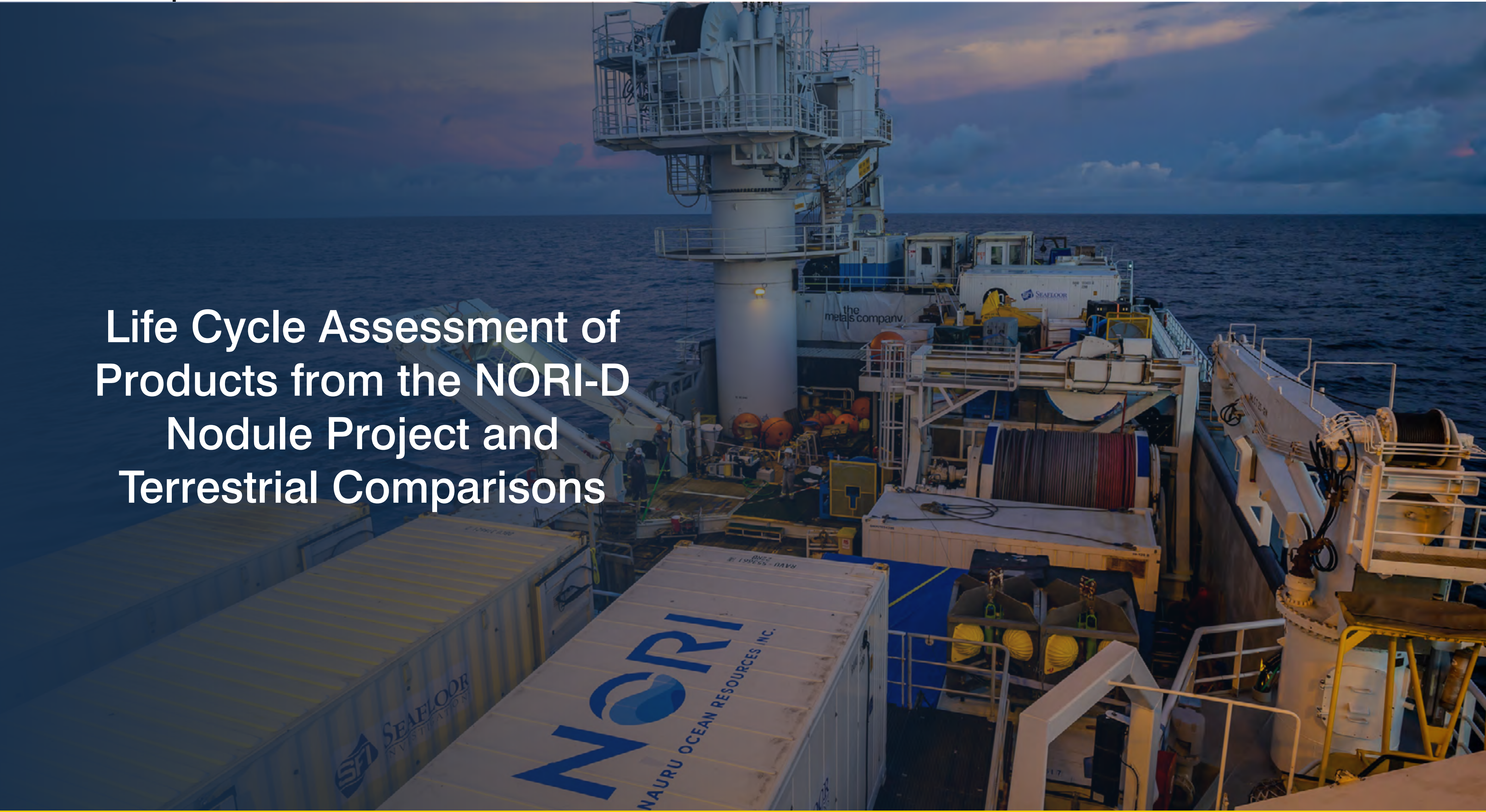
the metals company



Life Cycle Assessment of Products from the NORI-D Nodule Project and Terrestrial Comparisons

September 2025

This is a summary of the life cycle assessment (LCA) of the environmental impacts of products from the NORI-D Polymetallic Nodule Project and comparison to key terrestrial production routes today. This ISO-standards-compliant LCA completed by Ecoquant has undergone an independent critical review by an external panel and it meets the requirements of the international standards for LCA according to ISO 14040:2006 and ISO 14044:2006. The polymetallic nodule project data is based on TMC's 2025 Pre-Feasibility Study (PFS) scenario for the NORI-D Polymetallic Nodule Project and quantifies the impacts associated with the production of manganese silicate ($MnSiO_3$), NiCuCo matte, copper cathode, nickel sulfate hexahydrate ($NiSO_4 \cdot 6H_2O$) and cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$). The downstream production of silicomanganese from manganese silicate is also assessed. The LCA provides insights into other NORI-D project scenarios and sensitivity analysis to quantitatively assess the impacts that decisions regarding energy inputs as well as methodological choices can have on the results. The selection of the terrestrial routes reflects the most common current pathways for sourcing these metals, while also including a few lower impact routes for comparison with the NORI-D project, providing a broader and more balanced perspective.

Overview

The Metals Company (TMC) commissioned environmental consultancy Ecoquant to conduct an LCA of the NORI-D project, covering the full process from seafloor collection of nodules to production of manganese silicate ($MnSiO_3$), NiCuCo matte, copper cathode, nickel sulfate hexahydrate ($NiSO_4 \cdot 6H_2O$) and cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$). The study also extends TMC's system boundary to include the production of silicomanganese (SiMn) from TMC's $MnSiO_3$, which will be performed by downstream customers. The assessment quantified the life cycle impact assessment (LCIA) categories available in the environmental footprint (EF) method 3.1 version.

Polymetallic nodules located on the deep seafloor of the Clarion-Clipperton Zone (CCZ) in the northeast Pacific Ocean at a depth of roughly 4,500m represent the largest known resource of nickel, cobalt, copper and manganese – key materials for infrastructure, energy, manufacturing and defense. Unlike terrestrial mining, where cutting, drilling and/or blasting are often used to access the ore body, polymetallic nodules lie unattached on the seafloor and can be collected directly. The high grades of four metals and low levels of impurities enable collection and processing of nodules without the large volumes of waste and overburden often generated by land mining, while also eliminating tailings production. TMC aims to further minimize waste generation by turning the whole nodule into useful products.

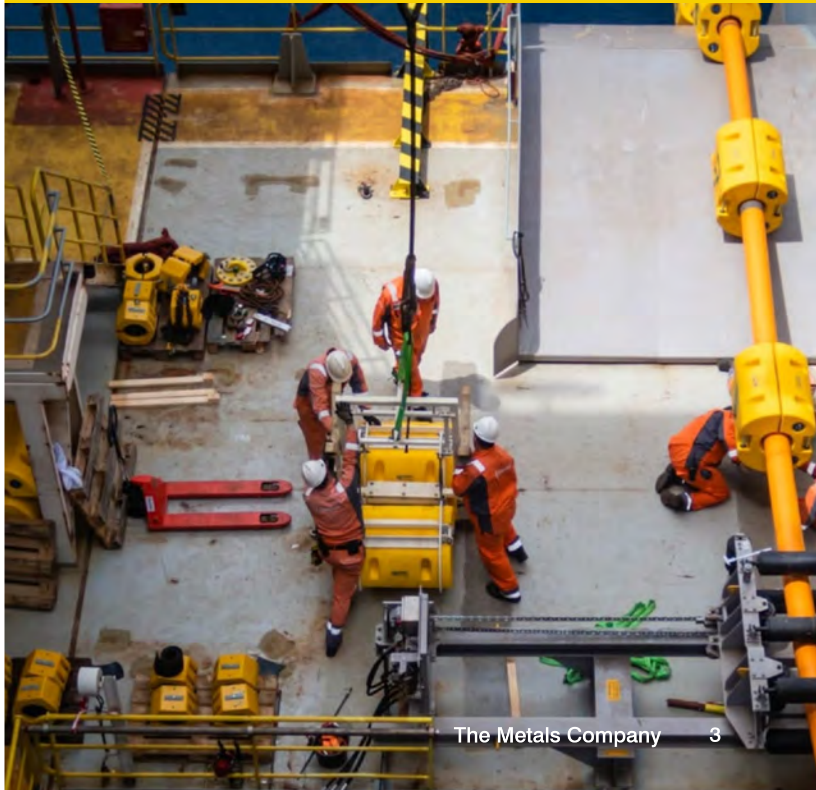
While producing SiMn is not part of TMC's NORI-D project scope, the project produces $MnSiO_3$, a pre-reduced intermediate. This intermediate product is expected to reduce downstream emissions for those producing SiMn from conventional land-based manganese ores and this comparison is assessed.

This study does not measure the environmental impacts on the 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 sound framework for adequately quantifying these impacts; thus, this should be considered a limitation of this study.

TMC has an environmental research program that assesses the impacts of our future operations on the ecosystem in NORI-D. This involves over a decade of data collection through multiple offshore campaigns followed by analysis by academic and industry organizations. This LCA report is only one of the tools that TMC uses to get a better understanding of our environmental impacts.

The goals of this study are as follows:

- Quantify environmental impacts associated with the production of 1kg of $MnSiO_3$, NiCuCo matte, $NiSO_4 \cdot 6H_2O$, copper cathode and $CoSO_4 \cdot 7H_2O$, and the impact associated with the collection and processing of 1kg of dry nodules from the NORI-D polymetallic nodule project.
- Quantify environmental impacts associated with the production of SiMn using $MnSiO_3$ from the NORI-D polymetallic nodule project.
- Compare the difference in the environmental impacts of producing TMC's products from the NORI-D polymetallic nodule project versus the same products produced via traditional terrestrial production routes, including SiMn production from terrestrial manganese ores.



Scope

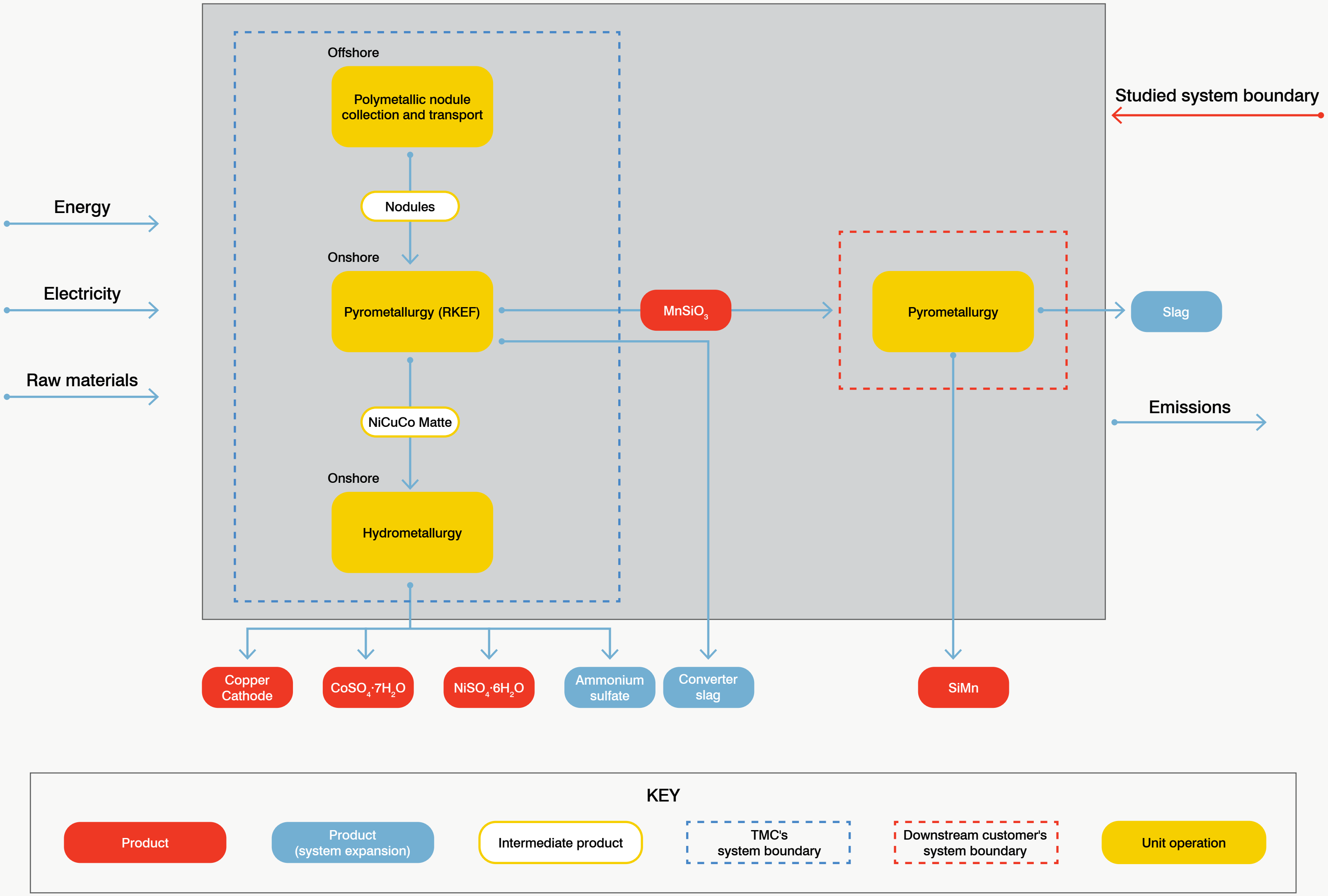
This LCA is a cradle-to-gate study. TMC's plan to collect nodules offshore in the CCZ (cradle), transport these to onshore processing facilities, and process them to refined products for shipment (gate) comprises the product system under study. The NORI-D Project scenario, as detailed in TMC's 2025 Pre-Feasibility Study, is analyzed in this report. TMC's onshore processing consists of a high temperature pyrometallurgical circuit followed by a hydrometallurgical circuit, and this study assess impacts when nodules are processed at different locations as shown on table below.

TMC NORI-D Onshore Scenarios

Scenario	Onshore Pyrometallurgical location	Products	Electricity Sources	Onshore Hydrometallurgical location	Products	Electricity Sources
TMC NORI-D Indonesia	Indonesia	– $MnSiO_3$ – NiCuCo matte – Converter slag	Indonesia Grid – 63% coal – 23% natural gas – 7% hydropower – 7% other	South Korea	– $NiSO_4 \cdot 6H_2O$ – $CoSO_4 \cdot 7H_2O$ – Copper cathode – Ammonium sulfate	South Korea Grid – 34% natural gas – 33% coal – 28% nuclear – 2% hydropower – 3% other
TMC NORI-D Japan	Japan	– $MnSiO_3$ – NiCuCo matte – Converter slag	Japan Grid – 35% natural gas – 31% coal – 9% solar – 9% nuclear	South Korea	– $NiSO_4 \cdot 6H_2O$ – $CoSO_4 \cdot 7H_2O$ – Copper cathode – Ammonium sulfate	South Korea Grid – 34% natural gas – 33% coal – 28% nuclear – 2% hydropower – 3% other
TMC NORI-D Texas	Texas	– $MnSiO_3$ – NiCuCo matte – Converter slag	US-TRE Grid – 49% natural gas – 24% wind – 17% coal – 10% other	Texas	– $NiSO_4 \cdot 6H_2O$ – $CoSO_4 \cdot 7H_2O$ – Copper cathode – Ammonium sulfate	US-TRE Grid – 49% natural gas – 24% wind – 17% coal – 10% other

The cradle-to-gate study evaluates the impacts of all inputs and outputs from raw material extraction up to the point of production of the products under study. The system boundary for the NORI-D project, including downstream processing of $MnSiO_3$ is shown in the figure below.

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



Functional Unit

The **functional unit** provides the reference from 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. To align with the goals and intended application of this study, the functional units were chosen as:

1 kg of dry nodules collected and processed

1 kg of Mn in $MnSiO_3$ (40% Mn)

1 kg of NiCuCo matte (40.7% Ni, 30.5% Cu, 3.4% Co)

28 Ni Nickel 58.693

29 Cu Copper 63.546

27 Co Cobalt 58.933

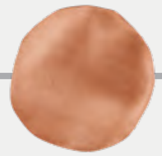
1 kg of Mn in SiMn (68.9% Mn)

1 kg of Ni in $NiSO_4 \cdot 6H_2O$ (22% Ni)

28 Ni Nickel 58.693

1 kg of Co in $CoSO_4 \cdot 7H_2O$ (21% Co)

27 Co Cobalt 58.933



1 kg of copper cathode (99.99% Cu)

29 Cu Copper 63.546

NORI-D Project Operations

NORI-D project operations can be divided into offshore and onshore operations.

- **Offshore operations:** include the seafloor collection of polymetallic nodules far offshore and transport of nodules to shore for processing.
- **Onshore operations:**
  - Pyrometallurgical process: Nodules are processed into $MnSiO_3$ and NiCuCo matte.
  - Hydrometallurgical process: NiCuCo matte is refined into $NiSO_4 \cdot 6H_2O$, $CoSO_4 \cdot 7H_2O$ and copper cathode.

OFFSHORE

ONSHORE

Nodule Collection

Upstream Transportation

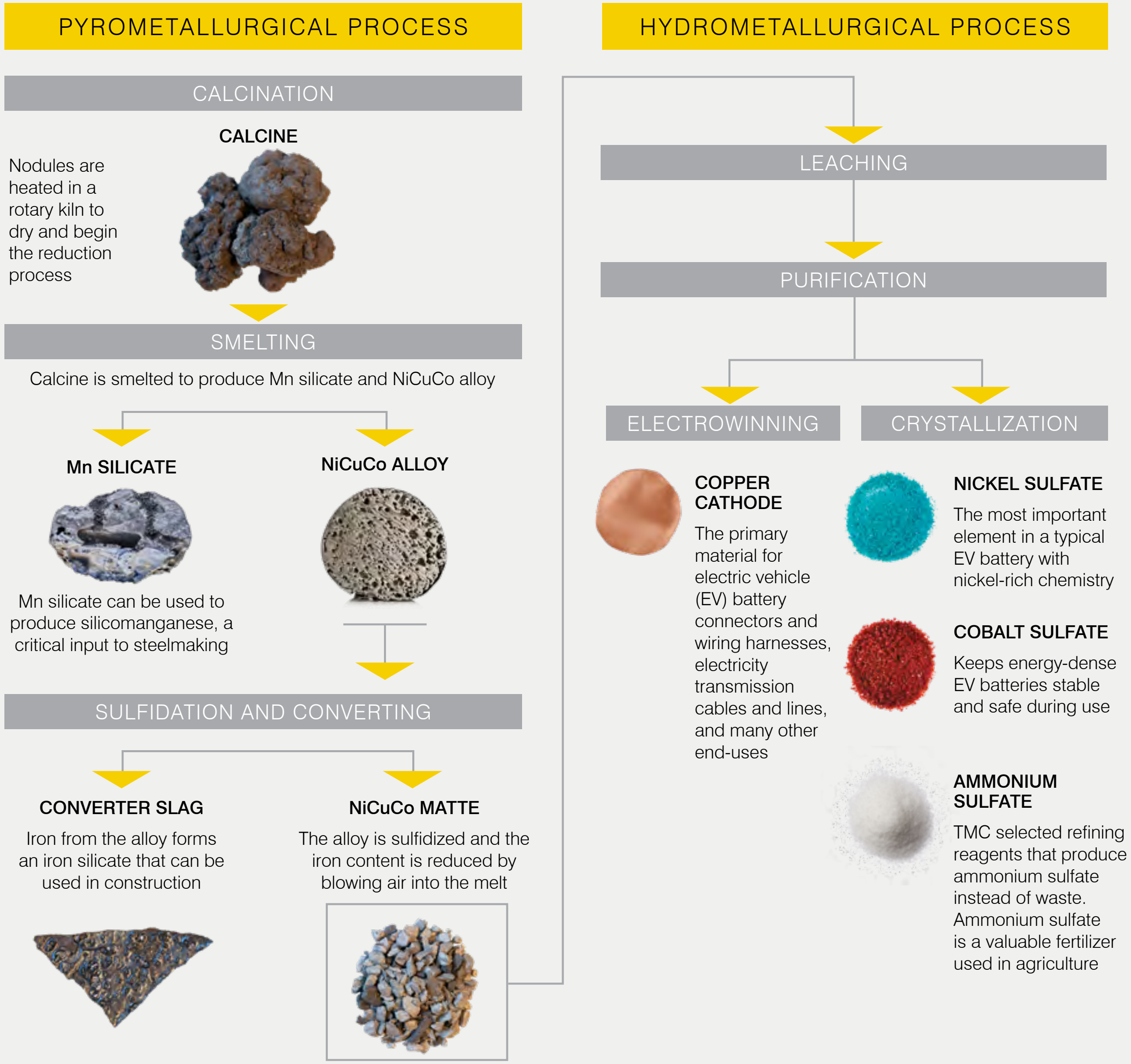
Pyrometallurgical and Hydrometallurgical Processing

Polymetallic nodules will be collected from the seafloor by self-propelled, tracked collector vehicles that use water jets to lift the nodules from the seafloor. Nodules are then pumped to the surface using an airlift riser system. Once at the surface, nodules are dewatered, transferred to another ship and then onwards to bulk carriers that transport them to onshore processing. Offshore operations are fueled with marine gas oil (MGO). The production vessel uses the ship's power plant and diesel generator to provide electricity for vessel operations, the collector vehicles, and compressor.

Onshore processing 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 a manganese-rich silicate ($MnSiO_3$) from the RKEF process, a fayalite slag from the later converting stage, which may be utilized in road construction as an aggregate; and a matte containing nickel, copper, and cobalt, which is sent for further refining through hydrometallurgical methods to yield high-purity metals: $NiSO_4 \cdot 6H_2O$, $CoSO_4 \cdot 7H_2O$ and copper cathode. Ammonium sulfate is also generated during this stage as a co-product, not from the matte itself but as a byproduct of the processing operations.

Three NORI-D onshore scenarios were assessed:

- Nodules are transported to Indonesia to undergo pyrometallurgical processing in Indonesia then NiCuCo matte is transported to South Korea for hydrometallurgical processing.
- Nodules are transported to Indonesia, transferred to another vessel (due to logistics) to be shipped to Japan where nodules undergo pyrometallurgical processing, and then NiCuCo matte is transported to South Korea for hydrometallurgical processing.
- Nodules are transported to Texas where they undergo both pyrometallurgical and hydrometallurgical processing.



PYROMETALLURGICAL PROCESS

CALCINATION

CALCINE

Nodules are heated in a rotary kiln to dry and begin the reduction process

SMELTING

Calcine is smelted to produce Mn silicate and NiCuCo alloy

Mn SILICATE

Mn silicate can be used to produce silicomanganese, a critical input to steelmaking

NiCuCo ALLOY

SULFIDATION AND CONVERTING

CONVERTER SLAG

Iron from the alloy forms an iron silicate that can be used in construction

NiCuCo MATTE

The alloy is sulfidized and the iron content is reduced by blowing air into the melt

HYDROMETALLURGICAL PROCESS

LEACHING

PURIFICATION

ELECTROWINNING

CRYSTALLIZATION

COPPER CATHODE

The primary material for electric vehicle (EV) battery connectors and wiring harnesses, electricity transmission cables and lines, and many other end-uses

NICKEL SULFATE

The most important element in a typical EV battery with nickel-rich chemistry

COBALT SULFATE

Keeps energy-dense EV batteries stable and safe during use

AMMONIUM SULFATE

TMC selected refining reagents that produce ammonium sulfate instead of waste. Ammonium sulfate is a valuable fertilizer used in agriculture

Differences from Minviro's LCA

In May 2025, TMC released a NORI-D LCA conducted by Minviro using the assumptions of a 2024 internal Pre-Feasibility Study for the NORI-D Project. As TMC moves closer to commercial operations, more details are being defined at higher resolution and, as such, Ecoquant updated these assumptions based upon the scenario used in the SK-1300 compliant NORI-D PFS Technical Report Summary published in August 2025. The key distinguishing features of this study as compared to Minviro's LCA are summarized on the table below.

TMC NORI-D LCA Report – Minviro	TMC NORI-D LCA Report – Ecoquant
Offshore marine fuel usage based on internal 2024 PFS	Offshore marine fuel usage based on 2025 PFS
Nodule moisture content: 24%	Nodule moisture content: 28%
Ecoinvent 3.10	Ecoinvent 3.11
Indonesia and Japan NORI-D scenarios	Texas, Indonesia and Japan NORI-D scenarios
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, $NiSO_4{\cdot}6H_2O$, copper cathode and $CoSO_4{\cdot}7H_2O$

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 shares the same unit processes.

For the nodule collection stage, when the NiCuCo 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 NiCuCo matte was the functional unit, system expansion by substitution was applied on the converter slag as it is assumed to serve as an aggregate in the construction industry.

For the nodule collection stage, when $NiSO_4{\cdot}6H_2O$, $CoSO_4{\cdot}7H_2O$ and copper cathode are the studied functional units, 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. 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, and KOH used during cobalt solvent extraction). 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 are summarized in the table below.

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%
NiCoCu matte	9.5%	30.4%	1.5%	7.5%	7.5%	100.0%	–	–	–	–	9.5%
Ni in $NiSO_4{\cdot}6H_2O$	63.6%	63.6%		63.6%	63.6%	63.6%	63.6%	63.6%	92.4%	–	63.6%
Copper cathode	21.8%	21.8%		21.8%	21.8%	21.8%	21.8%	21.8%	–	–	21.8%
Co in $CoSO_4{\cdot}7H_2O$	14.6%	14.6%		14.6%	14.6%	14.6%	14.6%	14.6%	7.6%	–	14.6%

⬜ Mass Allocation 🟨 Economic Allocation 🟦 Energy Allocation ⬛ Metal Mass Allocation

Note: Only those impacts associated to the production of matte are allocated to the $NiSO_4{\cdot}6H_2O$, $CoSO_4{\cdot}7H_2O$ and copper cathode.

Impact Categories

All impact categories contained in the EF 3.1 method were assessed in this report – climate change, ozone depletion, human toxicity, particulate matter, acidification, eutrophication, freshwater ecotoxicity, ionizing radiation, photochemical ozone formation, water use, land use, and resource depletion. Although each offer value, the climate change impact category is one where the EF method and other LCIA methodologies do particularly well.

These are midpoint indicators which focus on single environmental problems. Definitions of all environmental impact categories assessed in this study are listed in the table below.

EF 3.1 Environmental Impact Categories

Impact Category	Description	Units
Climate Change	This indicator refers to the increase in average global temperatures as a result of greenhouse gas (GHG) emissions.	kg CO_2eq
Ozone Depletion	This indicator measures the depletion of the stratospheric ozone (O_3) layer which protects us from hazardous ultraviolet radiation (UV-B).	kg CFC-11eq
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
Human Toxicity, Non-Cancer Effects	This indicator refers to potential impacts on human health caused by the absorption of substances from the air, water and soil.	CTUh
Particulate Matter Formation	This indicator measures the adverse impacts on human health caused by emissions of Particulate Matter (PM) and its precursors (e.g. NOx, SO_2).	Disease incidence
Ionizing Radiation	This indicator measures the adverse impacts from the exposure to ionizing radiation (radioactivity) on human health. The EF method only considers emissions under normal operating conditions (no accidents in nuclear plants are considered).	kg U235eq
Photochemical Ozone Formation	This indicator refers to the formation of ozone in the troposphere from substances, resulting in harmful impacts to plants and animals, and leading to respiratory issues for humans.	kg NMVOCeq
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
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 limit growth in the original ecosystem.	mol N eq
Eutrophication, Freshwater	Substances containing nitrogen or phosphorus promote 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
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 in nitrogen. This indicator measures the potential impact of substances contributing to marine eutrophication.	kg N eq
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

EF 3.1 Environmental Impact Categories, continued

Impact Category	Description	Units
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
Water Use	The extraction 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
Resource Use, Fossils	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
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

The impacts on the seafloor 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, are also not adequately captured. Social impacts are not quantified in this study, nor the impacts from potential failures of tailing dams.

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.

Results

NORI-D Climate Change Impacts

The climate change impact for each of the six functional units analyzed is provided on the tables below. Per functional unit, three potential NORI-D onshore routes are assessed:

- Texas – pyrometallurgy + hydrometallurgy
- Indonesia – pyrometallurgy + South Korea – hydrometallurgy
- Japan – pyrometallurgy + South Korea – hydrometallurgy

Each graph provides results for two onshore electricity scenarios:

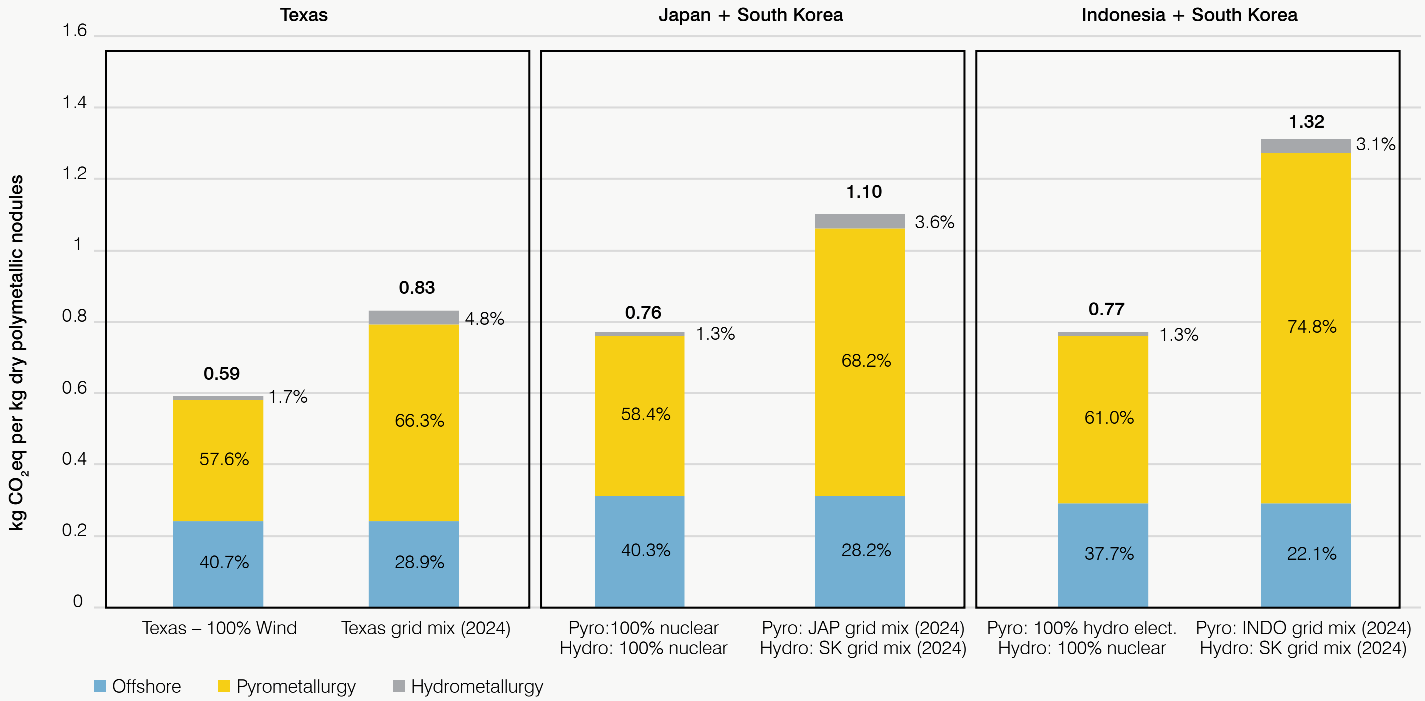
- Grid electricity (base case)
- Non-fossil-fuel electricity (for Texas this is assumed to be wind, for Japan nuclear and for Indonesia hydroelectric)

The graphs include a breakdown between the three major operational steps: offshore collection, pyrometallurgy and hydrometallurgy. Results of all other impact categories and more details on the impact contribution of each input per step can be found in the full LCA report.

The results of the non-fossil-fuel electricity scenario are provided along with the base case scenario of grid electricity, as TMC may be able to source these alternatives via market-based instruments in the future. 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.

Climate Change Impact – NORI-D Indonesia, Japan and Texas

Kg of Dry Polymetallic Nodules – Base Case vs. Non-Fossil-Fuel Electricity

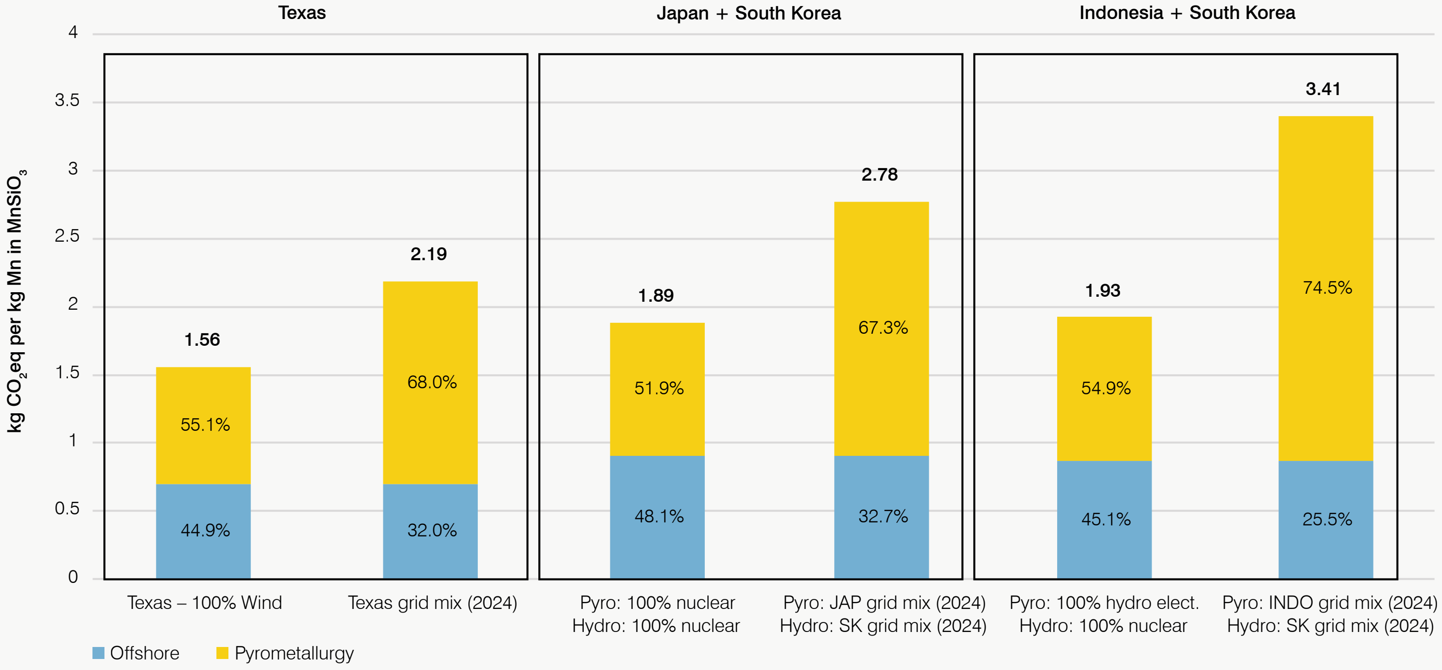


The pyrometallurgical step has the biggest impact across all scenarios accounting for 0.55 for Texas, 0.75 for Japan and 0.98 for Indonesia of total kg of CO_2e emissions per kg of dry polymetallic nodules when grid electricity is used. This impact is highest when processing occurs in Indonesia due to 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. When using non-fossil-fuel electricity, the pyrometallurgical impact decreases to 0.34 for Texas, 0.45 for Japan and 0.47 for Indonesia. This represents a total reduction per kg of dry nodule of 29%, 31% and 42% for Texas, Japan and Indonesian routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity. Offshore operations are the second biggest source of impact mainly due to the use of MGO, accounting for 0.24 for Texas, 0.31 for Japan and 0.29 for Indonesia of total emissions. The 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 stop in Indonesia), and thus the greatest marine fuel use.

Mn in $MnSiO_3$

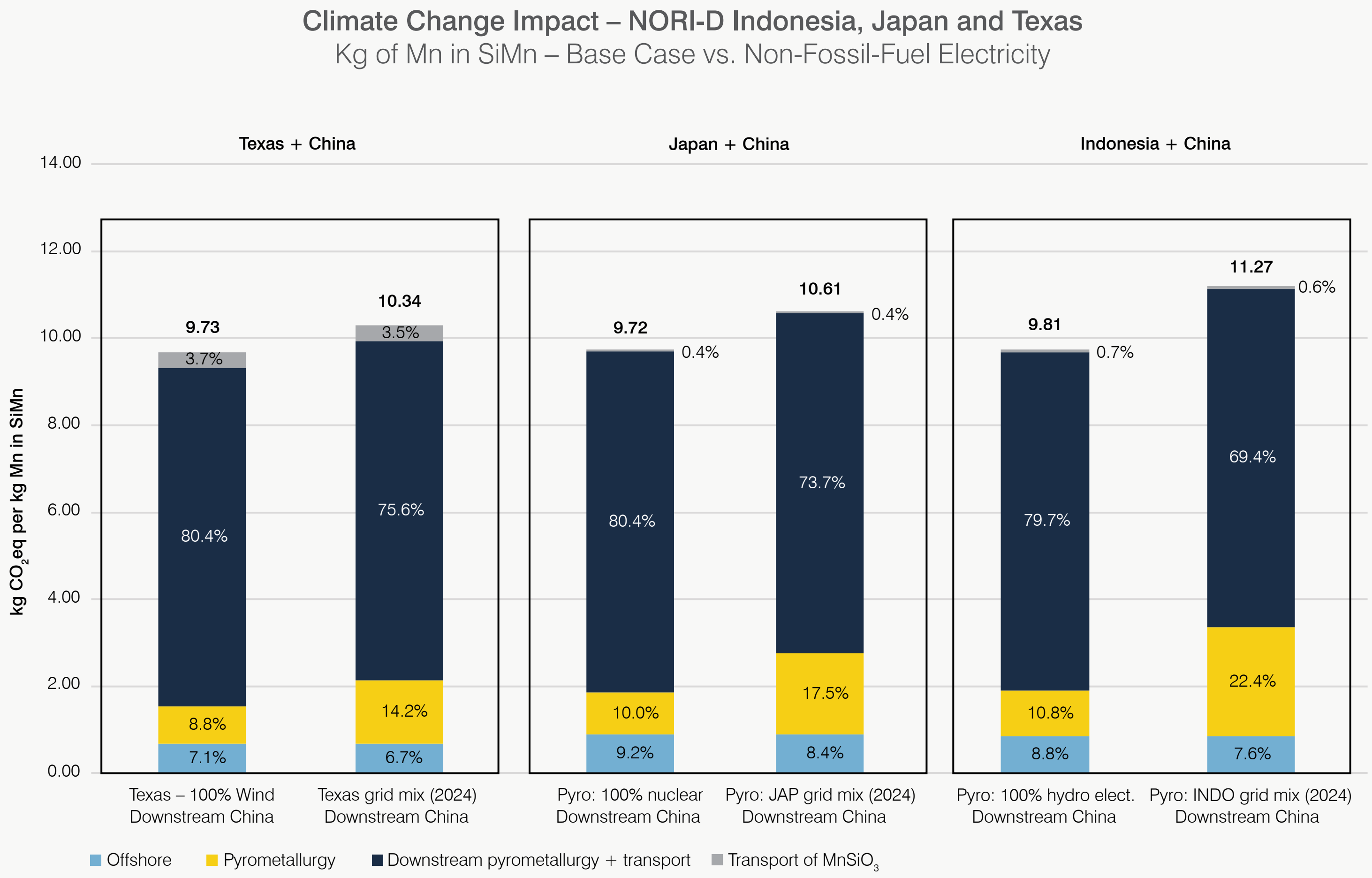
Climate Change Impact – NORI-D Indonesia, Japan and Texas

Kg of Mn in $MnSiO_3$ (40% Mn) – Base Case vs. Non-Fossil-Fuel Electricity



The pyrometallurgical step has the biggest impact across all scenarios accounting for 1.49 for Texas, 1.87 for Japan and 2.54 for Indonesia of total kg of CO_2e emissions per kg of Mn in $MnSiO_3$ when grid electricity is used. When using non-fossil-fuel electricity, it decreases to 0.86 for Texas, 0.98 for Japan and 1.06 for Indonesia. This represents a total reduction per kg of Mn in $MnSiO_3$ of 29%, 32%, and 43% for Texas, Japan, and Indonesian routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity. Offshore operations are the second biggest source of impact mainly due to the use of MGO, accounting for 0.70 for Texas, 0.91 for Japan and 0.87 for Indonesia of total emissions.

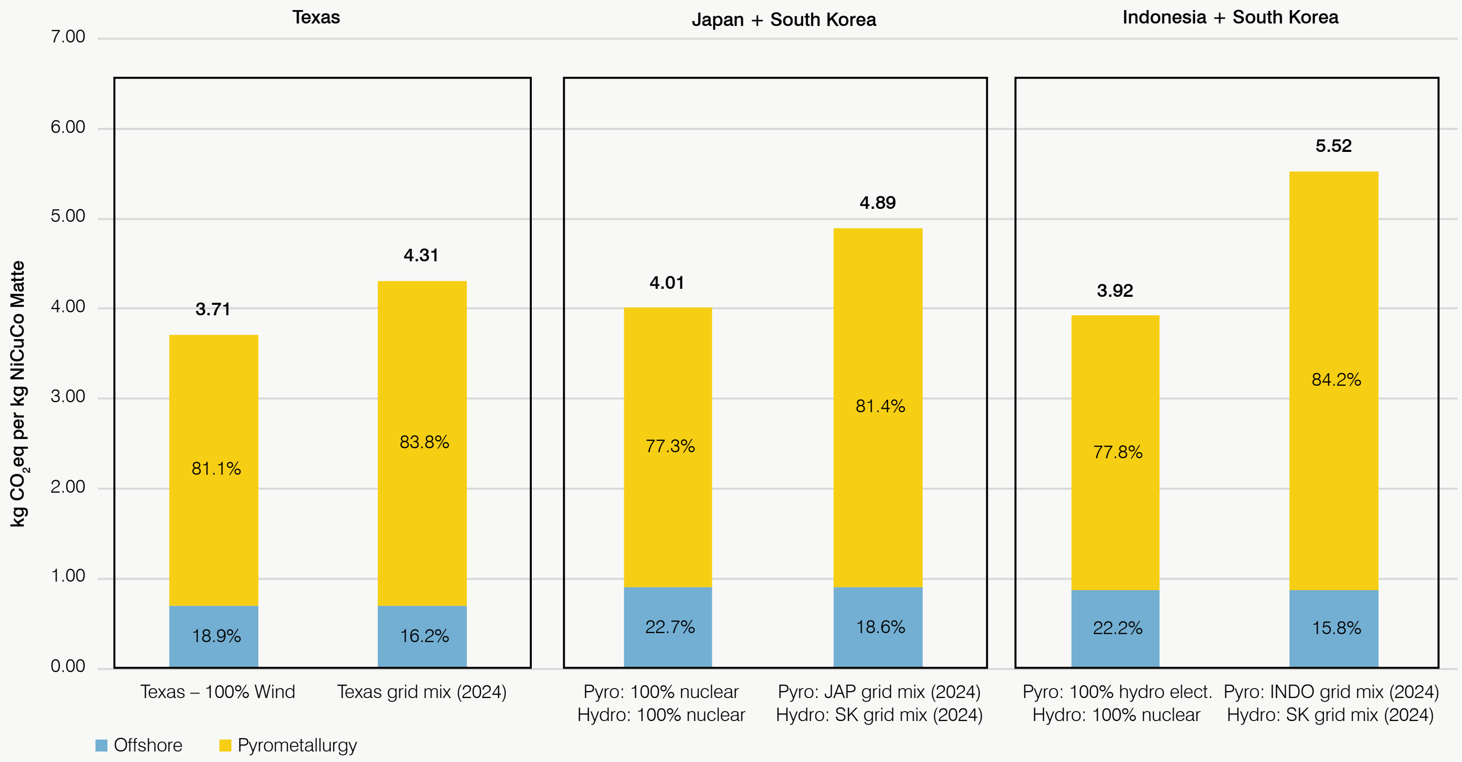
Mn in SiMn



The production of silicomanganese (SiMn) is performed by downstream customers in the steel industry, and assumes the use of NORI-D $MnSiO_3$ as input. China is the largest producer of SiMn, so it is assumed that the downstream customers' pyrometallurgical process uses China's electricity grid. This downstream step represents more than 70% of SiMn production emissions for all scenarios. This assumption is not changed as TMC does not have control over it, so the base case scenario and non-fossil-fuel electricity scenarios focus only on NORI-D $MnSiO_3$. For the base case scenario, the total kg of CO_2e emissions per kg of SiMn is 10.34 for Texas, 10.61 for Japan and 11.27 for Indonesia when grid electricity is used, for which NORI-D $MnSiO_3$ accounts for 2.17, 2.77 and 3.39, respectively. When using non-fossil-fuel electricity, the total value per kg of SiMn decreases to 9.73 for Texas, 9.72 for Japan and 9.81 for Indonesia, for which NORI-D $MnSiO_3$ accounts for 1.56, 1.89 and 1.93, respectively. These differences represent a total reduction of 6%, 8%, and 13% for Texas, Japan + South Korea, and Indonesia + South Korea routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity.

NiCuCo Matte

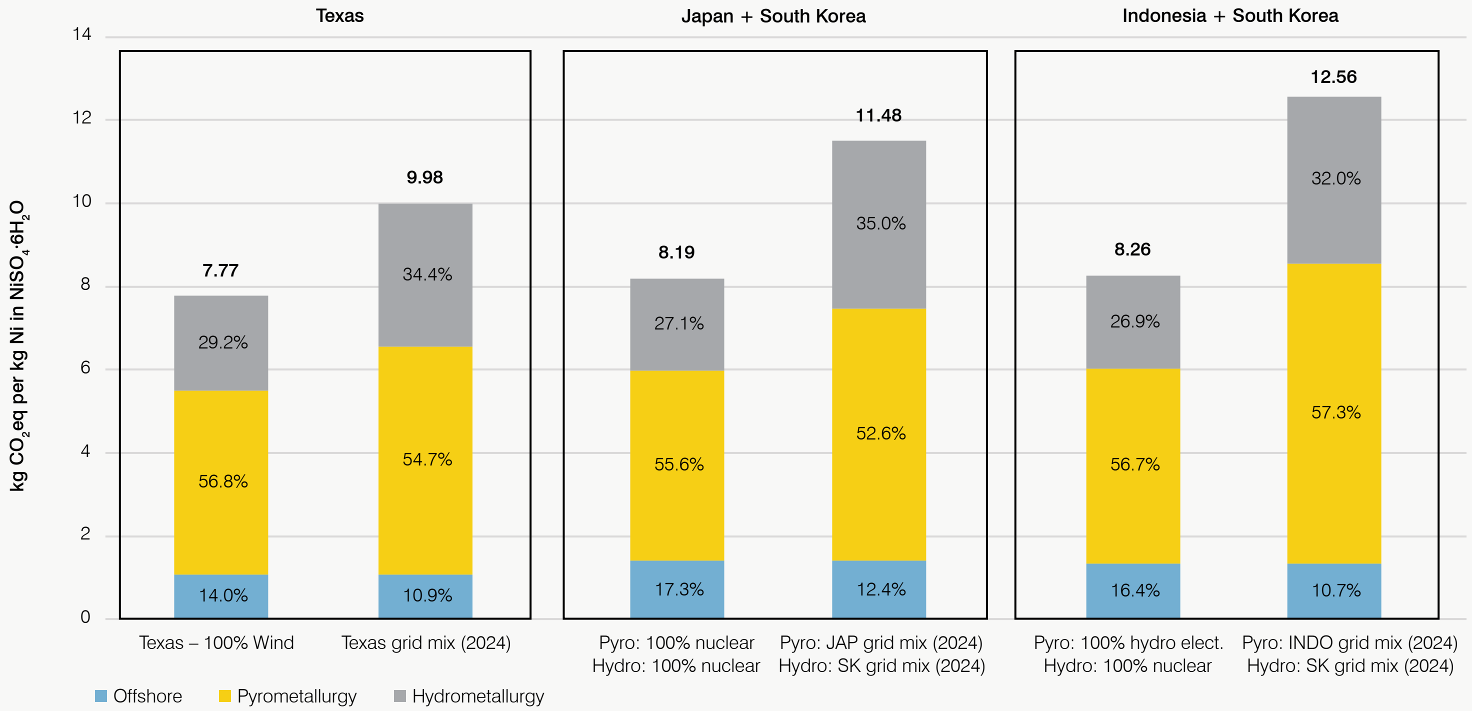
Climate Change Impact – NORI-D Indonesia, Japan and Texas
Kg of NiCuCo Matte – Base Case vs. Non-Fossil-Fuel Electricity



The pyrometallurgical step has the biggest impact across all scenarios accounting for 3.61 for Texas, 3.98 for Japan and 4.65 for Indonesia of total kg of CO_2e emissions per kg of NiCoCu matte when grid electricity is used. When using non-fossil-fuel electricity, the total decreases to 3.01 for Texas, 3.1 for Japan and 3.05 for Indonesia. This represents a total reduction per kg of NiCoCu Matte of 14%, 18%, and 29% for Texas, Japan, and Indonesia routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity. Offshore operations are the second biggest source of impact mainly due to the use of MGO, accounting for 0.70 for Texas, 0.91 for Japan and 0.87 for Indonesia of total emissions.

Ni in $NiSO_4 \cdot 6H_2O$

Climate Change Impact – NORI-D Indonesia, Japan and Texas
Kg of Ni in $NiSO_4 \cdot 6H_2O$ – Base Case vs. Non-Fossil-Fuel Electricity

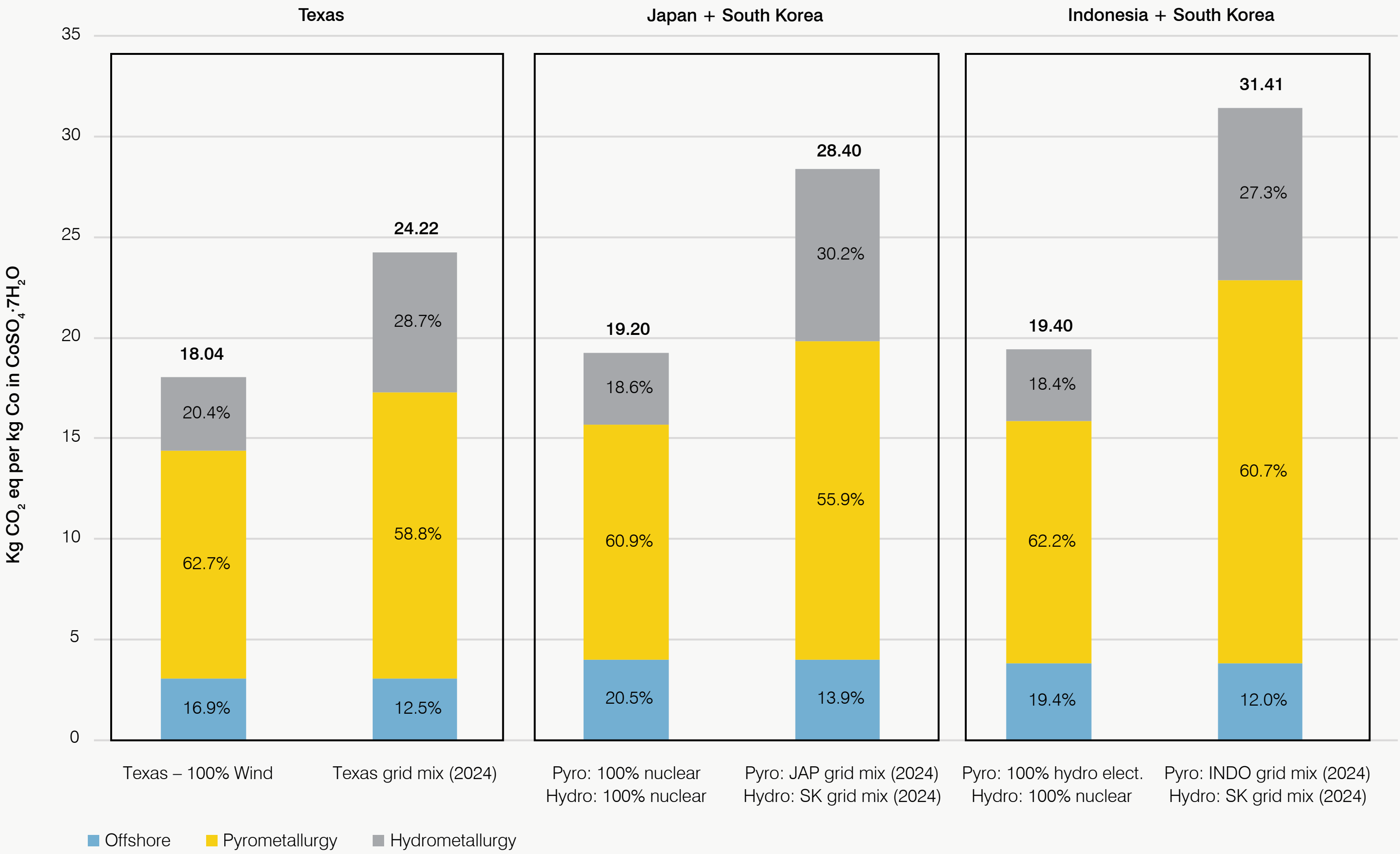


The pyrometallurgical step has the biggest impact across all scenarios accounting for 5.46 for Texas, 6.05 for Japan and 7.19 for Indonesia of total kg of CO_2e emissions per kg of Ni in $NiSO_4 \cdot 6H_2O$ when grid electricity is used. When using non-fossil-fuel electricity, the total decreases to 4.41 for Texas, 4.55 for Japan and 4.68 for Indonesia. The hydrometallurgical step is the second biggest source of impact, accounting for 3.43 for Texas, and 4.02 for Japan and Indonesia of total emissions for base case; when using non-fossil-fuel electricity, those values are 2.27 for Texas and 2.22 for South Korea. These differences, for both hydrometallurgical and hydrometallurgical steps, represent a total reduction per kg of Ni in $NiSO_4 \cdot 6H_2O$ of 22%, 29%, and 34% for Texas, Japan + South Korea, and Indonesia + South Korea routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity.

Co in $CoSO_4 \cdot 7H_2O$

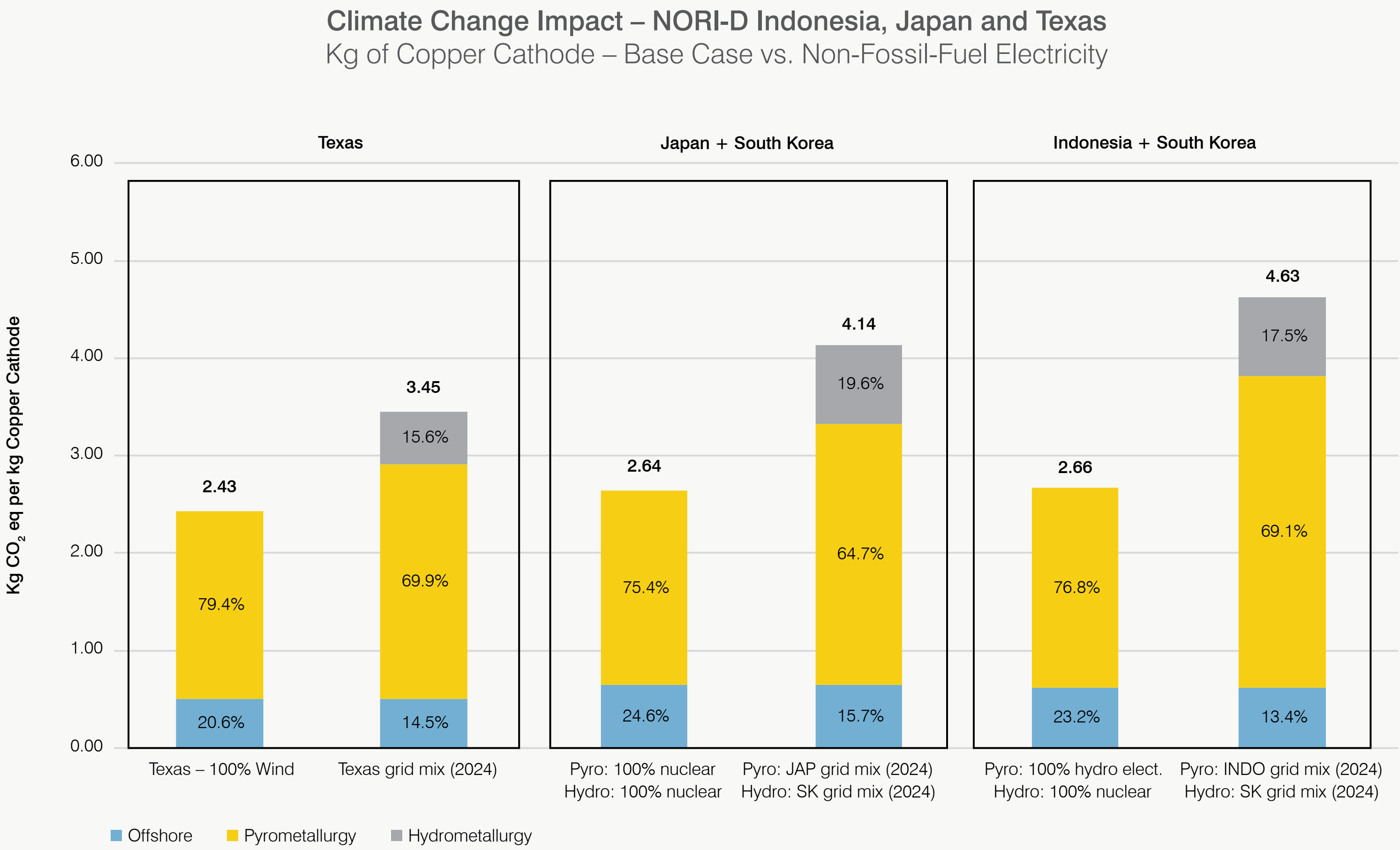
Climate Change Impact – NORI-D Indonesia, Japan and Texas

Kg of Co in $CoSO_4 \cdot 7H_2O$ – Base Case vs. Non-Fossil-Fuel Electricity



The pyrometallurgical step has the biggest impact across all scenarios accounting for 14.24 for Texas, 15.86 for Japan and 19.06 for Indonesia of total kg of CO_2e emissions per kg of Co in $CoSO_4 \cdot 7H_2O$ when grid electricity is used. When using non-fossil-fuel electricity, the total decreases to 11.31 for Texas, 11.71 for Japan and 12.07 for Indonesia. The hydrometallurgical step is the second biggest source of impact, accounting for 6.94 for Texas and 8.58 for Japan and Indonesia of total emissions for base case; when using non-fossil-fuel electricity, those values are 3.68 for Texas and 3.57 for South Korea. These differences, for both hydrometallurgical and hydrometallurgical steps, represent a total reduction per kg of Co in $CoSO_4 \cdot 7H_2O$ of 26%, 32%, and 38% for Texas, Japan + South Korea, and Indonesia + South Korea routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity.

Copper Cathode

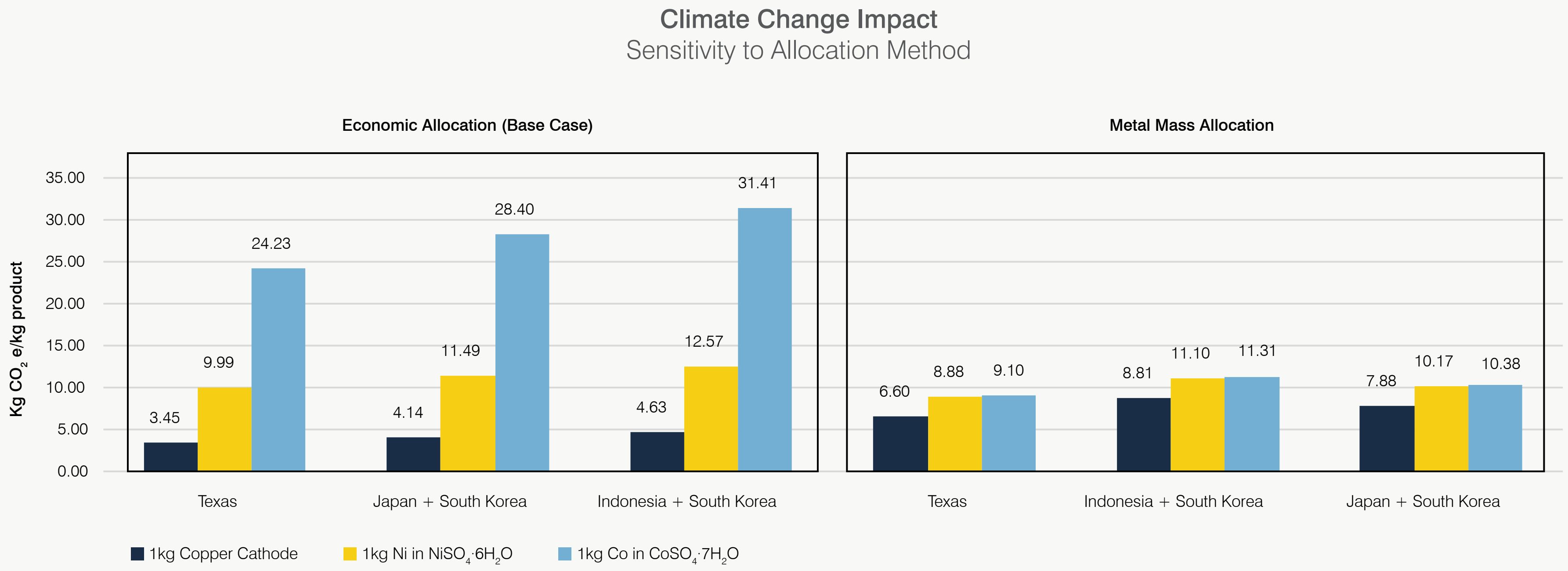


The pyrometallurgical step has the biggest impact across all scenarios accounting for 2.41 for Texas, 2.68 for Japan and 3.2 for Indonesia of total kg of CO_2e emissions per kg of copper cathode when grid electricity is used. When using non-fossil-fuel electricity, the total decreases to 1.93 for Texas, 1.99 for Japan and 2.05 for Indonesia. The hydrometallurgical step is the second biggest source of impact, accounting for 0.54 for Texas and 0.81 for South Korea of total emissions for base case; when using non-fossil-fuel electricity, those values go to zero for all the routes. These differences, for both pyrometallurgical and hydrometallurgical steps, represent a total reduction per kg of copper cathode of 30%, 36%, and 43% for Texas, Japan + South Korea, and Indonesia + South Korea routes, respectively, when grid electricity is replaced with non-fossil-fuel electricity.

ALLOCATION SENSITIVITY ANALYSIS

In addition to assessing the impact of using non-fossil-fuel electricity, the LCA did a sensitivity analysis on how the use of economic allocation for refined co-products affects the results as compared to metal mass allocation.

Sensitivity Analysis – Metal Mass Allocation



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 $CoSO_4{\cdot}7H_2O$. The climate change impact for copper cathode increases by approximately 90% from the base case when metal mass allocation is considered. The climate change impact of Co in $CoSO_4{\cdot}7H_2O$ decreases by approximately 64% from the base case when metal mass allocation is considered. The climate change impact of Ni in $NiSO_4{\cdot}6H_2O$ 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.

Additional sensitivity analysis can be found on the full LCA report.

NORI-D Climate Change Impacts and Comparison to Terrestrial Routes

This section presents an analysis of the products SiMn, $NiSO_4 \cdot 6H_2O$, Copper cathode, and $CoSO_4 \cdot 7H_2O$ produced via traditional land-based routes as compared to the same products from NORI-D. For the terrestrial comparisons, each route was based on the best available data which is available 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 the table below.

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	$NiSO_4 \cdot 6H_2O$ (22% Ni)
Indonesia to Japan	Ni saprolite	1.8%	RKEF	Indonesia	Matte	LX-SX	Japan[1]	$NiSO_4 \cdot 6H_2O$ (22% Ni)
Indonesia to China	Ni saprolite	1.8%	RKEF	Indonesia	Matte	LX-SX	China	$NiSO_4 \cdot 6H_2O$ (22% Ni)
Canada to Norway	NiCuCo sulfide	1.8%	Smelting	Canada[2]	Matte	MCLE	Norway[3]	$NiSO_4 \cdot 6H_2O$ (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 (99.99% Cu)
Peru to China	Copper sulfide	0.36%	Crushing, concentration	Peru	Copper concentrate	Smelting refining	China[4]	Copper cathode (99.99% Cu)
USA	Copper sulfide	0.32%	Crushing, concentration	New Mexico & Arizona	Copper concentrate	Smelting refining	Texas, USA	Copper cathode (99.99% Cu)
USA	Copper oxide	0.23%	Crushing, heap leaching	Arizona	PLS	SX-EW	Arizona, USA	Copper cathode (99.99% Cu)
DRC to China	CuCo	2.44% Cu 0.47% Co	Hydrometallurgy, Co synthesis	DRC	Crude cobalt hydroxide	Refining (SX-EW)	China	$CoSO_4 \cdot 7H_2O$ (21 Co)
Indonesia to China	Ni laterite	<1.4% Ni <0.15% Co	HPAL	Indonesia	MHP	LX-SX	China	$CoSO_4 \cdot 7H_2O$ (21 Co)
China	Copper sulfide	0.36%	Crushing & concentration	China[5]	Copper concentrate	Smelting refining	China[4]	Copper cathode (99.99% Cu)
China	Mn ore	35.70%	Mining & beneficiation	China	Mn concentrate	Pyrometallugy	China	SiMn (68.9% Mn)

1. For the nickel matte refined in Japan, due to 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 $NiSO_4 \cdot 6H_2O$ 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 preocessing methods in Peru. To improve 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.

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.

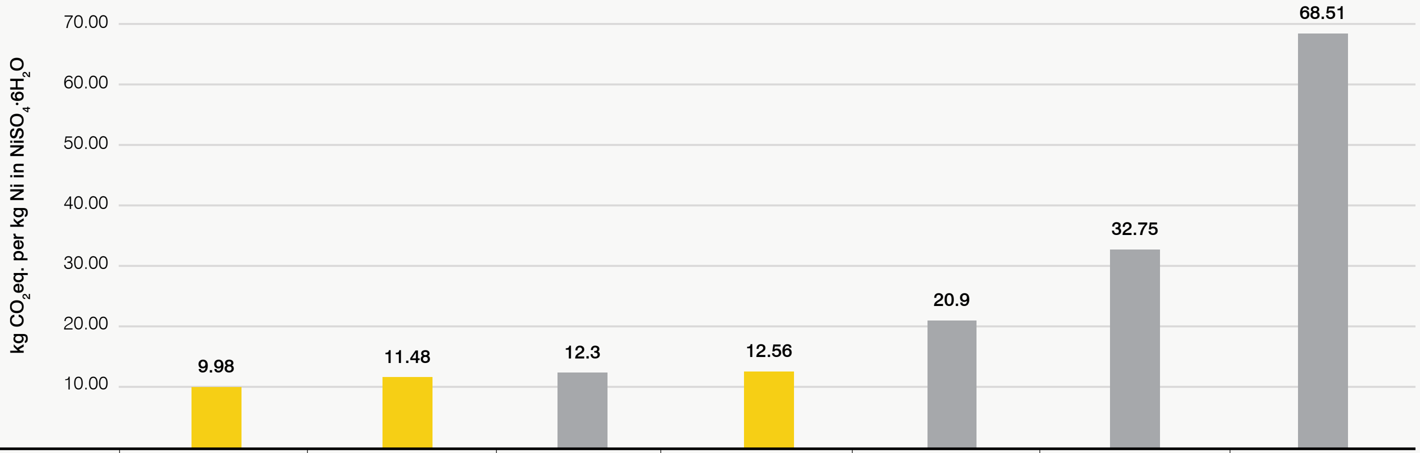
Ni in $NiSO_4 \cdot 6H_2O$

Indonesia is the world's largest producer of mined nickel accounting for 60% of global production, the majority of which is shipped to China, positioning the Indonesia-China (RKEF) route as a critical pathway for the production of $NiSO_4 \cdot 6H_2O$. While the Indonesia-Japan (RKEF) route accounts for only a small portion of global $NiSO_4 \cdot 6H_2O$ production, it was included as context of a lower impact route because of access to a significant share of renewables.

Indonesia is also the leading global producer of mixed hydroxide precipitate (MHP), the majority of which is shipped to China, positioning this route as a critical pathway for the production of $NiSO_4 \cdot 6H_2O$. The production of MHP is forecasted to grow further in coming years as ore grades decline.

Canada is the world's second-largest producer of nickel matte with the majority shipped to Norway. This route is considered a low impact route for the production of $NiSO_4 \cdot 6H_2O$ due to the large share of renewables on the Canadian and Norwegian grid.

1kg Ni in $NiSO_4 \cdot 6H_2O$ (22% Ni) – **Climate Change Impact** by processing technology and location



Impact Category	Unit	Nodules NORI-D Texas RKEF	Nodules NORI-D Japan RKEF	Sulfides Canada Norway Smelting	Nodules NORI-D Indonesia RKEF	Limonite Indonesia-China HPAL	Saprolite Indonesia-Japan RKEF	Saprolite Indonesia-China RKEF
Climate Change	kg CO$_2$eq	🟦 9.98	11.48	12.30	12.56	20.90	32.75	🟥 68.51
Freshwater + Terrestrial Acidification	mol H+ eq	🟦 0.064	0.082	0.072	0.088	0.465	🟥 1.000	0.577
Eutrophication Freshwater	kg P eq	0.004	🟦 0.004	0.026	0.008	0.032	0.006	🟥 0.092
Terrestrial Eutrophication	mol N eq	🟦 0.051	0.088	0.055	0.104	0.381	0.433	🟥 0.966
Freshwater Ecotoxicity	CTUe	🟦 -260.0	-259.0	🟥 539.0	-252.0	383.0	57.8	242.0
Marine Eutrophication	kg N eq	🟦 0.003	0.007	0.006	0.009	0.034	0.042	🟥 0.106
Ionising Radiation	kg U235eq	0.42	0.79	🟥 19.90	0.58	0.74	0.43	🟦 0.41
Photochemical Ozone	kg NMVOCeq	🟦 0.02	0.03	0.03	0.04	0.13	0.16	🟥 0.27
Human Toxicity, Cancer Effects	CTUh	🟦 -3.11E-10	2.35E-10	6.69E-09	7.96E-10	2.63E-08	9.26E-09	🟥 3.65E-08
Human Toxicity, Non-Cancer Effects	CTUh	🟦 9.18E-08	9.45E-08	1.39E-07	1.32E-07	1.50E-06	🟥 5.83E-04	7.10E-07
Particulate Matter Formation	Disease incidence	🟦 3.67E-07	4.60E-07	1.83E-06	6.34E-07	2.58E-06	🟥 1.44E-03	6.94E-06
Ozone Depletion	kg CFC-11eq	🟦 5.15E-08	1.01E-07	9.43E-08	8.76E-08	1.34E-07	🟥 3.77E-07	2.67E-07
Resource Use, Minerals+Metals	kg Sb eq	🟦 -2.34E-05	-2.09E-05	2.72E-04	-2.11E-05	🟥 1.93E-03	1.30E-04	1.34E-04
Resource Use, Fossils	MJ	🟦 114	142	379	148	206	344	🟥 831
Water Use	m_3	🟦 1.2	2.1	🟥 46.0	2.3	20.2	45.4	11.4
Land Use	Pts	🟦 10.0	17.7	34.5	15.6	93.3	31.4	🟥 119.0

🟦 Best 🟥 Worst

The climate change impact associated with the production of 1kg of Ni in $NiSO_4{\cdot}6H_2O$ is lower for the NORI-D Texas and Japan routes than all land-based production routes evaluated. The impact of NORI-D Texas is lowest at 9.98 kg CO_2eq. 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 GWP advantages assessed for the NORI-D routes are driven by various factors. Firstly, the relatively high grade of nickel in the nodules leads to less material use per ton of extracted nickel, as opposed to lower grade land-based ore. Secondly, offshore operations have a relatively small climate change impact. Finally, the unique processing pathway produces multiple co-products that share the environmental load.

The Canada-Norway production route demonstrates a comparable climate change impact to the NORI-D routes, performing slightly better than the 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 temperatures 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 surrounding human communities.

The Indonesia-Japan and Indonesia-China (saprolite) routes shows the largest climate change impact. These routes require high-temperature furnaces for smelting and consume 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.

The acidification impact of NORI-D Texas is lowest. 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, 1,341% for the Indonesia-China (RKEF) route, and 1,406% for the Indonesia-Japan (RKEF) route. The higher acidification impact of the Indonesia-China (RKEF) and Indonesia-Japan routes is 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.

The freshwater eutrophication impact is lower across all TMC's NORI-D project locations compared to the traditional land-based production routes evaluated. The impact of NORI-D Texas is lowest at 9.97 and increases by approximately 56% for NORI-D Indonesia route, 78% for the 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.

The Indonesia-China (HPAL) route has the second highest impact on freshwater eutrophication of the routes analyzed. The impact primarily comes from the tailings, large volumes of which are generated during the production of MHP.

Copper Cathode

Chile is the largest producer of mined copper in the world and ranks among the top three for refined copper production. Heap leaching accounts for approximately 30-40% of annual copper production in Chile, making this a key route for the production of copper cathode.

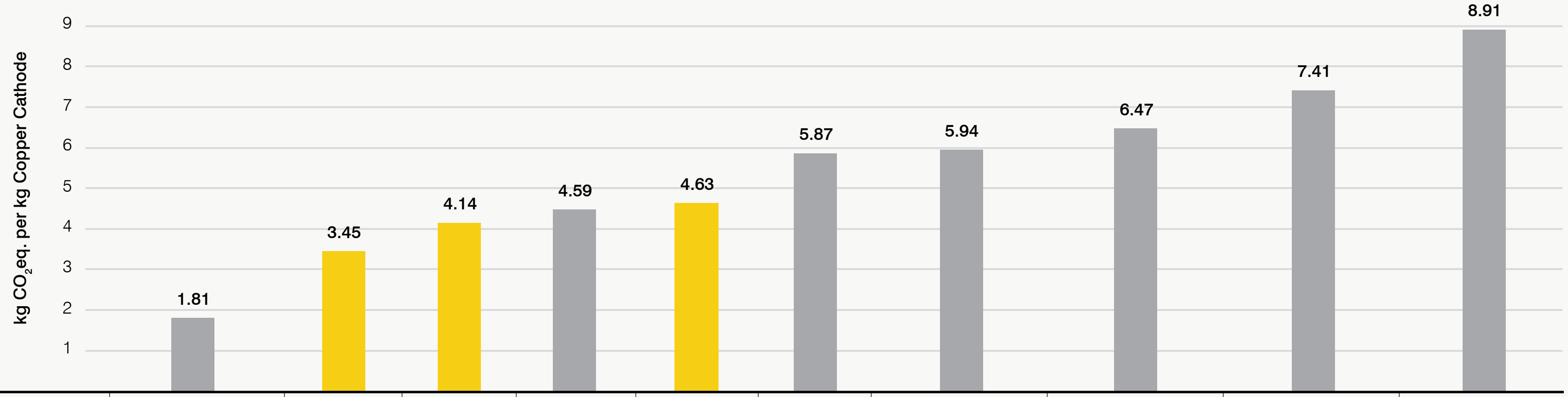
While Chile is the largest producer of mined copper in the world, they currently lack the refining facilities to match their mined output. Therefore, the majority of their copper concentrate is exported, mostly to China. Consequently, this route represents a major route to produce copper cathode. China ranks fourth in terms of global copper mine production, but first in terms of refined copper production due to the sheer volume of copper concentrates that are shipped to China for refining.

Peru ranks second or third in terms of global copper mine production. However, they also lack the facilities to refine their mined copper output, and thus export the majority of their copper, mostly to China.

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 which now ranks among the top three in the world for refined copper production.

The United States ranks fifth in terms of mined production and sixth in terms of refined production.

1kg Copper Cathode (99.99% Cu) – Climate Change Impact by processing technology and location



Impact Category	Unit	Copper-Cobalt DRC Hydrometallurgy	Nodules NORI-D Texas RKEF	Nodules NORI-D Japan RKEF	Copper Oxide Chile Heap Leach	Nodules NORI-D Indonesia RKEF	Copper Oxide USA Heap leach	Copper Sulfide USA Pyrometallurgy	Copper Sulfide Peru-China Pyrometallurgy	Copper Sulfide Chile-China Pyrometallurgy	Copper Sulfide China Pyrometallurgy
Climate Change	kg CO$_2$eq	🟦 1.81	3.45	4.14	4.59	4.63	5.87	5.94	6.47	7.41	8.91
Freshwater + Terrestrial Acidification	mol H+ eq	0.06	🟦 0.03	0.03	0.07	0.04	0.08	0.04	0.06	🟥 0.09	0.07
Eutrophication Freshwater	kg P eq	0.005	0.002	🟦 0.001	0.003	0.003	0.006	0.061	🟥 0.082	0.037	0.020
Terrestrial Eutrophication	mol N eq	0.22	🟦 0.02	0.03	0.19	0.04	0.19	0.16	0.21	🟦 0.29	0.22
Freshwater Ecotoxicity	CTUe	175	🟦 -120	-120	15	-117	31	658	🟥 1250	132	232
Marine Eutrophication	kg N eq	0.015	🟦 0.001	0.002	0.018	0.003	0.018	0.017	0.021	🟥 0.028	0.021
Ionising Radiation	kg U235eq	🟦 0.02	0.18	0.35	0.04	0.26	🟥 0.92	0.67	0.12	0.13	0.79
Photochemical Ozone	kg NMVOCeq	0.05	🟦 0.01	0.01	0.06	0.01	0.06	0.05	0.06	🟥 0.08	0.06
Human Toxicity, Cancer Effects	CTUh	6.52E-10	🟦 -3.71E-10	-1.89E-10	1.48E-09	6.83E-11	2.64E-09	1.39E-09	2.32E-09	🟥 2.85E-09	1.78E-09
Human Toxicity, Non-Cancer Effects	CTUh	🟦 1.16E-08	3.57E-08	3.48E-08	9.26E-08	5.20E-08	🟥 1.77E-07	4.53E-08	4.17E-08	4.11E-08	4.87E-08
Particulate Matter Formation	Disease incidence	3.46E-07	1.35E-07	1.67E-07	3.12E-07	2.47E-07	3.37E-07	🟦 1.31E-07	2.61E-07	4.76E-07	🟥 6.23E-07
Ozone Depletion	kg CFC-11eq	2.70E-08	🟦 1.45E-08	3.38E-08	6.60E-08	2.74E-08	1.01E-07	🟥 1.04E-07	6.23E-08	8.42E-08	5.50E-08
Resource Use, Minerals+Metals	kg Sb eq	7.51E-06	🟦 -1.33E-05	-1.31E-05	9.97E-05	-1.32E-05	🟥 1.87E-04	1.22E-05	1.18E-05	1.50E-05	1.15E-05
Resource Use, Fossils	MJ	🟦 19.30	42.90	52.00	76.80	54.60	113.00	86.90	84.70	105.00	🟥 114.00
Water Use	m_3	0.22	🟦 -0.42	-0.27	1.28	-0.17	3.42	1.05	🟥 37.40	0.62	1.03
Land Use	Pts	6.64	🟦 2.17	5.08	🟥 338.00	4.13	238.00	40.10	55.10	30.3	26.1

🟦 Best 🟥 Worst

NORI-D Texas route is lower for all evaluated routes except the DRC route. The NORI-D Indonesia and Japan routes also perform better than most routes evaluated. The 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 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.

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 the high energy use and large volumes of fossil-based reductants required for 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 smelting and heap leach routes have an impact that is the rough average of all 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. Lower grade ores tend to require more diesel use in mining as they are required to be moved as opposed to higher grade ores. Lime used for neutralization also carries a significant climate change impact.

The Peru-China and Chile-China routes are towards the higher end of the scale of the evaluated routes for climate change impacts. This is mostly due to the processing of concentrate in China which 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 acidification impact is lower across all NORI-D routes than all of the land-based production routes evaluated. The impact of NORI-D Texas is lowest. It increases by:

- 27% for the NORI-D Japan route
- 36% for the 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.

In general, the impacts on freshwater eutrophication 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 NORI-D Japan is lowest 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.

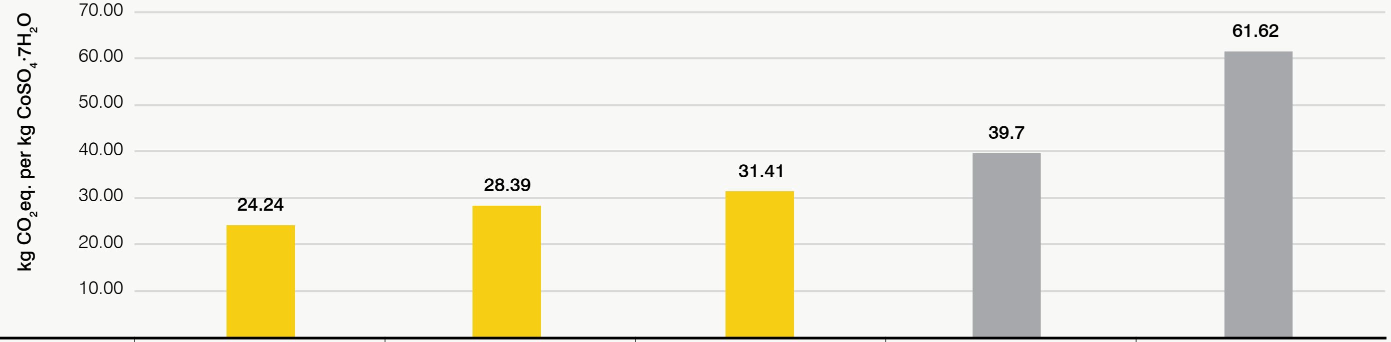
Co in $CoSO_4·7H_2O$

The DRC is the world's largest producer of cobalt, accounting for 70-80% of global mined 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 four-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 three months until the end of September. On September 21, the DRC authorities announced that the seven-month long ban on cobalt exports would be replaced with a strict quota system limiting exports to less than half of 2024 production.

Because of the sheer volume of MHP produced in Indonesia, which is mainly shipped to China, this route has emerged as a dominant route for the production of $CoSO_4·7H_2O$.

1kg Co in $CoSO_4·7H_2O$ (21% Co) – Climate Change Impact by processing technology and location



Impact Category	Unit	Nodules NORI-D Texas RKEF	Nodules NORI-D Japan RKEF	Nodules NORI-D Indonesia RKEF	Copper-Cobalt DRC-China Hydrometallurgy	Limonite Indonesia-China HPAL
Climate Change	kg CO_2eq	24.24	28.39	31.41	39.70	61.62
Freshwater + Terrestrial Acidification	mol H+ eq	0.08	0.12	0.11	0.63	1.38
Eutrophication Freshwater	kg P eq	0.008	0.006	0.006	0.320	0.095
Terrestrial Eutrophication	mol N eq	0.24	0.11	0.09	2.19	1.13
Freshwater Ecotoxicity	CTUe	-744	-743	-744	9260	1810
Marine Eutrophication	kg N eq	-0.002	0.006	0.004	0.167	0.102
Ionising Radiation	kg U235eq	1.16	2.18	1.60	1.68	2.20
Photochemical Ozone	kg NMVOCeq	0.03	0.05	0.05	0.50	0.12
Human Toxicity, Cancer Effects	CTUh	-4.55E-12	1.08E-09	2.43E-10	9.32E-08	7.80E-08
Human Toxicity, Non-Cancer Effects	CTUh	2.34E-07	2.32E-07	2.18E-07	5.16E-07	4.43E-06
Particulate Matter Formation	Disease incidence	7.33E-07	9.21E-07	9.26E-07	4.79E-06	1.37E-06
Ozone Depletion	kg CFC-11eq	1.39E-07	2.56E-07	1.92E-07	4.62E-07	3.97E-07
Resource Use, Minerals+Metals	kg Sb eq	2.16E-01	-6.04E-05	-6.23E-05	0.0004	0.0007
Resource Use, Fossils	MJ	-6.16E-05	2.28E+02	2.27E+02	4.52E+02	6.10E+02
Water Use	m_3	3.19	4.11	3.79	7.75	8.04
Land Use	Pts	10.4	27.5	16.4	284.0	276.0

🟦 Best 🟥 Worst

The climate change impact is lower across all NORI-D project locations compared to the land-based production routes evaluated. The impact of NORI-D Texas is lowest at 24.23 kg CO_2eq. It increases by approximately 17% for the NORI-D Japan route, 30% for the NORI-D Indonesia route, 64% for the DRC-China route and by 154% for the Indonesia-China route.

For the DRC-China route, most of the impact occurs during the refining stage in China, largely attributable 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 $CoSO_4 \cdot 7H_2O$ is highest via the Indonesia-China (HPAL) route compared to 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 used during MHP production.

The acidification impact is lower across all TMC's NORI-D routes than all land-based production routes evaluated. The impact of NORI-D Texas is lowest. It increases by approximately 30% for the NORI-D Indonesia route, 50% for the NORI-D Japan route, 675% for the DRC-China route, and 1,565% for the Indonesia-China route.

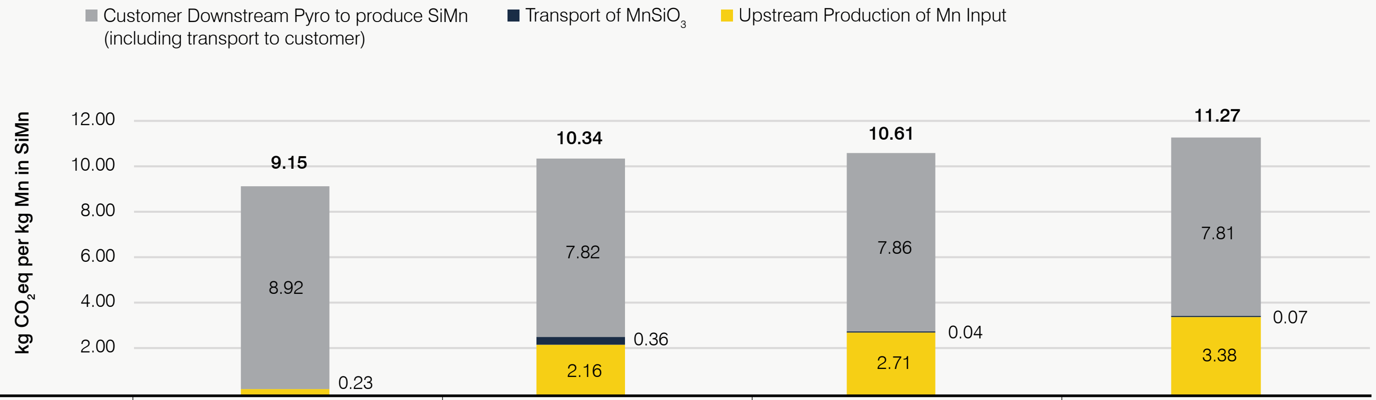
The impact on freshwater eutrophication is lower across all TMC's NORI-D project locations compared to the traditional land-based production routes evaluated. The impact of NORI-D Indonesia is lowest and increases by approximately 1% for NORI-D Japan route, 21% for the Indonesia-China route, 1,389% for the Indonesia-Japan route, and 4,907% for the DRC-China route.

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

Mn in SiMn

China is the leading producer of silicomanganese. SiMn 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. It is produced via the carbothermic reduction of manganese ores and silica in a submerged electric arc furnace (EAF) which is an energy intensive process. 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. The terrestrial scenario analyzed in this LCA assumes Mn ore mined in China and processed into SiMn in China.

1kg Mn in SiMn (68.9% Mn) – Climate Change Impact by processing technology and location



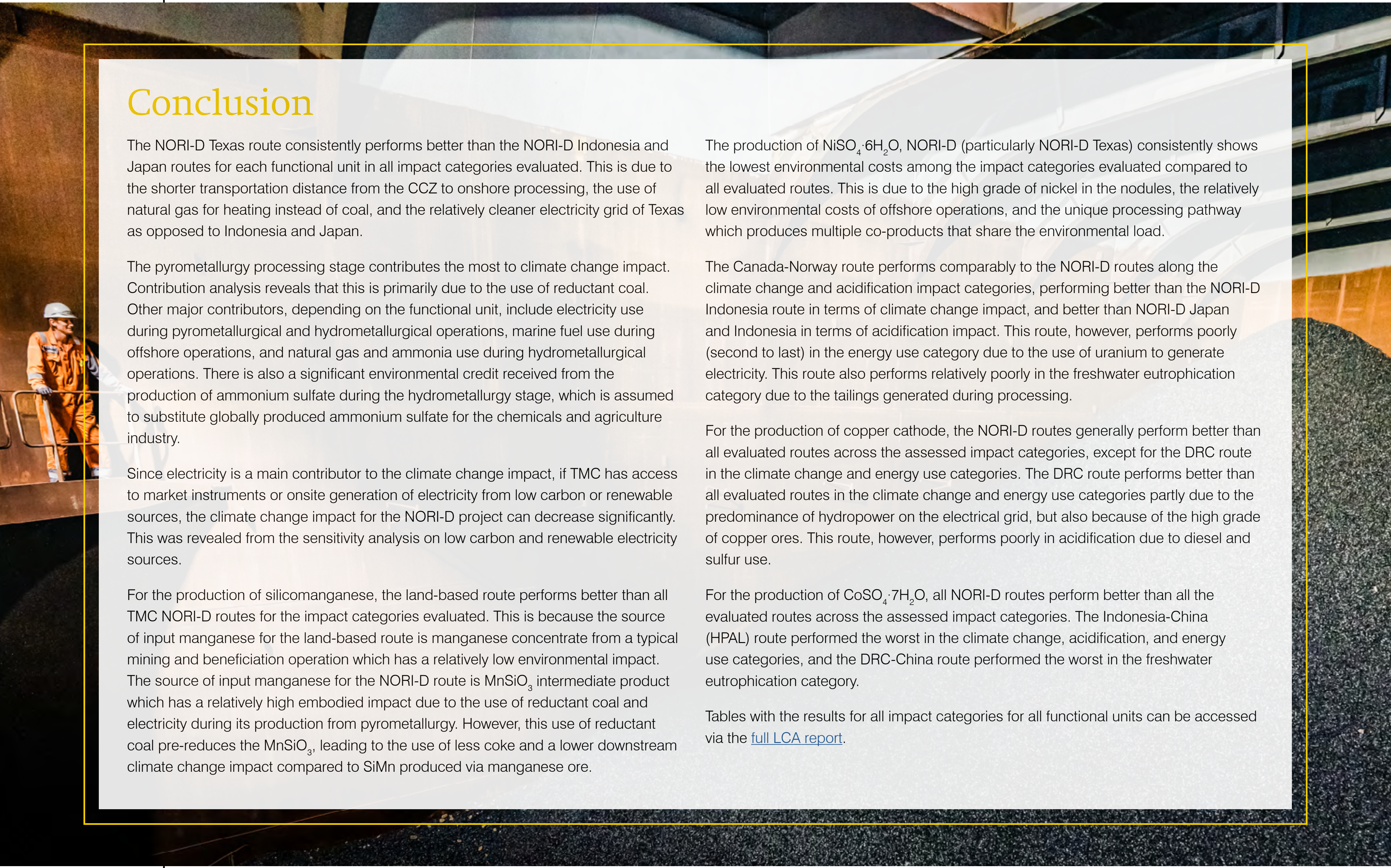
Impact Category	Unit	Manganese Ore China Pyrometallurgy	Nodules NORI-D Texas-China RKEF	Nodules NORI-D Japan-China RKEF	Nodules NORI-D Indonesia-China RKEF
Climate Change	kg CO$_2$eq	🟦 9.15	10.34	🟥 10.61	11.27
Freshwater + Terrestrial Acidification	mol H+ eq	🟦 0.007	0.056	0.055	🟥 0.064
Eutrophication Freshwater	kg P eq	🟦 0.00149	🟥 0.21	0.04	0.07
Terrestrial Eutrophication	mol N eq	🟦 0.09	🟥 2.74	0.59	0.91
Freshwater Ecotoxicity	CTUe	24.30	24.50	🟦 20.90	🟥 28.70
Marine Eutrophication	kg N eq	🟥 0.008	🟦 0.004	0.007	0.005
Ionising Radiation	kg U235eq	🟥 0.157	0.147	0.145	🟦 0.017
Photochemical Ozone	kg NMVOCeq	0.014	🟦 0.008	🟥 0.022	0.014
Human Toxicity, Cancer Effects	CTUh	🟦 4.98E-09	7.49E-09	🟥 7.97E-09	7.89E-09
Human Toxicity, Non-Cancer Effects	CTUh	🟦 -7.25E-04	4.19E-08	5.74E-08	🟥 6.29E-08
Particulate Matter Formation	Disease incidence	🟦 -7.22E-05	7.58E-07	4.36E-07	🟥 9.03E-07
Ozone Depletion	kg CFC-11eq	🟦 1.37E-08	2.55E-08	🟥 1.15E-07	2.89E-08
Resource Use, Minerals+Metals	kg Sb eq	🟥 7.73E-06	2.60E-06	2.79E-06	🟦 2.45E-06
Resource Use, Fossils	MJ	🟦 87.5	105.0	🟥 113.0	🟥 113.0
Water Use	m_3	🟦 0.93	1.13	🟥 2.32	1.18
Land Use	Pts	🟥 261	180	🟦 170	195

🟦 Best 🟥 Worst

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. The impact is 10.3% lower than NORI-D Texas, 13.7% lower than NORI-D Japan, and 18.3% lower than NORI-D Indonesia for base case scenario. If using non-fossil-fuel electricity for the production of $MnSiO_3$, the difference would be closer to 6% for all the NORI-D routes.

TMC's NORI-D $MnSiO_3$ has a relatively high embodied carbon due to the use of reductant coal and electricity in pyrometallurgical operations. However, TMC's $MnSiO_3$ is pre-reduced from the coal, thus decreasing the amount of reductant needed in downstream processing by 14%. 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.

The SiMn produced via the traditional land-based route performs better in the acidification and freshwater eutrophication categories than SiMn produced from NORI-D $MnSiO_3$. The higher acidification impact in the TMC NORI-D routes is mainly attributed to the usage of marine gas oil in offshore operations including $MnSiO_3$ transport to China. The higher freshwater eutrophication 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.



Conclusion

The NORI-D Texas route consistently performs better than the NORI-D Indonesia and Japan routes for each functional unit in all impact categories evaluated. This is due to the shorter transportation 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 as opposed to Indonesia and Japan.

The pyrometallurgy processing stage contributes the most to climate change impact. Contribution analysis reveals 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 use 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, the 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.

For the production of silicomanganese, 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 the NORI-D route is $MnSiO_3$ 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.

The production of $NiSO_4 \cdot 6H_2O$, NORI-D (particularly NORI-D Texas) consistently shows the lowest environmental costs 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 costs of offshore operations, and the unique processing pathway which produces multiple co-products that share the environmental load.

The Canada-Norway route performs comparably to the NORI-D routes along the climate change and acidification impact categories, 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 (second 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.

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

Tables with the results for all impact categories for all functional units can be accessed via the full LCA report.

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