SUPPORTING INFORMATION FOR:

**Exploring Raw Material Contributions to the Greenhouse Gas Emissions of Lithium-ion Battery Production**.

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This supporting information provides information on the base life cycle inventories used for the assessment and additional results from parameterizing essential levers in the entire battery value chain.

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# Bill of material and cell manufacturing energy

The bill of materials used for each cell chemistry is calculated based on methodology from CELLEst [1], while the manufacturing energy is for a 6 GWh/a capacity based on the battery production model [2].

***Table S1: Cell Characteristics***

|  |  |  |  |
| --- | --- | --- | --- |
| Characteristics | Unit | LFP | NMC811 |
| Geometry |  | Pouch | |
| Cell dimensions (L x W x t) | mm | 254 x 157 x 10.5 | |
| Energy Density | Wh/kg | 201 | 278 |

***Table S2: BOM for LIB Cells (g/kWh)***

|  |  |  |
| --- | --- | --- |
| Component | LFP | NMC811 |
| Cathode active material | 1595 | 1171 |
| Graphite | 701 | 605 |
| Carbon black - Anode | 0 | 0.0 |
| Carbon black - Cathode | 8 | 7 |
| Binder SBR/CMC - Anode | 70 | 51 |
| Binder SBR/CMC - Cathode | 28 | 24 |
| Binder PVDF - Anode | 35 | 26 |
| Binder PVDF - Cathode | 42 | 36 |
| Copper - Foil | 53 | 39 |
| Copper - Tab | 562 | 355 |
| Aluminum - Foil | 32 | 22 |
| Aluminum - Tab | 322 | 203 |
| Aluminum - Container | 10 | 7 |
| Electrolyte LiPF6 | 455 | 309 |
| Electrolyte EC | 33 | 28 |
| Electrolyte DMC | 92 | 79 |
| Plastic PE - Separator | 92 | 79 |
| Plastic CPP - Container | 365 | 230 |
| Plastic PET - Container | 303 | 206 |
| Nylon/Carbon Fiber - Container | 66 | 45 |

***Table S3: Process energy for cell production***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Process step | LFP | | NMC811 | |
| Electrical (kWh/kWh) | Thermal (MJ/kWh) | Electrical (kWh/kWh) | Thermal (MJ/kWh) |
| Mixing anode | 2.05E-02 | 0.0 | 1.54E-02 | 0.0 |
| Mixing cathode | 1.65E-01 | 0.0 | 1.51E-01 | 0.0 |
| Coating anode | 8.46E-03 | 0.0 | 5.07E-03 | 0.0 |
| Coating cathode | 2.18E-02 | 0.0 | 1.31E-02 | 0.0 |
| Drying anode | 5.77E+00 | 7.3 | 3.46E+00 | 4.1 |
| Drying cathode | 2.98E+01 | 42.4 | 1.79E+01 | 24.8 |
| Calendering anode | 4.87E-03 | 0.0 | 2.92E-03 | 0.0 |
| Calendering cathode | 1.26E-02 | 0.0 | 7.54E-03 | 0.0 |
| Slitting anode | 1.08E-02 | 0.0 | 6.50E-03 | 0.0 |
| Slitting cathode | 1.08E-02 | 0.0 | 6.50E-03 | 0.0 |
| Stacking | 7.05E-02 | 0.0 | 4.87E-02 | 0.0 |
| Filling | 2.35E-02 | 0.0 | 1.62E-02 | 0.0 |
| Formation | 1.64E+01 | 0.0 | 1.09E+01 | 0.0 |
| Floor heating | 7.64E-03 | 0.0 | 7.63E-03 | 0.0 |
| Dry room | 1.10E+01 | 22.2 | 1.10E+01 | 22.1 |
| Miscellaneous | 2.56E+00 | 0.0 | 2.56E+00 | 0.0 |
| Total | 65.9 | 71 | 46 | 51.1 |

# Life cycle inventory of cell-level components and subcomponents

***Table S4: Aggregated Inventory on the cell level***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Component | LFP | NMC811 | units | Comments |
| Input |
| Cathode | 2.08 | 1.50 | kg | Modelled using the CELLEst approach |
| Anode | 1.37 | 1.05 | kg |
| Cell Container | 0.94 | 0.64 | kg |
| Electrolyte | 0.22 | 0.19 | kg |
| Separator | 0.36 | 0.23 | kg |
| Thermal Energy | 71 | 51 | MJ | Modelled with the battery production model |
| Electrical Energy | 66 | 46 | kWh |
| Cell Manufacturing Facility | 4.00E-10 | 4.00E-10 | unit | 6 GWH annual capacity for 50 years lifetime |
| Output | | | | |
| Cell [Functional Unit] | 1 kWh of cell capacity | | | |

***Table S5: Inventory of cell subcomponents***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Component | Sub-components | LFP | NMC811 | | | Units | References | |
| Cathode | Inputs | | | | | | | |
| Cathode Paste | 0.84 | 0.86 | | | kg | [3] | |
| Positive Current Collector [Al] | 0.16 | 0.14 | | | kg |
| Output | | | | | | | |
| Cathode | 1 kg of cathode material | | | | | | |
| Anode | Input | | | | | | | |
| Anode Paste | 0.57 | 0.64 | | | kg | [3] | |
| Negative current collector [Cu] | 0.43 | 0.36 | | | kg |
| Output | | | | | | | |
| Anode | 1 kg of anode material | | | | | | |
| Cell Container | Input | | | | | | | |
| Aluminium Tab | 0.49 | | 0.49 | kg | | | [3] |
| Plastic CPP | 0.32 | | 0.32 | kg | | |
| Plastic PET | 0.07 | | 0.07 | kg | | |
| Nylon/Carbon Fibre | 0.12 | | 0.12 | kg | | |
| Output | | | | | | | |
| Cell Container | 1 kg of cell container material | | | | | | |
| Electrolyte | Input | | | | | | | |
| LiPF6 | 0.15 | | 0.15 | kg | | | [3] |
| EC | 0.43 | | 0.43 | kg | | |
| DMC | 0.43 | | 0.43 | kg | | |
| Chemical factory | 1.7e-11 | | 1.7e-11 | unit | | |
| Output | | | | | | | |
| Electrolyte | 1 kg of electrolyte | | | | | | |
| Separator | Inputs | | | | | | | |
| polyethylene | 1 | | 1 | kg | | | [3] |
| Extrusion, plastic film | 1 | | 1 | kg | | |
| Plastic Processing Facility | 2.9e-11 | | 2.6e-11 | unit | | |
| Output | | | | | | | |
| Separator | 1 | | 1 | kg | | |  |

***Table S6: Inventory of cell subcomponents for cathode and anode paste.***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Component | Sub-components | LFP | NMC811 | Units | References |
| Cathode Electrode Paste | Inputs | | | | |
| Cathode active material | 0.91 | 0.91 | kg | [3] |
| Carbon black | 0.04 | 0.04 | kg |
| Binder SBR/CMC | 0.02 | 0.02 | kg |
| Binder PVDF | 0.03 | 0.03 | kg |
| NMP | 0.03 | 0.02 | kg |
| Chemical Plant | 1.4e-10 | 1.4e-10 | unit |
| Output | | | | |
| Cathode | 1 kg of cathode paste | | | |
| Anode Electrode Paste | Input | | | | |
| Anode active material (graphite) | 0.90 | 0.90 | kg | [3] |
| Carbon black | 0.01 | 0.01 | kg |
| Binder SBR/CMC | 0.036 | 0.036 | kg |
| Binder PVDF | 0.054 | 0.054 | kg |
| Water Use | 0.37 | 0.32 | kg |
| Chemical Plant | 6.3e-11 | 7.5e-11 | unit |
| Output | | | | |
| Anode | 1 kg of anode paste | | | |

# Life cycle inventory for cathode active material production

1. **NMC active material production**

A diagram of a chemical process

Description automatically generated with low confidence

***Table S7: Material and energy flows for NMC active material production***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | NMC811 | | Units | References |
| Preparation of hydroxide precursor | Inputs | | | | |
| NiSO4 | 1.27 | | kg | Simplified process model based on [4] |
| CoSO4 | 0.16 | | kg |
| MnSO4 | 0.16 | | kg |
| NaOH | 0.66 | | kg |
| NH4OH | 0.58 | | kg |
| Electricity | 2.28 | | kWh |
| Thermal | 4.15 | | MJ |
| Chemical Plant | 4e-10 | | unit |
| Output | | | | |
| NMCOH2 precursor | 1 kg of NMCOH2 precursor | | | |
| Solid State Synthesis | Input | | | | |
| NMCOH2 precursor | 0.95 | | kg | Process model based on [4] |
| LiOH | 0.26 | | kg |
| Thermal Energy | 0.92 | | MJ |
| Chemical plant | 4e-10 | | kg |
| Output | | | | |
| NMC active material | | 1 kg of NMC active material | | |

1. **LFP active material preparation**

***Table S8: Material and energy flows for LFP active material production***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | | Units | References |
| LFP active material | Inputs | | | | |
| Iron Phosphate | 0.89 | | kg | [5] |
| Lithium carbonate | 0.22 | | kg |
| Glucose | 0.10 | | kg |
| Nitrogen | 0.22 | | kg |
| Deionized water | 0.00 | | kg |
| Electricity | 0.50 | | kWh |
| Natural gas | 29.04 | | MJ |
| Output | | | | |
| LFP active material | 1 kg of LFP | | | |
| Iron Phosphate Production | Input |  | |  |  |
| FeSO4 | 0.81 | | kg | [5] |
| H3PO4 | 1.80 | | kg |
| H2O2 | 0.33 | | kg |
| NaOH | 1.85 | | kg |
| Water | 50.00 | | kg |
| Electricity | 0.97 | | kWh |
| Natural gas | 11.29 | | MJ |
| Output | | | | |
| Iron Phosphate | | 1 kg of iron phosphate | | |
| Lithium carbonate | See the value chain section below. | | | | |

# Energy and Material flow for the raw material supply model

The raw material supply model is built using the parametric raw materials model [6], and necessary extensions are added to process base metals to battery-grade materials.

1. **Aluminum value chain**

Aluminum metal from the parametric model is also converted into films using a rolling sheet process and extra chemicals to remove impurities.

***Table S9: Material and energy flows for aluminum film***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | NMC811 | Units | References |
| Aluminium film production |  | Inputs | | | |
| Aluminium ingot | 1 | 1 | kg | From parametric model |
| Sodium hydroxide | 0.33 | 0.33 | kg | [7] |
| Sulfuric acid | 0.21 | 0.21 | kg |
| Sheet rolling | 1 | 1 | kg |
| Output | | | | |
| Aluminium film | 1 kg of aluminum film | | | |

1. **Copper value chain**

Copper metal from the parametric model is also converted into films using a rolling sheet process and extra chemicals to remove impurities.

***Table S10: Material and energy flows for copper film***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | NMC811 | Units | References |
| Copper film production |  | Inputs | | | |
| Copper metal | 1 | 1 | kg | From parametric model |
| Sodium hydroxide | 0.33 | 0.33 | kg | [7] |
| Sulfuric acid | 0.21 | 0.21 | kg |
| Sheet rolling | 1 | 1 | kg |
| Output | | | | |
| Copper film | 1 kg of copper film | | | |

1. **Manganese sulfate**

Manganese sulfate is produced by reacting manganese concentrate from the parametric model with sulfur dioxide based on the process described in ecoinvent.

***Table S11: Material and energy flows for manganese sulfate***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | NMC811 | Units | References |
| Manganese Sulfate Production |  | Inputs | | | |
| Manganese concentrate |  | 0.906 | kg | From parametric model |
| Chemical factory, organics |  | 4.00E-10 | p | [8] |
| Electricity, medium voltage |  | 0.416 | kWh |
| Heat, district or industrial, natural gas |  | 2.15 | MJ |
| Heat, from steam, in the chemical industry |  | 0.2 | MJ |
| sulfur dioxide, liquid |  | 0.447 | kg |
| tap water |  | 0.026 | kg |
| non-sulfidic overburden, off-site |  | -0.385 | kg |
| Wastewater, average |  | -2.7 | kg |
| Output | | | | |
| Manganese Sulfate | 1 kg of Manganese Sulfate | | | |

1. **Nickel Sulfate**

The acid dissolution of class produces nickel sulfate I nickel (from the parametric model) in sulfuric acid.

***Table S12: Material and energy flows for nickel sulfate***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | NMC811 | Units | References |
| Nickel Sulfate Production |  | Inputs | | | |
| Nickel metal |  | 0.399 | kg | From parametric model |
| chemical factory, organics |  | 4.00E-10 | p | [8] |
| Electricity, medium voltage |  | 0.416 | kWh |
| Heat, district or industrial, natural gas |  | 2.150 | MJ |
| Heat, from steam, in the chemical industry |  | 0.470 | MJ |
| Nitrogen, liquid |  | 0.153 | kg |
| sulfuric acid |  | 0.667 | kg |
| tap water |  | 0.026 | kg |
| Output | | | | |
| Nickel Sulfate | 1 kg of Nickel Sulfate | | | |

1. **Cobalt Sulfate**

***Table S13: Material and energy flows for cobalt sulfate***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | NMC811 | Units | References |
| Cobalt Sulfate Production |  | Inputs | | | |
| Cobalt hydroxide |  | 0.645 | kg | From Ecoinvent |
| Sulfuric acid (93%) |  | 1.91 | kg | [9] |
| Calcium carbonate |  | 2.4E-01 | kg |
| Sodium hydroxide (50%) |  | 7.9E-01 | kg |
| Flocculant (organic chemical) |  | 9.1E-05 | kg |
| Quicklime |  | 2.6E-01 | kg |
| Exxsol D80 (paraffin) |  | 2.4E-03 | kg |
| Di-(2-ethylhexyl)phosphoric acid (organic solvent) |  | 1.18E-03 | kg |
| Electricity |  | 1.54 | kWh |
| Natural gas |  | 5.61 | MJ |
| Sodium sulfate (sulfidic tailings) |  | 2.83 | kg |
| Diesel |  | 0.367 | MJ |
| Output | | | | |
| Cobalt Sulfate | 1 kg of cobalt Sulfate | | | |

1. **Lithium carbonate and hydroxide**

The base inventory for lithium carbonate and hydroxide is taken from Kelly et al. [10] for the production routes from brine and spodumene

***Table S14: Material and energy flows for lithium carbonate and hydroxide***

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Process Stage | Sub-components | LFP | | NMC811 | | Units | References | |
| Brine Route | | | | | | | | |
| Brine extraction |  | Inputs | | | | | | |
| Lithium brine | 24.1 | | 24.1 | | kg | [10] | |
| Freshwater | 0.00372 | | 0.00372 | | m3 |
| Electricity | 0.624 | | 0.624 | | MJ |
| Diesel | 0.346 | | 0.346 | | MJ |
| Output | | | | | | | |
| Concentrated brine | 1 kg of concentrated brine (6%) | | | | | | |
| Lithium carbonate from brine |  | Inputs | | | | | | |
| Lithium brine | 4.00 |  | | kg | | | [10] |
| Soda ash | 2.00 |  | | kg | | |
| Organic Solvents | 0.0167 |  | | kg | | |
| Lime | 0.0725 |  | | kg | | |
| Sulfuric Acid | 0.0252 |  | | kg | | |
| Hydrochloric acid | 0.0400 |  | | kg | | |
| Alcohol | 0.0005 |  | | kg | | |
| Sodium hydroxide | 0.0000 |  | | kg | | |
| Bentonite | 0.0144 |  | | kg | | |
| Electricity | 1.5 |  | | MJ | | |
| Diesel | 0.4 |  | | MJ | | |
| Natural gas | 2.8 |  | | MJ | | |
| Output | | | | | | | |
| Lithium Carbonate | 1kg of Lithium carbonate | | | | | | |
| Lithium hydroxide from brine | Inputs | | | | | | | |
| Lithium carbonate |  | 1.05 | | Kg | | | [10] |
| Calcium oxide |  | 1.15 | | Kg | | |
| Water consumption |  | 0.005 | | M3 | | |
| Electricity |  | 5 | | MJ | | |
| Diesel |  | 3 | | MJ | | |
| Natural gas |  | 21 | | MJ | | |
| Output | | | | | | | |
| Lithium hydroxide | 1 kg of Lithium hydroxide | | | | | | |
| Spodumene Route | | | | | | | | |
| Spodumene concentrate | From the parametric model [6] | | | | | | | |
| Lithium hydroxide | Inputs | | | | | | | |
| Spodumene concentrate |  | 1.52 | | kg | | | From parametric model |
| Sulfuric acid |  | 1.52 | | kg | | | [10] |
| Sodium carbonate |  | 0.03 | | kg | | |
| Sodium hydroxide |  | 1.18 | | kg | | |
| Calcium carbonate |  | 0.60 | | kg | | |
| Electricity, medium voltage |  | 12.6 | | kWh | | |
| Heat |  | 71.34 | | MJ | | |
| Output | | | | | | | |
| Lithium hydroxide | 1kg of lithium hydroxide | | | | | | |
| Lithium carbonate | Inputs | | | | | | | |
| Spodumene concentrate | 7.3 |  | | kg | | | From parametric model |
| Sulfuric acid | 1.71 |  | | kg | | | [10] |
| Sodium carbonate | 2.05 |  | | kg | | |
| Sodium hydroxide | 0.05 |  | | kg | | |
| Calcium carbonate | 0.7 |  | | kg | | |
| Electricity, medium voltage | 6.48 |  | | kWh | | |
| Heat | 136 |  | | MJ | | |

# Cell-producing countries.

***Table S15: Percentage contributions of cell manufacturing***

|  |  |  |
| --- | --- | --- |
| Country | % Production | Reference |
| China | 79.2 % | [11] |
| USA | 6.2 % |
| Hungary | 4.0 % |
| Poland | 3.1 % |
| South Korea | 2.5 % |
| Japan | 2.4 % |
| Germany | 1.6 % |
| Sweden | 0.6 % |
| UK | 0.3 % |
| Australia | 0.1 % |

# GHG emissions of reference material supply

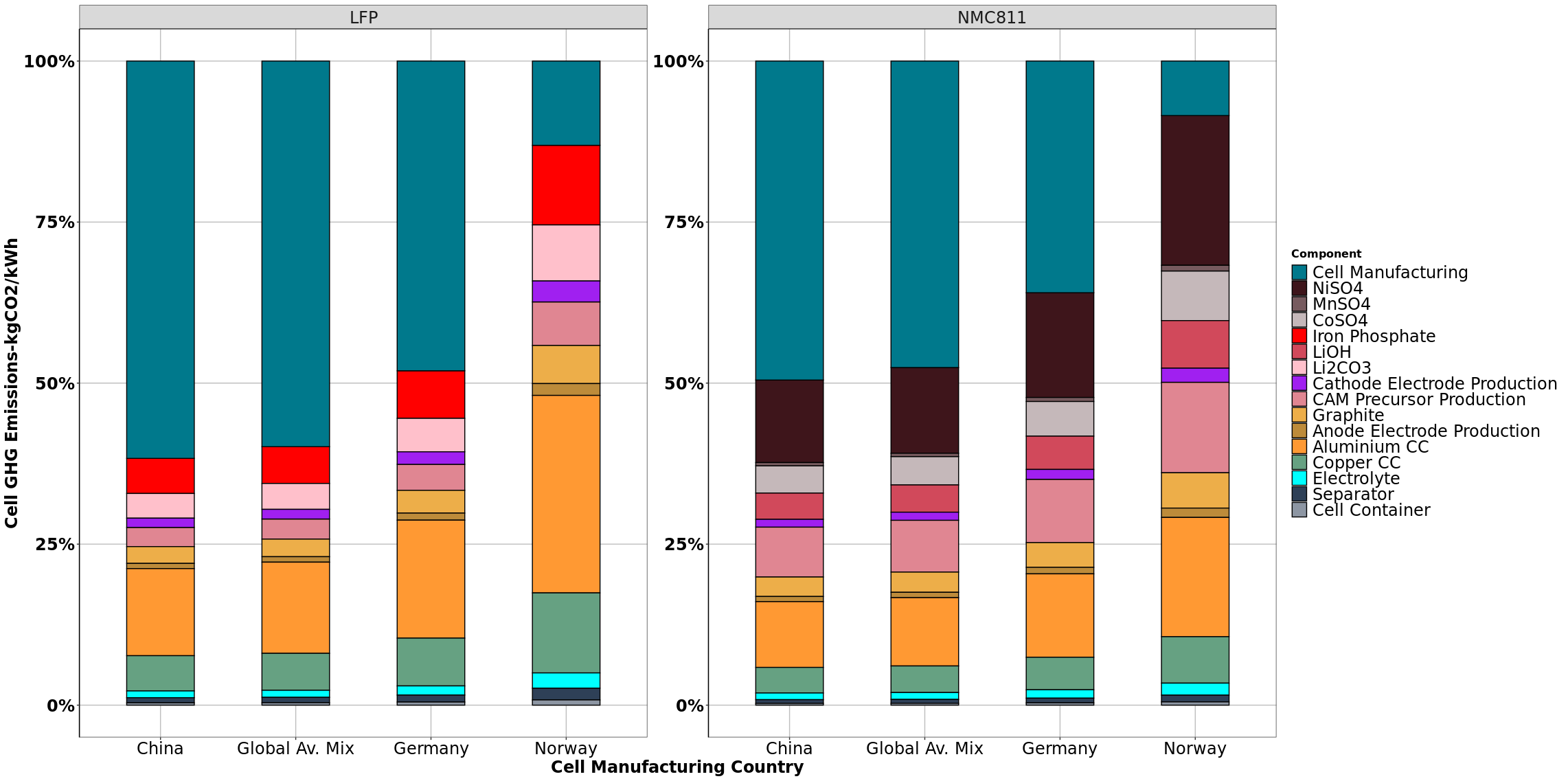
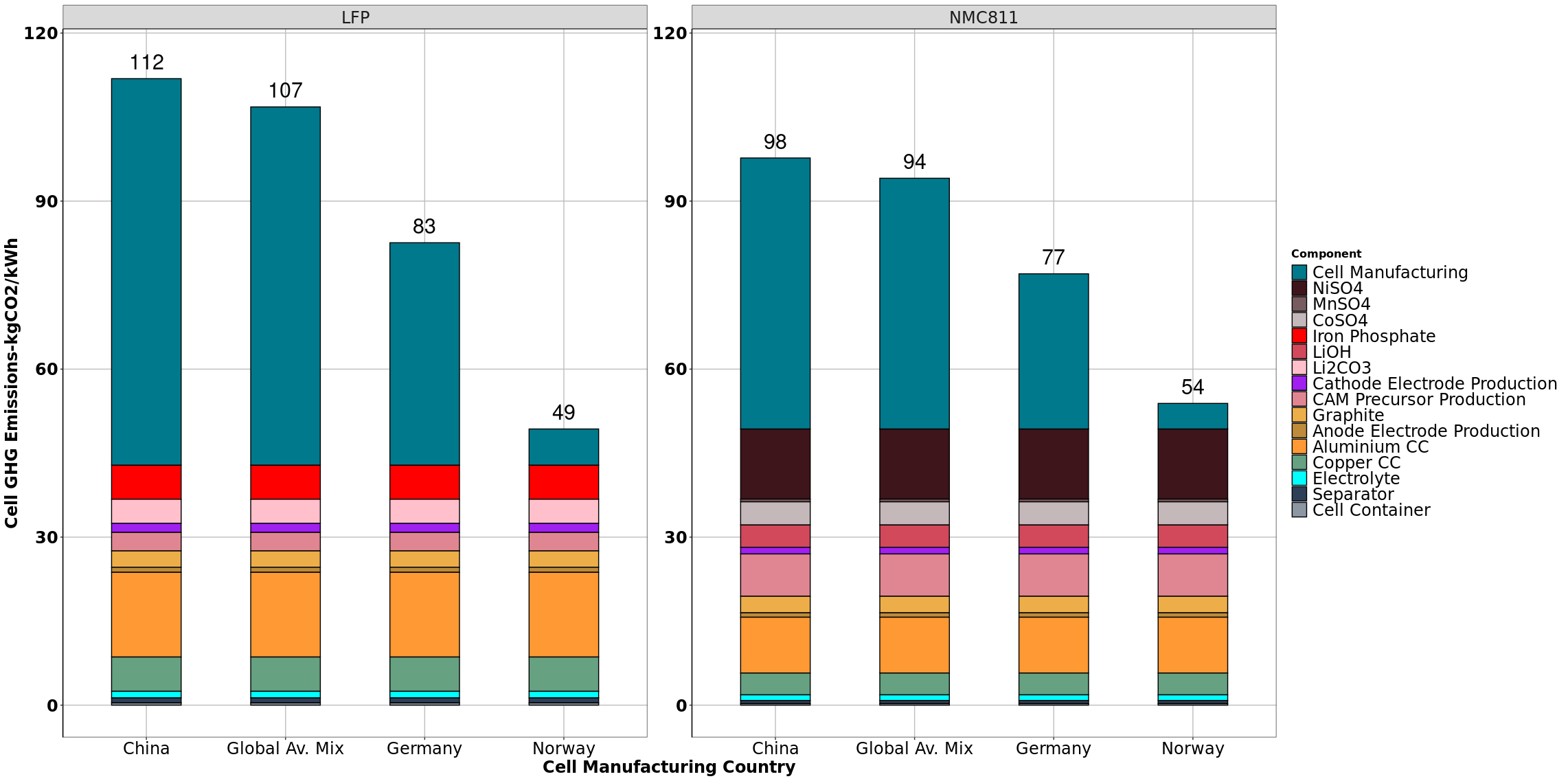
***Table S16: GHG emissions of base metals for the global reference estimate***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Material  FU=1kg of material | Calculated GHG values based on a parametric model | Reference GHG value (kgCO2e/kg) | Reference | Explanations |
| Copper | 7.7 | 8.6 | Ecoinvent | Use of weighted averages to represent country mixes of producing countries. Reason for the difference though that the base inventory is the same as the one in ecoinvent |
| Aluminum | 16.4 | 16.5 | IAI | Based on 90% Prebake and 10% Søderberg |
| MnSO4 | 1.2 | 0.8 | Ecoinvent | The difference is principally due to the use of weighted averages of production to create a global electricity mix which differs from the one used in ecoinvent. even though the base inventory values are identical for the global set. |
| NiSO4 | 8.4 | 7.8 | Ecoinvent | Use of weighted averages to represent country mixes of producing countries. |
| LiOH spodumene | 17.2 | 15.7 | Kelly et al. | Principally differences in background processes |
| LiOH Brine | 5.0 | 7.1 | Kelly et al. | Principally differences in background processes |
| CoSO4 | 18.1 | 19 | Cobalt Institute | Comparable |
| Synthetic Graphite | 4.4 | 4.11 - 5.59 | Dunn et al. | Comparable |

# GHG emissions of reference Scenario

***Table S17: GHG contributions for the global reference estimates* in kgCO2e/kWh**

|  |  |  |  |
| --- | --- | --- | --- |
| Component | Sub-component | NMC811 | LFP |
| Cathode | NiSO4 | 12.5 | -- |
| CoSO4 | 4.1 | --- |
| MnSO4 | 0.5 | -- |
| LiOH | 3.98 | -- |
| Li2CO3 | - | 4.28 |
| Iron Phosphate | -- | 6.09 |
| Lithium carbonate | -- | 4.3 |
| CAM Precursor Production | 7.6 | 3.3 |
| Cathode Electrode Production | 1.2 | 1.6 |
| Anode | Graphite | 3.0 | 2.9 |
| Anode Electrode Production | 0.8 | 0.9 |
| Aluminium CC | | 10.0 | 15.1 |
| Copper CC | | 3.9 | 6.1 |
| Electrolyte | | 1.0 | 1.2 |
| Separator | | 0.6 | 0.9 |
| Cell Container | | 0.3 | 0.4 |
| Cell Manufacturing [Global Average] | | 44.8 | 63.9 |
| Cell Manufacturing [China] | | 48.38 | 69 |
| Cell Manufacturing [Germany] | | 27.7 | 40 |
| Cell Manufacturing [Norway] | | 4.6 | 6.5 |



***Figure S1: GHG emissions of reference scenarios and for country-specific cell manufacturing: Absolute values (top) and percentage contributions (bottom)***

Please note that Table S17 contains data regarding greenhouse gas (GHG) emissions from cell manufacturing for global average, Norway, Germany, and China. Tables S18 through S22 display solely the material contributions and cell manufacturing GHG emissions for global average, Norway, Germany, and China are not repeated.

# Total GHG variabiity interval

*Table S18: Overall variability for the best (Scenario1) and worst (Scenario 6) conditions.*

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario Name | Sub-components | GHG for LFP  kgCO2e/kWh | GHG for NMC811  kgCO2e/kWh |
| **Scenario 1** | Cathode Paste | 9.6 | 15.1 |
| Anode Paste | 1.8 | 1.6 |
| Aluminium | 4.5 | 3.2 |
| Copper | 2.2 | 1.4 |
| Others | 2.5 | 1.6 |
| **Scenario 2** | Cathode Paste | 11.0 | 18.2 |
| Anode Paste | 2.4 | 2.1 |
| Aluminium | 6.8 | 4.8 |
| Copper | 3.0 | 1.9 |
| Others | 2.5 | 1.6 |
| **Scenario 3** | Cathode Paste | 12.5 | 22.2 |
| Anode Paste | 3.0 | 2.6 |
| Aluminium | 9.5 | 6.5 |
| Copper | 3.9 | 2.5 |
| Others | 2.5 | 1.6 |
| **Scenario 4** | Cathode Paste | 14.2 | 27.5 |
| Anode Paste | 3.8 | 3.2 |
| Aluminium | 12.6 | 8.6 |
| Copper | 4.9 | 3.1 |
| Others | 2.5 | 1.6 |
| **Scenario 5** | Cathode Paste | 16.2 | 36.5 |
| Anode Paste | 4.6 | 3.9 |
| Aluminium | 16.2 | 11.0 |
| Copper | 6.4 | 4.0 |
| Others | 2.5 | 1.6 |
| **Scenario 6** | Cathode Paste | 18.7 | 79.6 |
| Anode Paste | 5.4 | 4.7 |
| Aluminium | 20.5 | 13.8 |
| Copper | 10.9 | 6.9 |
| Others | 2.5 | 1.6 |

# Parameter contribution

***Table S19: Ore grade contributions to GHG variability***

|  |  |  |  |
| --- | --- | --- | --- |
| **Ore grade contributions** | Sub-components | GHG for LFP  kgCO2e/kWh | GHG for NMC811  kgCO2e/kWh |
| **OG 1** | Cathode Paste | 15.1 | 27.2 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.1 | 10.2 |
| Copper | 4.9 | 3.1 |
| Others | 2.5 | 1.6 |
| **OG 2** | Cathode Paste | 15.1 | 27.6 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.1 | 10.2 |
| Copper | 4.9 | 3.1 |
| Others | 2.5 | 1.6 |
| **OG 3** | Cathode Paste | 15.2 | 28.3 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.1 | 10.3 |
| Copper | 5.0 | 3.2 |
| Others | 2.5 | 1.6 |
| **OG 4** | Cathode Paste | 15.3 | 29.5 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.2 | 10.3 |
| Copper | 5.1 | 3.3 |
| Others | 2.5 | 1.6 |
| **OG 5** | Cathode Paste | 15.4 | 32.2 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.2 | 10.3 |
| Copper | 5.4 | 3.4 |
| Others | 2.5 | 1.6 |
| **OG 6** | Cathode Paste | 15.8 | 46.3 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.3 | 10.4 |
| Copper | 7.4 | 4.7 |
| Others | 2.5 | 1.6 |

***Table S20: Technology contributions to variability***

|  |  |  |  |
| --- | --- | --- | --- |
| **Technology Contributions** | Sub-components | GHG for LFP  kgCO2e/kWh | GHG for NMC811  kgCO2e/kWh |
| **T 1** | Cathode Paste | 12.1 | 25.3 |
| Anode Paste | 3.8 | 3.2 |
| Aluminium | 15.2 | 10.3 |
| Copper | 6.2 | 4.0 |
| Others | 2.5 | 1.6 |
| **T 2** | Cathode Paste | 12.8 | 27.4 |
| Anode Paste | 3.9 | 3.4 |
| Aluminium | 15.2 | 10.3 |
| Copper | 6.2 | 3.9 |
| Others | 2.5 | 1.6 |
| **T 3** | Cathode Paste | 13.6 | 29.7 |
| Anode Paste | 4.0 | 3.5 |
| Aluminium | 15.4 | 10.4 |
| Copper | 6.1 | 3.9 |
| Others | 2.5 | 1.6 |
| **T 4** | Cathode Paste | 14.3 | 32.1 |
| Anode Paste | 4.1 | 3.6 |
| Aluminium | 16.0 | 10.8 |
| Copper | 6.1 | 3.9 |
| Others | 2.5 | 1.6 |
| **T 5** | Cathode Paste | 15.0 | 34.8 |
| Anode Paste | 4.3 | 3.7 |
| Aluminium | 16.8 | 11.3 |
| Copper | 6.1 | 3.8 |
| Others | 2.5 | 1.6 |
| **T 6** | Cathode Paste | 15.7 | 37.5 |
| Anode Paste | 4.4 | 3.8 |
| Aluminium | 17.8 | 12.0 |
| Copper | 6.0 | 3.8 |
| Others | 2.5 | 1.6 |

***Table S21: Material recovery contributions to variability***

|  |  |  |  |
| --- | --- | --- | --- |
| **Material recovery efficiency** | Sub-components | GHG for LFP  kgCO2e/kWh | GHG for NMC811  kgCO2e/kWh |
| **98** | Cathode Paste | 14.5 | 28.7 |
| Anode Paste | 3.7 | 3.7 |
| Aluminium | 15.0 | 10.2 |
| Copper | 5.6 | 3.6 |
| Others | 2.5 | 1.6 |
| **94.4** | Cathode Paste | 14.8 | 30.4 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.1 | 10.2 |
| Copper | 5.8 | 3.7 |
| Others | 2.5 | 1.6 |
| **90.8** | Cathode Paste | 15.2 | 32.3 |
| Anode Paste | 3.8 | 3.7 |
| Aluminium | 15.1 | 10.2 |
| Copper | 6.1 | 3.8 |
| Others | 2.5 | 1.6 |
| **87.2** | Cathode Paste | 15.7 | 34.4 |
| Anode Paste | 3.8 | 3.8 |
| Aluminium | 15.2 | 10.3 |
| Copper | 6.3 | 4.0 |
| Others | 2.5 | 1.6 |
| **83.6** | Cathode Paste | 16.1 | 36.9 |
| Anode Paste | 3.9 | 3.8 |
| Aluminium | 15.2 | 10.3 |
| Copper | 6.6 | 4.2 |
| Others | 2.5 | 1.6 |
| **80** | Cathode Paste | 16.6 | 39.8 |
| Anode Paste | 3.9 | 3.8 |
| Aluminium | 15.3 | 10.4 |
| Copper | 7.0 | 4.4 |
| Others | 2.5 | 1.6 |

***Table S22: Electricity mix intensity contributions to variability***

|  |  |  |  |
| --- | --- | --- | --- |
| **Carbon intensity of value chain mix (gCO2/kWh)** | Sub-components | GHG for LFP  kgCO2e/kWh | GHG for NMC811  kgCO2e/kWh |
| **40** | Cathode Paste | 12.8 | 19.9 |
| Anode Paste | 1.9 | 1.6 |
| Aluminium | 4.4 | 3.2 |
| Copper | 3.1 | 2.0 |
| Others | 2.5 | 1.6 |
| **260** | Cathode Paste | 13.5 | 23.2 |
| Anode Paste | 2.4 | 2.2 |
| Aluminium | 6.9 | 4.8 |
| Copper | 4.0 | 2.5 |
| Others | 2.5 | 1.6 |
| **470** | Cathode Paste | 14.2 | 26.5 |
| Anode Paste | 2.9 | 2.8 |
| Aluminium | 9.5 | 6.5 |
| Copper | 4.9 | 3.1 |
| Others | 2.5 | 1.6 |
| Cell Manufacturing | 35.3 | 25.3 |
| **690** | Cathode Paste | 14.9 | 29.7 |
| Anode Paste | 3.5 | 3.4 |
| Aluminium | 12.0 | 8.2 |
| Copper | 5.9 | 3.7 |
| Others | 2.5 | 1.6 |
| **900** | Cathode Paste | 15.6 | 33.0 |
| Anode Paste | 4.0 | 3.9 |
| Aluminium | 14.5 | 9.8 |
| Copper | 6.8 | 4.3 |
| Others | 2.5 | 1.6 |
| **1120** | Cathode Paste | 16.4 | 36.3 |
| Anode Paste | 4.5 | 4.5 |
| Aluminium | 17.0 | 11.5 |
| Copper | 7.7 | 4.9 |
| Others | 2.5 | 1.6 |

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