MINVIRO

Unlocking Low Carbon Battery Manufacturing in the Nordics

Carbon Footprint of Product Study for Battery Norway | Minviro 2025

This insight report is an outcome from the work carried out by Minviro Ltd for Battery Norway. This study was conducted according to the requirements of the ISO-14040:2006, ISO-14044:2006, and ISO-14067: 2018 standards. This study has undergone an independent critical panel review and is intended to support comparative assertions.

A Critical Hub For Battery Value Chains

The Nordic countries are emerging as a critical hub for Europe's battery value chain, leveraging abundant renewable energy, raw material reserves, and advanced industrial capabilities. Norway is taking a leadership role through initiatives like the Battery Norway Platform, which unites government, academia, and industry to build a localised, low-carbon supply chain. In light of the EU battery regulations, Nordic value-chains may be pivotal in unlocking and securing low carbon batteries

To support these efforts, Battery Norway commissioned Minviro to explore the potential climate change impacts of manufacturing prismatic battery cells, NMC811 in Sweden and LFP in Norway, utilising Nordic raw materials and renewable energy.

These were compared to batteries produced using raw materials representing global average production routes and energy mixes based on battery manufacturing facilities in China, the US, and Europe. Additionally, the potential for Finnish hydrometallurgical recycling of NMC811 cells was evaluated.

This partial Carbon Footprint of Product (CFP) study was conducted in accordance with ISO 14067 and underwent third-party panel critical review.

Alternative versions of this report are available that include a data quality rating, sensitivity analysis and comparative uncertainty analyses. Please contact Battery Norway directly about inquiries to their full LCA report from Minviro.

Key carbon footprint findings at a glance

51-85%	lower from Nordic raw materials compared to global average routes
Up to 55%	lower from Nordic battery cells compared to other major regions
Up to 36%	lower from manufacturing LFP chemistry compared to NMC811 across all scenarios

Hydrometallurgical recycling of NMC811 can potentially maintain a low carbon footprint and may offer an additional *6% benefit

**This number is subject to uncertainties and assumptions made.*

Norway
- Graphite for battery anodes
- LFP battery manufacturing

Sweden
- NMC battery manufacturing

Finland
- Nickel, cobalt, and lithium cathode raw materials
- Battery recycling

These are illustrative value chains based on existing and prospective strategic Nordic projects.

Context & Stakeholders

In March 2025, Battery Norway commissioned Minviro Ltd., with financial support from the Nordic Council of Ministers, to conduct a partial Carbon Footprint of Product (CFP) study focused on Nordic lithium-ion battery cell production and raw materials. A steering committee comprising representatives from Battery Norway, Finnish Battery Industries, and the Swedish Energy Agency oversaw the project's progress and provided valuable input throughout its execution.

Study Objective

The goal of this partial Carbon Footprint of Product (CFP) study was to evaluate the potential CO_2e value proposition of Nordic battery raw materials and cell manufacturing. Two chemistries were assessed:

- NMC811 (modelled for Sweden)
- LFP (modelled for Norway)

The objectives were to benchmark the carbon footprints of Nordic raw materials versus global averages, compare Nordic battery cell production with scenarios using electricity mixes from Europe, the United States and China, and assess the impact of NMC811 battery recycling in Finland

Scope & Methodology

This study complies with ISO-14040, ISO-14044, and ISO-14067 and underwent an independent critical review panel. The primary scope was cradle-to-gate, covering life cycle stages such as:

- Resource extraction
- Material processing and refinement
- Battery cell production

A secondary cradle-to-grave analysis was also included, evaluating the potential of closed-loop NMC811 hydrometallurgical recycling in Finland using Minviro's bespoke developed model. The study functional was defined as 1 kWh of battery cell capacity.

> "We leveraged Minviro's extensive know-how of global battery value chains, rich mining database, and stakeholder engagement to explore the CO_2e value proposition of the Nordics. To uphold scientific rigor and compliance to international standards, our study underwent a panel review of three independent LCA practitioners and battery experts.
>
> — Dr. Joris Šimaitis, Lead Consultant at Minviro.

Data & Comparisons

The analysis focussed on four Nordic raw material routes for:

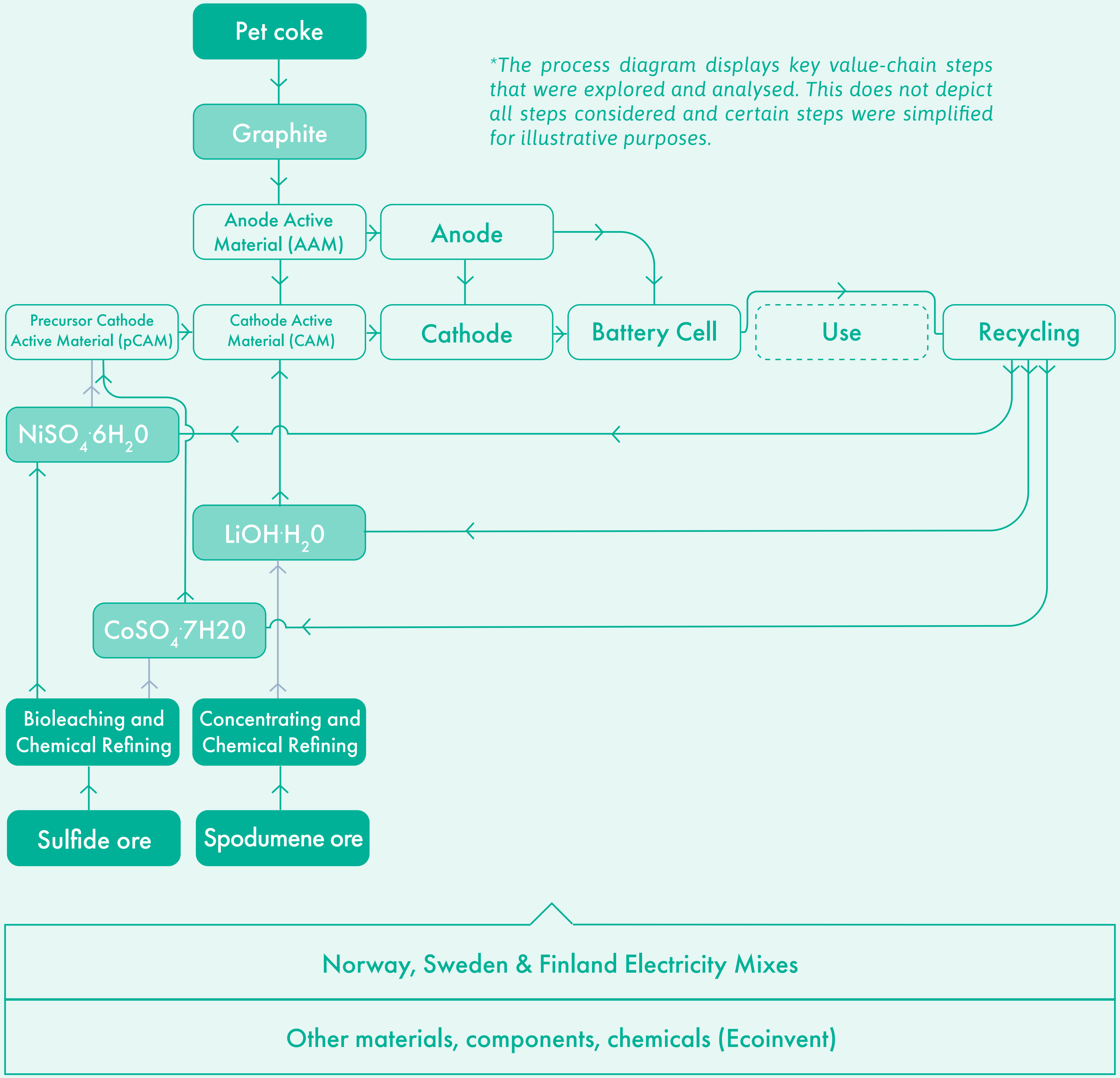
Norway
- Synthetic graphite from pet coke (Vianode)

Finland
- Nickel sulfate hexahydrate from sulfide ore bioleaching
- Cobalt sulfate heptahydrate from sulfide ore bioleaching
- Lithium hydroxide monohydrate from spodumene refining

These routes were derived from previous LCA studies, publicly available reports and literature, and Minviro's in-house modelling. Each route was benchmarked against global average production routes informed by the Minviro Database. For cell manufacturing, Swedish and Norwegian electricity mixes were used and compared to weighted mixes representative of current battery manufacturing locations in China, the US, and Europe.

The findings were intended for strategic insight and public communications for stakeholders across the battery value-chain.

Project Scope



**The process diagram displays key value-chain steps that were explored and analysed. This does not depict all steps considered and certain steps were simplified for illustrative purposes.*

Product Function

This study models prismatic NMC811 and LFP cells for energy storage applications (e.g. electric vehicles), with impacts evaluated per kilowatt-hour (kWh) of stored energy. Norwegian LFP parameters were based on assumptions provided by Morrow Batteries. NMC811 values were derived to match energy output via functional equivalence, using typical gravimetric energy density. In general, the models mostly used representative assumptions and not directly operational data from specific manufacturers.

Functional Unit

Impacts were calculated per 1 kWh of battery cell capacity. Reference flow was defined by the cell mass needed to meet this FU, enabling consistent comparison across chemistries and scenarios.

Assumptions Limitations

- This CFP focused exclusively on climate change impacts. To support more comprehensive sustainability decision-making, further work is required to expand this CFP into a full LCA that incorporates additional environmental impact categories.
- While some primary data was used, the study is primarily exploratory in nature and relies on representative secondary sources. Regional comparisons and global averages indicate broader market trends. Assessments of data quality, uncertainty, and sensitivity were conducted to account for potential variability and to strengthen the robustness of the findings.
- The use phase of the battery was excluded from this study to focus on raw material extraction and production stages. Although product systems maintained consistent system boundaries, this represents a partial CFP. Findings may evolve with the inclusion of battery lifetimes and end-use scenarios.
- The analysis focused on battery cells using two specific chemistries within the prismatic format. Additional research may be needed to evaluate cylindrical and pouch cell formats, as well as alternative chemistries, which may present different environmental profiles.

Nordic Battery Materials Lead in Low Carbon Performance

This advantage stems from innovative technologies that offer exceptional material- and energy-efficiencies while leveraging the Nordics low-carbon power like hydro, nuclear and biomass.

Nickel & Cobalt Efficiency Excellence: Finnish technology demonstrates how innovative processing can transform material impacts. Nickel sulfate may achieve a 67% lower carbon impact through sulfide ore bioleaching, a process immensely more efficient than the dominant Indonesian-China laterite ore High Pressure Acid Leaching (HPAL) route. Combined with Finland's low-carbon electricity grid and fuel sources, this creates a fundamental competitive carbon advantage.

Similarly, cobalt sulfate could show a 51% lower impact by avoiding the conventional Democratic Republic of Congo mining followed by the Chinese refining route, which generates significantly higher impacts due to intensive reagent usage and cumulatively high energy consumption.

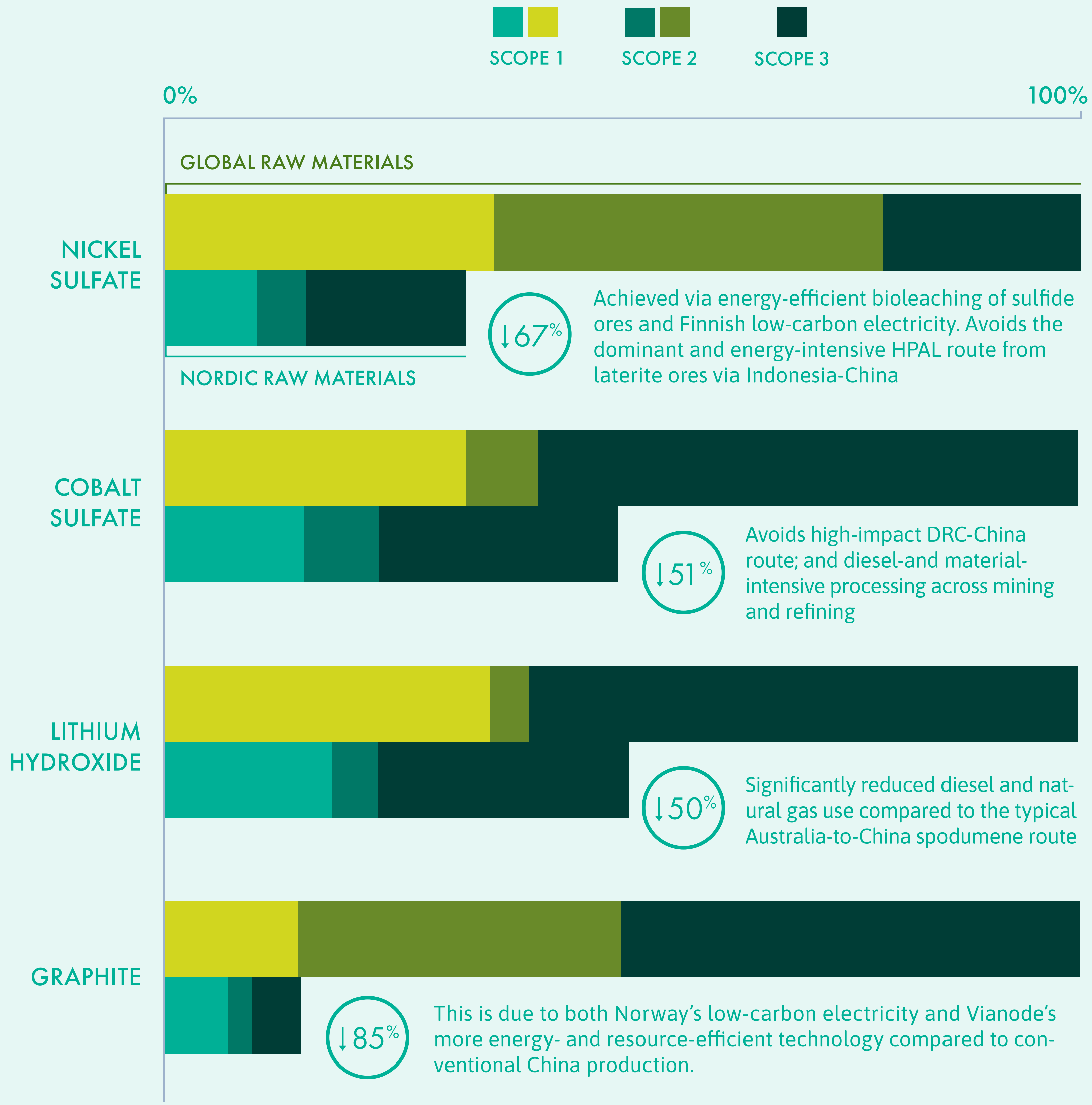
Vertically Integrated Lithium: The potential 50% lower impact of Finnish lithium hydroxide could unlock the power of vertical integration. By combining Finnish spodumene resources with direct refining operations and efficiency improvements, cumulative diesel and natural gas demands can be significantly reduced compared to the prevailing Australia-China route with its associated multistage operations and processing requirements.

Vianode's Revolutionary Technology: Perhaps most significantly, Vianode's synthetic graphite achieves 85% lower climate impact across all emission scopes.

This breakthrough stems from Norway's ultra-low-carbon electricity grid combined with innovative production technology that fundamentally reimagines conventional graphite manufacturing, significantly reducing energy consumption, raw material requirements, and direct greenhouse gas emissions.

Battery Raw Materials Carbon Footprints

% CO_2 eq. contribution, respectively made relative to their comparison



Nordic Cells Offer Low-Carbon Manufacturing and LFP May Hold a Climate Advantage Over NMC811

NMC811 production in Sweden results in 13-17% lower climate impacts compared to regions like China, the US, and Europe. This is largely due to Sweden's clean electricity mix of hydropower, nuclear, and wind. When switching to Nordic raw materials, footprints drop even further - by up to 53-55%.

LFP production in Norway shows 25-33% lower climate impact than other regions when using global average raw materials. Thanks to Norway's low-carbon electricity mix, climate impacts are further reduced by up to 49-55% when Nordic raw materials are used. LFP batteries have a clearer climate advantage over NMC811, with 35% lower impacts when using global raw materials. Even with Nordic sourcing, LFP still shows 19% lower emissions than NMC811. This is mainly due to the absence of high-impact materials like nickel and cobalt in LFP, making it a consistently lower-carbon choice.

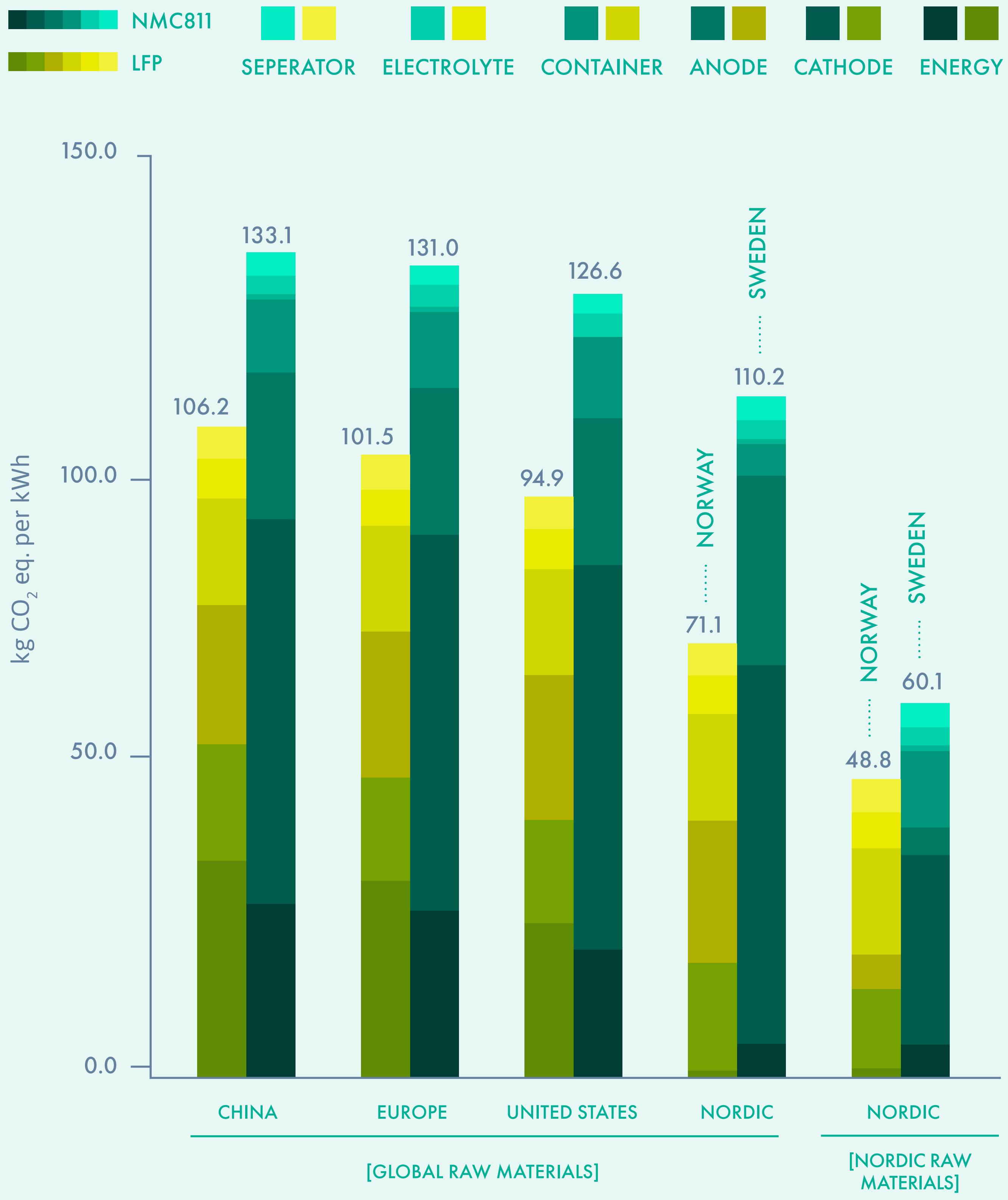
When accounting for the actual locations of battery manufacturing in this analysis, the differences in grid carbon intensities between China, Europe, and the United States become more comparable than when using nation-wide grid averages.

Alternative versions of this report are available that include a data quality rating, sensitivity analysis and comparative uncertainty analyses. Please contact Battery Norway directly about inquiries to their full LCA report from Minviro.

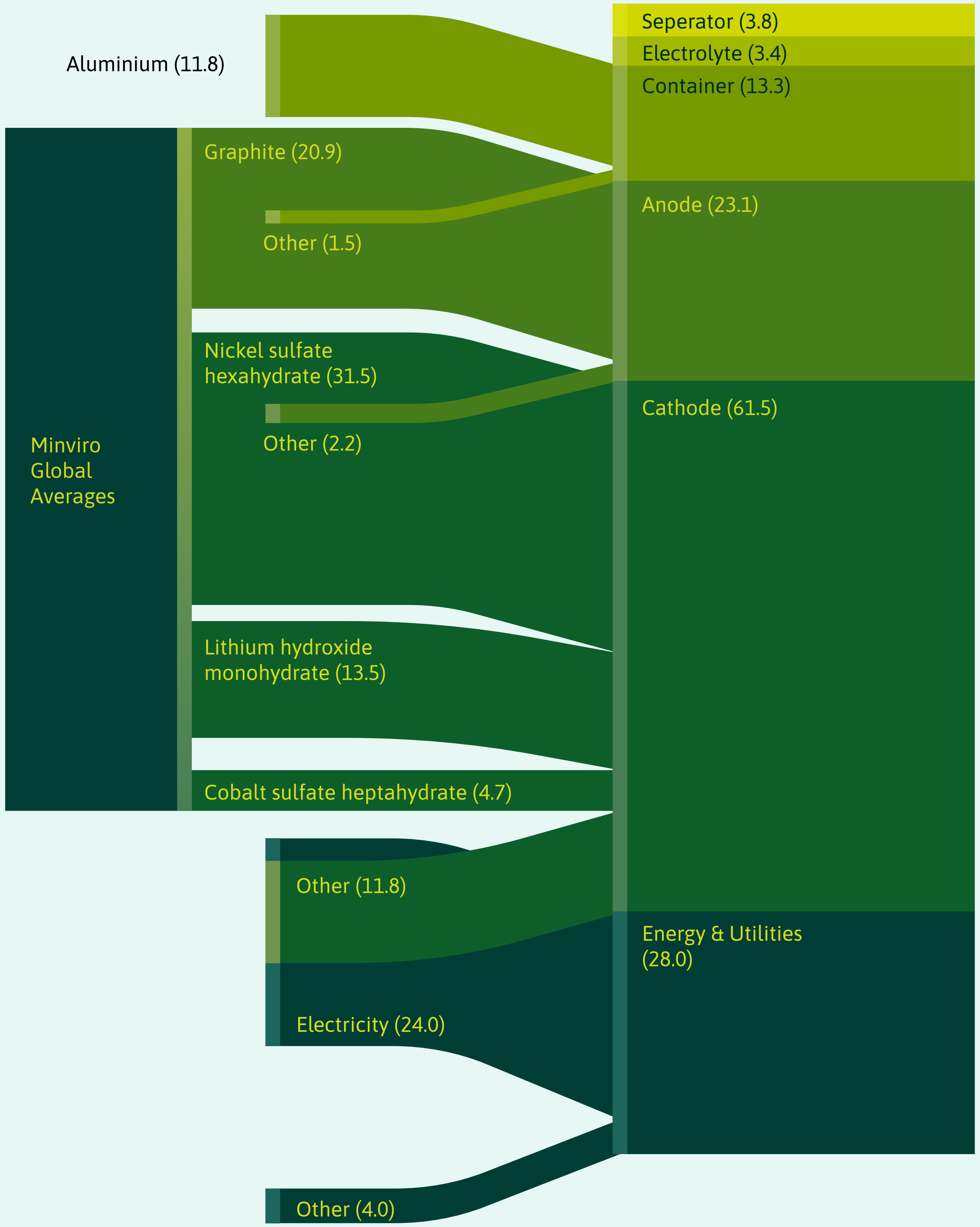
Climate Change Impacts - NMC811 & LFP

Regional comparisons by key component

NMC811 and LFP cell comparative climate change impacts by region. Energy refers to the total electricity and natural gas consumption for precursor, active material, and cell production stages.



Combining Clean Energy & Nordic Materials Deliver Best Results



NMC811 Battery Production in China using

Global Average Raw Materials

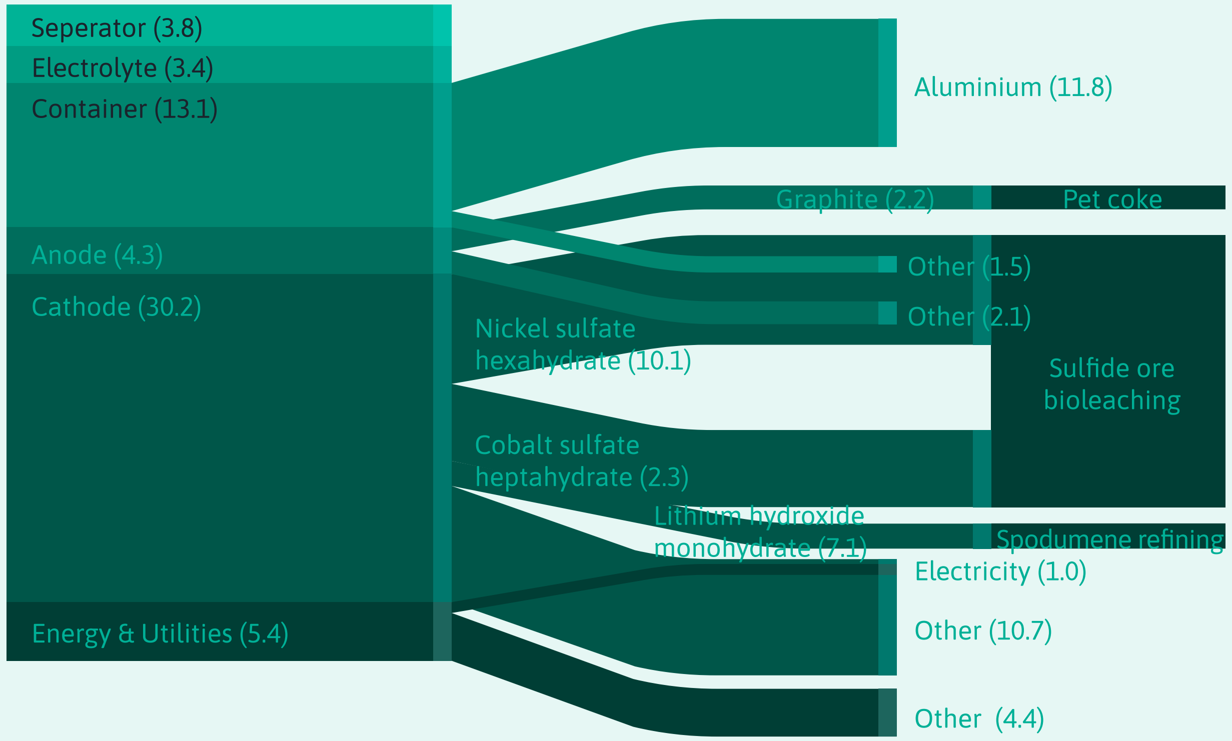
Total impact 133.1 kg CO_2e per kWh

NMC811 Battery Production in Sweden using

Nordic Raw Materials

Total impact 60.1 kg CO_2e per kWh

*Please note that minor differences between scenarios may arise due to variations in background data, including regional datasets and transport-related assumptions.



Combining Clean Energy & Nordic Materials Deliver Best Results

LFP Battery Production in China using

Global Average Raw Materials

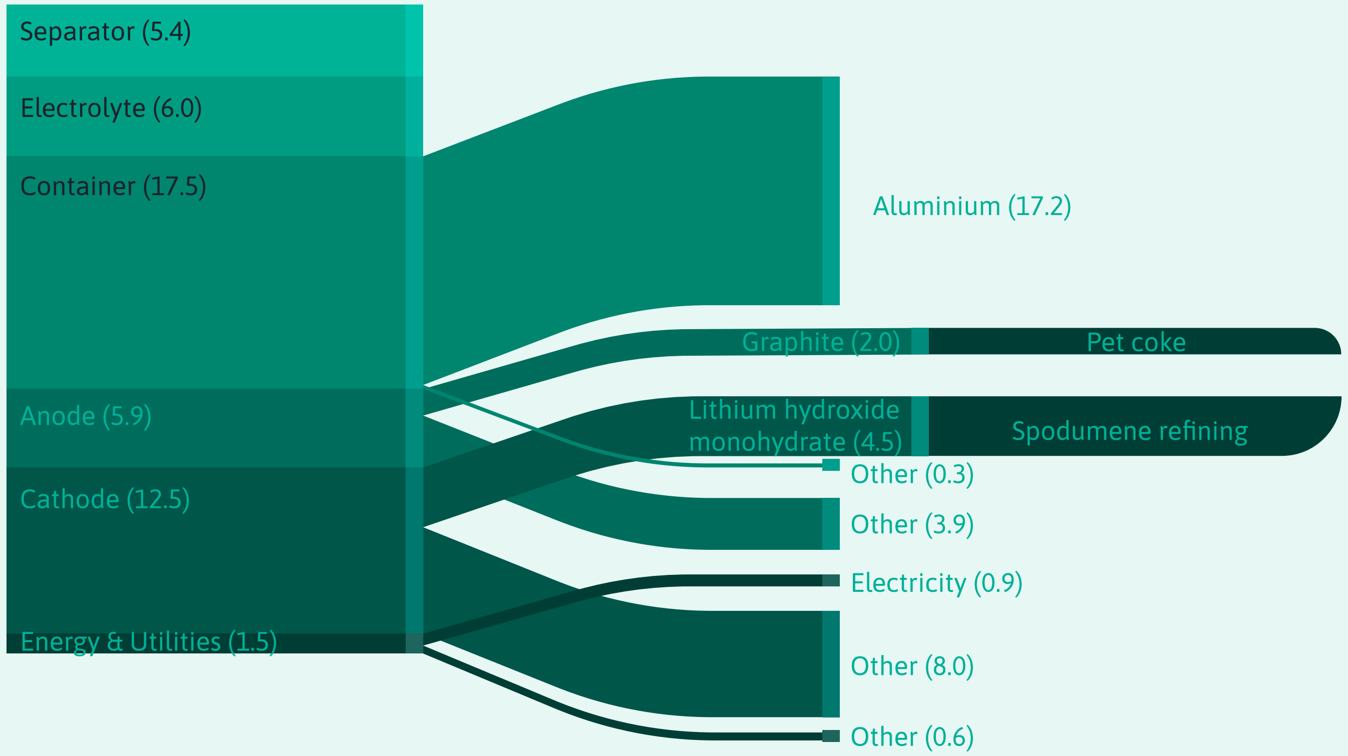
Total impact 106.2 kg CO_2e per kWh

LFP Battery Production in Norway using

Nordic Raw Materials

Total impact 48.8 kg CO_2e per kWh

*Please note that minor differences between scenarios may arise due to variations in background data, including regional datasets and transport-related assumptions.



Closed-Loop Recycling May Maintain a Low Carbon Footprint

Finnish closed-loop hydrometallurgical recycling of NMC811 cells could help maintain a low carbon footprint. Although the recycling process increases cell impacts by 20%, the recovery of battery-grade lithium, nickel, and cobalt enables the generation of recycling credits, resulting in a net 6% reduction in the total climate impact of the cell.

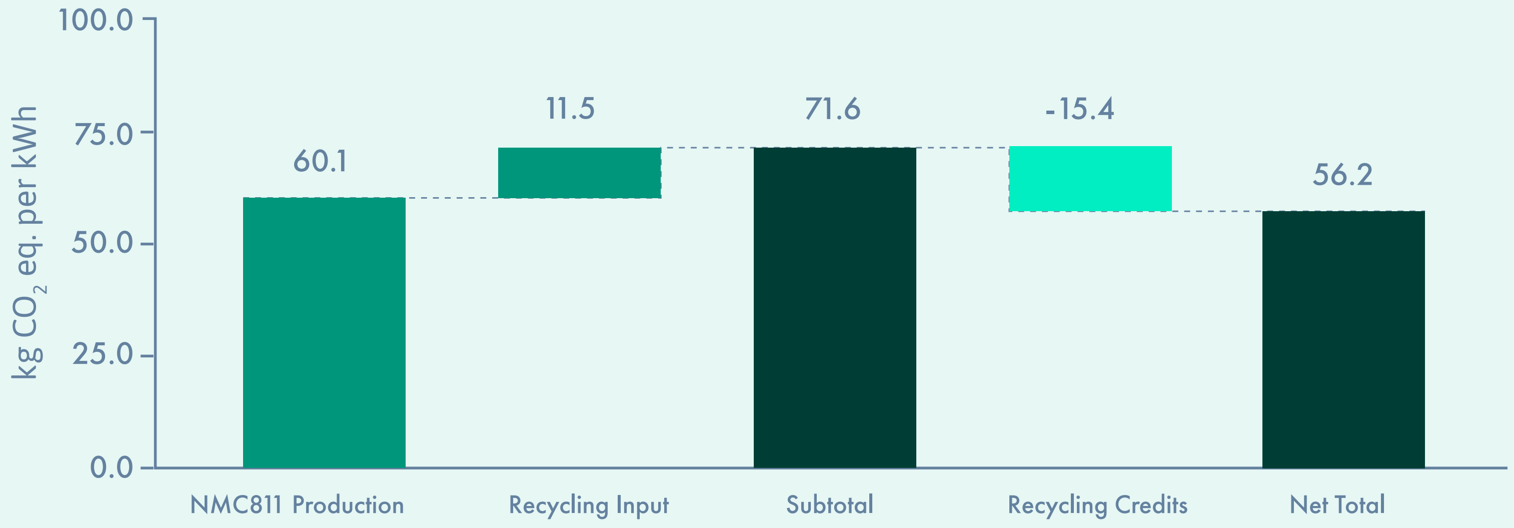
While this reduction is relatively modest and subject to uncertainties in the underlying assumptions, it supports the potential for sustaining a low overall carbon footprint. It also highlights potential opportunities to strengthen secondary materials supply chains and circularity in battery production. Additionally, emerging initiatives - such as the recently announced Fortum and Vianode collaboration on graphite recovery - present promising avenues for further evaluation.

While low-carbon electricity supports a lower overall footprint for recycling processes, significant impact hotspots often remain, particularly from the use and replenishment of chemicals such as diluents like kerosene and extractants like Cyanex.

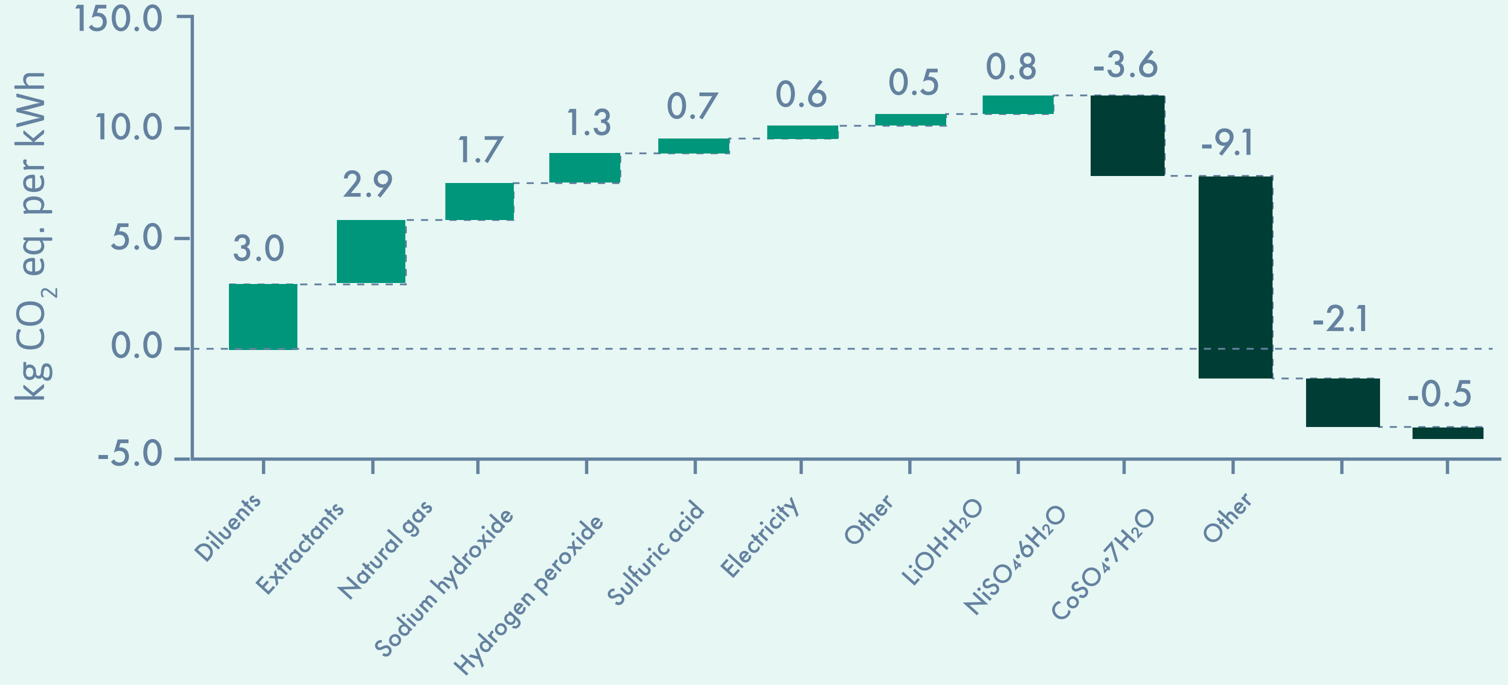
Climate change impacts - NMC811 recycling

By overall input vs credit impacts

NMC811 climate change impacts across a cradle-to-grave system boundary, including contributions from grouped inputs and outputs of the recycling process.



By grouped inputs and outputs



“The recycling assessment underscores how Nordic advantages extend beyond primary production. Even with process impacts and chemical hotspots, the ability to recover battery-grade materials while maintaining relatively low carbon performance positions the region uniquely for comprehensive circular manufacturing.

- Haley McKercher, Senior Analyst

Conclusions

This study highlighted the strong climate advantages of using Nordic raw materials and renewable electricity for battery production, with significantly lower carbon footprints seen in Sweden and Norway compared to global averages. LFP batteries consistently showed lower carbon footprints than NMC811 due to simpler, less carbon-intensive materials, though both chemistries have roles depending on application. Additionally, closed-loop recycling in Finland offers promising, if modest, climate benefits - underscoring the importance of circular solutions in maintaining low carbon footprints

The study was explorative, using assumptions and secondary data, meaning results should be viewed as directional rather than definitive. Key uncertainties remain around recycling processes and the exclusive focus on carbon footprint. To build a more robust picture, future work should expand to full LCA, incorporate a broader set of environmental indicators and continue stakeholder engagement in refining data collection and new project developments

The study underwent a critical panel reviewer with independent experts in LCA and batteries and found to be in compliance with ISO-14067. For the complete technical report, please contact Battery Norway

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