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

May 2025

This is a summary of the life cycle assessment (LCA) of the environmental impacts of products from the NORI-D Nodule Project. This ISO-standards-compliant LCA completed by Minviro has undergone an independent critical review. It is based on The Metals Company's (TMC) pre-feasibility study (PFS) scenario for the NORI-D Nodule Project and quantifies the impacts associated with the production of manganese silicate ($MnSiO_3$), NiCuCo matte, copper cathode, nickel sulphate hexahydrate ($NiSO_4 \cdot 6H_2O$), and cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$). It also provides insights into other scenarios and sensitivity analysis to quantitatively understand the impacts that decisions regarding energy inputs as well as methodological choices can have on the results.

Overview

In August 2023, The Metals Company (TMC) commissioned LCA practitioner Minviro Ltd to conduct an LCA quantifying the environmental impacts associated with the production of manganese silicate ($MnSiO_3$), NiCuCo matte, copper cathode, nickel sulphate hexahydrate ($NiSO_4 \cdot 6H_2O$), and cobalt sulfate heptahydrate ($CoSO_4 \cdot 7H_2O$) from polymetallic nodules.

A significant resource of polymetallic nodules, rich in nickel, manganese, cobalt, and copper, is located on the deep seafloor of the Clarion-Clipperton Zone (CCZ) in the northeast Pacific Ocean at a depth of roughly 4,000m. TMC has identified an opportunity to recover these nodules to meet the growing demand for energy, defense, manufacturing and infrastructure. Unlike terrestrial ores which require the removal of overburden and waste rock, polymetallic nodules lie unattached on the seafloor and can be collected directly without extensive land disturbance. Given their high metal concentrations, processing nodules does not require large-scale waste or tailings facilities. TMC aims to further minimize waste generation by turning the whole nodule into useful products.

NORI-D Project Operations

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

- **Offshore operations:** includes 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.

Polymetallic nodules will be collected from the seafloor by self-propelled, tracked collector vehicles that use water jets to dislodge and gently lift the nodules. Nodules are then transported to the surface using an airlift riser system. Once at the surface, nodules are moved to a transfer vessel and onwards to bulk carriers that transport them to Indonesia.

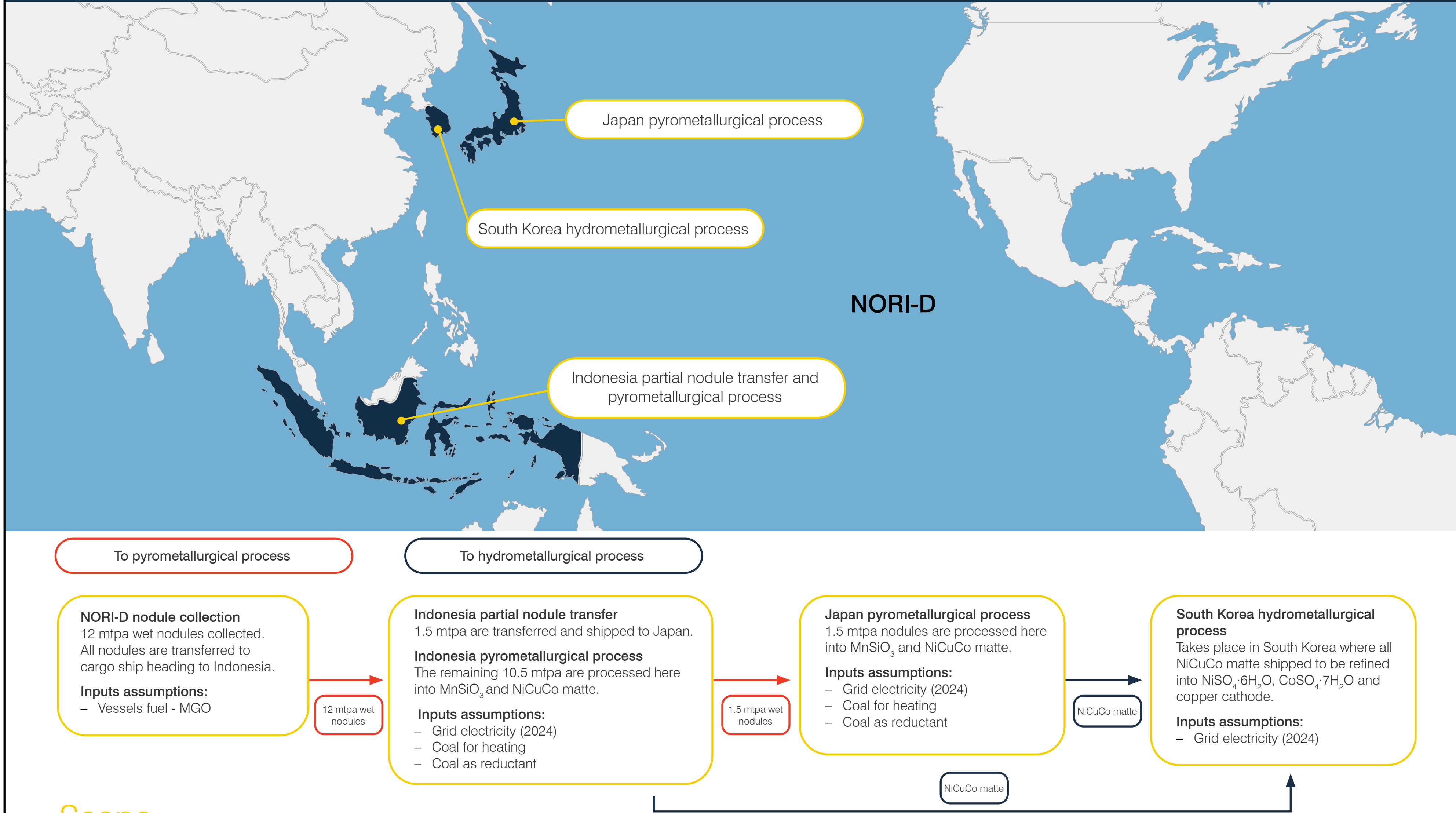
Once in Indonesia, approximately 89% of the nodules will go through a pyrometallurgical process. The remaining 11% will be shipped to Japan where they will also undergo identical pyrometallurgical processing. In both cases, the pyrometallurgical process produces $MnSiO_3$ and NiCuCo matte. First, nodules are calcined and smelted into a manganese silicate slag and metal alloy using a Rotary Kiln Electric Furnace (RKEF) process, before undergoing sulphidization and conversion into a sulphidized matte. The resulting NiCuCo matte from both locations is then shipped to South Korea where it undergoes hydrometallurgy to produce $iSO_4 \cdot 6H_2O$, $CoSO_4 \cdot 7H_2O$ and copper cathode.

It is important to note that in this LCA study, the total environmental impacts are considered separately for each location where pyrometallurgy occurs. Specifically, the study presents results for the environmental impacts per functional unit when pyrometallurgy is conducted either in Indonesia or Japan.

The goals of the study are to:

- Quantify the environmental impacts associated with the production of $MnSiO_3$, NiCuCo matte, $NiSO_4 \cdot 6H_2O$, $CoSO_4 \cdot 7H_2O$ and copper cathode in relation to the full spectrum of impact categories available with Environmental Footprint (EF) methodology.
- Quantify the environmental impacts associated with 1 kg of polymetallic nodules processed.
- Identify environmental hotspots within the product system.
- Perform sensitivity analysis assessing the systems response to variations in electricity mix (non-fossil energy instead of grid mix), heating fuel type (natural gas instead of coal) and allocation methodology.

NORI-D PFS scenario



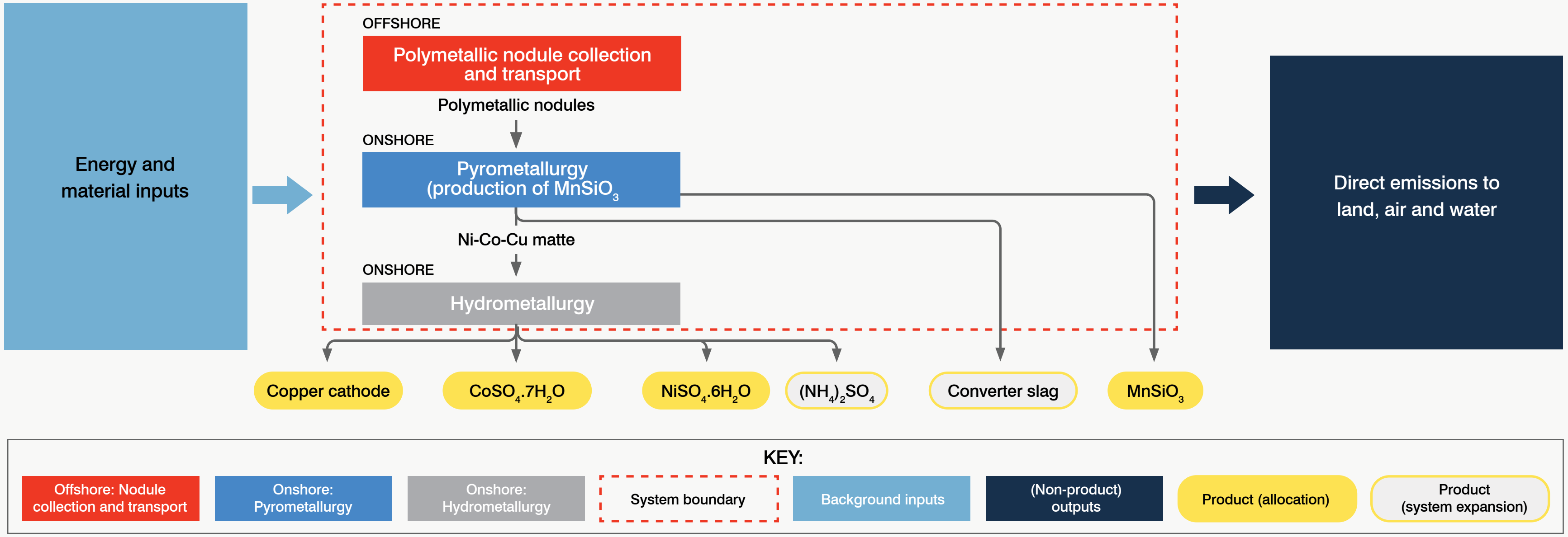
Scope

Minviro's LCA is a cradle-to-gate study, meaning the life cycle impact of the product has been assessed from 'cradle,' the point at which polymetallic nodules are collected offshore to 'gate,' the production of $MnSiO_3$, copper cathode, NiCuCo matte, $NiSO_4{\cdot}6H_2O$ and $CoSO_4{\cdot}7H_2O$ (unpackaged) ready for shipment. An overview of the system boundaries adopted is presented in **Figure 1**.

The system boundary includes the production of $MnSiO_3$, an intermediate product sold into the manganese alloy market. The NiCuCo matte product is transported to South Korea where it is further refined in a hydrometallurgical circuit to produce copper cathode, $NiSO_4{\cdot}6H_2O$ and $CoSO_4{\cdot}7H_2O$.

The LCA conducted is an attributional LCA and its report has been prepared in accordance with the ISO-14040:2006 and ISO-14044:2006 standards.

Figure 1. System boundary applied to the life cycle assesment study



Functional Unit

LCA uses a **functional unit** as a reference to evaluate the components within a single system or among multiple systems on a common basis. The functional unit is the quantitative reference used for all inventory calculations and impact assessments; and for the purpose of the LCA those functional units have been set at:

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

Ni Cu Co

1 kg of Ni in $NiSO_4{\cdot}6H_2O$ (22.4% Ni)

Ni

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

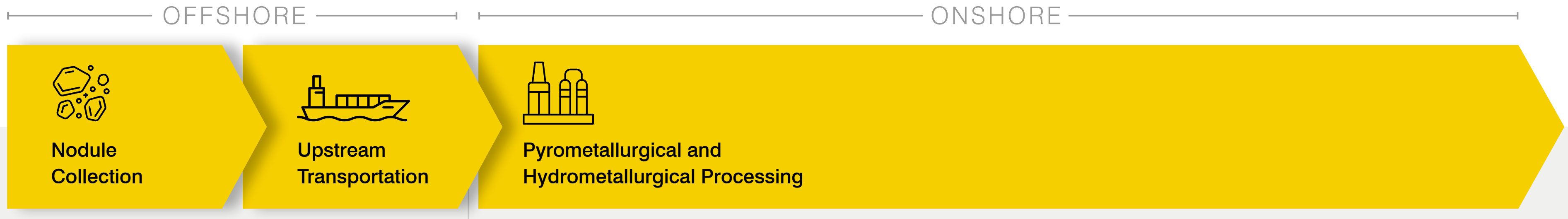
Co

1 kg of copper cathode (99.99% Cu)

Cu

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

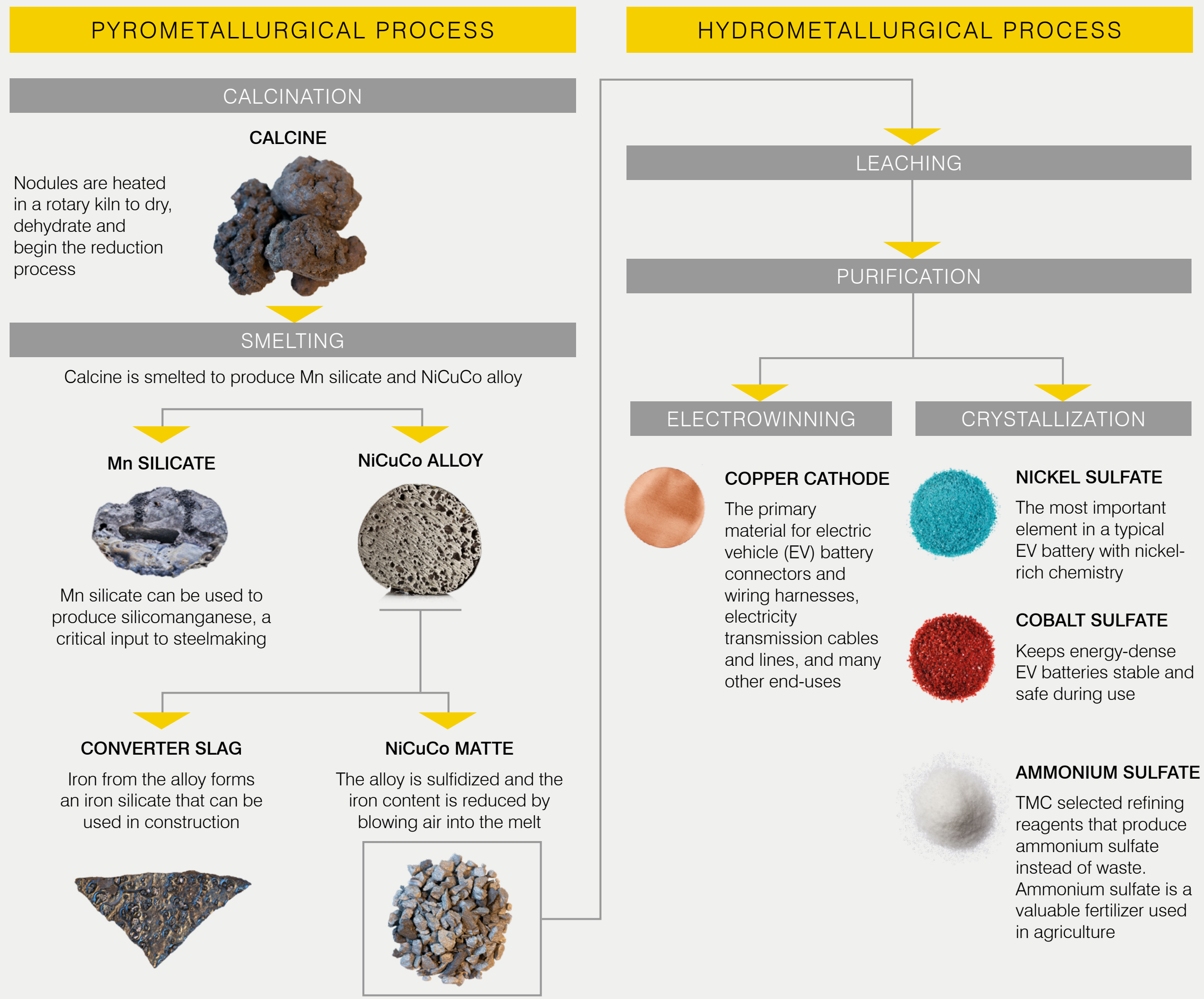
1 kg processed dry nodules



Key Assumptions

TMC's processes were modelled using foreground data from their internal PFS (November 2024) and offshore data from SK-1300 compliant NORI Initial Assessment (March 2021). The background data was sourced from ecoinvent database 3.10 and the life cycle impact assessment (LCIA) methodology applied was Environmental Footprint (3.1) across all impact categories. Key assumptions include:

- 12 megatonnes of wet polymetallic nodules are collected annually, 24% moisture content
- Collected nodules are transported to Indonesia, before going to pyrometallurgical processing, a total of 1.5 mtpa will head from there to Japan to also undergo pyrometallurgical processing.
- The NiCuCo matte that is produced in Indonesia and Japan is then shipped to South Korea where it undergoes hydrometallurgy. At the South Korean plant, it is assumed that a grid electricity mix (2023) is applied.
- In Indonesia and Japan, it is assumed that the pyrometallurgical process uses the national grid electricity mix (2023).



Key Assumptions (cont.)

- In Indonesia and Japan, it is assumed that coal is used as the reductant.
- In Indonesia and Japan, it is assumed that coal is also used for heating due to current infrastructure limitations at the scenario facilities to access natural gas.
- Pyrometallurgy yields three marketable products: $MnSiO_3$, NiCuCo matte and converter slag. A mixture of co-product management methods was employed to resolve the issue of multifunctionality.
- Hydrometallurgy yields four marketable products: $NiSO_4{\cdot}6H_2O$, $CoSO_4{\cdot}7H_2O$, copper cathode and ammonium sulfate. A mixture of co-product management methods was employed to resolve the issue of multifunctionality. Ammonium sulfate has various applications within the chemicals and agriculture industry. As such, the system expansion was performed on TMC's ammonium sulfate, assuming it substitutes globally commercially produced ammonium sulfate.

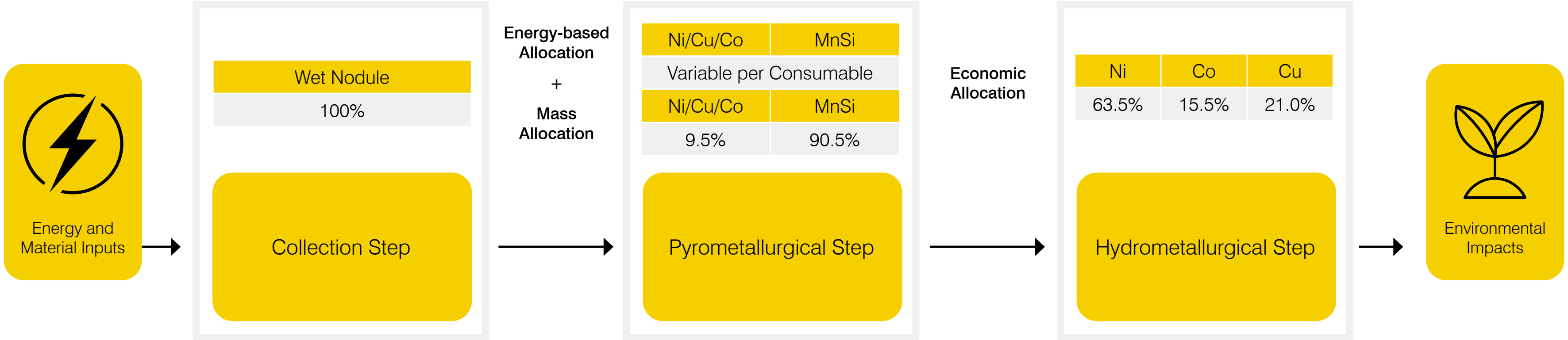
Comparison to Benchmark's LCA

In March 2023, TMC released a NORI-D LCA conducted by Benchmark using the assumptions of NORI-D PEA scenario. As TMC gets closer to commercial operations, more details are being defined at higher resolution and, as such, Minviro has updated these assumptions based upon the internal NORI-D PFS scenario. The key distinguishing features of this study as compared to the previous LCA are summarized on the table below. In terms of allocation methodology, both Benchmark and Minviro have independently followed the same allocation logic with the updated values.

Parameter	PEA NORI-D LCA — Benchmark	PFS NORI-D LCA — Minviro report
Quantity of polymetallic nodules processed annually (million tonnes per annum)	12.5 mtpa wet nodules	12 mtpa wet nodules
Location of core processes	1. Offshore: NORI-D 2. Pyrometallurgy: Texas 3. Hydrometallurgy: Texas	1. Offshore: NORI-D 2. Pyrometallurgy: Japan and Indonesia 3. Hydrometallurgy: South Korea
Energy inputs	1. Offshore: MGO 2. Pyrometallurgy: 100% wind electricity, natural gas for heating 3. Hydrometallurgy: 100% wind electricity	1. Offshore: MGO 2. Pyrometallurgy: Indonesia and Japan grid mix (2023), coal for heating 3. Hydrometallurgy: South Korea grid mix (2023)
Functional units	– 1 kg of $MnSiO_3$ – 1 kg of NiCuCo matte – 1 kg of Ni in $NiSO_4{\cdot}6H_2O$ – 1 kg of Co in $CoSO_4{\cdot}7H_2O$ – 1 kg of copper cathode	– 1 kg of $MnSiO_3$ – 1 kg of NiCuCo matte – 1 kg of Ni in $NiSO_4{\cdot}6H_2O$ – 1 kg of Co in $CoSO_4{\cdot}7H_2O$ – 1 kg of copper cathode – 1 kg of dry polymetallic nodules processed
Other products (by-products)	– Ammonium sulfate – Converter slag	– Ammonium sulfate – Converter slag
Foreground data sources	Project scenario and data based on SK-1300 compliant NORI-D Project Initial Assessment (March 2021)	Project scenario based on TMC's NORI-D Project internal PFS (November 2024) and onshore technical data was taken from SK-1300 compliant NORI-D Project Initial Assessment (March 2021)
Background data source	Ecoinvent 3.8	Ecoinvent 3.10
Energy sources breakdown	Texas – 100% wind energy	**Indonesian grid mix (2023)** — 65% lignite, 22% nat. gas, 7% hydro, 6% other **Japanese grid mix (2023)** — 33.4% coal, 45% natural gas, 8% hydro, 4.6% nuclear, 2% petroleum, 2% woodchips, 5.4% other **South Korean grid mix (2023)** — 33.4% coal, 29.1% nat. gas, 27.6% nuclear, 4.5% solar, 1.1% hydro, 1.0% oil, 3.3% other

Allocation

Environmental impacts in the pyrometallurgical circuits were partitioned between the co-products ($MnSiO_3$ and NiCuCo matte) based on mass and energy base allocation. In the hydrometallurgical circuit, environmental impacts were partitioned between the co-products (Ni, Cu and Co) on the basis of economic allocation using 10-year average values for the price of copper, nickel and cobalt. System expansion (by substitution) was applied to account for ammonium sulfate and converter slag produced during the sulphidization and conversion stages. Ammonium sulfate was assumed to substitute globally produced ammonium sulfate for the chemicals and agriculture industry, while converter slag was assumed to serve as aggregate in road construction. Where the co-products did not share similar processes, sub-division was carried out.



Energy-based allocation:

- **Reductant Coal:**
  - A total of 20% of this coal ends as heat of which 92.5% was allocated to $MnSiO_3$ and the remainder to the NiCuCo matte.
  - Of the remaining 80% that works in the reduction, 62% was allocated to $MnSiO_3$ and the remainder to the NiCuCo matte.
- **Heating Coal:**
  - This is used in this scenario instead of natural gas, and 92.5% was allocated to $MiSiO_3$ and the remainder to the NiCuCo matte.

Impact Categories

The LCA categories selected for detailed investigation are all impact categories available through the EF methodology: climate change, acidification, eutrophication, freshwater ecotoxicity, ionizing radiation, photochemical ozone formation, human toxicity, ozone depletion, and resource depletion. These are midpoint indicators which focus on single environmental problems. Definitions of all environmental impact categories assessed in this study are listed on the table below.

Term	Definition	Units
Climate change	Increase in the average global temperature resulting from greenhouse gas emissions (GHG).	kg CO_2 eq
Freshwater and terrestrial acidification	Acidification from air, water, and soil emissions (primarily sulphur compounds) mainly due to combustion processes in electricity generation, heating, and transport.	mol H+ eq
Aquatic freshwater eutrophication	Eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilisers, combustion, sewage systems.	kg P eq
Terrestrial eutrophication	Eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilisers, combustion, sewage systems.	mol N eq
Aquatic marine eutrophication	Eutrophication and potential impact on ecosystems caused by nitrogen and phosphorous emissions mainly due to fertilisers, combustion, sewage systems.	kg N eq
Freshwater ecotoxicity	Impact of toxic substances on freshwater ecosystems.	CTUe
Ionizing radiation: human health	Impact of exposure to ionising radiations on human health.	kg U-235 eq
Photochemical ozone formation	Potential of harmful tropospheric ozone formation ("summer smog") from air emissions.	kg NMVOC eq
Human toxicity, cancer effects – carcinogenic	Impact on human health caused by absorbing substances through the air, water, and soil. Direct effects of products on humans are not measured.	CTUh
Human toxicity, non-cancer effects – non-carcinogenic	Impact on human health caused by absorbing substances through the air, water, and soil. Direct effects of products on humans are not measured.	CTUh
Respiratory	Impact on human health caused by particulate matter emissions and its precursors (e. g. sulphur and nitrogen oxides).	disease incidence
Ozone depletion	Depletion of the stratospheric ozone layer protecting from hazardous ultraviolet radiation.	kg CFC-11 eq
Resource use, minerals and metals depletion	Depletion of non-renewable resources and deprivation for future generations.	kg Sb eq
Resource use, fossil fuel depletion	Depletion of non-renewable resources and deprivation for future generations.	MJ
Water	Assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived.	m^3
Land use	Transformation and occupation use of land for agriculture, roads, housing, mining or other purposes. The impact can include loss of species, organic matter, soil, filtration capacity, permeability.	dimensionless – pt

These impact categories provide a comprehensive overview of the environmental impacts associated with a product or process, helping to identify areas for improvement and guide decision-making towards more responsible practices. More details can be found in the **full LCA report**..

Hidden Gem – NORI-D Project's first production vessel

Hector – pilot seafloor collector tested in NORI-D area in 2022

Sensitivity Analysis

A sensitivity analysis was conducted to explore how variations in key input parameters affect the total climate change impacts associated with the final products. Sensitivity analysis is a useful exercise that helps assess the robustness of the methodology and provides insights into how changes in scenario assumptions could impact the results.

This analysis was used to evaluate the influence of two main variables, allocation methodology for the hydrometallurgical step and energy inputs for both, the pyrometallurgical and hydrometallurgical steps.

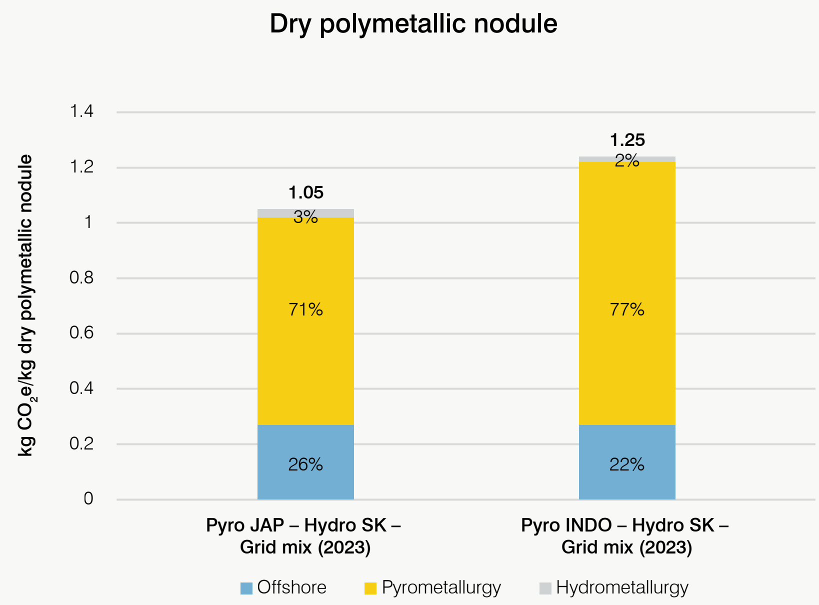
- **Allocation Methodology.** This part of the analysis looks at the impacts of the allocation factor used in the hydrometallurgical step. The NORI-D PFS scenario assumed economic allocation using the last 10-year average price for nickel, copper and cobalt metal for the years 2014-2023. Two sensitivity analyses were conducted for this latest LCA.
  - *Price Forecast.* Use of CRU's 10-year average forecast values for nickel, copper, and cobalt metal for the years 2026-2035.
  - *Metal Allocation.* Use of metal mass-based allocation instead of economic allocation.
- **Energy Inputs.** The analysis looked at energy source changes for onshore operations, including non-fossil electricity instead of 2023 grid mixes heavily reliant upon fossil fuels, as well as the use of natural gas for heating instead of coal. This analysis helps TMC understand the climate change impact of future decarbonization plans. The NORI-D PFS scenario assumes a 2023 electrical grid mix for all locations and the use of coal instead of natural gas for pyrometallurgical heating. Below are the scenarios analyzed.
  - *Electricity Mix.* Use of non-fossil fuel electricity was analyzed.
    - Indonesian pyrometallurgy plant: Electricity mix comprising 25% solar and 75% coal combustion
    - Indonesian pyrometallurgy plant: 100% hydroelectricity
    - Japanese pyrometallurgy plant: 100% nuclear energy
    - South Korean hydrometallurgy plant: 100% nuclear energy
  - *Heating Input.* Use of natural gas instead of coal was analyzed.

Results

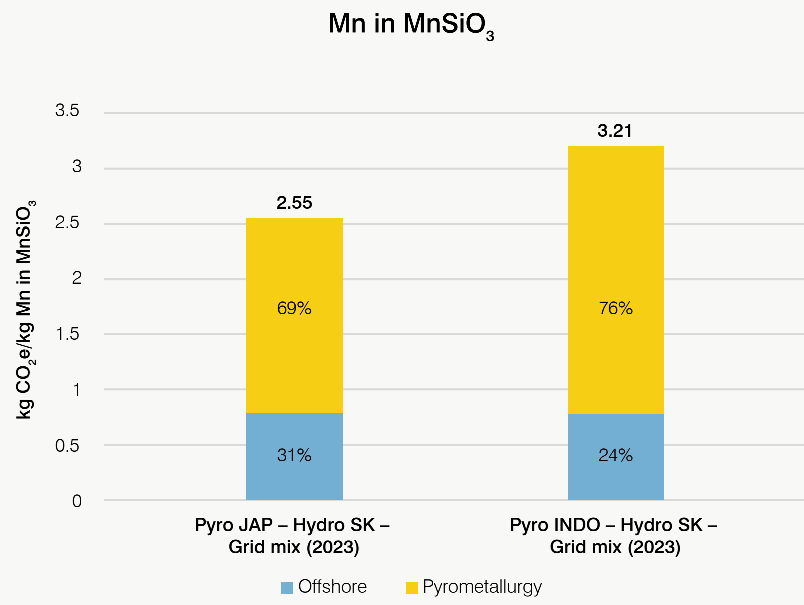
Climate Change Impacts

The climate change impact for each of the six functional units analyzed is provided in the tables below. Two locations for pyrometallurgical processing are part of the NORI-D PFS scenario, therefore values for products processed via the Indonesia-pyrometallurgy + South Korea-hydrometallurgy route and the Japan-pyrometallurgy + South Korea-hydrometallurgy route are provided. The graphs include a breakdown between the three major operational steps: offshore, pyrometallurgy and hydrometallurgy. More details on the impact contribution of each input per step can be found in the **full LCA report**.

Climate Change Impact



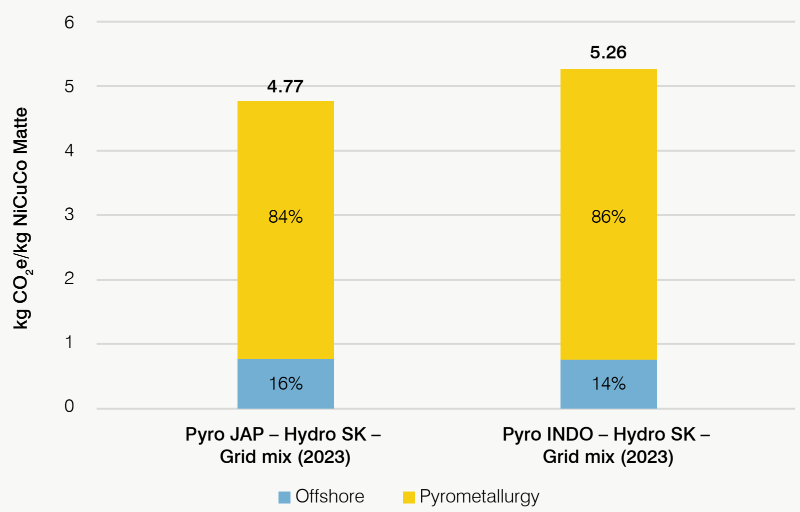
The pyrometallurgical step accounts for 71-77% of emissions, with electricity use responsible for 30% of total emissions per kg of dry polymetallic nodules when processed in Japan and 41% when processed in Indonesia. Followed by MGO and reductant coal which are each responsible for 25% of total carbon emissions for Japan and 21% for Indonesia.



The pyrometallurgical step accounts for 69-76% of emissions, with electricity use responsible for 33% of total emissions per kg of Mn in $MnSiO_3$ when processed in Japan and 47% when processed in Indonesia. Followed by MGO representing 30% for Japan, 24% for Indonesia and reductant coal 23% for Japan, 18% for Indonesia.

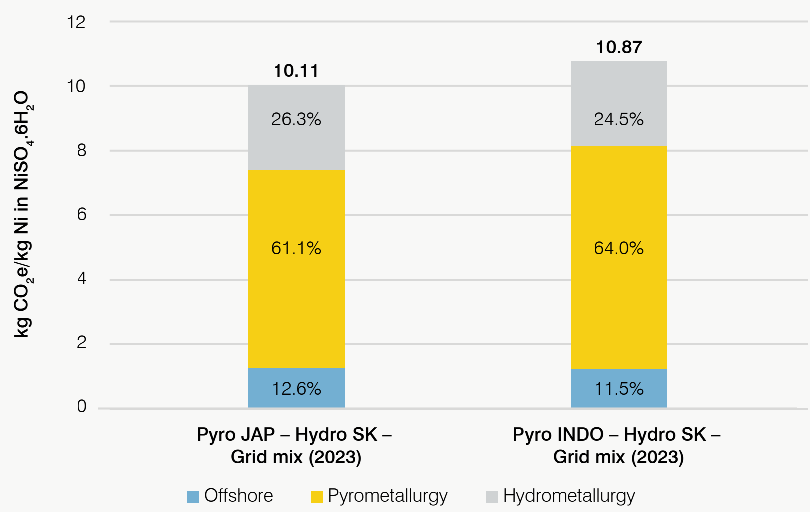
Climate Change Impact

NiCuCo Matte



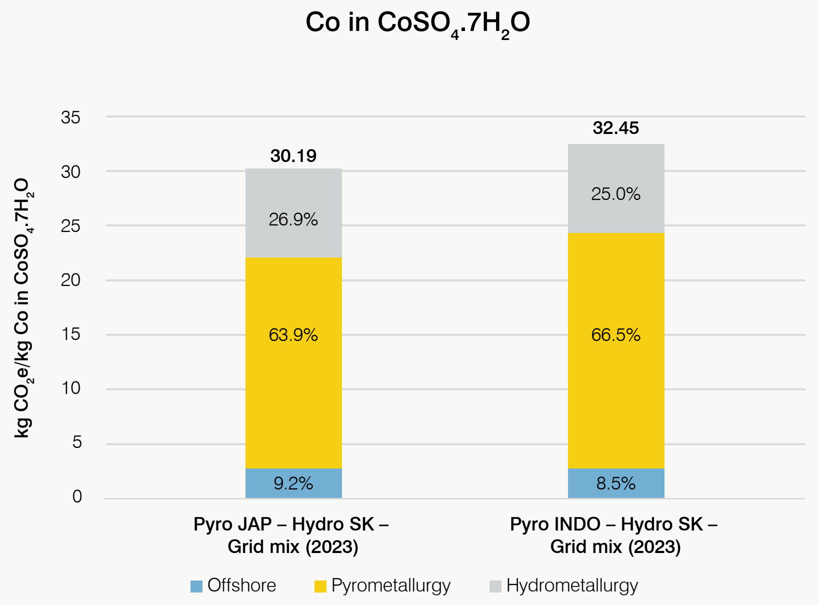
The pyrometallurgical step accounts for 84-86% of emissions, and coal as a reductant is responsible for 55% of total emissions per kg of NiCuCo matte when pyrometallurgy takes place in Japan and 49% when processed in Indonesia. Followed by electricity use of 21% Japan, 31% Indonesia and MGO 16% Japan, 14% Indonesia.

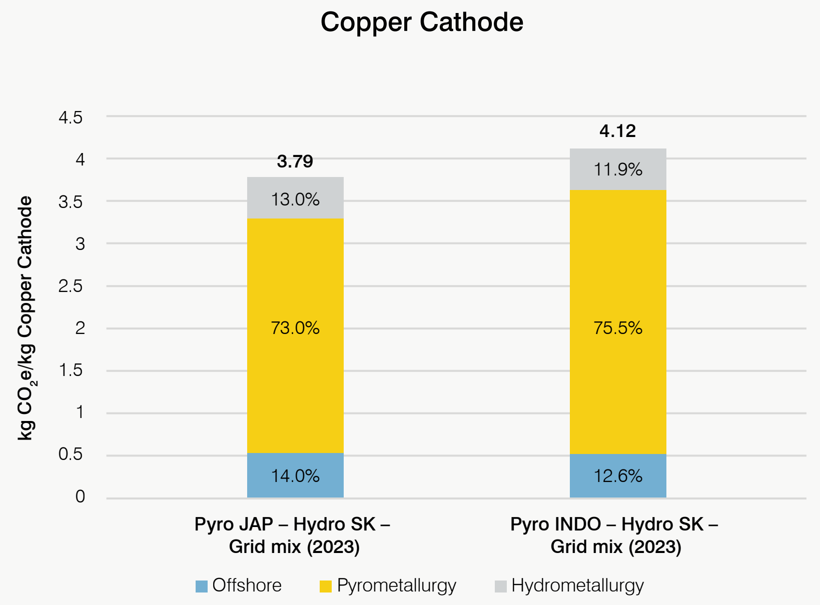
Ni in $NiSO_4.6H_2O$



NiCuCo matte production is the biggest contributor to the climate change impact of 1 kg of Ni in $NiSO_4.6H_2O$ accounting for 74% of the total for the Japan + South Korea route and 76% for the Indonesia + South Korea route. The remaining carbon impact comes mainly from electricity use during the hydrometallurgical step adding 17% to the Japan + South Korea route and 15% to the Indonesia + South Korea route. The credit (offset) received from the production of ammonium sulfate via system expansion is equal to 22% for Japan + South Korea and 20% for Indonesia + South Korea of the total impact.

Climate Change Impact





NiCuCo matte production is the biggest contributor to the climate change impact of 1 kg of Co in $CoSO_4.7H_2O$ accounting for 73% of the total for Japan + South Korea route and 75% of Indonesia + South Korea route. The remainder is mainly from electricity use during the hydrometallurgical step adding 17% to the Japan + South Korea route and 15% to the Indonesia + South Korea route. The credit (offset) received from the production of ammonium sulfate via system expansion is equal to 22% of the total impact for Japan + South Korea route and 20% for Indonesia + South Korea route.

NiCuCo matte production is the biggest contributor to the climate change impact of 1 kg of copper cathode accounting for 87% of the total of the Japan + South Korea route and 88% of the Indonesia + South Korea route. The remaining is mainly from electricity use during the hydrometallurgical step adding 20% to the Japan + South Korea route and 18% to the Indonesia + South Korea route. The credit (offset) received from the production of ammonium sulfate via system expansion is equal to 26% for Japan + South Korea and 23% for Indonesia + South Korea of the total impact.

Sensitivity Analysis Impacts

ALLOCATION METHODOLOGY

Price average forecast. Economic allocation was applied to the hydrometallurgical step of the NORI-D Nodule Project. To assess the sensitivity of this allocation to price fluctuations, a sensitivity analysis was conducted using CRU's 10-year average forecast (2026-2035) values for nickel, copper and cobalt metal instead of the last 10 years (2014-2023) price average used in the base scenario.

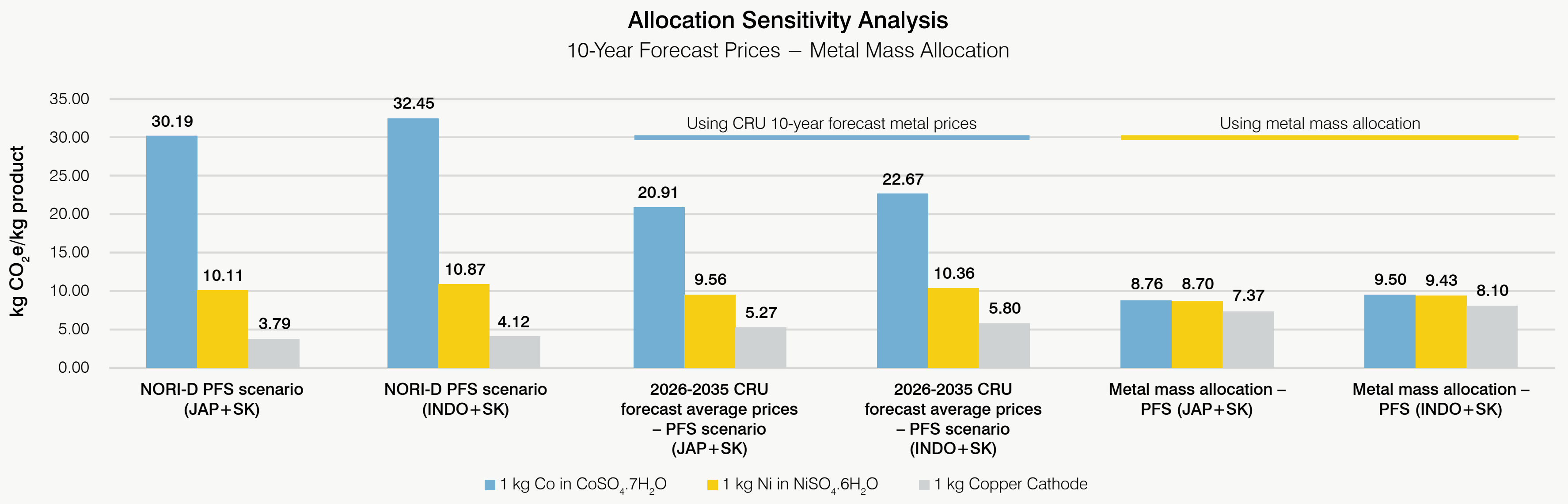
The results show a high sensitivity to price variations. A climate change impact decrease of 31% for the Japan + South Korea route and 30% for the Indonesia + South Korea route for Co in $CoSO_4.7H_2O$, a 5% decrease for Ni in $NiSO_4.6H_2O$ for both routes and an increase of 39% the Japan + South Korea route and 41% of the Indonesia + Japan route for copper cathode.

Metal mass allocation is another allocation approach that could be used instead of economic allocation. If this is employed, the climate change impact increases by 94% for the Japan + South Korea route and 97% for the Indonesia + South Korea route for copper cathode, decreases by 71% for Co in $CoSO_4.7H_2O$ for both routes and decreases by 14% for the Japan + South Korea route and 13% for the Indonesia + South Korea route for Ni in $NiSO_4.6H_2O$.

Allocation factors per allocation approach

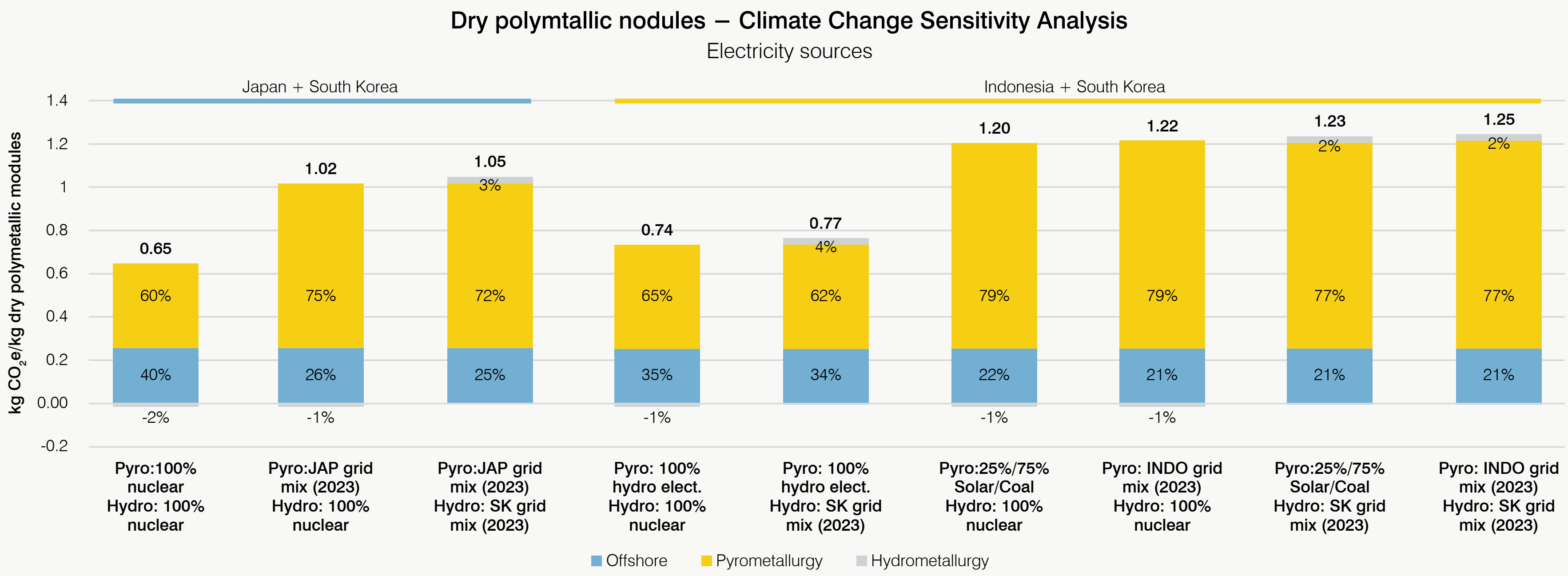
	Average price (2014-2023) (US$/tonne)	Economic allocation factor	CRU 10-year forecasted price (2026-2035) (US$/tonne)	Economic allocation factor (CRU forecast)	Metal mass allocation factor
Copper cathode	6,873	21.0%	11,145	29.2%	40.8%
Co in $CoSO_4.7H_20$	46,069	15.5%	37,179	10.7%	4.5%
Ni in $NiSO_4.6H_2O$	15,540	63.5%	17,118	60.1%	54.7%

Allocation by mass is generally preferred when the economic value per unit of output between co-products is similar. This is due to the fact that mass remains relatively constant over time while market value is subject to market fluctuations. As guidance, EN 15804 defines “small” as less than a 25% difference in value. Having the metal mass allocation and testing the price forecast in the economic allocation gives us a clear picture of how this allocation choice in the hydrometallurgical step impacts the end products carbon impact.

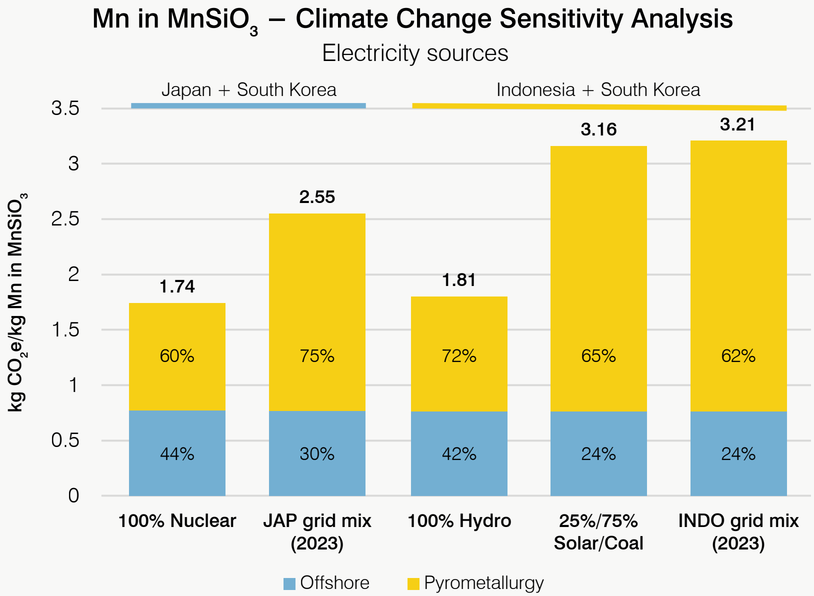


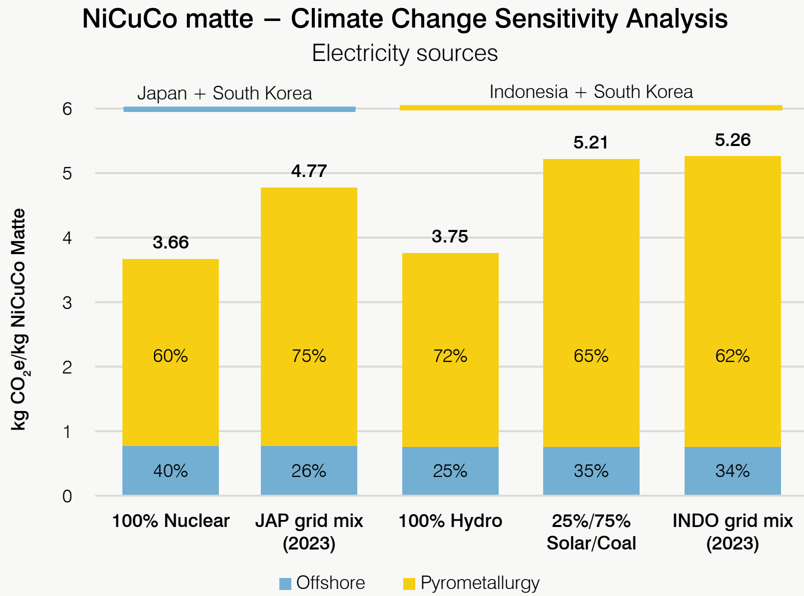
ENERGY INPUTS

Electricity mix. The NORI-D PFS scenario (base scenario) assumes the use of electricity available through the national grid mixes in Indonesia, Japan and South Korea for both the pyrometallurgical and hydrometallurgical processes. Currently, these grids consist of a high percentage of fossil fuel sources. Given the projected growth and investment potential of non-fossil fuel electricity in these regions, it is relevant to understand the impact that its use would have on the climate change impact of NORI-D products.



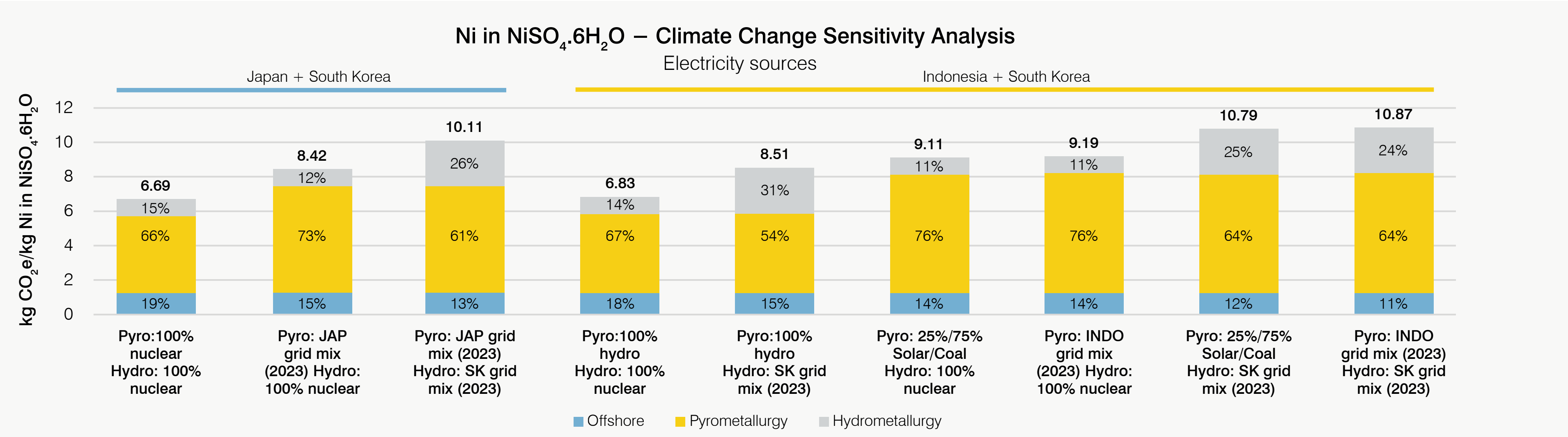
The use of non-fossil fuel electricity would result in a significant reduction in carbon emissions for the processing of polymetallic nodules. When moving from 2023 grid mix electricity to non-fossil fuel electricity in both the pyrometallurgical and hydrometallurgical processes, a climate change value reduction of up to 38% for nodules processed via the Japan + South Korea route can be achieved, or 41% for nodules processed via the Indonesia + South Korea route .



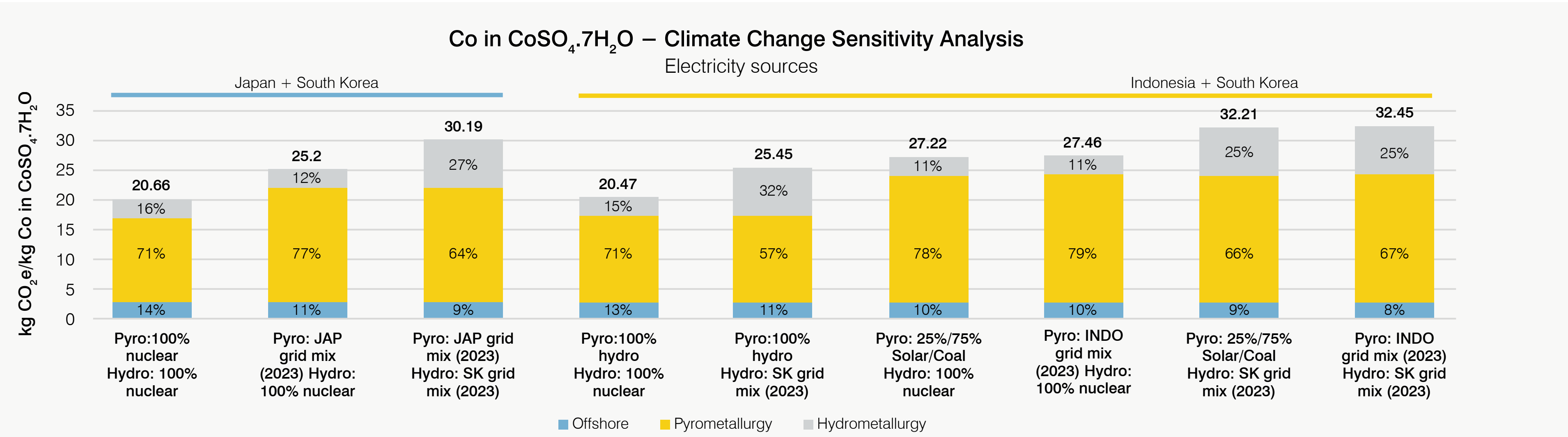


The use of non-fossil fuel electricity would result in a significant reduction in carbon emissions for the production of Mn in $MnSiO_3$. When moving from 2023 grid mix electricity to non-fossil fuel electricity in both the pyrometallurgical and hydrometallurgical processes, a climate change value reduction of up to 32% in Japan can be achieved, or 44% for the Indonesian route.

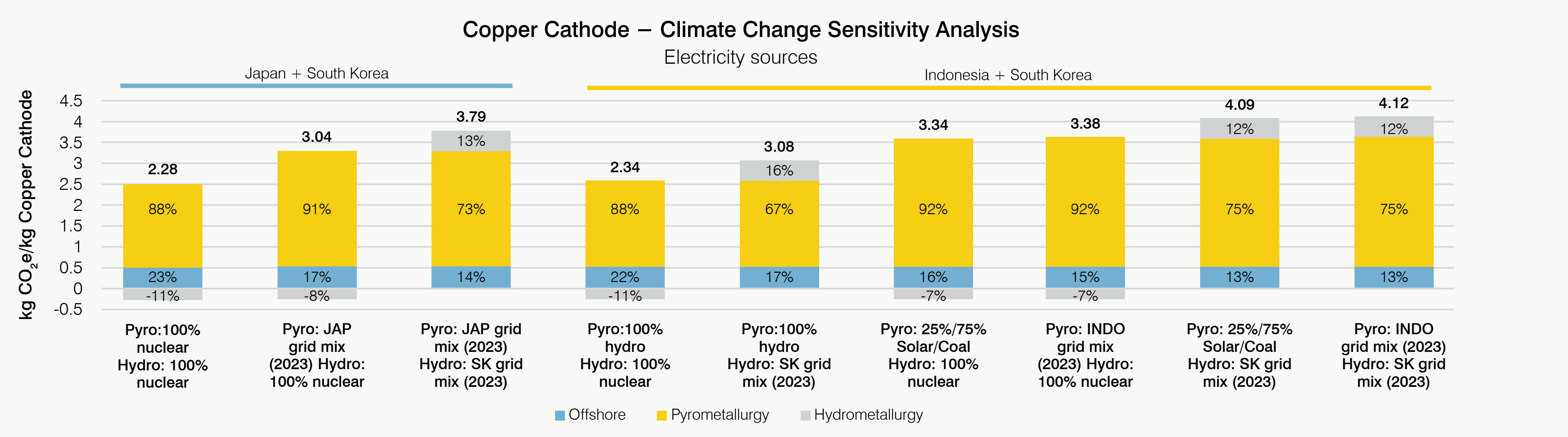
The use of non-fossil fuel electricity would result in a significant reduction in carbon emissions for the production of NiCuCo matte. When moving from 2023 grid mix electricity to non-fossil fuel electricity in both the pyrometallurgical and hydrometallurgical processes, a climate change value reduction of up to 23% in Japan can be achieved, or 29% for the Indonesian route.



For Ni in nickel sulfate, a climate change value reduction of up to 34% for the Japan + South Korea route can be achieved when moving from 2023 grid mix electricity to non-fossil fuel electricity both in the pyrometallurgical and hydrometallurgical processes, and a 37% reduction for the Indonesia + South Korea route.



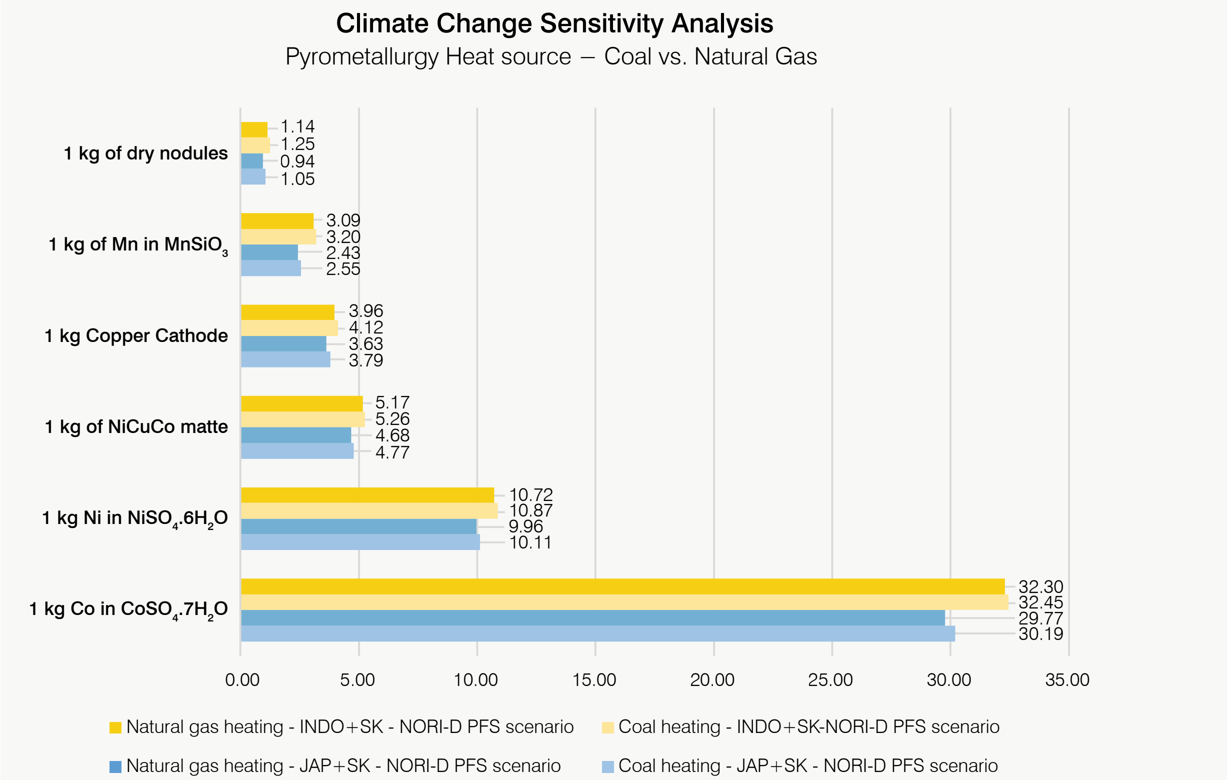
For Co in cobalt sulfate, a climate change value reduction of up to 34% for the Japan + South Korea route can be achieved when moving from 2023 grid mix electricity to non-fossil fuel electricity both in the pyrometallurgical and hydrometallurgical processes, and a 37% for the Indonesia + South Korea route.



For copper cathode, a climate change value reduction of up to 40% for the Japan + South Korea route can be achieved when moving from 2023 grid mix electricity to non-fossil fuel electricity both in the pyrometallurgical and hydrometallurgical processes, and a 43% for the Indonesia + South Korea route.

Heating input. Given infrastructure limitations, the NORI-D PFS scenario assumes the use of coal for heating instead of natural gas for the pyrometallurgical step both in Indonesia and Japan. A sensitivity analysis was done to understand how the use of natural gas instead of coal for heating impacts the climate change results.

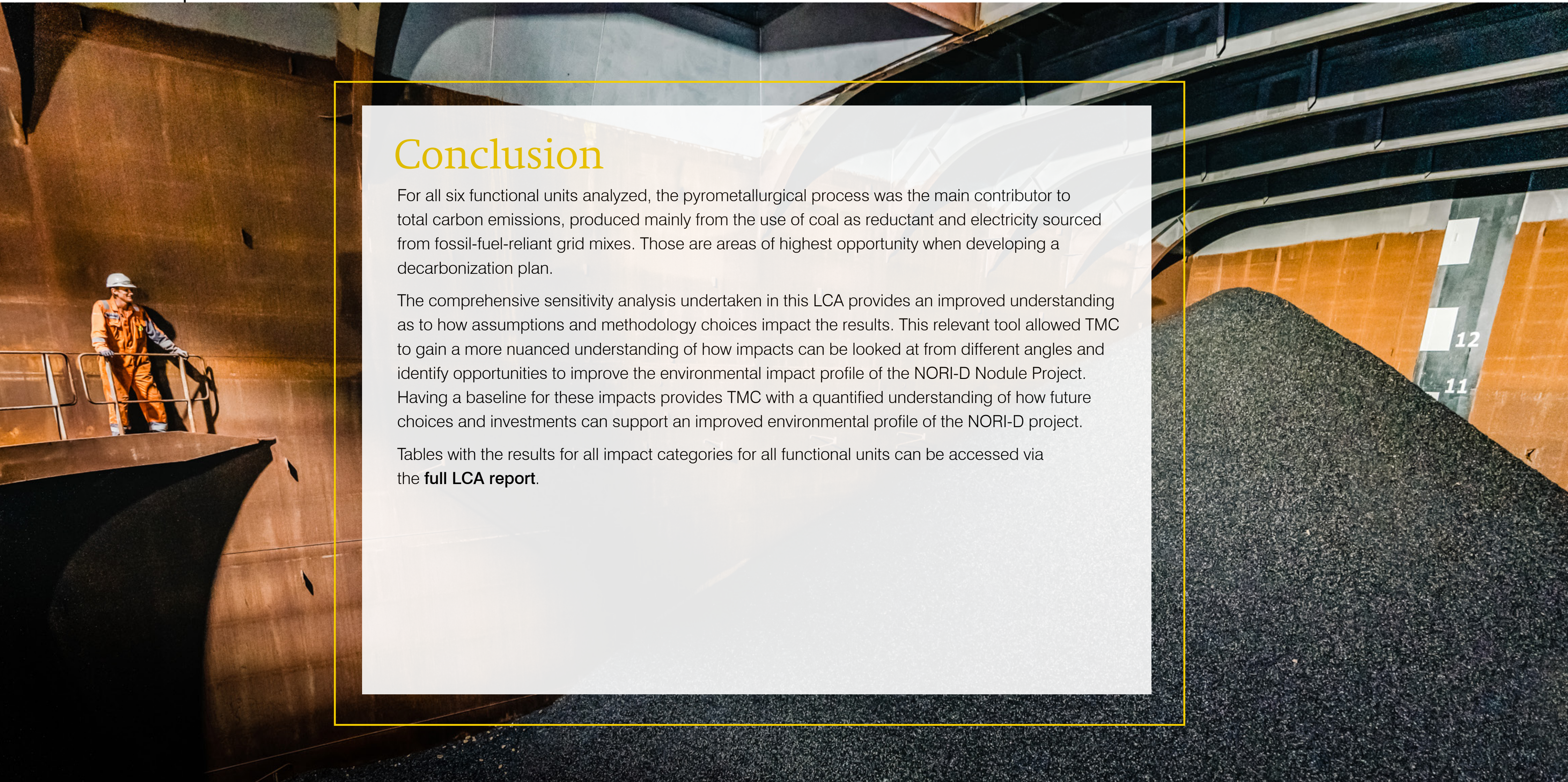
The move from coal to natural gas for heating in the pyrometallurgical step decreases the climate impact of producing dry nodules the most with a 9% decrease when processed in Indonesia compared to a 10% decrease when processed in Japan. The climate change impact for Mn in $MnSiO_3$ decreases by 3% in Indonesia and 5% in Japan; and by 4% for both locations when considering copper cathode. For the remaining products, the reduction is in the range of 1-2%.



Summary Table of All Impact Categories

In the table below is a summary of LCA results obtained for the base-case scenarios, when pyrometallurgy occurs in either Indonesia or Japan for all functional units.

Impact category	Units	Per kg dry nodules processed		Per kg Mn in $MnSiO_3$		Per kg NiCuCo matte		Per kg Ni in $NiSO_4.6H_2O$		Per kg Co in $CoSO_4.7H_2O$		Per kg copper cathode	
		Indonesia	Japan	Indonesia	Japan	Indonesia	Japan	Indonesia	Japan	Indonesia	Japan	Indonesia	Japan
Climate change	kg CO_2-eq	1.25	1.05	3.21	2.55	5.26	4.77	10.87	10.11	32.45	30.19	4.12	3.79
Freshwater + terrestrial acidification	mol H+eq	0.01	0.01	0.03	0.02	0.05	0.04	0.07	0.06	0.21	0.18	0.03	0.02
Freshwater eutrophication	kg P-eq	0.0011	0.0027	0.0031	0.0005	0.0041	0.0012	0.0069	0.0024	0.0206	0.0071	0.0029	0.0009
Terrestrial eutrophicaton	mol N-eq	0.013	0.012	0.034	0.024	0.058	0.043	0.252	0.228	0.749	0.679	0.031	0.021
Freshwater ecotoxicity	CTUh	-2.91	-4.02	7.65	4.28	12.8	8.51	-259.00	-266.00	-764.00	-784.00	-116.00	-119.00
Marine eutrophication	kg N-eq	0.0013	0.0033	0.0037	0.0022	0.0061	0.0041	0.0066	0.0036	0.0199	0.0108	0.0024	0.0010
Ionising radiation	kg U235-eq	0.0126	0.0370	0.0067	0.0645	0.0109	0.0315	0.5150	0.5470	1.5500	1.6400	0.2240	0.2380
Photochemical ozone	kg NMVOC	0.004	0.006	0.011	0.008	0.018	0.014	0.030	0.024	0.090	0.071	0.012	0.009
Carcinogenic	CTUh	5.58E-10	2.48E-03	2.14E-09	2.73E-09	4.82E-09	4.90E-09	-3.80E-09	-3.63E-09	-9.87E-09	-9.36E-09	-2.70E-09	-2.63E-09
Non-carcinogenic	CTUh	8.73E-09	2.48E-03	2.51E-08	1.41E-08	3.68E-08	2.37E-08	3.58E-08	1.54E-08	1.09E-07	4.83E-08	1.30E-08	4.03E-09
Respiratory	disease i.	1.04E-07	2.48E-03	2.89E-07	1.84E-07	4.02E-07	2.91E-07	6.22E-07	4.49E-07	1.86E-06	1.34E-06	2.54E-07	1.77E-07
Ozone depletion	kg CFC-11	6.37E-09	2.48E-03	2.89E-07	1.84E-07	4.02E-07	2.91E-07	1.37E-07	1.47E-07	4.08E-07	4.39E-07	2.56E-08	3.03E-08
Minerals + metals	kg Sb-eq	-5.57E-06	2.47E-03	5.55E-07	6.66E-07	9.86E-07	9.52E-07	8.13E-02	8.13E-02	2.41E-01	2.41E-01	-1.25E-04	-1.25E-04
Fossils	MJ	13.3	11.9	33.9	29	53.5	41.9	130.0	112.0	388.0	334.0	49.6	41.5
Water	m^3 world eq.	0.11	0.07	0.29	0.14	0.39	0.13	1.15	0.75	3.48	2.29	-0.01	-0.19
Land	points	0.2260	0.2270	0.0043	0.0002	0.0047	0.0003	10.80	10.80	33.00	33.00	3.42	3.42



Conclusion

For all six functional units analyzed, the pyrometallurgical process was the main contributor to total carbon emissions, produced mainly from the use of coal as reductant and electricity sourced from fossil-fuel-reliant grid mixes. Those are areas of highest opportunity when developing a decarbonization plan.

The comprehensive sensitivity analysis undertaken in this LCA provides an improved understanding as to how assumptions and methodology choices impact the results. This relevant tool allowed TMC to gain a more nuanced understanding of how impacts can be looked at from different angles and identify opportunities to improve the environmental impact profile of the NORI-D Nodule Project. Having a baseline for these impacts provides TMC with a quantified understanding of how future choices and investments can support an improved environmental profile of the NORI-D project.

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

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