Project	Lithium-ion battery's life cycle: safety risks and risk management at workplaces
Work package	WP2: Life cycle assessment
Task	T. 2.2 Life cycle assessment of li-ion batteries
Responsible organisation	GAIKER
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Abstract

This task report is part of the “Lithium-ion battery’s life cycle: safety risks and risk management at workplaces” research project and focuses on the Life Cycle Assessment (LCA) of Lithium-ion batteries (LIBs). The overall value chain of the LIB was taken into account. In this context, the results of T2.1 (Mass Flow Assessment) constitute the basic material flow for the assessment, and they were later complemented by additional information related to auxiliary material consumption and energy balance.

According to the LCA results obtained, the production of the battery cell makes the highest contribution to the overall environmental impacts. The two elements that drive the environmental impact in the production phase are firstly the anode, and then the cathode. The materials with the highest impact in the production phase are copper, nickel sulphate and lithium hexafluorophosphate.

During the use phase, the study assessed the potentially significant implications for human health and the environment of incidents leading to explosions/fires, which in turn are linked to the emission of hazardous gases. However, the results indicate that the relevance of these impacts to the overall LCA is limited.

In the end-of-life phase, dominated by a set of processes leading to material recovery and recycling, the pyrometallurgical phase was identified as that which presents the highest environmental impacts, due to the associated high energy intensity.

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1 Methods

In this project, Life Cycle Assessment (LCA) was used to evaluate the environmental implications of NMC-811 Lithium-ion batteries (LIBS) used in off-road vehicles. The LCA is a recognised methodology for analysing the environmental impacts associated with a product, process, or activity by identifying and quantifying inputs (energy and materials used) and outputs (emissions and wastes released into the environment) and calculating the key environmental indicators. The assessment covers the entire life cycle of the product, process or activity, from the extraction of resources to the end of life, as well as the different production and transport operations, and the use phase.

LCA steps (see Figure 1): goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation (European Commission 2016):

- The goal and scope phase defines the aims of the study, namely the intended application, the reasons for carrying out the study and the intended audience. The main methodological choices are also made during this step.
- Life Cycle Inventory (LCI): this phase involves the data collection and the calculation procedure for quantifying the inputs and outputs of the studied system.
- Life Cycle Impact Assessment (LCIA): The LCI results are associated with environmental impact categories and indicators. The LCIA is performed using LCIA methods which first classify emissions into impact categories, and second, characterise them as common units to enable comparison.
- Life Cycle Interpretation: the results from the LCI and LCIA are interpreted according to the stated goal and scope.

Performing an LCA in such a confidential field as LIBs has required overcoming certain limitations. The access to primary data is extremely limited for both production (centralised in China, Korea and Japan) and the end of life. Moreover, there are many different LIB configurations and their traceability over the supply chain is difficult. Finally, the LCI data in commercial databases is also scarce.

At the same time, early evaluation is fundamental in minimising environmental impacts. In this context, the LCA presented in this report was based on the Mass Flow Assessment (MFA) carried out in T.2.1. Data from databases and the literature sources was added to the LCI.

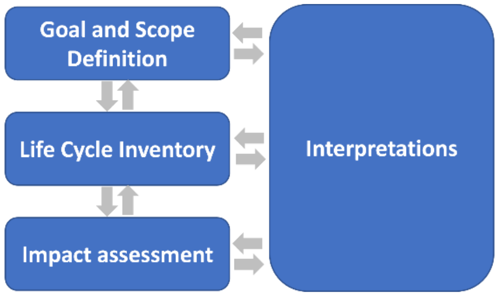

Figure 1. Methodological steps of the Life Cycle Assessment.

1.1 Goal and scope of LCA

The goal of this study was to evaluate the environmental impacts of the whole life cycle of a representative LIB. The NMC-811 LIB was selected as a representative case study for this project, due to its relevance in the sector, to both vehicles and stationary installations. For the use phase, the application of the battery in off-road vehicles was selected on the basis of the following premises: a) it represents a growing market which has a high impact on the industrial network; b) it has been studied less than the use of LIBs in electric vehicles for transport; c) the collaboration of an off-road EV provider is expected to offer further insights into this phase of the life cycle.

In this LCA, a cradle-to-cradle approach was taken, which means that the extraction of the resources, the production of materials and components, the final battery production, the use phase and the end-of-life phase (EoL) were all included.

However, a number of key aspects were considered for the definition of the goal and scope of the LCA:

- Despite the LCA by definition implying that the environmental assessment is approached from a global perspective, the project focused on materials, and to an even greater extent, strategic and hazardous materials.
- The limited product-specific data on industry makes it difficult to gather high quality data. Performance-related data (such as energy losses during the use phase) are scarce in the literature and represent great uncertainty.

Based on these premises, this study did not consider energy inputs and outputs during the use phase, and therefore, these are outside its scope.

On the other hand, potential LIB failures and accidents, as well as the emission of toxic gases during these events are within the scope of the study.

The results of this LCA study will be used for the following purposes:

- To address the emission of hazardous substances into the environment during the life cycle of NMC-811 batteries.
- To identify the key parameters and stages of the life cycle of the NMC-811 LIB model that show higher impact and to propose measures to reduce their environmental effects.
- To provide an overall picture of the impacts of these batteries on the environment throughout their value chain.

The results of the study are only valid for the NMC-811 batteries used in off-road vehicles, as the quantities of the materials, especially in the production and use phase, were modelled on this configuration. The results cannot be used for comparative purposes (with other battery types, cathode/anode designs, etc.), nor as support for product-specific sustainability claims.

1.2 Functional unit

The functional unit selected was an NMC-811 model battery pack weighing 684 kg, to be used in off-road vehicles such as forklifts.

1.3 System description

The table below (Table 1) shows all the materials needed to create the selected LIB.

Table 1. Materials needed to create the selected LIB

Component	Materials
Cathode active material (CAM)	Lithium hydroxide Sodium hydroxide Nickel sulphate Cobalt sulphate Manganese sulphate Ammonium hydroxide
Cathode	CAM Carbon black PVDF (Polyvinylidene fluoride) Aluminium NMP (N-Methyl-2-pyrrolidone)
Anode	Graphite Copper Water
Electrolyte	LiPF6 (lithium hexafluorophosphate) EC (ethylene carbonate) DMC (dimethyl carbonate) VC (vinyl carbonate)
Separator	PP (polypropylene) PE (polyethylene)
Non-cell materials	Copper Aluminium Steel PET (polyethylene terephthalate) Electronics

1.4 System boundaries

The LCA carried out for the selected NMC-811 LIB included (Figure 2):

- Obtaining the materials and energy sources (including the extraction phase)
- Manufacturing battery components
- The use phase[1], including accidents
- The EoL phase

Impacts that could be avoided due to the metals recovered in the recycling phase were not included in the study. The lack of high-quality information to model this aspect is considered a key issue.

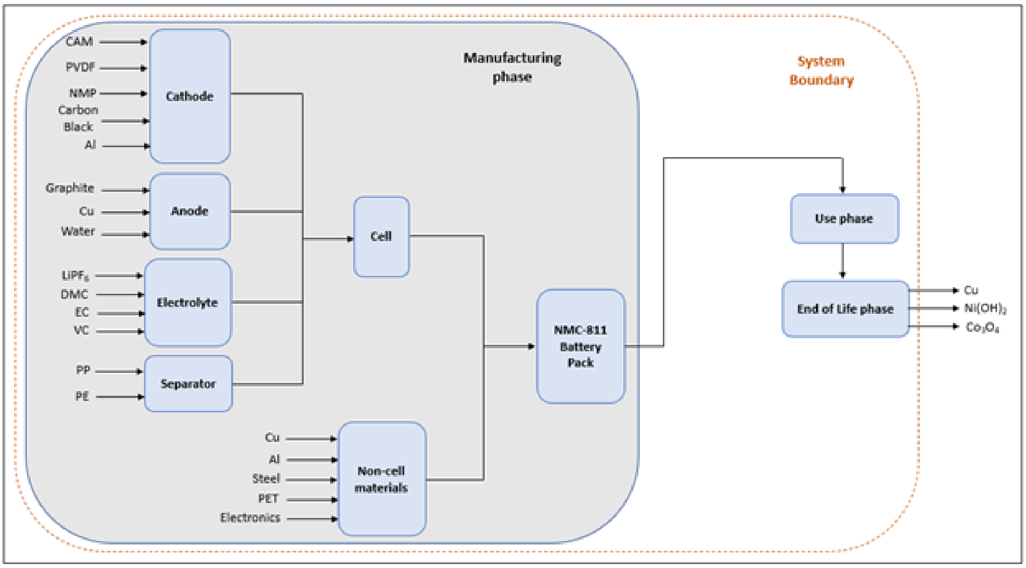

Figure 2. Life cycle assessment system boundaries for NMC-811 LIBs.

[1] As stated above, energy losses during the life cycle of the battery were not considered.

1.5 Assumptions

The inputs and outputs of the life cycle assessed were calculated on the basis of the following assumptions:

- Production phase:

The production of the components of the cell, as well as the main electronics, were considered to take place in China, and average production processes were based on the information in the literature. In this context, the production of these elements was modelled on the basis of the actual energy mix in China, and transport operations to Europe were also included. On the other hand, the production of the non-cell elements and the battery assembly were considered to take place in Europe, assuming an average energy mix.

- Use phase:

The average durability and use rate of industrial forklifts were considered. The rate of explosion and/or fire was extrapolated from data on electric vehicles, based on life hours and use rate. The emission of toxic gases was calculated on the basis of literature sources (Essl et al. 2020, Sun et al. 2016 and Amano, et al. 2022) as described in the MFA (Task 2.1).

- End-of-life phase:

Given the current European scenario, it was assumed that all batteries from off-road vehicles are collected and sent to specific recycling installations. The UMICORE process was selected as one of the most advanced processes in Europe, as it has major recycling capacity (Cheret & Santen 2007, Pinegar & Smith 2009 and Sojka et al. 2020). As explained in T.2.1, the recycling process is formed of pyrometallurgical and hydrometallurgical processes, recovering cobalt, nickel and copper (shown in Figure 3).

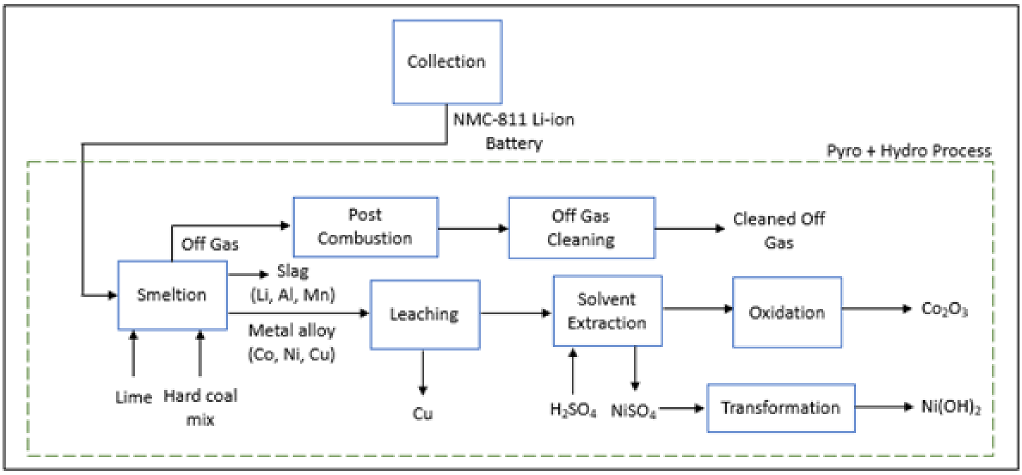

Figure 3. The process selected for the EoL phase of the NMC-811 LIB. Modified from Pinegar & Smith., (2009) and Sojka et al., (2020).

1.6 Allocation

The cut-off allocation procedure was taken into account in the selection of the system model for LCI data Ecoinvent 3.7, which implies that the first production of a material is always allocated to their primary user. If a material is recycled, the primary producer does not receive any credit for the provision of any recyclable materials. As a consequence, recyclable materials are available burden-free to recycling processes, and secondary (recycled) materials bear only the impacts of the recycling processes.

In the EoL phase, impacts avoided through the recovery of the materials were not considered.

1.7 Life Cycle Impact Assessment (LCIA) methodology

The Environmental Footprint (EF) LCIA methodology was selected to evaluate the potential contribution to the environment of the inputs (e.g. consumption of resources) and outputs (e.g. emissions) inventoried in the LCI. This methodology was developed following the mandate from the DG Environment, and therefore is the method recommended by the European Commission for enabling the comparability of EF indicators, calculated on the basis of LCA (Saouter et al., 2020). This study does not fulfil the requirements to calculate an EF, according to the guides published by the European Commission (Zampori et al., 2019). However, despite the simplified approach presented, the EF LCIA method was selected because of its degree of actualisation and completeness, its geographical scope, and its degree of recognition.

The EF method first calculates the contribution of the assessed system to a set of impact categories:

- Climate change (kg-CO2 eq):
- Ozone depletion (kg CFC11 eq)
- Ionising radiation (kBq U-235 eq)
- Photochemical ozone formation (kg NMVOC eq)
- Particulate matter (disease inc.)
- Human toxicity, non-cancer (CTUh)
- Human toxicity, cancer (CTUh)
- Acidification (mol H+ eq)
- Eutrophication, freshwater (kg P eq)
- Eutrophication, marine (kg N eq)
- Eutrophication, terrestrial (mol N eq)
- Ecotoxicity, freshwater (CTUe)
- Land use (Pt)
- Water use (m3 water eq of deprived water)
- Resource use, fossils (MJ)
- Resource use, minerals and metals (kg Sb eq)

As these indicators are expressed in different units, they cannot be compared to each other, and it is not possible to obtain an overall picture of the global environmental loads. The EF methodology enables a weighting step, in which the indicators mentioned above are multiplied by a set of weighting factors (as %), which reflect the perceived relative importance of the impact categories considered. Weighted results may be directly compared across impact categories, and also summed across impact categories to obtain a single overall score.

In this study the results are shown using the weighted results and are therefore dimensionless, expressed as impact points (Pt).

SimaPro 9.2.0.1 software was used to carry out the LCA and to quantify the environmental impacts according to the ILCD methodology.

1.8 Data sources

The LCI complies with the inputs and outputs of all the stages of the system studied. In this project, due to the already mentioned unavailability of primary data, secondary data were used to model the LCI. In this context, the secondary data used belong to the following categories:

- LCI database Ecoinvent 3.7
- Published research and scientific literature
- Product- and process-related data published by companies (e.g. technical datasheets, patents, etc.)
- Calculated data.

A more detailed description of the data sources is presented in Section 2.1.

2 Life Cycle Inventory

The LCI of the NMC-811 LIB was based mainly on literature sources, due to the already mentioned lack of primary data. This section summarises main data sources for each life cycle phase.

2.1 LCI manufacturing phase

The main mass flows already available from the MFA (details in T.2.1) were the starting point of the LCI inventory, which was later undertaken in order to include data related to energy requirements and specific non-product outputs (atmospheric emissions, wastewater and waste flows). Table 2 summarises the main inputs and outputs in the production process, which, together with the data sources used, quantify each flow in the process and model the environmental burdens associated with each of these flows.

Table 2. Summary of data used to produce 1 battery pack of selected battery (684kg).

Flows by component/process	Data source	
	Flow quantification in production processes	Secondary data
CAM		
Materials input		
Lithium hydroxide	Dai et al. (2019)	Lithium hydroxide - Ecoinvent 3.7
Sodium hydroxide		Sodium hydroxide - Ecoinvent 3.7
Nickel sulphate		Nickel sulphate - Ecoinvent 3.7
Cobalt sulphate		Zhang et al. (2021)
Manganese sulphate		Manganese sulphate - Ecoinvent 3.7
Ammonium hydroxide		Ammonia - Ecoinvent 3.7
Process water		water, deionised - Ecoinvent 3.7
Energy input		
Electricity	Based on Dai et al. (2019)	Electricity, medium voltage (CN) - Ecoinvent 3.7
Natural Gas		Heat, industrial, natural gas - Ecoinvent 3.7
Outputs		
Water into air	Ecoinvent 3.7 database	Water - Ecoinvent 3.7
Water to water		

Cathode		
Materials input		
Carbon black	Based on Dai et al. (2019)	Carbon black - Ecoinvent 3.7
PVDF		Polyvinylfluoride - Ecoinvent 3.7
Aluminium		Aluminium - Ecoinvent 3.7
NMP	Based on Accardo et al. (2021)	N-methyl-2-pyrrolidone - Ecoinvent 3.7
Energy input		
Electricity, medium voltage (KWh)	Ecoinvent 3.7 database	Electricity, medium voltage (CN) - Ecoinvent 3.7
Heat, district or industrial, natural gas (MJ)		Heat, industrial, natural gas - Ecoinvent 3.7
Outputs		
Water into air	Ecoinvent 3.7 database	Water - Ecoinvent 3.7
Water to water		
Residue from shredder fraction from manual dismantling	Ecoinvent 3.7 database	Residue from shredder fraction from manual dismantling - Ecoinvent 3.7
Wastewater, average (m3)		Wastewater, average - Ecoinvent 3.7
Anode		
Materials input		
Graphite	Based on Dai et al. (2019)	Graphite, battery grade - Ecoinvent 3.7
Copper		Copper, anode - Ecoinvent 3.7
Water solvent	Based on Accardo et al. (2021)	Water, deionised - Ecoinvent 3.7
Latex	Ecoinvent 3.7 database	Latex - Ecoinvent 3.7
Sulphuric acid		Sulphuric acid - Ecoinvent 3.7
Water, deionised		Water, deionised - Ecoinvent 3.7
Energy input		
Electricity, medium voltage (kWh)	Ecoinvent 3.7 database	Electricity, medium voltage (CN) - Ecoinvent 3.7
Heat, district or industrial, natural gas (MJ)		Heat, industrial, natural gas - Ecoinvent 3.7
Outputs		

Water into air	Ecoinvent 3.7 database	Water- Ecoinvent 3.7
Water to water		
Wastewater, average (m3)	Ecoinvent 3.7 database	Wastewater, average - Ecoinvent 3.7
Electrolyte		
Materials input		
Lithium hexafluorophosphate	Based on Dai et al. (2019)	Lithium hexafluorophosphate - Ecoinvent 3.7
Ethylene carbonate		Ethylene carbonate - Ecoinvent 3.7
Dimethyl carbonate		Dimethyl carbonate - Ecoinvent 3.7
Vinyl carbonate	Based on Crenna et al. (2021)	Crenna et al., (2021)
Water	Ecoinvent 3.7 database	Water - Ecoinvent 3.7
Energy input		
Electricity, medium voltage	Crenna et al. (2021)	Electricity, medium voltage (CN) - Ecoinvent 3.7
Outputs		
Water into air	Ecoinvent 3.7 database	Water - Ecoinvent 3.7
Water to water		
Separator		
Materials input		
Polypropylene	Based on Dai et al. (2019)	Polypropylene, granulate - Ecoinvent 3.7
Polyethylene		Polyethylene, low density, granulate - Ecoinvent 3.7
Energy input		
Heat, district or industrial, natural gas	Based on Crenna et al. (2021)	Heat, industrial, natural gas - Ecoinvent 3.7
Non-Cell Materials		
Materials input		
Copper	Based on Accardo et al. (2021)	Copper, anode - Ecoinvent 3.7
Aluminium		Aluminium - Ecoinvent 3.7
Steel		Steel - Ecoinvent 3.7
PET		Polyethylene terephthalate, granulate, - Ecoinvent 3.7
Electronics		Electronics, for control - Ecoinvent 3.7

2.2 Use phase

Flows by component/process	Data source	
	Flow quantification	Secondary data
Outputs		
Ethene into air	Based on Essl et al. (2020), Sun et al. (2016) and Amano et al. (2022)	-
Ethane into air		-
Methane into air		-
Carbon monoxide		-
Water		-
Carbon dioxide		-
Butane		-
Hydrogen fluoride		-
Hydrogen		-
Hydrogen cyanide		-

2.3 End-of-life phase

Flows by component/process	Data source	
	Flow quantification	Secondary data
Pyrometallurgical process		
Material Inputs		
Lime	Lewrén (2019)	Lime - Ecoinvent 3.7
Hard coal		Hard - Ecoinvent 3.7
Energy Inputs		
Electricity	Lewrén (2019)	Electricity, medium voltage (EU) - Ecoinvent 3.7
Heat, natural gas		Heat, industrial, natural gas - Ecoinvent 3.7
Outputs		
Slag	Based on Daniel Cheret & Sven Santen (2007)	Blast furnace slag - Ecoinvent 3.7
Hydrometallurgical process		
Material inputs		
Sulphuric acid	Based on Lewrén., (2019) and Daniel Cheret & Sven Santen (2007)	Sulphuric acid - Ecoinvent 3.7
Sodium hydroxide		Sodium hydroxide- Ecoinvent 3.7

Water		Water - Ecoinvent 3.7
Energy inputs		
Heat, natural gas	Based on Lewrén (2019) and Daniel Cheret & Sven Santen (2007)	Heat, industrial natural gas - Ecoinvent 3.7

3 Results

The results of the LCA show that the manufacturing phase of the NMC-811 battery pack is the phase with highest impact. In fact, it can be clearly seen that practically all the impacts are associated with this phase, mainly with the metal consumption involved. It must be highlighted, however, that the energy losses during the use phase were not taken into account, in accordance with the goal and scope of the study.

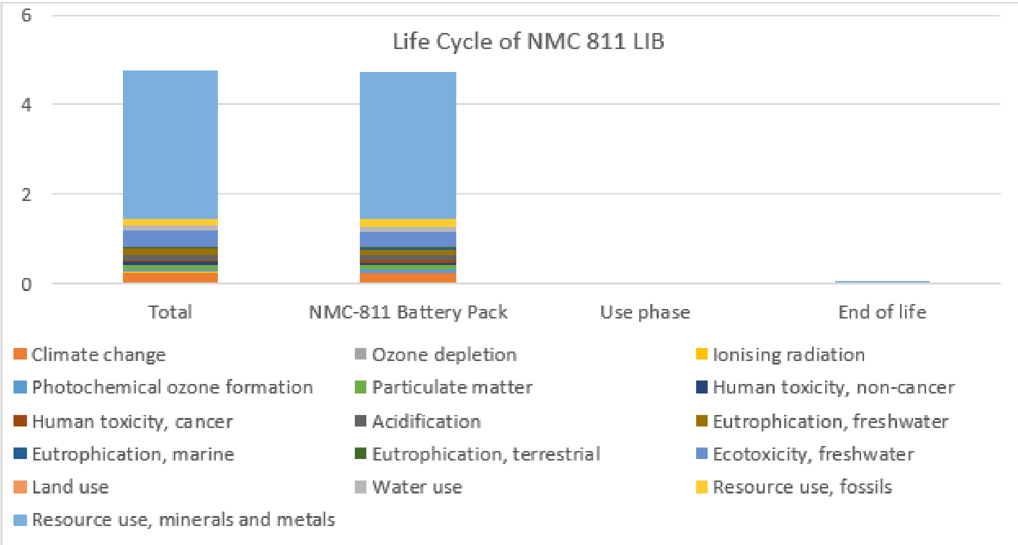

Figure 4. LCA of entire value chain of NMC-811 battery.

3.1 Production phase

The main contribution to the impacts in the production phase are linked to the cell manufacturing stage, followed by the production of the non-cell elements (Figure 5).

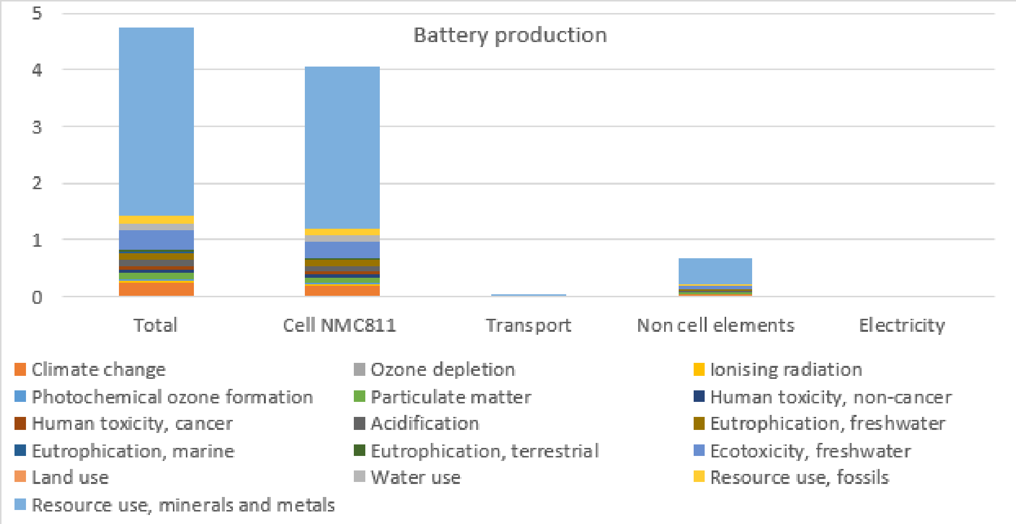

Figure 5. LCA of NMC-811 battery pack production.

The clear dominance of the impacts associated with the metal extraction and processing operations were common to all the components.

Analysis of the impacts associated with the production of the cell revealed that the anode was the element with the highest contribution (Figure 6), followed by the cathode. The electricity used in the cell manufacturing process made a smaller contribution than the two components, even smaller than that of natural gas.

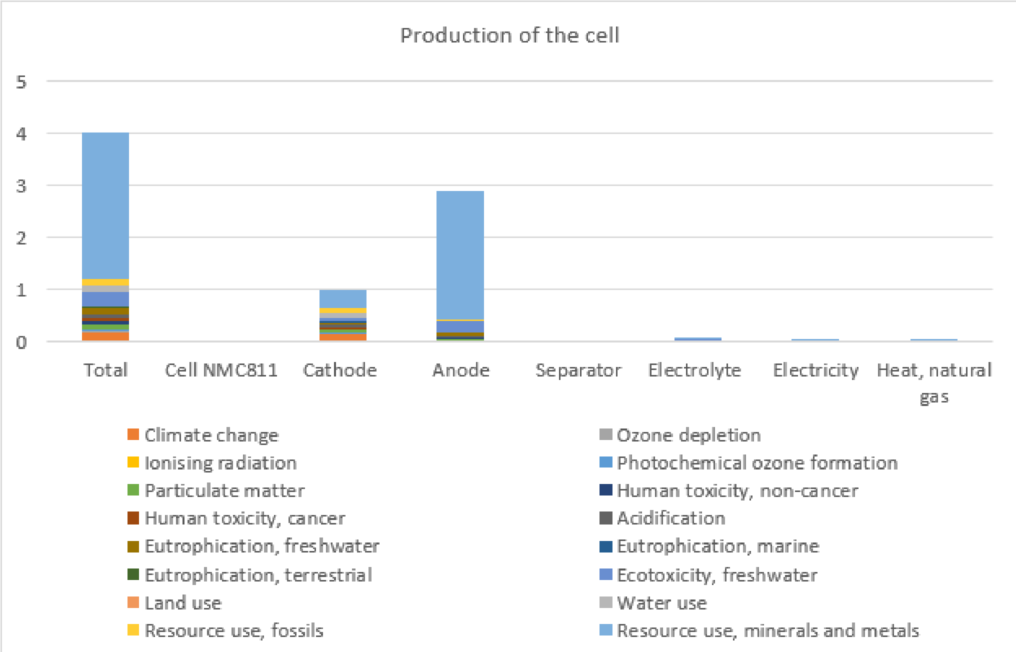

Figure 6. LCA results of production of cell.

Error! Reference source not found. and **Error! Reference source not found.** provide an insight into the environmental aspects of the main components integrating the LIB.

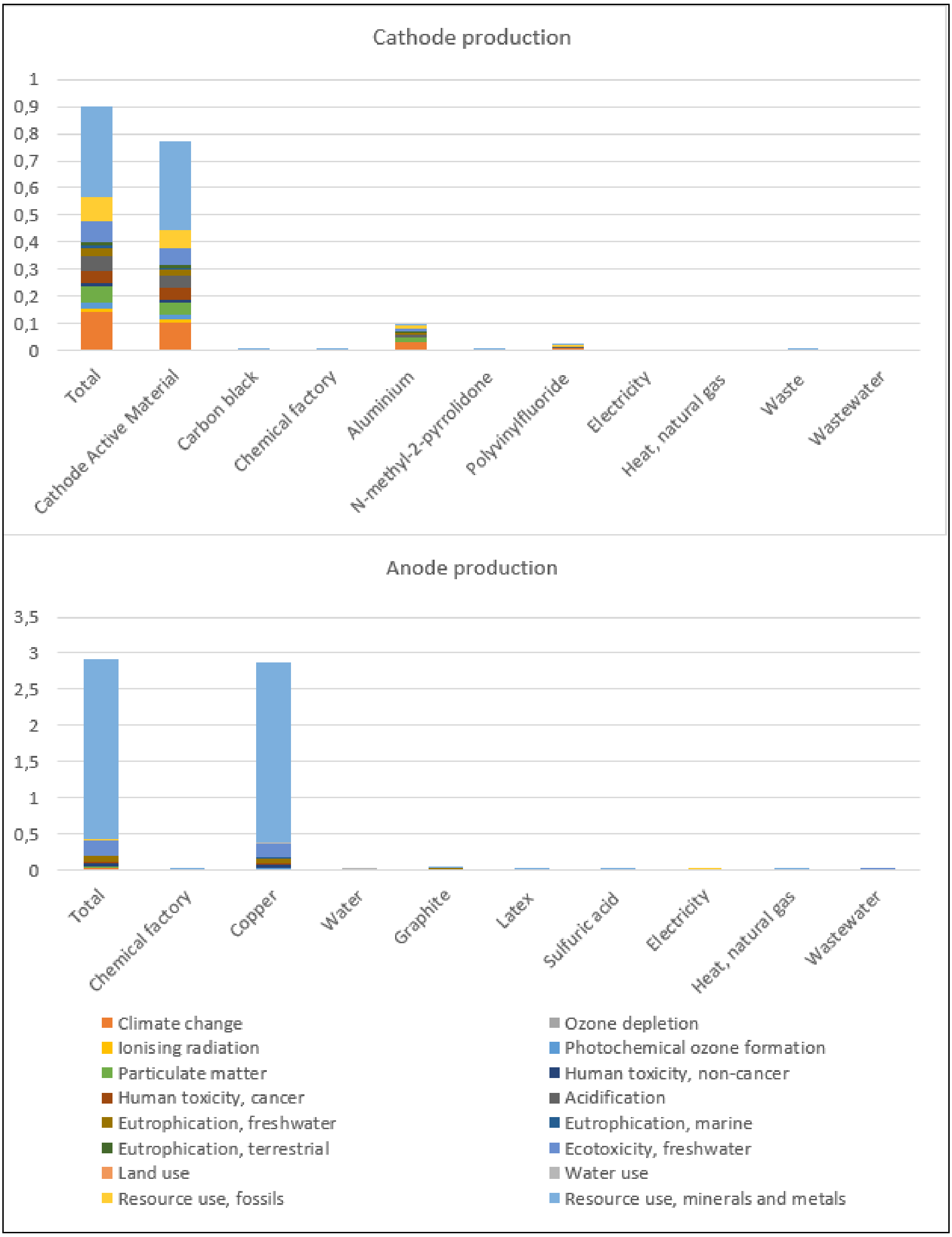

Figure 7. LCA results of production of anode and cathode.

The environmental impacts of anode production are linked to the copper extraction and processing stages (Figure 8), mainly due to their contribution to mineral and metal resource depletion.

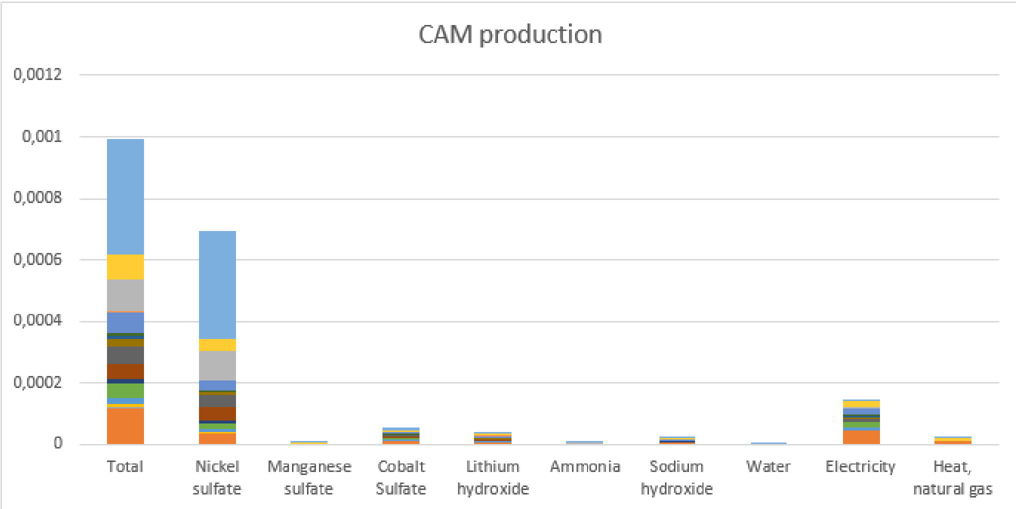

Figure 8. LCA results of production of electrolyte and CAM.

Regarding cathode production, the CAM made the greatest contribution to the environmental impacts. Metals have a major impact on CAM production, but electricity consumption also plays a significant role. Nickel shows the highest impact, while lithium and cobalt compounds contribute to a lower degree, mainly due to the smaller amounts consumed.

In electrolyte production, the LiPF6 shows the highest environmental impact (Figure 8). In this case, the most relevant impact categories are the use of mineral and metallic resources. The contribution to the global warming potential took second place. These impacts, however, are not linked to Lithium metal, but to the chemicals used in LiPF6 production. The emission of toxic and ecotoxic substances are also relevant at this point, but to a much lower degree.

In general terms, during the cell manufacturing process, electricity and heat consumption is only significant for CAM production.

Regarding the remaining components of the NMC-811 battery pack, the non-cell materials also contribute significantly to the total environmental loads during the production phase (see Figure 9).

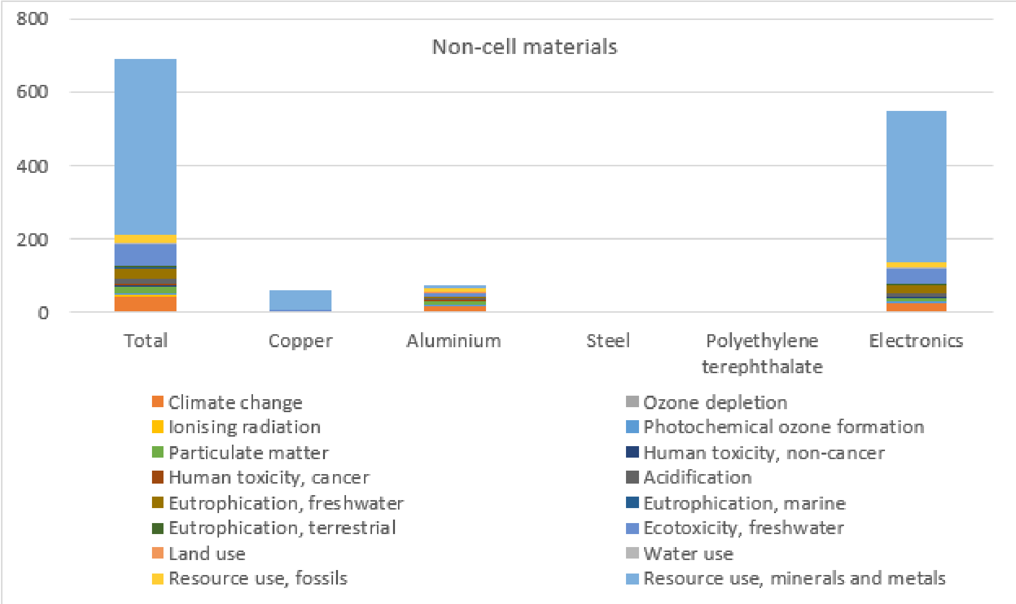

Figure 9. LCA results for production of non-cell materials (Pt/1000).

The electronic components are responsible for most of the environmental loads of non-cell elements, contributing mainly to the metal resource depletion impact category. These impacts are linked to the extraction and transformation processes that are necessary to obtain the precious and scarce metals used in printed wired boards and other electronic components.

3.2 Use phase

The impacts in this phase are directly related to the emission of contaminants during accidents or failures leading to fire. According to the estimations carried out in order to quantify the frequency and consequences of these events, the impact at this phase is very low in comparison to that in the production phase.

Considering the scope of the project, however, the contribution of the emitted gases to the impact categories related to damage to human health and the ecosystem is highly relevant. In this context, the following figures show the details of the four impact categories affected by these gas emissions: climate change, photochemical ozone formation, human health (non-cancer) and freshwater ecotoxicity.

The contribution to Human Toxicity and Ecotoxicity is very small in comparison to the other impacts. The most affected impact categories are global warming potential and Photochemical Ozone Formation.

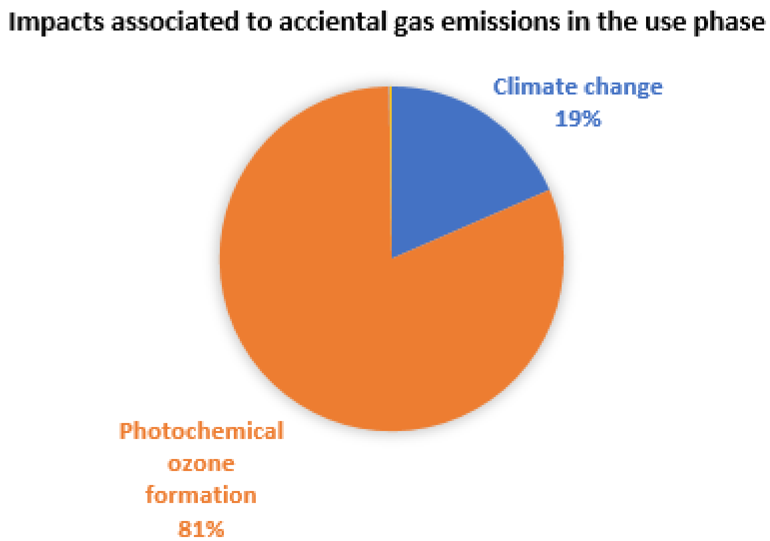

Figure 10. Main impact categories affected by gas emissions derived from accidental fires during use phase.

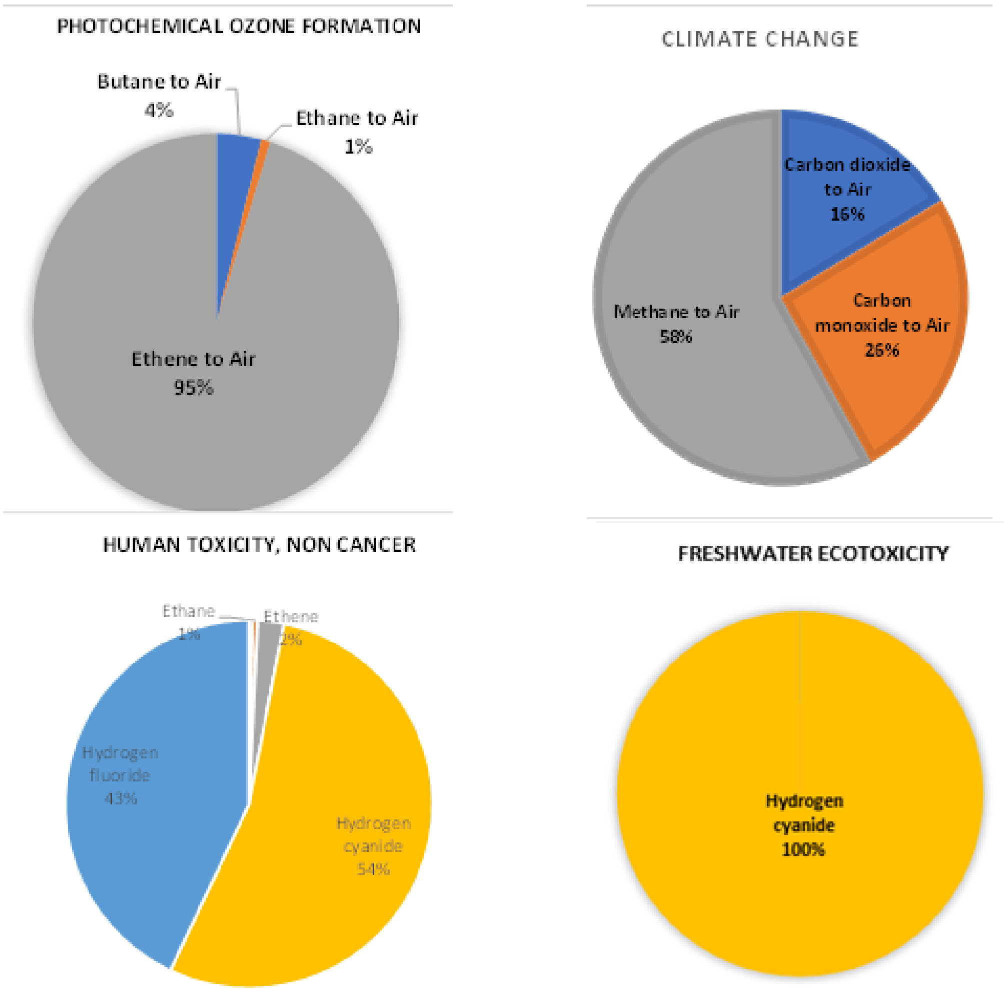

Figure 11. Relative contribution to different impact categories of gases emitted during fire incidents.

The emission of hydrogen cyanide affects both human toxicity (being responsible for more than 50% of the impacts) and ecotoxicity (being the only emission contributing to this impact). The emission of hydrogen fluoride also has a significant influence on human toxicity.

3.3 End-of-life phase

The environmental impacts of the recycling process are driven by both pyrometallurgical and hydrometallurgical steps, the contributions of which are similar.

The pyrometallurgical process contributes mainly to the global warming potential and fossil resource depletion potential (linked to energy consumption), whereas the impacts of the hydrometallurgical process are more diverse (see Figure 12).

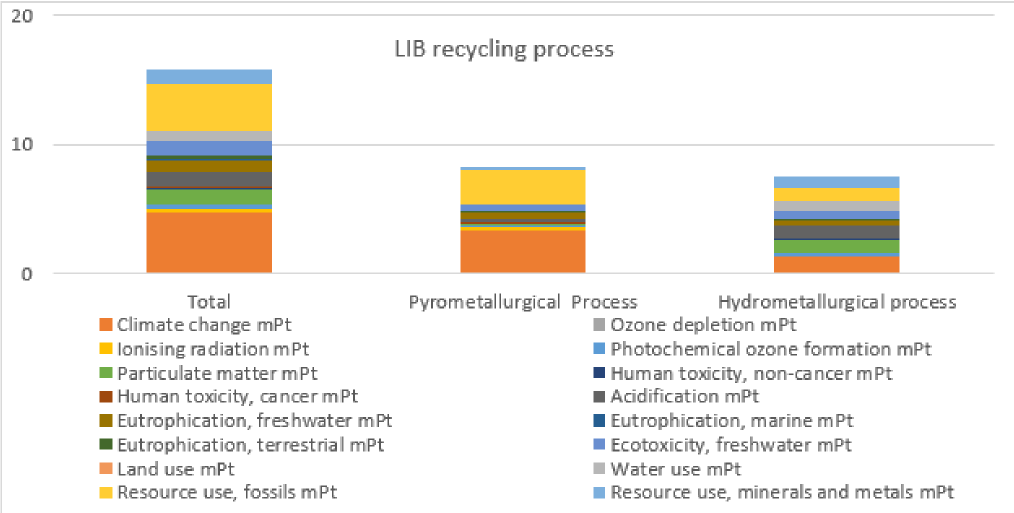

Figure 12. LCA results of recycling process of NMC-811 battery pack.

To give a more detailed overview, Figure 13 shows the final single point indicator for the environmental impacts associated with the LIB recycling processes.

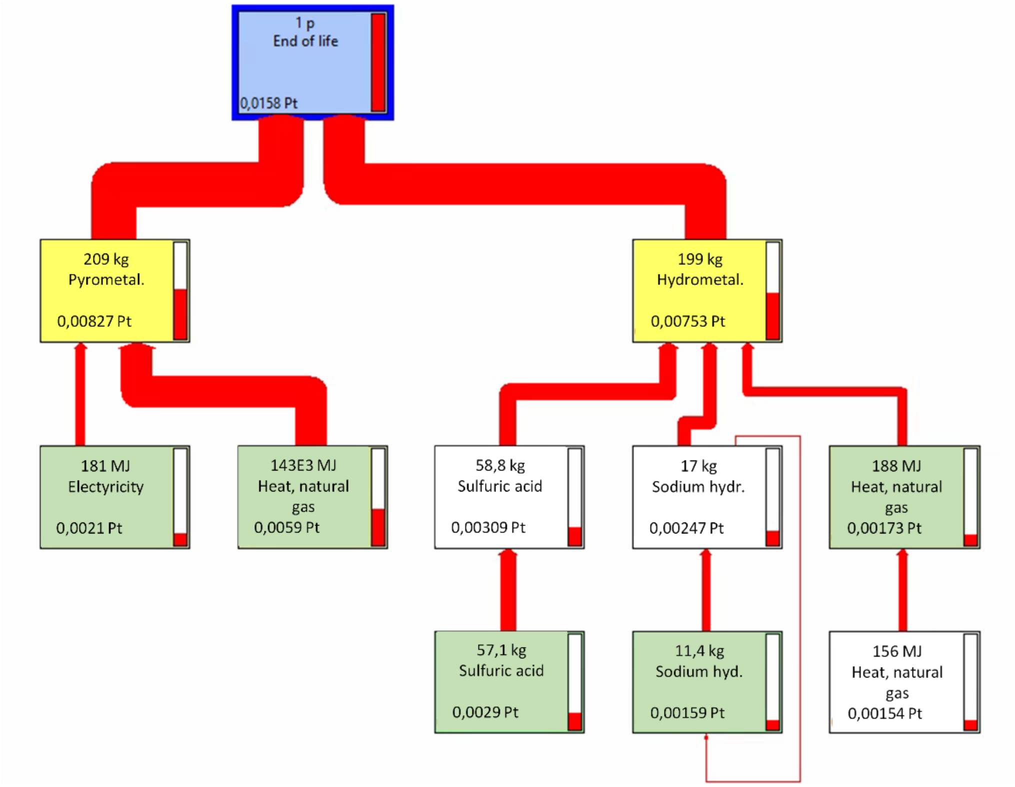

Figure 13. Environmental impacts associated with recycling process, Unique Punctuation.

As Figure 13 shows, the natural gas consumption in the pyrometallurgical process makes the greatest contribution to this impact category, whereas in the hydrometallurgical process, chemicals such as sodium hydroxide are associated with higher impacts than the energy resources for the process.

The impacts avoided due to metal recovery in this phase were included in the analysis. According to the literature data, the process enables the recovery of approximately 200 kg of metallic compounds from the evaluated battery (10.85 kg of Cu, 90.16 kg of Ni(OH)2 and 10.875 kg of Co3O4).

In this context, the impact of the recycling process can be considered 7.94E-05 Pt per kg of metallic compound recovered. As a reference value, the environmental impacts of nickel and cobalt compounds (NiSO4 and CoSO4) and the copper entering the process amount to 1.6E-02 Pt. Although the nature, quality and purity of the materials are different, these values provide an example of the value-reduced impact of recycled materials.

4 Conclusions

The environmental LCA focused on the overall value chain of the selected NMC-811 battery pack of a forklift. For the analysis, the impacts of the extraction of the raw materials on the EoL process were considered.

Regarding the main impacts of the life cycle of LIBs, we highlight the following results:

- Metallic and mineral resource use is the dominant impact throughout the production phase of LIBS, linked to the metal extraction and transformation necessary for the production of these batteries.
- The lithium and cobalt present in the battery are not as significant as other metals (e.g. nickel and copper) in terms of environmental impact.
- The production of the anode is the phase that makes the greatest contribution, due to the high impacts attributed to copper, mainly its contribution to mineral resource depletion.
- Regarding the production process, the environmental impacts associated with the energy requirements is not a relevant aspect, except in the production of CAM, in which electricity is the element with the second highest impact.
- The use phase has only been linked to potential gas emission during incidents leading to explosion and/or fire, as no record on maintenance operations or their implications is yet available. The impacts of the gas emissions, however, are very small in comparison to the environmental load of the production phase, due to the expected low frequency of the failure/accidental incidents.
- The gases potentially emitted during the use phase may affect four impact categories: climate change, photochemical ozone formation, human health (non-cancer) and freshwater ecotoxicity. The contribution to photochemical ozone formation is very small in comparison to the other impacts. The most affected impact categories are global warming potential and freshwater ecotoxicity.
- The emission of hydrogen cyanide affects both human toxicity (being responsible for more than 50% of the impact) and ecotoxicity (being the only emission contributing to this impact). The emission of hydrogen fluoride also has a significant influence on potential human toxicity impacts.

- In the EoL phase, although the total impacts associated with the pyrometallurgical and hydrometallurgical recycling processes do not show a great difference, the use of fossil resources is much higher in the pyrometallurgical process, due to its energy intensity.

As already mentioned, due to the significant information limitations encountered during the data gathering process, the results of this study must be considered preliminary. More accurate results would require resolving at least the limitations found in the following fields:

- Better primary data are necessary in order to properly assess inputs and outputs during the production and EoL phase of the products.
- The information on the composition of LIBs over the supply chain is limited, making it extremely difficult to evaluate the potential variation of the impacts according to the batteries' chemical composition.
- No historical information about the real performance of batteries during their use phase (proven durability, maintenance operations, etc.) is available that could have a significant influence on the LCA results. These aspects may also be key in future comparisons of different LIB chemistries to find the most sustainable options.
- No historical information is available on the frequency of the incidents leading to explosions/fires during the life cycle of LIBs, especially during the use phase of electric forklifts. These values would be very important for evaluating the potential impacts of the use phase and their relevance.

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