SHIFTING THE LENS:

The Growing Importance of Life Cycle Impact Data in the Battery Material Supply Chain

October 2021

Authors
Phoebe Whattoff, Jordan Lindsay, Robert Pell,
Carolina Paes, Alex Grant, Laurens Tijsseling

MINVIRO

www.minviro.com

More about the authors

Phoebe Whatoff MSc.

Phoebe is Sustainability Analyst at Minviro. She is a geologist by training and has previously studied the carbon sequestration potential of minerals.

Robert Pell PhD.

Robert founded Minviro after completing his PhD at Camborne School of Mines & Tsinghua. Robert has specialist knowledge in life cycle assessment and rare earth elements.

Alex Grant MSc.

Alex is a Partner at Minviro and Principal at Jade Cove Partners & co-founder of Lilac Solutions, a Silicon Valley direct lithium extraction technology company.

Jordan Lindsay PhD.

Jordan recently completed his PhD at Camborne School of Mines and has experience in mining engineering. His PhD was focussed on PGM geology

Carolina da Silva Paes MSc.

Carolina has a MSc in Sustainable and Innovative Natural Resources Management with knowledge on LCA for Lithium and Cobalt.

Laurens Tijsseling MSc.

Laurens is Sustainability Manager at Minviro. He previously worked as a Process Engineer in Sibelco Group. Laurens has a focus on life cycle assessment of cobalt and nickel.

The growing importance of supply chains

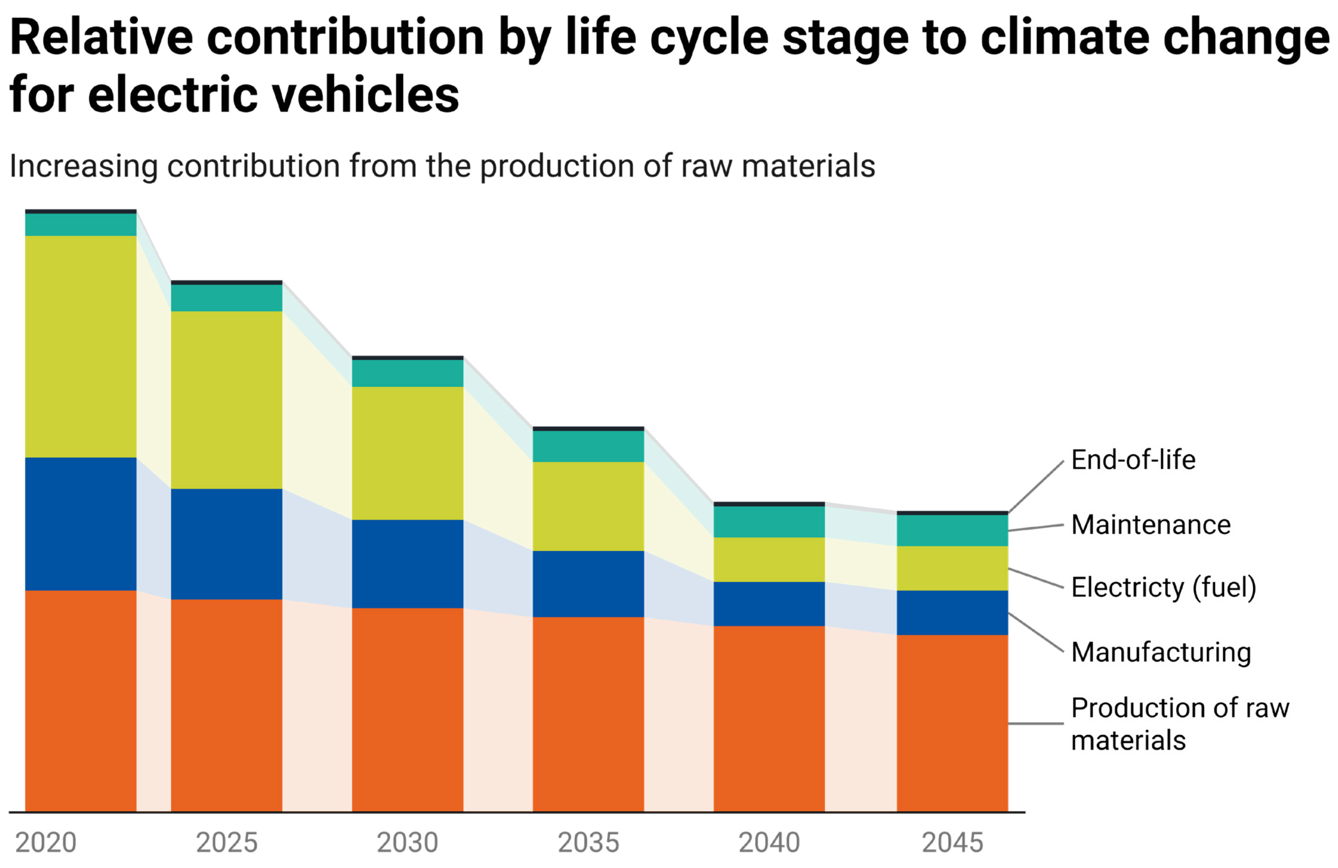


Figure 1 - *Relative contribution of the electric vehicle life cycle to the climate change impact category over time.*

The route to global decarbonisation requires an unprecedented amount of raw materials to manufacture batteries, motors, magnets and other key components of electric equipment designed to replace fuel-combustion technology.[1] A range of production routes for these key materials can carry significantly different embodied environmental impacts into batteries depending on how they are produced.[2]

Most life cycle assessments (LCAs) of lithium-ion batteries have assumed static impact values for producing component materials.[3,4] The exception to this is an academic paper exploring regional variability of manufacturing and production for a lower nickel content battery chemistry.[5] The quality of the environmental impact data for each battery raw material also varies and on occasions can underestimate the impact of certain materials.[6] This means there is an impetus to understand the environmental impacts of different production routes for key raw materials. In this whitepaper, the impacts of currently operational production routes for making key materials in electric vehicle (EV) batteries are presented at the level of an entire vehicle.

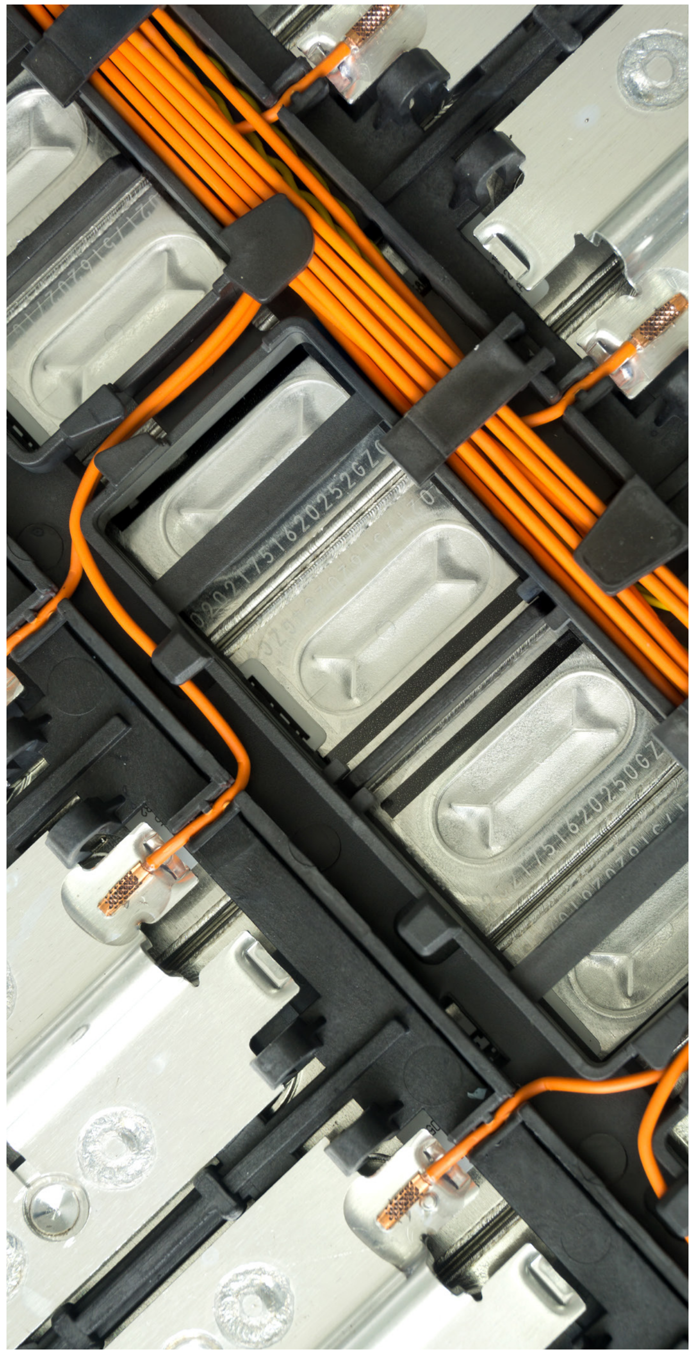
In the coming decades, many regions will see significant changes in electricity mixes with increased renewables and lower CO_2 per kWh of power generated.[7] This positive development will significantly cut environmental impacts during the manufacturing and use phase of batteries and EVs, but the relative contribution to produce the raw materials will increase (Figure 1). This is because the decarbonisation of raw material production that will feed these batteries is more challenging, and lower grade, and less pure resources will be used as feedstock to produce these

A range of production routes

There are numerous battery chemistries currently in use in EVs, and each has a distinct bill-of-materials. Battery development is a dynamic and fast-evolving sector with many new battery technologies developed in quick succession with new material requirements. In this whitepaper, climate change impacts for a high nickel content, nickel-manganese-cobalt (NMC) lithium-ion battery (NMC-811) are considered. However, as discussed within this paper, the story is ultimately the same for any battery chemistry: the raw material source for the batteries can have wide-ranging and often underestimated impacts embedded into the final product.

There are numerous supply chain stages to produce NMC-811, from raw material extraction to final product manufacturing. There are distinct mining, mineral processing and refining routes that utilise unique processes and different quantities of materials and energy. Certain aspects of these production routes are more difficult than others to decarbonise. For example, pyrometallurgical processes are energy-intensive and require thermal and electrical inputs. Hydrometallurgical routes can be less energy-intensive, but in contrast, may require significant quantities of chemicals and consumables that themselves can have high embodied impacts or create challenging waste management pathways.

The cumulative environmental impact of a NMC-811 battery will depend upon the supply chain choices made by the battery manufacturer. A thorough understanding of where the most significant environmental impacts lie within complex multi-phase supply chains, like those for battery production, can offer insights into the impacts of alternative routes and support sustainable manufacturing.



Why use Life Cycle Assessment?

LCAs are used to quantify the global environmental impacts to produce a given product, incorporating both the direct impacts associated with manufacturing processes and the embodied impacts of producing the required energy, reagents, and raw materials.

When applying LCA approaches to battery products, it is possible to set the functional unit (i.e., the final product referenced against which all impacts are normalised) to a kWh of storage, allowing the environmental performance of different batteries to be accurately compared and contrasted. It should be noted that although not captured in this paper, the use phase and end of life of batteries will have important implications for life cycle impact assessments and can vary depending on battery chemistry and application. Battery design, chemistry, manufacturing processes, and supply chain choices can materially affect longevity, failure rate, and recyclability of the battery and the consumer product within which it is housed.

Many different impact categories are quantifiable using LCA, including global warming potential (GWP, measured in kg CO_2 equivalent), acidification potential, eutrophication potential, ozone depletion potential, water use and more. LCA can be used to ensure that impacts are not being transferred from one impact category to another or displaced to other parts of the supply chain. This study focuses on GWP, but a number of other impact categories are included in Minviro databases. LCA supports decision-makers to select the product/process/technology that results in the lowest impact on the environment.

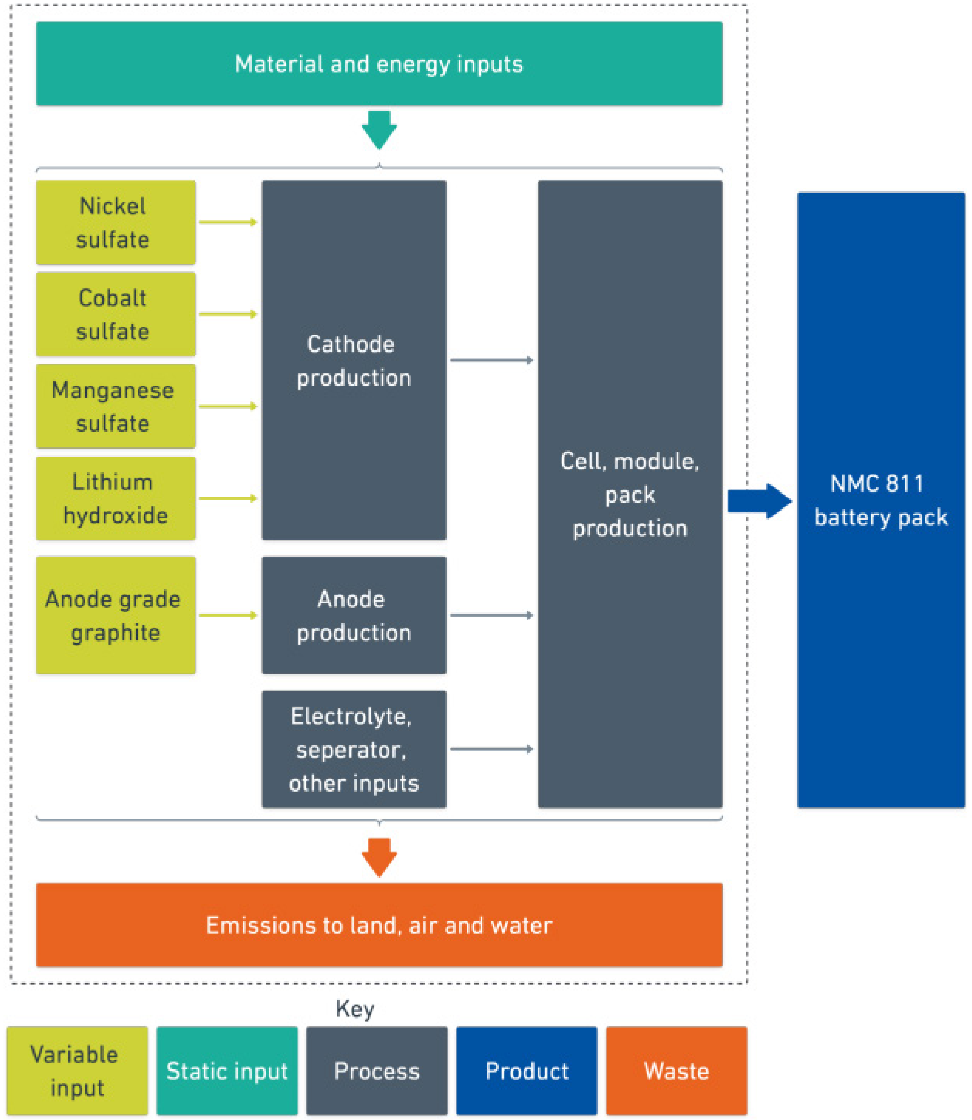


Figure 2 - *Simplified system boundary for the production of NMC-811 lithium-ion batteries.*

Methodology

The life cycle inventory for this study was constructed using a bill-of-materials from GREET for a NMC-811 battery for EV applications. [3] NMC-811 was selected for the comparison as it currently occupies 32% of the global EV battery market share, and this figure is increasing steadily against other technologies. [8]

New LCA model results are presented herein for NMC-811 pack production using Minviro's high-resolution impact database for (i) low, (ii) baseline, and (iii) high impact operational production routes for nickel sulfate, cobalt sulfate, manganese sulfate, and lithium hydroxide for cathode precursors, and graphite for the anode. The system boundary for the study is shown in Figure 2. These five variable inputs in the LCA were selected because they exhibit a wide range of life cycle impacts in asset-specific LCAs that Minviro has conducted, depending on where and how they are acquired and processed, and this study explores how these variances influence the overall battery impact.

All other data for the bill-of-materials was taken from Ecoinvent 3.7.1. [9] This includes material and energy inputs for cathode precursor manufacturing and material inputs for final battery assembly, including cathode, anode, electrolyte, separator, and casing. Impacts associated with the transportation of raw materials, fuel and reagents are not included The manufacturing impact for the cell assembly and finishing was assumed as a static 25 kg CO$_2$ eq. per kWh. This is a relatively low impact for manufacturing and it should be noted that this figure can vary depending on the availability of renewable energy in production regions vs. fossil

Results

A comparison of LCA results for GWP (in kg CO$_2$ eq. per kWh) for all three impact scenarios is shown in Figure 3. The baseline scenario indicates a total impact of 82 kg CO$_2$ eq. per kWh. The scenario utilising low impact battery raw materials was calculated as 70 kg CO$_2$ eq. per kWh, while the higher impact production routes have an impact of 138 kg CO$_2$ eq. per kWh. A higher-resolution breakdown of contributions towards cathode impacts for the low and high impact scenarios is shown in Figure 4, highlighting the criticality of cathode component supply chain variability in particular.

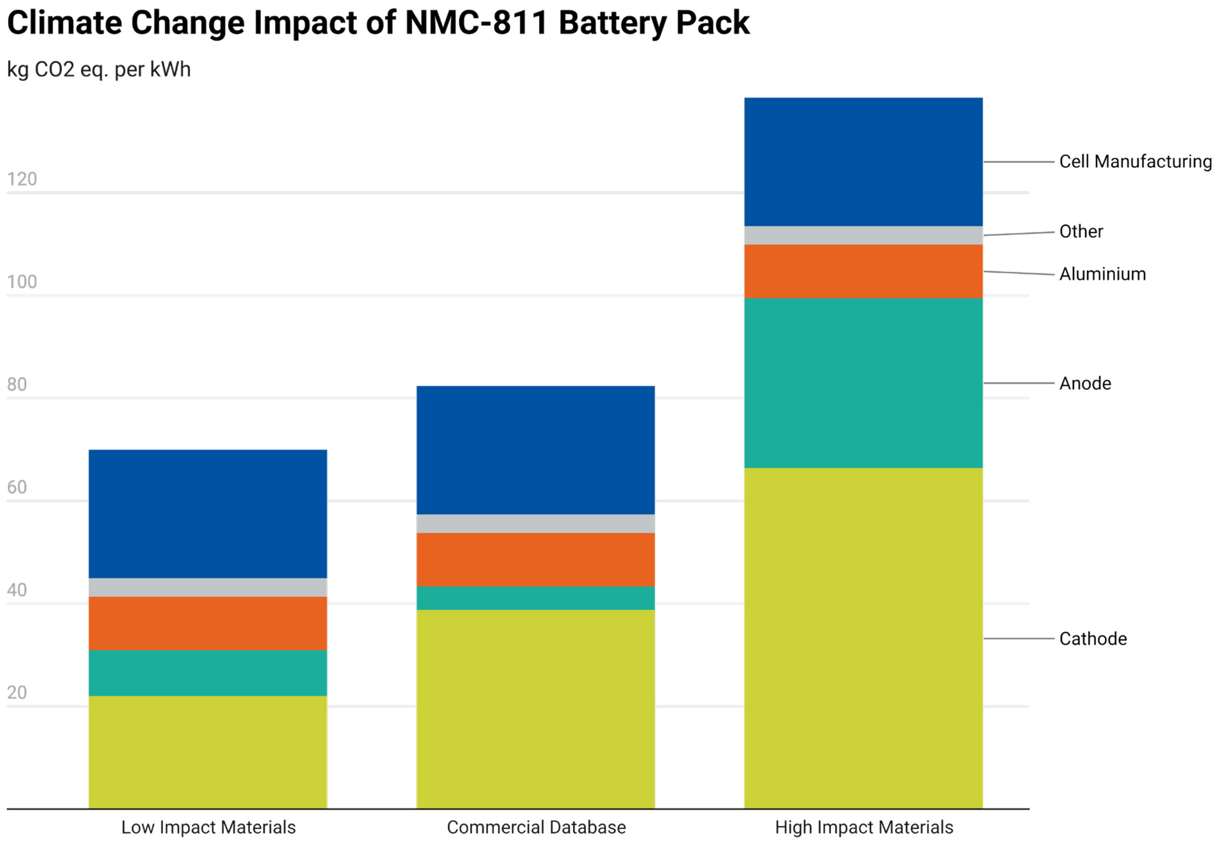


Figure 3 - *Full battery contribution analysis for battery production via the baseline, low impact and high impact supply chain scenarios*

Nickel
Expectedly, the high proportion of nickel in NMC-811 makes the product CO$_2$ impact sensitive to changes in the environmental impact of nickel sulfate production. Nickel is extracted from laterites or sulfidic ores. Amongst other factors, the grade, geometry, location, project scale, and mineralogy of the nickel orebody will contribute to the intensiveness of processing on a per-kg of nickel sulfate basis. Depending on the production route, nickel projects' acidification and ecotoxicity potential can be significantly higher than other commodities. [12]

The large tonnage of typical nickel-hosting orebodies requires processing through one of two commercial routes: energy and consumable intensive processing for treating the whole orebody for laterites (high pressure acid leaching or HPAL), or electrically-intensive concentration processes followed by thermal energy intensive refining for sulfide ores.

A "new" process route has been suggested for taking the energy intensive processing of laterite orebodies (nickel pig iron smelting) to nickel matte intermediate [13], after which nickel sulfate can be produced. Overall this is expected to be an electrically intensive process. For all of described routes, the electricity supply is of critical importance, as some locations offer low-carbon electricity while others require burning coal to generate power. The sheer amount of nickel sulfate contained in most NMC-811 batteries result in significant material and energy costs associated with this commodity in basedline (i), low (ii) and high (iii) impact scenarios (Figure 4). [14]

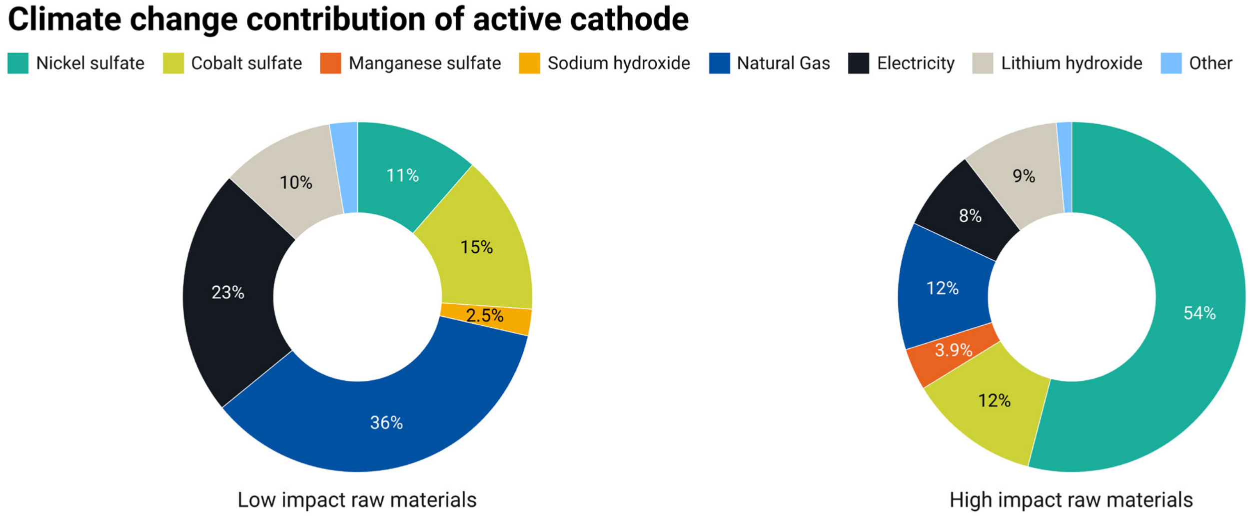


Figure 4 - *Comparison of the relative contribution by material input to cathode climate change impact for low and high impact supply chain scenarios. Key works clockwise from nickel sulfate.*

Graphite

Graphite is a common anode material that can contribute significantly to overall battery impacts and has often been overlooked in LCAs. A recent whitepaper by Minviro highlighted the historic under-representation of graphite environmental impacts as a function of localised energy demand, and this is especially relevant within full battery supply chains. [15] Producing anode-grade graphite is energy-intensive. Hence, graphite anode material processed in regions with dominant renewable energy grid mixes can result in substantially lower GWP for NMC-811 than coal-dominated areas like Inner Mongolia. In this study, graphite contribution to anode impacts increases by a factor of around nine between low and high impact scenarios to account for approximately a quarter of all impacts in the latter scenario (Figure 3). This reaffirms graphite's status as the 'hidden' impactor in battery manufacturing and highlights the importance of accurately defined regional energy mixes in life cycle impact assessments.

Lithium

Unsurprisingly one of the highest-profile components in its namesake lithium-ion batteries and has received significant attention in the LCA community in the last few years. [15] The processing routes from brine or hard rock resources produce different environmental impacts, especially when coupled with future geothermal energy potential. Compared to nickel and cobalt sulfates, lithium hydroxide is slightly less impactful and variable as a cathode component (Figure 4) but represents a significant opportunity for OEMs to secure sustainable supply chains by selecting one of the lower-impact extraction methods. [16]

Cobalt, manganese and aluminium

The change in contribution between scenarios from manganese and cobalt inputs for the NMC-811 cathode type is marginal. It must be noted that cobalt is considered a material with significant economic importance and substantial supply risks. [17] Even when used in an 8:1 mass ratio with nickel in an NMC-811 cathode, it can produce a comparable GWP impact (i.e., in the low impact scenario; Figure 4). Manganese is perhaps the least-studied NMC-811 component in a LCA context. Data may need to be revised or updated if battery demand continues to rise, as this could present a grey area in supply chain comprehension. Despite its relatively small contribution per battery, aluminium carries a significant impact per unit mass (Figure 3) and cannot be left out of the discussion surrounding battery supply chains. In our modelled low impact scenarios, static wrought aluminium impacts (from Ecoinvent 3.7.1) exceed those from anodes, if using a conservative impact for graphite production in a renewable energy dominant region.

Future outlook

Battery manufacturers will likely see intense competition for lower impact battery raw materials as they target low impact battery manufacturing and battery products. For example, Northvolt has publicly stated the goal of 10 kg CO_2 eq. per kWh for their batteries [18]. This ambitious target will only be achieved with strategic sourcing of low impact battery raw materials combined with impact reduction at the manufacturing stage. This will likely involve collaboration between companies such as Northvolt and their suppliers to reduce supply chain impacts.

> *The LCA model format created for this study is easily applied to different battery bills-of-materials, including other NMC set-ups, LFP, LMO and future battery technologies in development.*

This study of NMC-811 battery pack illustrates how sourcing different raw materials within a single supply chain can produce a wide range of impacts. These impacts only represent currently used production routes and some future routes could potentially lead to an even broader range of impacts. As conventional technologies expected to be applied to lower grade and less pure resources, environmental impacts will increase alongside increased reagent, material and energy use. Meanwhile, deployment of more sophisticated technologies that more selectively extract lithium from resources for example may reduce environmental impacts for some projects. The LCA model format created for this study is easily applied to different battery bills-of-materials, including other NMC set-ups, LFP, LMO and future battery technologies in development.

The dominance of NMC batteries in the market (for now) and the large quantity of metals required in their production will inevitably bring attention to impacts associated with nickel sulfate, cobalt sulfate, and manganese sulfate supply chains. The production of lithium is a key player for a broad range of batteries and still provides a clear and accessible route to more sustainable supply chains.

Graphite presents a significant immediate opportunity for impact reduction in the battery raw material value chain. The incumbent production route involves extremely energy-intensive processes such as graphitisation in Inner Mongolia, China, with a high carbon intensity per kWh [15]. Other projects in development have the opportunity to mitigate the impact by taking advantage of low impact electricity from hydroelectric sources.

Although this study uses specific example routes for each of the five major battery components, the same message applies across all material chains: differences in embodied impacts of individual raw material projects can have huge repercussions on overall final product impacts, some more so than others. Lower impact production routes could be emerging for almost all battery materials. As legislation tightens around supply chain environmental credentials, LCA is the optimum methodology for recognising, mitigating and reducing raw material impacts in the pursuit of global decarbonisation.

Acknowledgements

The authors would like to thank Mark Saxon, Lyle Trytten, Gloria Esposito for reviewing the whitepaper and providing constructive feedback. The authors would like to thank Gina Glasø for designing and formatting the whitepaper.

References

1. World Energy Outlook Special Report. The Role of Critical Minerals in Clean Energy Transitions. (2021).

2. Pell, R. et al. Towards sustainable extraction of technology materials through integrated approaches. Nature Reviews Earth & Environment 2, 665–679 (2021).

3. Dai, Q., Kelly, J. C., Gaines, L. & Wang, M. Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications. Batteries 5, 48 (2019).

4. Temporelli, A., Carvalho, M. L. & Girardi, P. Life Cycle Assessment of Electric Vehicle Batteries: An Overview of Recent Literature. Energies 13, 2864 (2020).

5. Kelly, J. C., Dai, Q. & Wang, M. Globally regional life cycle analysis of automotive lithium-ion nickel manganese cobalt batteries. Mitigation and Adaptation Strategies for Global Change 25, 371–396 (2020).

6. Pell, Robert., Tijsseling, L., Whattoff, P., Lindsay, J. The climate impact of graphite production. (2021).
7. Net Zero by 2050 A Roadmap for the Global Energy Sector. (2021).

8. EV batteries in China & rest of world by chemistry 2020. https://www.statista.com/statistics/964355/ev-batteries-elements-market-share-in-china-vs-rest-of-world/.

9. ecoinvent 3.7.1. https://ecoinvent.org/the-ecoinvent-database/data-releases/ecoinvent-3-7-1/.
10. Erakca, M. et al. Energy flow analysis of laboratory scale lithium-ion battery cell production. iScience 24, 102437 (2021).

11. Porzio, J. & Scown, C. D. Life-cycle assessment considerations for batteries and battery materials. Adv. Energy Mater. 11, 2100771 (2021).

12. LeVine, S. A new battery breakthrough that could save electric vehicles during a recession. Marker https://marker.medium.com/a-new-battery-breakthrough-that-could-save-electric-vehicles-during-a-recession-c193ebdd3a5d (2020).

13. Trytten, L. Matte from NPI - A Good Idea? (2021)

14. Nickel sulphate life cycle data. https://nickelinstitute.org/media/8d9409c7c0bdfc8/lca-nickel-sulphate-july-2021.pdf (2021).

15. EV batteries in China & rest of world by chemistry 2020. https://www.statista.com/statistics/964355/ev-batteries-elements-market-share-in-china-vs-rest-of-world.

16. Grant, et al. The CO2 Impact of the 200s Battery Quality Lithium Hydroxide Supply Chain. (2020).

17. Keersemaker, M. Critical Raw Materials. in Suriname Revisited: Economic Potential of its Mineral Resources (ed. Keersemaker, M.) 69–82 (Springer International Publishing, 2020). doi:10.1007/978-3-030-40268-6_9.

18. Carlsson, P. northvolt overview (https://worldmaterialsforum.com/files/Presentations2021/PS1-Peter-Carlsson.pdf)

SHIFTING THE LENS:

The Growing Importance of Life Cycle Impact Data in the Battery Material Supply Chain

October 2021

Authors
Phoebe Whattoff, Jordan Lindsay, Robert Pell,
Carolina Paes, Alex Grant, Laurens Tijsseling

MINVIRO