additional information, looking at the exchanges, the cobalt sulfate dataset in ecoinvent is produced from cobalt hydroxide containing 61.4% Co. The cobalt sulfate produced in this study from the DRC route is produced from crude cobalt hydroxide containing approx.. 40% Co. This will affect the results significantly as well. The functional unit has been stated in the goal. Values for the metals were not taken from ecoinvent, but have been modelled directly from published company values. References for all datapoints have now been added.	Can you please add this in the interpretation? Comment closed.
168	EB	Medium	"The higher land use impact..." I would say that this is also, because land under water is not considered. While points don't matter here, land use as an indicator of ecosystem intervention does not work with this method.	Land use impacts has been removed and replaced with freshwater eutrophication, a recommended impact category for mining LCA's.	Comment closed.
pg26	CA	Medium	Figure E 18: Comparison of the climate change impact of 1 kg of Ni in NiSO4.6H2O produced via various land-based routes vs TMC's NORI-D processing routes, It's not clear which are the land based routes and which are the deep sea mining routes	Nodules are from the deepsea. All other ores (sulfides, limonite, saprolite) are the terrestrial ones.	Comment closed. please make mention in the report
pg4. and pg.36	CA	Medium	"The GHG emission data from this study will be used as a part of TMC's application for a commercial recovery/permit license" - pg 4 please can you clarify in the report that the other LCA impact categories will not be used for comparison.	This has now been clarified.	Comment closed.
pg 51	CA	Medium	Unclear why this statement is needed; emission factors are secondary data and data quality assessment of secondary data is still required 3.8 "It should be noted that companies typically do not have control over the source of emission factors used to calculate the emissions associated with their foreground data. Therefore, the source of emission factor has no	Different standards describe secondary data differently. For example, ideally we would have supplier specific emission factors for all activity data. In this case, the emissions factors would be primary data. This is usually not plausible and I do not know of a study that have achieved this. This is why it is aid that companies do not have control over the source of emissions factor.	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
			bearing on the classification to meet the primary data requirement, and emission factors do not need to be classified as primary or secondary."	The normal case is to use databases such as ecoinvent for emission factors. Since these are not supplier specific, they are referred to as secondary data.	
pg 54 - 55	CA	Medium	Terminology in the DQR table from GHG protocol is inconsistent with what is used in the report. Temporal representativeness vs Time, Precision vs Reliability	An excerpt was adapted from the ghg protocol, terminology (temporal vs time) carry the same meaning.	Comment closed.
pg 54 - 55	CA	Medium	Reliability of the data is not considered despite it is a criteria in the DQR approach being used	Completeness and reliability are included in temporal and technological representativeness (see section 3.8.2.1 and 3.8.2.2.). Reliability considers the degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable. The technological representativeness talks about how the data was generated (i.e. from Hatch and Allseas) and thus contains the reliability. Completeness considers the degree to which the data are statistically representative of the relevant activity and considers seasonal and normal fluctuations in data. These are also considered in the technological, geographical, and temporal representativeness. The yearly averages representing the year 2024 in the data collection account for any fluctuations (section 3.8.2.1)	Comment closed.
Pg 58 - 59	CA	Medium	Table 11: EF 3.1 Environmental Impact Categories.17, consider a column that references the actual methodology used for the impact category (e.g. Land use measured using Soil quality index based on the LANCA methodology) as it will help to understand if the model is relevant for the scope of this study	This could be done, however the additional effort taken for the insights is unwarranted. For example, one may still need soil quality index to be defined. The methodology for the impact categories are covered in theEF methodology and can be read from documentation. Characterization models have now been added.	These tables are readily available and can be easily added to the document Comment closed.
Pg 154, pg 165	CA	Medium	7.4.10 Land Use Results, unsure if the methodology for land use i.e. soil quality index considers the seabed and how this has been factored in the assessment	See previous responses. Land use has been replaced with freshwater eutrophication.	Okay as this limitation is mentioned in section 3.10 however it could have been better to breakdown the limitations in detail, for the amount of work carried out, the novelty and prospective-ness of the study. Comment closed.
Page 1	MF	Low	Typo: please check the section numbering throughout.	Adjusted.	Comment closed.
Page 6, III.II	MF	Low	Please define PFS at first mention.	Adjusted.	Comment closed.
Page 10. Figure E 5	MF	Low	Typo in key: Downstream processing	Fixed	Comment closed.
Page 31. Section 1.1	MF	Low	Define CCZ at first mention.	Defined	Comment closed.
Page 32. Section 1.2	MF	Low	Define LCI at first mention (perhaps in the paragraph above).	Defined	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
Page 32. Section 1.2	MF	Low	Typo: results are critically assessed,	modified	Comment closed.
Page 32. Section 1.2	MF	Low	Suggested edit: All phases are iterative	modified	Comment closed.
Page 49. Table 6	MF	Low	What do the * mean?	The price is not relevant for those co-products. I added this statement to the caption as well.	Comment closed.
Page 50. Section 4.8	MF	Low	Typo: mass, balance, should this be mass balance?	Typo adjusted	Comment closed.
Page 52. Section 3.8.3	MF	Low	Typo: PCF should be LCA	Adjusted	Comment closed.
Page 74. Figure 12	MF	Low	Typo: Indoneisa - please check throughout the report for the spelling of Indonesia.	Corrected throughout	Comment closed.
Page 76. Figure 13	MF	Low	Typo: Indoneisa	Corrected	Comment closed.
Page 91. Section 6.1	MF	Low	Typo: 100 should be 100%	Corrected	Comment closed.
Page 118. Section 7.3.1	MF	Low	Please define MHP at first mention.	Adjusted	Comment closed.
Page 133. Section 7.3.8	MF	Low	...lowest at 114 and increases...' Please add units	Units added	Comment closed.
Page 134. Section 7.4.1	MF	Low	Define DRC at first mention.	Defined	Comment closed.
Page 163. Section 7.5.5	MF	Low	...lowest at 10.40 and increases...' Please add unit and check that units have been included throughout the report.	removed	Comment closed.
Table E1 and elsewhere	MF	Low	Clarify Mtpa as mega tonnes per year as it can be interpreted as metric tonnes per year.	defined in glossary	Comment closed.
Table E5 and elsewhere	MF	Low	Please a key for acronyms HPAL, RKEF, LX-SX, MCLE, SX-EW.	defined in glossary LX-SX is leaching followed by solvent extraction LX-SX-EW is leaching followed by solvent extraction followed by electrowinning MCLE is matte chlorine leaching. These have now all been added to the glossary, with additional keys for missing acronyms as well."	Glossary contains LX-SX-EW. What is the difference between LX-SX and SX-EW. MCLE is not in the glossary. Please check that all abbreviations are within the glossary. Comment closed.
Page 33. Section 2.	MF	Low	Check numbering of bullet points (starts on 4).		Comment closed.
Page 45. Section 3.5.3.2	MF	Low	Landfilling or iron-containing residue is excluded. This could have been included using a proxy. If it is immaterial it can be excluded as long as it is listed as an exclusions in Table 5.	No data on this residue.	Comment closed.
p1	EB	Low	TYPO: The method is version is EF3.1 (3.11 is the current version of ecoinvent)	Corrected	Comment closed.
62	EB	Low	Please specify what these values refer to "The total climate change impact associated with the collection and processing	You are correct	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
			(pyrometallurgy and hydrometallurgy) of 1kg of dry nodules is 1.32 kg CO2eq., 1.10 kg CO2eq., and 0.83 kg CO2eq." My understanding is that the 1st is IND, 2nd JP 3rd Texas.		
Figure 31	EB	Low	Can we make the base-case better visible? Plus, it makes the most sense	A star symbol has now been added above the base case bars.	Comment Closed.
102ff	EB	Low	Could you please provide a justification of the 10% threshold. The risk of this "Ceteris paribus" approach with a uniform application of 10% is that each measure individually won't exceed an impact variation of 10%. Alternatives are: (1) evaluate a combination of levers and/or (2) a substitution of materials aiming to evaluate best-and worst-case.	Yes, the variation of all of these parameters will likely not exceed 10%. Justification added in text.	Comment closed.
Figure 50	EB	Low	use same format like the other graphs	formatted the same. scientific notations used when decimal places before the decimal exceed 2.	Comment closed. Please note that the formatting of numbers is not consistent, but this is "cosmetics".
Cover page	CA	Low	Typo on the date, 30st of May, 2025	Corrected.	Comment closed.
Pg. 1 Statement	CA	Low	"NORI-D Polymetallic Nodules" can you expand the abbreviation or explain what NORI-D is short for. A better approach would be to have a list of abbreviations and a glossary before going into the details of the report.	Glossary added.	Comment closed.
Pg. 28, Table of content	CA	Low	This comes 28 pages later, I'm not sure if it helps the reader navigate the report properly	The executive summary is extensive. The table of contents appears right after.	Comment closed.
Pg. 2, Goal and pg36	CA	Low	Missing in Scope chapter: mention the software used for conducting the LCA	Not included	Comment closed. some LCAs do mention Excel software used
Pg 38 Table 4	CA	Low	In identifying the differences between both studies conducted in 2024 and the new study where does the study conducted in 2023 by Benchmark Mineral Intelligence fit into this? TMC has already published a recent study in 2023 conducted by Benchmark Minerals Intelligence https://metals.co/wp-content/uploads/2023/03/TMC_NORI-D_LCA_Final_Report_March2023.pdf The Metals Company – Life Cycle Assessment for TMC's NORI-D polymetallic nodule project and comparison to key land-based routes for producing nickel, cobalt and copper.	Benchmark study was done first. The 2024 study which is now published has a table talking about the differences between benchmark's and itself. This study only speaks about the differences between itself and the 2024 study.	Comment closed.
Pg 38 Table 4	CA	Low	It could be useful if the table had a first column that showed the topics fuel type, moisture content, database, routes, system boundary and scope	This could be useful, however most of this data is included in the report.	Comment closed.
pg. 41 Table 5	CA	Low	Capital goods are typically excluded in these types of LCA however are there any parts of the infrastructure or machinery that need to be changed regularly for example any type of consumables used for the vessels?	No, vessels are immaterial to the footprint of the products.	Comment closed. please mention
General	CA	Low	The study is illustrative with useful diagrams for the reader to understand the system boundary and allocation rules. However it lacks in illustrations of the technology and process being described especially when this is a new concept that many may not be familiar with.	The only new concept is the collection of the nodules offshore. Though not descibe4d schematically, it was described in detail in text.	Comment closed. for readers who may not know about this technology a diagram of the process or reference would have been useful
Pg 62 - 90, Chapter 5	CA	Low	The message is consistent all throughout that the Indonesia process has the highest impact followed by Japan and the Texas. Similarly, the offshore process tends to have the lowest impact followed by hydrometallurgy and	Correct	Comment closed.

Page number of comment	Reviewer initials	Priority	Reviewer comment	Practitioner of the LCA study response	Reviewer response
			pyrometallurgy. The key factor driving this is the electricity grid mix of those regions		
Pg 67	CA	Low	Figure 5 on page 67 has a mistake on the figure naming	corrected	Comment closed.
Pg 69	CA	Low	Figure 7 is on pg 71 whilst figure 8 is on page 69	corrected	Comment closed.
pg26	CA	Low	Figure E 18: Comparison of the climate change impact of 1 kg of Ni in NiSO4.6H2O produced via various land-based routes vs TMC’s NORI-D processing routes, It's not clear which are the land based routes and which are the deep sea mining routes	See response in cell F99	Comment closed.
Pg 170	CA	Low	Given that the process of deep-sea mining has uncertainties and the premise of the work has discussed the benefit of the CCZ mining on the impact of electrification, it might be beneficial for a consequential LCA to be conducted later on by TMC to bring perspective of environmental impact as a result of its mining processes that have otherwise not been considered	This can be a good future study.	Comment closed. could be proposed as a recommendation
95	EB	Low	New comment: 5.1.7 you mean Co not copper cathode?	Yes good catch, typo adjusted.	Comment Closed.
p 72	EB	Low	New comment: Numbering of headline is wrong (5.11.2 while it should be 5.1.2)	Adjusted	Comment Closed.

Dr Matthew Fishwick – CV 1-pager

Bio

Matthew is an environmental chemist and specialist consultant offering deep technical expertise in LCA, EPD, and product, organisational, and supply chain environmental footprinting. His project experience of over 18 years spans a wide range of sectors including, chemicals, oil and gas, construction, and food and drink. Past clients include 3M, Saint-Gobain, BP, PepsiCo, ArcelorMittal, and Johnson & Johnson. He has PhD, MRes, MSc and BSc degrees in environmental chemistry and is a member of the Royal Society of Chemistry (MRSC).

Professional experience

Fishwick Environmental Ltd, Environmental Consultant, Oct. 2012 – present (12+ years)
Outline: consultant focused on environmental accounting services, working directly with clients and subcontracting for larger consulting firms (e.g. Anthesis, ERM, Intertek) across a range of sectors including chemicals, construction, oil and gas, food and drinks, and packaging.
Key responsibilities: delivering environmental accounting projects (e.g. LCA, supply chain footprinting, science-based targets (SBTs), impact disclosure), critical reviews / verification, project management, client management, proposal writing, line management, QA/QC, strategy, and general management of a small business.
Example projects:

- Approved individual EPD verifier for The International EPD system and IBU.
- Carried out >400 EPD verifications and LCA critical reviews.
- Performing GHG audits via leading assurance companies.
- Carrying out an EPD of an acoustic insulation panel for Allsfär, which was published by BRE Global.
- Carrying out two EPDs of lifts for FUJITEC, which were published by the International EPD System.
- Carrying out an EPD of a polymer for Aquapak, which was published by the International EPD System.
- Performing a number of LCAs for British American Tobacco and developing a tool to assess reduction initiatives.
- Carrying out a comparative ISO 14040/44 of different coil coating technologies for a major paint manufacturer.
- Developing a model to assess avoided burdens associated with the eBay platform for their circular economy goals.
- Carrying out a comparative LCA of various chemical and biochemical routes to an important platform chemical.
- Carrying out a number of EN 15804 EPDs of steel reinforcement products, one of which (Hy-ten) was published by the International EPD System.
- Supply chain mapping and visualisation and impact comparison of suppliers for IKEA.
- Developing a method to assess resource efficiency throughout a large community housing group.
- Developing a benchmarking tool to calculate the whole life carbon of buildings for the Scottish Futures Trust.
- Providing support in quantifying costs and benefits of Courtauld 2025 for WRAP.

Previous employment: Anthesis, ERM, JP Morgan.

Education

- PhD Environmental Chemistry, Plymouth University, Oct. 2012 – July 2016
- MSc Environmental Toxicology and Pollution Monitoring, The University of Ulster, Sept. 2009 – May 2011 (PgDip), Sept. 2016 – May 2017 (research project), Pass with Distinction
- MRes Clean Chemical Technology, The University of York, Oct. 2006 – Sept. 2007, Pass with Distinction
- BSc (Hons) Environmental Science, Plymouth University, Sept. 2003 – May 2006, First Class Honours

Cynthia Adu

Sustainability Manager | Sustainable Materials & Manufacturing | LCA Practitioner | CEnv

Bedfordshire, UK | LinkedIn Profile | Publications

Personal Statement

Sustainability professional with a doctorate in sustainable materials and manufacturing, leveraging engineering expertise to drive ESG strategy, life cycle assessment, and circular economy innovation across biotech, consulting, and manufacturing sectors.

Professional Experience

Sustainability Manager | Biotech & Materials Company | Sep 2023 – Present

- Lead sustainability strategy, regulatory standards and supply chain sustainability
- ESG reporting, investor relations and implementation of ISO 14001 EMS and ISO14040/44 LCA

Sustainability Management Consultant | Accenture UK & Ireland| Sep 2022 – Sep 2023

- LCA software architect for a large FMCG manufacturer (7,500 SKUs) and 16 impact categories
- Scope 3 reporting and SBTi advisory across FTSE 200 FMCG, fashion, extractive industry and technology
- LCA and circularity subject matter advisor for nuclear waste metals recovery methods

Sustainability Consultant Manager | Avieco (part of Accenture) | Nov 2019 – Aug 2022

- Sustainability consultant on LCA, GHG reporting and circular economy transition for multinationals (automotive manufacturers, fiber optic installation, offshore energy)
- Management of scope 1, 2 and 3 reporting and carbon footprint verification projects to ISO14604:1,2,3 (up to 300 sites, warehouses, stores and data centres)

Education

Doctorate in Engineering (EngD) Sustainable Materials & Manufacturing |University of Warwick, Cranfield & Exeter (Jointly awarded) | 2015 – 2019

- Thesis: Designing a circular business model from industrial by-products. Lead author (105 citations)
- Graduate voice, awarded for outstanding thesis by Worshipful Company of Founders

Other Education

- MSc Engineering & Management of Manufacturing Systems |Cranfield University | Distinction
- BSc Computer-Aided Mechanical Engineering |Oxford Brookes University | 2:1

Awards & Affiliations

- Member of the Institute of Materials, Minerals and Mining (IOM3), Strategic Advisors IOM3 (Chartered Environmentalist (CEnv)

Key Skills

- LCA (GaBi, Ecoinvent, OpenLCA) | ESG Strategy | Circular Economy | ISO 14001 Lead Implementer | Scope 3 Reporting | CAD (CATIA, SolidWorks) | Data Visualisation | Stakeholder Engagement

Principal Sustainability Consultant

Curriculum Vitae

Elke Breitmayer

+15 years of professional experience in the field of sustainability and management of international project teams.

Services: CSRD/ESRS (TÜV-Süd certified), Decarbonization Strategy, Corporate Carbon Accounting (GHG protocol), DMA & Environmental Risk Assessments, Product Carbon Footprint (ISO 14067), Life Cycle Assessment (ISO 14040/44, PEF, Critical reviews, EPDs), Project Management

Industries: chemicals, oil & gas, biotechnology, pharmaceuticals, automotive, retail, food, C&PC, transport and logistics and more

Professional Experience

Since 09/2024

Freelancer
Empowering your success!

02/2023–09/2024

Lead analyst / Principal Consultant
Quantis GmbH & Co.KG

Footprinting Lead, Data Strategy and Reporting

Accomplishments:

- Services: LCA, Corporate Carbon Footprints, Methodology and Database development for Digital Solutions, Sustainability strategy support, Preparation of Audit and reporting requirements
- Lead and participated in various multinational industry projects in the sustainability field
- Line managing a team of 4-8 consultants
- Integration of CSRD into the team and projects

07/2022 – 01/2023

Principal Consultant
Sphera Solutions GmbH

Portfolio Sustainability Assessment (WBSCD)

Accomplishments:

- Supported Portfolio Sustainability Assessments based on the WBCSD guidance for two clients in the chemical industry

LANGUAGES

English	■■■■■□
German (native)	■■■■■■

Höninger Weg 122
50969 Cologne, Germany

FON +49 (0) 0174 61 21 525
MAIL e.breitmayer@ @360-sustainability.de

SOFTWARE & CERTIFICATES

MS Office	■■■■■■
Simapro, SoFi, GaBi	■■■■■□
Jira, Confluence	■■■■■□

Various ESG Softwares

Certified CSRD Manager (TÜV-Süd)

INTERESTS

Hiking, sailing, dancing, cooking, cabaret and theatre

Curriculum Vitae

01/2021 –
07/2022

Senior Consultant / PO
WAVES S.a.r.L.

Methodological conception of a SAAS to conduct carbon footprints of transports, and support Corporate GHG Reporting

Accomplishments:
- Product Owner to develop a Corporate GHG Reporting Tool
- Development of a tool aiming to assess GHG emissions of intermodal transports based on GLEC and EN 16258

01/2020 –
12/2020

Project manager / Senior Consultant
Environmental Resource management (ERM)

Life cycle assessments, Corporate Sustainability

Accomplishments:
- Successful acquisition of various projects
- Consulting of industrial clients on sustainability strategies and external communication
- Execution of product life cycle assessments, carbon neutrality projects, SBTi, Corporate GHG Reporting

08/2013 –
12/2019

Project manager / Sustainability Consultant
nova-Institut GmbH

Life cycle assessments, techno-economic evaluations, and policy analysis in the fields of bioeconomy, circular economy and CCU

Accomplishments:
- Lead and participation of various national, and EU-wide sustainability projects
- Industry consulting in the field of Sustainability strategies and Communication
- Support acquisition of EU and national projects

08/2010 –
07/2013

Researcher
University of Hohenheim Hohenheim

- Life cycle assessment of agricultural value chains in the North China Plain

Curriculum Vitae

10/2007 – 07/2010	**Specialist ERP Systems / Project Assistant / Trainee** Kaufland Fleischwaren

(Multi)Projektmanagement, SAP Rollout

Accomplishments:

- Project management of multiple industrial projects (IT and Logistics) and successful organization of trainings and Go-lIfe of SAP

Education

10/2005 – 10/2007	**University of Hohenheim** Agricultural Economics MSc.
10/2002 – 10/2005	**University of Hohenheim** Agricultural Sciences BSc.
In between	**Volunteer at im Asian Rural Institute, Japan**
	Andreae-Gymnasium Herrenberg Abitur