Supplemental information for Das et al. (2024)

Section I

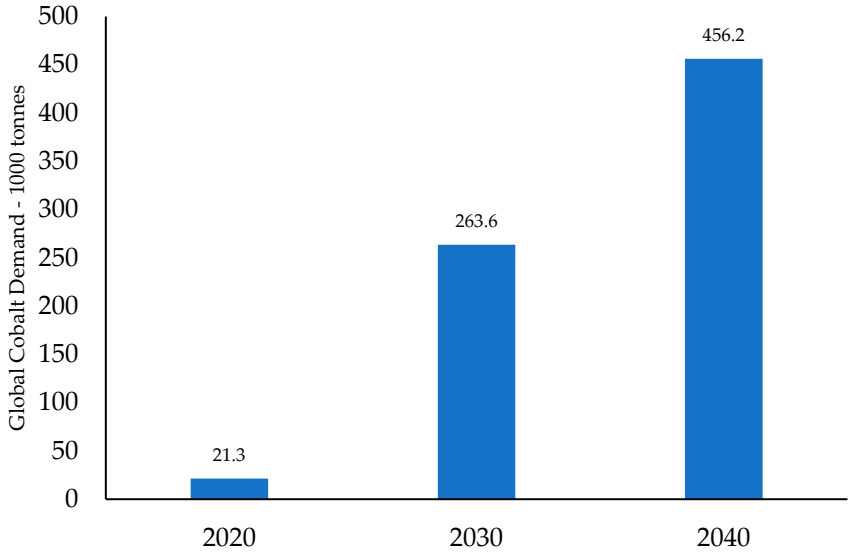

Figure S1: Projected cobalt demand, 2020-2040 [72].

Section II

Description of Cobalt Supply Chain Used in Study

1. Cobalt Mining

The first step in the supply chain is the mining of copper–cobalt ore. Mining data are based on the Tenke Fungurume Mine (TFM) in the DRC, which accounted for 29% of production capacity in 2017 [7]. This data set is the most complete available and contains primary data directly from the mine [46]. The ore grades used in this study, 0.3% cobalt and 2.95% copper, were reported by China Molybdenum (2018) [63] on the TFM, which is representative of other mines in the region [12]. Open-pit mining is used to extract ore from the copper–cobalt-bearing deposits in the DRC. Energy consumed during the mining phase at the TFM is sourced from the combustion of diesel fuel used in the equipment for loading and hauling the blasted material to the crusher [46]. Overburden material is removed through drilling and the use of blasting agents and then hauled to the waste ore stockpile [64]. A strip ratio of 2.8 (e.g., the ratio of waste generated per unit of ore [64]) was used to quantify the amount of waste rock produced.

Water is consumed for dust control, drinking water, sanitation, and ore washing, and is pumped from a nearby groundwater well [64]. Particulate matter (PM) emissions were estimated from vehicle exhaust, run-of-mill crushing, mine drilling, blasting, road entrainment, and wind erosion [46].

2. Processing

After the copper–cobalt ore has been mined, transported, and crushed, it is then processed to make cobalt hydroxide ($Co(OH)_2$) at a plant on-site at the TFM [64]. A process yield of 80% for converting the cobalt contained in ore into $Co(OH)_2$ and 95% for converting the copper content into copper cathodes was taken from Dai et al. (2018) [46]. All electricity consumed at the TFM for ore processing is generated from nearby hydropower facilities [64]. The raw ore contains cobalt in the insoluble trivalent form, Co^{3+}, so sulfur dioxide, sulfuric acid, and water are added to leach the soluble divalent form, Co^{2+}. The sulfuric acid and sulfur dioxide used in this process are produced at an on-

site plant using sulfur and recovered sulfur dioxide from ore processing [46]. Sodium hydroxide is then added to neutralize the leached copper–cobalt solution [64]. Copper and cobalt are separated through solvent extraction. The cobalt-rich solution then undergoes a purification step where limestone and lime are added to remove iron, aluminum, and manganese impurities and to recover any remaining copper. Finally, $Co(OH)_2$ is precipitated out of the solution through the addition of magnesia (MgO). Because the copper has been removed at this point, the impacts from the MgO are allocated to the $Co(OH)_2$ [46]. The other inputs and emissions are allocated based on a ratio between the total mass of the $Co(OH)_2$ and the copper cathode produced during this phase. The tailings, which contain toxic metals that can migrate into the environment from storage facilities, are disposed of at an on-site tailings pond [64,13]. Data for the quantity and impacts of tailings management at TFM were not available; thus, Ecoinvent (v. 3.8) background data were used.

3. Refining

Data for the refining of $Co(OH)_2$ into $CoSO_4$ was gathered from the Tongxiang plant of Huayou Cobalt [46]. In 2017, Huayou Cobalt accounted for 34% of China's refined cobalt production and 20% of worldwide production. The refining process begins with $Co(OH)_2$ being leached with sulfuric acid and $Na_2S_2O_5$. It then undergoes solvent extraction where kerosene and other reagents are added to the mix, separating the cobalt from any nickel, after which the solution is evaporated and crystallized, filtered, and dried to produce $CoSO_4$ suitable for batteries. To allocate impacts of the $CoSO_4$ appropriately to the cobalt, the inputs and outputs were multiplied by the percentage of cobalt by molecular mass in $CoSO_4$. Data regarding the sources of electricity for the State Grid Corporation of China are based on Ecoinvent (v 3.8) background data. Refinery locations outside of China were chosen to understand how location may impact the LCA results. Finland's Kokkola facility was chosen because it is the largest cobalt refinery outside of China (though it provides only 10% of total refined production [7]). Canada's Electra Battery Materials was chosen given that this facility (now under construction) would be the first cobalt refinery in Canada (i.e., Cobalt, Ontario, Canada). Although site-specific data for these plants could not be located, the impacts were modeled using the same method as Kelly et al. (2020) [47] by adjusting the grid mix and LCI inputs of the data from the Chinese refinery to be representative of location-specific sources when available.

4. Transportation

Due to security concerns and the unreliability of rail transport in the DRC region, $Co(OH)_2$ is transported from the TFM by truck [64] to Dar es Salaam, Tanzania (2030 km), for shipping; it is the closest port to the TFM used for the export of cobalt products [46,4]. From there, cobalt is shipped to the Port of Shanghai (12,971 km), where it is trucked an additional 200 km to the Tongxiang cobalt refinery [46]. For the Finland refinery scenario, Co(OH)2 is shipped from Dar es Salaam to the Port of Kokkola (16,325 km), which is located next to the refinery. In the Canada refining scenario, $Co(OH)_2$ is shipped from Dar es Salaam to the Port of Toronto (22,970 km), where it is transported by freight rail an additional 505 km to the Electra Battery Materials refinery.

Transportation distances from the specific cobalt refinery to a cathode manufacturing facility depend on the cathode chemistry. For NMC (111 and 811) cathodes, China, Korea, and Japan are the top manufacturers, with 55%, 18%, and 27% market shares, respectively, while for NCA, the respective market shares are 7%, 5%, and 88% [53-54]. Battery-grade $CoSO_4$ is assumed to travel by truck from the Tongxiang refinery to the Port of Shanghai for export to South Korea and Japan. Then, the $CoSO_4$ is shipped to the port closest to the largest cathode manufacturer in the country. If the exact distance to the cathode production facility was not available, a transport distance of 200 km was assumed. A weighted average was calculated by multiplying the market share of each country by the total transport distances to move $CoSO_4$ to the largest cathode manufacturer. Once the battery-grade $CoSO_4$ has been refined and transported to a cathode manufacturing facility, there is no additional material requirement or environmental burden from the cobalt supply chain, so no further impacts are allocated to cobalt from the battery manufacturing processes.

5. Use

LIBs are used as BESSs in both utility-scale grids and microgrids. Excess generation from either wind and solar power sources, or from grid power, can be used to charge batteries. They are dispatched when demand is high and the facilities are not generating enough power to meet it. The energy densities used in this study for NMC111, NCA,

and NMC811 [48] are 143 Wh/kg, 159 Wh /kg, and 149 Wh/kg, respectively. The highest energy density of NCA LIBs allows them to store more energy per unit of mass, reducing the material intensity on a per MWh basis compared to NMC111 and NMC811.

A 500 MW LIB is assumed for this study. LIBs are designed to discharge a specific number of times before replacement. Both the LIB chemistries are assumed to have a cycle life of 7300 cycles (approximately 1 cycle per day for 20 years). There are many factors that influence the efficiency and storage capacity of batteries, such as operating temperature, age, and internal (electrical) resistance. In the use phase, the battery capacities are augmented at specific intervals of time to ensure that usable storage capacity is close to 100% at all times. This research specifically includes the impact of battery augmentation on the total life-cycle GWP of batteries from the cobalt supply chain. Augmentation accounts for battery degradation (approximately 2% per year) and ensures that a battery's installed capacity and usable capacity are at or above the contractually required capacity (500 MW) imposed on the company (Table 5 shows the schedule).

6. End-of-life

Given the lack of data available to quantify the impacts of recycling for different battery chemistries and the nascent stage of recycling in general [42,1], recycling is not included in this research. Additional LCAs of recycling, specifically for ESSs, will be necessary to compare the impacts of recycling with the virgin cobalt supply chain; however, currently there is a lack of data regarding the impacts of these recycling processes.

Section III

Table S1: Top five global producers of Cobalt [6]

Country	Production in 2022 (Metric tons)
Democratic Republic of Congo (DRC)	130000
Russia	8900
Australia	5900
Canada	3900
Philippines	3800

Table S.2 summarizes some recent, significant LCA studies on LIBs. Often, the results for LCAs of LIBs are inconsistent or difficult to intercompare due to obscure life cycle inventories (LCIs), varying methodologies, variable system boundaries, and different products reviewed [48]. Because EVs and BESSs use the same LIB chemistries and cells, the LCIs from EV LCAs can be interchanged with those of grid-scale BESSs [1].

Table S2: LCA studies of LIBs published in the literature

Article	LIB variant under study	Application	Life cycle phases included in system boundary	Scope of the analysis
Tao et al. 2023 [24]	Ternary Li-Ion Battery	Mobility	Cradle to gate, recycling	Life cycle environmental assessment
Guven and Kayalica (2023) [25]	NMC, NCA, LFP	Passenger ferry	Cradle to gate	Life cycle environmental and cost assessment
Jiang et al. 2022 [26]	NMC111, LFP	Traction	Recycling	Life cycle environmental assessment
Yudhistira et al. 2022 [27]	NMC, NCA, LFP	Grid storage	Cradle to grave	Life cycle environmental assessment
Chordia et al.,2021 [28]	NMC811	Automotive applications	Cradle to grave	Life cycle environmental assessment
Varlet et al. 2020 [29]	LFP, LMO, NCA, NMC	Residential storage	Cradle to gate	Life cycle environmental analysis
Sun et al., 2020 [30]	NMC622, NMC811	Automotive applications	Cradle to grave	Life cycle environmental assessment
Wang et al. 2020 [31]	Li-O_2, NMC	Electric vehicles	Cradle to grave	Life cycle environmental assessment
Cusenza et al. 2019 [32]	NMC, LMO	Plug-in hybrid vehicle	Cradle to grave	Life cycle environmental analysis
Vandepaer et al. 2019 [33]	LFP	Grid storage	Cradle to gate, End of Life	Life cycle environmental assessment
Delgado et al. 2019 [34]	NMC	Stationary storage	Cradle to grave	Life cycle environmental assessment
Dai et al., 2019 [35]	NMC111	Automotive applications	Cradle to gate	Life cycle environmental assessment

Ryan et al. 2018 [36]	LFP, NMC, NCA	Stationary storage for frequency regulation	Cradle to gate End of life	Life cycle environmental assessment

Table S3: Base-case contribution analysis results

Process	Contributor	PMFP	FFP	FETP	FEP	GWP	HTPc	HTPnc	IRP	LOP	METP	MEP	SOP	OFHH	OFTE	ODP	TAP	TETP	WCP
		kg $PM2.5_{eq}$	kg oil $_{eq}$	kg 1,4-DCB	kg P_{eq}	kg CO_{2eq}	kg 1,4-DCB	kg 1,4-DCB	kBq $Co\text{-}60_{eq}$	m2a $crop_{eq}$	kg 1,4-DCB	kg N $_{eq}$	kg Cu $_{eq}$	kg NOx $_{eq}$	kg NOx $_{eq}$	kg CFC-11 $_{eq}$	kg $SO_{2\,eq}$	kg 1,4-DCB	m^3
Mining	Mining equipment	66.3 (73.6%)	539.34 (22.6%)	5.3 (0.27%)	0.1 (1%)	1957.9 (22.64%)	137.9 (12.6%)	18843 (12.6%)	1.08 (0.3%)	2.24 (0.3%)	5.1 (0.3%)	0.9 (36.56%)	0.11 (0.3%)	6.31 (12.6 %)	6.40 (12.6%)	0 (20.14%)	15.6 (22.26%)	0.1 (7.51%)	1.7 (0.87%)
	Treatment of overburden	0 (0%)	0.00	0 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Processing	Magnesia	6.3 (6.97%)	510.20 (21.4%)	44.6 (2.24%)	0.1 (2.21%)	1852.1 (21.42%)	124.6 (11.4%)	17019 (11.4%)	0.68 (0%)	1.40 (0.2%)	38.6 (2.23%)	0.3 (11.89%)	0.07 (0.2%)	5.70 (11.4 %)	5.78 (11.4%)	0 (1.45%)	3.4 (4.78%)	0.1 (6.48%)	2.6 (1.36%)
	Sulfur	2.3 (2.59%)	41.57 (1.7%)	2.4 (0.12%)	0 (0.15%)	150.9 (1.75%)	19.05 (1.7%)	2601 (1.7%)	5.51 (1.7%)	11.44 (1.7%)	1.1 (0.06%)	0 (0.75%)	0.58 (1.7%)	0.87 (1.7%)	0.88 (1.7%)	0 (1.12%)	11.2 (16.01%)	0 (3.67%)	0.2 (0.11%)
	Sodium hydroxide	0.2 (0.25%)	23.70 (0.9%)	2.9 (0.15%)	0 (0.68%)	86 (1%)	10.86 (0.9%)	1483 (0.9%)	3.14 (0%)	6.52 (0%)	2.7 (0.15%)	0 (0.97%)	0.33 (0%)	0.50 (0.9%)	0.50 (0.9%)	0 (3.28%)	0.4 (0.55%)	0 (0.62%)	2.3 (1.18%)
	Electricity production	0.1 (0.09%)	7.07 (0.3%)	0.5 (0.03%)	0 (0.09%)	25.7 (0.3%)	68.73 (6.3%)	9385 (6.3%)	0.94 (0%)	1.94 (0%)	0.5 (0.03%)	0 (0.18%)	0.10 (0%)	3.14 (6.3%)	3.19 (6.3%)	0 (0.08%)	0.1 (0.12%)	0 (0.18%)	115.7 (60.3%)
	Lime	0.1 (0.11%)	6.69 (0.3%)	1.1 (0.05%)	0 (0.15%)	24.3 (0.28%)	35.81 (3.2%)	4890 (3.2%)	0.89 (0%)	1.84 (0%)	1 (0.06%)	0 (0.26%)	0.09 (0%)	1.64 (3.2%)	1.66 (3.2%)	0 (0.08%)	0.1 (0.21%)	0 (0.63%)	0.5 (0.28%)
	Limestone	0.1 (0.13%)	1.16 (0%)	0 (0%)	0 (0.01%)	4.2 (0.05%)	55.11 (5%)	7525 (5%)	0.1(0%)	0.32 (0%)	0 (0%)	0 (0.16%)	0.02 (0%)	2.52 (5%)	2.56 (5%)	0 (0.03%)	0.1 (0.1%)	0 (0.06%)	0.1 (0.07%)
	Treatment of tailings	0 (0%)	0.00 (0%)	1695.7 (85.2%)	4.3 (70.13%)	0 (0%)	0.00 (0%)	0.00 (0%)	266.83 (84.5%)	554.31 (84.5%)	1460.7 (84.59%)	0.1 (3.85%)	27.91 (84.59 %)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0 (0.41%)	0 (0%)
	Sulfur dioxide	2.2 (2.43%)	0.00 (0%)	0 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	10.9 (15.6%)	0 (0%)	0 (0%)
Transportation	Transportation	1.88 (2.09%)	134.15 (5.6%)	3.04 (0.15%)	0.03 (0.51%)	486.99 (5.63%)	61.47 (5.6%)	8394 (5.6%)	0.18 (0%)	0.37 (0%)	4.17 (0.24%)	0.17 (6.63%)	0.02 (6.63%)	2.81 (5.6%)	2.85 (5.6%)	0 (5.21%)	4.69 (6.69%)	0.21 (19%)	0.69 (0.36%)
Refining	Sodium hydroxide	3.6 (3.96%)	369.94 (15.5%)	46 (2.31%)	0.7 (10.62%)	1342.9 (15.53%)	169.5 (15.5%)	23148 (15.5%)	0.49 (0%)	1.02 (0%)	41.5 (2.41%)	0.4 (15.16%)	0.05 (0%)	7.75 (15.5 %)	7.86 (15.5%)	0 (51.27%)	6.1 (8.66%)	0.1 (9.68%)	35.3 (18.42%)
	Electricity production	2.7 (2.97%)	336.76 (14.1%)	10.9 (0.55%)	0.2 (3.79%)	1222.5 (14.14%)	154.3 (14.1%)	21072 (14.1%)	0.45 (0%)	0.93 (0%)	10.1 (0.58%)	0.2 (7.51%)	0.05 (0%)	7.06 (14.1 %)	7.16 (14.1%)	0 (0.28%)	5.1 (7.28%)	0 (2.43%)	3.1 (1.64%)
	Hydrochloric acid	1.4 (1.59%)	133.44 (5.6%)	33.2 (1.67%)	0.2 (3.86%)	484.4 (5.6%)	61.15 (5.6%)	8349 (5.6%)	17.67 (5.6%)	36.71 (5.6%)	31.8 (1.84%)	0.1 (5.1%)	1.85 (5.6%)	2.80 (5.6%)	2.84 (5.6%)	0 (11.6%)	2.9 (4.1%)	0.3 (25.74%)	10.7 (5.55%)
	Heat	0.2 (0.18%)	113.87 (4.8%)	1.7 (0.08%)	0 (0.09%)	413.4 (4.78%)	52.18 (4.7%)	7125 (4.7%)	1.51 (0%)	3.13 (0%)	1 (0.06%)	0 (0.72%)	0.16 (0%)	2.39 (4.7%)	2.42 (4.7%)	0 (2.32%)	0.5 (0.7%)	0 (1.4%)	0.6 (0.29%)
	Ammonium bicarbonate	0.6 (0.64%)	100.25 (4.2%)	10.7 (0.54%)	0.1 (1.63%)	363.9 (4.21%)	45.94 (4.2%)	6273 (4.2%)	13.28 (4.2%)	27.58 (4.2%)	9.4 (0.55%)	0.1 (2.76%)	1.39 (4.2%)	2.10 (4.2%)	2.13 (4.2%)	0 (0.67%)	1.2 (1.65%)	0 (4.23%)	3.9 (2.05%)
	Sulfuric acid	2 (2.21%)	44.17 (1.8%)	129.6 (6.51%)	0.3 (4.72%)	160.3 (1.85%)	20.24 (1.8%)	2764 (1.8%)	0.58 (0%)	1.22 (0%)	117.2 (6.79%)	0.1 (2.9%)	0.06 (0%)	0.93 (1.8%)	0.94 (1.8%)	0 (0.88%)	7.5 (10.75%)	0.2 (17.24%)	13.2 (6.87%)
	Soda ash	0.1 (0.08%)	11.51 (0.3%)	1.5 (0.08%)	0 (0.21%)	41.8 (0.48%)	5.27 (0%)	720.06 (0%)	1.52 (0%)	3.17 (0%)	1.4 (0.08%)	0.1 (4.25%)	0.16 (0%)	0.24 (0%)	0.24 (0%)	0 (0.11%)	0.2 (0.24%)	0 (0.4%)	0.8 (0.39%)
	Sodium metabisulfite	0 (0.05%)	4.56 (0%)	0.6 (0.03%)	0 (0.13%)	16.5 (0.19%)	2.09 (0%)	285.06 (0%)	0.60 (0%)	1.25 (0%)	0.5 (0.03%)	0 (0.19%)	0.06 (0%)	0.10 (0%)	0.10 (0%)	0 (0.63%)	0.1 (0.11%)	0 (0.12%)	0.4 (0.23%)
	Kerosene	0 (0.03%)	2.40 (0%)	0.1 (0%)	0 (0.01%)	8.7 (0.1%)	66.59 (6.1%)	9093 (6.1%)	0.32 (0%)	0.66 (0%)	0.1 (0%)	0 (0.07%)	0.03 (0%)	3.04 (0%)	3.09 (0%)	0 (0.74%)	0.1 (0.12%)	0 (0.15%)	0 (0.01%)
	Lime	0 (0%)	0.10 (0%)	0 (0%)	0 (0%)	0.4 (0%)	0.05 (0%)	6.33 (0%)	0.01 (0%)	0.03 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0 (0.01%)	0 (0%)
	Limestone	0 (0%)	0.02 (0%)	0 (0%)	0 (0%)	0.1 (0%)	0.01 (0%)	1.02 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Disposal	Disposal	0 (0.02%)	1.18 (0%)	0 (0%)	0 (0%)	4.3 (0.05%)	0.54 (0%)	73.75 (0%)	0.16 (0%)	0.32 (0%)	0 (0%)	0 (0.07%)	0.02 (0%)	0.02 (0%)	0.03 (0%)	0 (0.1%)	0 (0.05%)	0 (0.04%)	0 (0.01%)
	Total	**31.48**	**2382.09**	**3714**	**6.18**	**8647.26**	**1091**	**149057**	**315.44**	**655.29**	**4730.5**	**0.22**	**33.00**	**49.91**	**50.62**	**0.00**	**65.69**	**54741**	**273.11**

Table S4: LCA results for mining and processing with varying ore grades

Ore Grade (% Co)	PMFP	FFP	FETP	FEP	GWP	HTPc	HTPnc	IRP	LOP	METP	MEP	SOP	OFHH	OFTE	ODP	TAP	TETP	WCP
Unit	kg $PM2.5_{eq}$	kg oil $_{eq}$	kg 1,4-DCB	kg P $_{eq}$	kg CO_{2eq}	kg 1,4-DCB	kg 1,4-DCB	kBq $Co\text{-}60_{eq}$	m^2a $crop_{eq}$	kg 1,4-DCB	kg N $_{eq}$	kg Cu $_{eq}$	kg NO_x $_{eq}$	kg NO_x $_{eq}$	kg CFC-11 $_{eq}$	kg SO_2 $_{eq}$	kg 1,4-DCB	m^3
0.05%	29.0	1563.9	4181.6	5.3	13606.8	2092.4	180322	229.2	634.4	5397.1	0.1	8.7	42.8	43.5	0.0027	52.7	11011.0	214.4
0.10%	23.7	1238.0	3673.4	4.9	7988.5	1320.4	156361	133.1	592.7	4697.4	0.1	6.7	34.4	34.9	0.0020	43.8	7312.0	202.9
0.15%	21.8	1121.1	3503.8	4.7	6094.1	1062.1	148369	100.8	573.9	4463.9	0.1	5.9	31.3	31.8	0.0018	40.5	6046.0	197.3
0.20%	20.7	1056.6	3418.9	4.7	5131.4	932.4	144370	84.4	561.0	4346.9	0.1	5.5	29.6	30.1	0.0017	38.7	5389.3	193.3
0.25%	20.0	1013.4	3367.8	4.6	4541.8	854.1	141967	74.3	550.5	4276.6	0.1	5.3	28.5	29.0	0.0016	37.4	4977.0	189.9
0.30%	19.4	980.8	3333.7	4.6	4139.1	801.4	140363	67.5	541.4	4229.6	0.1	5.1	27.6	28.1	0.0015	36.4	4687.6	186.8
0.35%	18.9	954.5	3309.2	4.6	3843.7	763.5	139216	62.5	533.1	4195.9	0.1	4.9	26.9	27.4	0.0015	35.5	4468.8	184.0
0.40%	18.5	932.3	3290.8	4.6	3615.4	734.9	138353	58.6	525.3	4170.5	0.0	4.8	26.3	26.8	0.0015	34.8	4294.7	181.4
0.45%	18.2	912.8	3276.5	4.6	3432.2	712.3	137681	55.5	518.0	4150.7	0.0	4.7	25.8	26.2	0.0014	34.2	4150.6	178.9
0.50%	17.8	895.3	3264.9	4.5	3280.8	694.1	137143	52.9	511.1	4134.8	0.0	4.6	25.3	25.7	0.0014	33.6	4027.8	176.5
0.55%	17.5	879.4	3255.5	4.5	3152.5	679.0	136701	50.8	504.4	4121.8	0.0	4.5	24.9	25.3	0.0014	33.0	3920.8	174.2
0.60%	17.3	864.6	3247.5	4.5	3041.9	666.2	136332	48.9	498.0	4110.9	0.0	4.4	24.5	24.9	0.0013	32.5	3825.8	171.9
0.65%	17.0	850.8	3240.8	4.5	2944.9	655.3	136019	47.3	491.8	4101.6	0.0	4.4	24.1	24.5	0.0013	32.0	3740.3	169.8
0.70%	16.7	837.8	3235.0	4.5	2858.7	645.9	135750	45.9	485.8	4093.5	0.0	4.3	23.7	24.1	0.0013	31.6	3662.4	167.7
0.75%	16.5	825.5	3229.9	4.5	2781.3	637.5	135516	44.6	480.0	4086.6	0.0	4.2	23.4	23.8	0.0013	31.1	3590.8	165.6
0.80%	16.3	813.8	3225.5	4.5	2711.1	630.2	135311	43.4	474.3	4080.4	0.0	4.2	23.0	23.4	0.0013	30.7	3524.3	163.6
0.85%	16.1	802.6	3221.6	4.5	2646.9	623.6	135130	42.4	468.8	4075.0	0.0	4.1	22.7	23.1	0.0012	30.3	3462.2	161.7
0.90%	15.9	791.9	3218.0	4.5	2587.8	617.6	134968	41.4	463.5	4070.1	0.0	4.1	22.4	22.8	0.0012	29.9	3403.9	159.8
0.95%	15.7	781.5	3214.9	4.5	2533.0	612.2	134823	40.5	458.3	4065.7	0.0	4.0	22.1	22.5	0.0012	29.6	3349.0	158.0
1%	15.5	771.6	3212.0	4.5	2482.0	607.3	134691	39.6	453.2	4061.8	0.0	3.9	21.9	22.2	0.0012	29.2	3296.8	156.2

Table S5: LCA results for three different battery chemistries for an ore grade of 0.3% and a refining location in China

LIB	PMFP	FFP	FETP	FEP	GWP	HTPc	HTPnc	IRP	LOP	METP	MEP	SOP	OFHH	OFTE	ODP	TAP	TETP	WCP
	kg $PM2.5_{eq}$	kg oil $_{eq}$	kg 1,4-DCB	kg P $_{eq}$	kg CO_{2eq}	kg 1,4-DCB	kg 1,4-DCB	kBq Co-60_{eq}	m^2a $crop_{eq}$	kg 1,4-DCB	kg N $_{eq}$	kg Cu $_{eq}$	kg NO_x $_{eq}$	kg NO_x $_{eq}$	kg CFC-11 $_{eq}$	kg $SO_{2\,eq}$	kg 1,4-DCB	m^3
NMC111	31.48	2383	3714.91	6.18	8647.2	1091.54	149057	315.4	655.29	4730.5	0.22	33.0	49.91	50.62	0.00	65.6	54741.6	273.1
NMC532	19.21	1427	2226.07	3.69	5189.80	648.67	88245.	187.5	389.14	2837.5	0.14	19.6	29.83	30.25	0.00	39.9	33171.9	164.9
NMC622	15.91	1186	1840.10	3.05	4287.2	537.10	72922.	155.3	322.08	2345.6	0.11	16.3	24.78	25.13	0.00	33.1	27638.9	136.3
NMC811	8.39	639.1	962.76	1.60	2230.5	283.58	38088.	82.15	169.68	1227.5	0.06	8.68	13.31	13.50	0.00	17.50	15078.0	71.25
NCA	11.98	902.4	1378.40	2.28	3211.2	404.17	54589.	117.0	242.53	1757.3	0.08	12.3	18.85	19.12	0.00	24.98	21223.6	102.0

Table S6: LCA results for the combined scenarios

#	Grade	Refining Location	LIB	PMFP	FFP	FETP	FEP	GWP	HTPc	HTPnc	IRP	LOP	METP	MEP	SOP	OFHH	OFTE	ODP	TAP	TETP	WCP
				kg $PM2.5_{eq}$	kg oil $_{eq}$	kg 1,4-DCB	kg P $_{eq}$	kg CO_{2eq}	kg 1,4-DCB	kg 1,4-DCB	kBq Co-60_{eq}	m^2a $crop_{eq}$	kg 1,4-DCB	kg N $_{eq}$	kg Cu $_{eq}$	kg NO_x $_{eq}$	kg NO_x $_{eq}$	kg CFC-11 $_{eq}$	kg $SO_{2\,eq}$	kg 1,4-DCB	m^3
1	0.1	0.75	394	33.67	2640.35	3842.98	6.29	13208.6	1610.57	165058	381.13	706.63	4906.93	0.23	34.5	56.66	57.47	0.00	69.56	55836.5	284.98
2	0.2	0.75	394	32.35	2458.91	3757.76	6.22	9958	1222.51	153064	332.33	674.90	4789.56	0.23	33.4	51.93	52.67	0.00	67.25	55134.6	278.55
3	0.3	0.75	394	31.48	2383.09	3714.91	6.18	8647.2	1091.54	149057	315.44	655.29	4730.51	0.22	33.0	49.91	50.62	0.00	65.69	54741.6	273.11
4	0.4	0.75	394	30.80	2334.55	3689.01	6.16	8499.89	1024.94	147047	306.56	639.23	4694.82	0.22	32.7	48.60	49.29	0.00	64.46	54474.7	268.19
5	0.5	0.75	394	30.22	2297.57	3671.61	6.14	8260.95	984.15	145836	300.92	624.96	4670.82	0.22	32.5	47.59	48.27	0.00	63.40	54272.7	263.64
6	0.6	0.75	394	29.71	2266.84	3659.06	6.13	8077.73	956.32	145025	296.91	611.87	4653.51	0.22	32.3	46.75	47.41	0.00	62.46	54109.3	259.37
7	0.7	0.75	394	29.52	2240.06	3649.56	6.12	7930.08	935.93	144443	293.85	599.67	4640.40	0.22	32.2	46.01	46.66	0.00	61.60	53971.1	255.35
8	0.8	0.75	394	29.11	2216.03	3644.30	6.11	7892.3	920.22	144004	291.39	588.21	4635.30	0.22	32.0	45.34	45.98	0.00	61.20	53912.2	253.40
9	0.9	0.75	394	28.82	2194.09	3642.10	6.11	7806.78	907.66	143660	289.35	577.37	4630.09	0.22	31.9	44.73	45.36	0.00	60.81	53850.7	251.54
10	1.0	0.75	394	28.43	2173.80	3636.06	6.10	7701.02	897.32	143384	287.60	567.09	4621.75	0.22	31.8	44.16	44.78	0.00	60.08	53743.6	247.91
11	0.1	0.18	394	34.67	2617.50	4114.11	6.34	12575.9	1608.22	164973	1028.6	714.55	5280.87	0.26	36.5	53.52	54.35	0.01	70.48	65110.5	327.92

12	0.2	0.18	394	31.65	2436.07	3859.53	6.13	9718.21	1220.16	152979	979.82	682.82	4930.33	0.24	35.4	48.78	49.55	0.00	65.33	63187.4	318.29
13	0.3	0.18	394	30.34	2360.24	3774.31	6.06	8325.76	1089.19	148972	962.93	663.20	4812.96	0.24	34.9	46.77	47.51	0.00	63.03	62485.6	311.86
14	0.4	0.18	394	29.47	2311.71	3731.46	6.02	8201.93	1022.59	146961	954.06	647.14	4753.92	0.23	34.7	45.46	46.18	0.00	61.47	62092.6	306.42
15	0.5	0.18	394	28.78	2274.72	3705.56	6.00	7867.2	981.80	145751	948.41	632.87	4718.22	0.23	34.4	44.45	45.15	0.00	60.23	61825.7	301.50
16	0.6	0.18	394	28.21	2244.00	3688.16	5.98	7628.26	953.97	144940	944.40	619.78	4694.22	0.23	34.3	43.60	44.29	0.00	59.17	61623.7	296.95
17	0.7	0.18	394	27.70	2217.21	3675.61	5.97	7445.04	933.58	144358	941.34	607.59	4676.91	0.23	34.1	42.86	43.54	0.00	58.23	61460.2	292.69
18	0.8	0.18	394	27.23	2193.19	3666.11	5.96	7297.39	917.87	143919	938.89	596.12	4663.80	0.23	34	42.19	42.86	0.00	57.38	61322	288.66
19	0.9	0.18	394	26.81	2171.25	3658.65	5.95	7174.09	905.31	143575	936.84	585.29	4653.49	0.23	33.93	41.58	42.24	0.00	56.59	61201.7	284.85
20	1.0	0.18	394	26.41	2150.95	3652.61	5.95	7068.33	894.98	143299	935.10	575.00	4645.15	0.23	33.8	41.01	41.66	0.00	55.85	61094.5	281.22
21	0.1	0.29	394	34.09	2529.16	3867.41	6.12	12119	1549.13	160484	787.43	15536.4	4960.34	0.24	20.1	51.16	51.94	0.01	70.11	35698.6	308.63
22	0.2	0.29	394	31.07	2347.73	3612.83	5.91	9261.23	1161.08	148490	738.62	15504.7	4609.80	0.23	18.9	46.42	47.14	0.00	64.96	33775.5	299.01
23	0.3	0.29	394	29.76	2271.90	3527.61	5.84	8068.78	1030.11	144483	721.73	15485.1	4492.44	0.22	18.4	44.41	45.10	0.00	62.65	33073.7	292.58
24	0.4	0.29	394	28.89	2223.37	3484.76	5.81	7744.95	963.51	142473	712.86	15469.0	4433.39	0.22	18.2	43.10	43.77	0.00	61.10	32680.7	287.14
25	0.5	0.29	394	28.20	2186.38	3458.86	5.78	7410.22	922.72	141262	707.21	15454.8	4397.70	0.22	18	42.09	42.74	0.00	59.86	32413.8	282.22
26	0.6	0.29	394	27.63	2155.66	3441.46	5.77	7171.28	894.88	140451	703.20	15441.7	4373.70	0.22	17.8	41.24	41.89	0.00	58.80	32211.8	277.67
27	0.7	0.29	394	27.12	2128.87	3428.92	5.75	6988.06	874.49	139869	700.14	15429.5	4356.39	0.21	17.6	40.50	41.13	0.00	57.86	32048.4	273.40
28	0.8	0.29	394	26.65	2104.85	3419.42	5.74	6840.41	858.79	139430	697.69	15418	4343.27	0.21	17.5	39.83	40.45	0.00	57.01	31910.2	269.38
29	0.9	0.29	394	26.23	2082.91	3411.95	5.73	6717.11	846.23	139087	695.64	15407.2	4332.96	0.21	17.4	39.22	39.83	0.00	56.21	31789.8	265.57
30	1.0	0.29	394	25.83	2062.61	3405.92	5.73	6611.35	835.89	138810	693.90	15396.9	4324.62	0.21	17.3	38.65	39.25	0.00	55.48	31682.7	261.94
31	0.1	0.75	230	21.78	1579.06	2427.16	3.85	6426.54	955.84	97715.8	226.45	419.53	3114.45	0.15	20.6	33.82	34.30	0.00	44.38	34725.4	174.45
32	0.2	0.75	230	19.99	1471.68	2276.50	3.73	5734.8	726.18	90617.5	197.57	400.75	2906.99	0.14	19.9	31.02	31.46	0.00	41.33	33587.2	168.75
33	0.3	0.75	230	19.21	1426.81	2226.07	3.69	5189.80	648.67	88245.8	187.58	389.14	2837.53	0.14	19.6	29.83	30.25	0.00	39.97	33171.9	164.95
34	0.4	0.75	230	18.70	1398.08	2200.70	3.66	4837.87	609.25	87056.2	182.32	379.64	2802.58	0.13	19.5	29.05	29.47	0.00	39.05	32939.3	161.73
35	0.5	0.75	230	18.29	1376.20	2185.38	3.65	4639.77	585.11	86339.6	178.98	371.19	2781.46	0.13	19.3	28.45	28.86	0.00	38.31	32781.3	158.82
36	0.6	0.75	230	17.95	1358.01	2175.08	3.64	4498.36	568.64	85859.7	176.61	363.44	2767.25	0.13	19.2	27.95	28.35	0.00	37.69	32661.8	156.13
37	0.7	0.75	230	17.65	1342.16	2167.65	3.63	4389.92	556.57	85515.1	174.80	356.23	2757.01	0.13	19.2	27.51	27.90	0.00	37.13	32565.0	153.60
38	0.8	0.75	230	17.38	1327.94	2162.03	3.63	4302.54	547.28	85255.3	173.34	349.44	2749.25	0.13	19.1	27.12	27.50	0.00	36.63	32483.3	151.22
39	0.9	0.75	230	17.12	1314.95	2157.61	3.62	4229.57	539.84	85052.1	172.13	343.03	2743.15	0.13	19.0	26.76	27.13	0.00	36.16	32412	148.96
40	1.0	0.75	230	16.89	1302.94	2154.04	3.62	4166.98	533.73	84888.5	171.10	336.94	2738.21	0.13	18.2	26.42	26.79	0.00	35.72	32348.6	146.82
41	0.1	0.18	230	21.22	1655.18	2439.93	3.88	6193.42	966.87	97916.8	231.53	430.18	3132.48	0.15	21.1	32.44	32.93	0.00	42.89	38853.3	175.04
42	0.2	0.18	230	19.43	1547.79	2289.25	3.76	5480.02	737.18	90817.4	202.64	411.40	2924.99	0.14	20.4	29.64	30.09	0.00	39.84	37715.0	169.35

43	0.3	0.18	230	18.66	1502.91	2238.81	3.71	4944.38	659.66	88445.4	192.64	399.79	2855.52	0.14	20.2	28.45	28.88	0.00	38.48	37299.6	165.54
44	0.4	0.18	230	18.14	1474.18	2213.44	3.69	4603.11	620.23	87255.6	187.39	390.28	2820.57	0.14	20.0	27.67	28.09	0.00	37.55	37067	162.32
45	0.5	0.18	230	17.74	1452.29	2198.11	3.68	4410.51	596.09	86538.9	184.05	381.84	2799.45	0.14	19.9	27.08	27.49	0.00	36.82	36909	159.41
46	0.6	0.18	230	17.39	1434.10	2187.81	3.67	4273.30	579.61	86058.9	181.67	374.09	2785.24	0.14	19.8	26.58	26.98	0.00	36.20	36789.4	156.72
47	0.7	0.18	230	17.09	1418.25	2180.38	3.66	4136.09	567.54	85714.3	179.86	366.87	2775.00	0.14	19.7	26.14	26.53	0.00	35.64	36692.7	154.19
48	0.8	0.18	230	16.82	1404.03	2174.76	3.65	4051.56	558.25	85454.5	178.41	360.08	2767.23	0.14	19.6	25.74	26.13	0.00	35.13	36610.9	151.81
49	0.9	0.18	230	16.57	1391.04	2170.34	3.65	3981.05	550.81	85251.2	177.20	353.67	2761.13	0.14	19.6	25.38	25.76	0.00	34.67	36539.6	149.55
50	1.0	0.18	230	10.16	1340.23	2132.92	3.58	3920.63	530.87	83634.1	159.21	173.74	2709.02	0.13	17.9	25.30	25.67	0.00	33.59	35124.9	85.65
51	0.1	0.29	230	21.39	1575.26	2428.13	3.85	6025.02	954.72	97743.6	226.67	421.18	3115.92	0.15	20.5	32.60	33.07	0.00	43.38	35290.2	174.51
52	0.2	0.29	230	19.60	1467.87	2277.44	3.73	5295.62	725.03	90644.2	197.78	402.40	2908.43	0.14	19.8	29.80	30.23	0.00	40.33	34151.9	168.81
53	0.3	0.29	230	18.83	1422.99	2227.00	3.69	4857.12	647.51	88272.3	187.78	390.79	2838.96	0.14	19.6	28.60	29.02	0.00	38.97	33736.5	165.00
54	0.4	0.29	230	18.31	1394.26	2201.64	3.67	4433.52	608.08	87082.5	182.53	381.28	2804.01	0.13	19.4	27.83	28.24	0.00	38.04	33503.9	161.78
55	0.5	0.29	230	17.91	1372.37	2186.31	3.65	4244.82	583.94	86365.8	179.19	372.83	2782.88	0.13	19.3	27.23	27.63	0.00	37.31	33345.9	158.87
56	0.6	0.29	230	17.26	1338.33	2168.58	3.63	4110.72	555.39	85541.2	175.00	357.87	2758.43	0.13	19.1	26.29	26.67	0.00	36.13	33129.6	153.65
57	0.7	0.29	230	16.99	1324.11	2162.96	3.63	4008.12	546.10	85281.3	173.55	351.08	2750.67	0.13	19.0	25.90	26.27	0.00	35.62	33047.8	151.27
58	0.8	0.29	230	16.74	1311.12	2158.54	3.62	3925.62	538.66	85078.1	172.34	344.67	2744.56	0.13	19.0	25.53	26.10	0.00	35.15	32976.5	149.01
59	0.9	0.29	230	17.56	1354.18	2176.01	3.64	3856.82	567.46	85885.8	176.81	365.09	2768.67	0.13	19.2	26.73	25.12	0.00	35.68	33226.3	156.18
60	1.0	0.29	230	10.33	1300.23	2121.12	3.55	3798.02	560.72	83461.0	164.35	164.74	2692.46	0.12	18.7	26.46	24.53	0.00	33.08	31561.8	150.11
61	0.1	0.75	190	18.02	1311.79	2006.25	3.18	6521.29	790.89	80746.3	187.48	347.18	2574.44	0.12	17.0	28.08	28.48	0.00	36.75	28922.4	144.17
62	0.2	0.75	190	16.55	1223.08	1881.77	3.08	5123.94	601.14	74881.6	163.62	331.67	2403.04	0.12	16.5	25.76	26.13	0.00	34.23	27982	139.47
63	0.3	0.75	190	15.91	1186.00	1840.10	3.05	4287.33	537.10	72922.1	155.36	322.08	2345.65	0.11	16.3	24.78	25.13	0.00	33.10	27638.9	136.32
64	0.4	0.75	190	15.48	1162.27	1819.15	3.03	4182.52	504.53	71939.3	151.02	314.22	2316.78	0.11	16.1	24.13	24.48	0.00	32.34	27446.7	133.66
65	0.5	0.75	190	15.15	1144.18	1806.49	3.02	4018.84	484.59	71347.2	148.26	307.25	2299.32	0.11	16.0	23.64	23.98	0.00	31.73	27316.2	131.26
66	0.6	0.75	190	14.86	1129.16	1797.98	3.01	4002.01	470.98	70950.7	146.30	300.85	2287.59	0.11	15.9	23.23	23.56	0.00	31.22	27217.4	129.03
67	0.7	0.75	190	14.61	1116.06	1791.84	3.00	3992.42	461.01	70666	144.80	294.88	2279.13	0.11	15.9	22.86	23.19	0.00	30.76	27137.5	126.95
68	0.8	0.75	190	14.39	1104.32	1787.20	3.00	3940.22	453.33	70451.4	143.60	289.28	2272.71	0.11	15.8	22.54	22.86	0.00	30.34	27069.9	124.98
69	0.9	0.75	190	14.18	1093.59	1783.55	2.99	3879.93	447.19	70283.5	142.60	283.98	2267.67	0.11	15.8	22.24	22.55	0.00	29.95	27011.1	123.11
70	1.0	0.75	190	13.99	1083.66	1780.60	2.99	3828.22	442.13	70148.3	141.75	278.95	2263.59	0.11	15.7	21.96	22.27	0.00	29.59	26958.7	121.34
71	0.1	0.18	190	63.10	4922.10	7256.12	11.5	6109.5	2875.35	291196	688.53	1279.30	9315.69	0.46	62.9	96.48	97.93	0.01	127.5	115538	520.56
72	0.2	0.18	190	57.79	4602.72	6807.98	11.1	4713.2	2192.26	270083	602.62	1223.44	8698.63	0.43	60.9	88.15	89.48	0.01	118.4	112152	503.62
73	0.3	0.18	190	55.48	4469.25	6657.98	11.0	3908.1	1961.71	263028	572.89	1188.92	8492.03	0.42	60.1	84.60	85.88	0.01	114.4	110917	492.30

74	0.4	0.18	190	53.94	4383.81	6582.54	10.9	3791.2	1844.47	259490	557.26	1160.64	8388.10	0.41	59.6	82.29	83.54	0.01	111.6	110225	482.72
75	0.5	0.18	190	52.74	4318.71	6536.96	10.9	3628.5	1772.67	257359	547.33	1135.53	8325.26	0.41	59.3	80.52	81.74	0.01	109.5	109755	474.07
76	0.6	0.18	190	51.73	4264.62	6506.32	10.9	3602.4	1723.68	255931	540.27	1112.48	8283.01	0.41	59.0	79.03	80.23	0.01	107.6	109400	466.06
77	0.7	0.18	190	50.83	4217.47	6484.24	10.8	3585.0	1687.78	254906	534.88	1091.02	8252.55	0.41	58.7	77.72	78.90	0.01	105.9	109112	458.55
78	0.8	0.18	190	50.01	4175.18	6467.52	10.8	3530.91	1660.13	254134	530.56	1070.84	8229.46	0.40	58.5	76.54	77.70	0.01	104.4	108869	451.46
79	0.9	0.18	190	49.27	4136.56	6454.38	10.8	3470.71	1638.03	253529	526.96	1051.76	8211.31	0.40	58.3	75.47	76.61	0.01	103.0	108657	444.75
80	1.0	0.18	190	48.57	4100.84	6443.75	10.8	3355.6	1619.83	253043	523.89	1033.66	8196.63	0.40	58.1	74.47	75.59	0.01	101.7	108468	438.37
81	0.1	0.29	190	63.61	4684.97	7221.09	11.4	5888.0	2839.31	290682	674.10	1252.57	9266.51	0.44	61.0	96.95	98.36	0.01	129.0	104959	518.97
82	0.2	0.29	190	58.30	4365.60	6772.96	11.0	4492.3	2156.21	269569	588.20	1196.71	8649.46	0.41	59.1	88.62	89.91	0.01	119.9	101574	502.02
83	0.3	0.29	190	55.99	4232.12	6622.95	10.9	3704.2	1925.67	262515	558.47	1162.19	8442.86	0.40	58.3	85.07	86.31	0.01	115.8	100338	490.71
84	0.4	0.29	190	54.45	4146.69	6547.51	10.9	3580.9	1808.43	258976	542.84	1133.91	8338.92	0.40	57.8	82.76	83.97	0.01	113.1	99646.4	481.13
85	0.5	0.29	190	53.25	4081.58	6501.93	10.8	3418.6	1736.63	256845	532.90	1108.79	8276.09	0.40	57.4	80.99	82.17	0.01	110.9	99176.5	472.47
86	0.6	0.29	190	52.24	4027.49	6471.29	10.8	3387.5	1687.63	255417	525.85	1085.75	8233.84	0.39	57.1	79.50	80.66	0.01	109.1	98820.9	464.46
87	0.7	0.29	190	51.34	3980.34	6449.21	10.8	3365.9	1651.74	254393	520.46	1064.29	8203.37	0.39	56.9	78.19	79.33	0.01	107.4	98533.2	456.95
88	0.8	0.29	190	50.52	3938.06	6432.49	10.7	3310.8	1624.09	253620	516.13	1044.11	8180.29	0.39	56.7	77.02	78.14	0.01	105.9	98290.0	449.87
89	0.9	0.29	190	49.77	3899.43	6419.35	10.7	3250.6	1601.98	253015	512.54	1025.03	8162.14	0.39	56.4	75.94	77.04	0.01	104.5	98078.1	443.16
90	1.0	0.29	190	49.08	3863.71	6408.72	10.7	3199.08	1583.79	252529	509.47	1006.93	8147.45	0.39	56.3	74.94	76.02	0.01	103.2	97889.5	436.77
91	0.1	0.75	94	9.50	704.78	1049.46	1.67	3364.4	416.01	42171.5	98.91	182.78	1346.94	0.07	9.08	15.03	15.25	0.00	19.40	15747.8	75.35
92	0.2	0.75	94	8.73	658.49	984.51	1.61	2635.24	316.99	39111.1	86.46	174.69	1257.50	0.06	8.79	13.82	14.02	0.00	18.09	15257.1	72.89
93	0.3	0.75	94	8.39	639.14	962.76	1.60	2230.52	283.58	38088.6	82.15	169.68	1227.55	0.06	8.68	13.31	13.50	0.00	17.50	15078.0	71.25
94	0.4	0.75	94	8.17	626.76	951.83	1.59	2198.35	266.58	37575.8	79.88	165.58	1212.49	0.06	8.61	12.98	13.16	0.00	17.10	14977.7	69.86
95	0.5	0.75	94	8.00	617.32	945.22	1.58	2120.94	256.18	37266.8	78.44	161.94	1203.38	0.06	8.56	12.72	12.90	0.00	16.79	14909.6	68.61
96	0.6	0.75	94	7.85	609.48	940.78	1.58	2055.97	249.07	37059.9	77.42	158.60	1197.26	0.06	8.51	12.50	12.68	0.00	16.52	14858.1	67.45
97	0.7	0.75	94	7.72	602.65	937.58	1.57	1959.22	243.87	36911.4	76.64	155.49	1192.84	0.06	8.48	12.31	12.49	0.00	16.28	14816.4	66.36
98	0.8	0.75	94	7.60	596.52	935.16	1.57	1900.55	239.86	36799.4	76.01	152.57	1189.50	0.06	8.44	12.14	12.31	0.00	16.06	14781.1	65.33
99	0.9	0.75	94	7.49	590.92	933.25	1.57	1850.09	236.66	36711.7	75.49	149.80	1186.86	0.06	8.41	11.99	12.16	0.00	15.86	14750.4	64.36
100	1.0	0.75	94	7.39	585.74	931.71	1.57	1819.1	234.02	36641.2	75.05	147.18	1184.74	0.06	8.39	11.84	12.01	0.00	15.67	14723.1	63.43
101	0.1	0.18	94	8.85	668.14	1049.75	1.62	3209.71	410.40	42094.4	262.47	182.37	1347.47	0.07	9.32	13.66	13.87	0.00	17.99	16626.2	83.67
102	0.2	0.18	94	8.08	621.85	984.80	1.56	2480.54	311.38	39034.1	250.02	174.27	1258.03	0.06	9.04	12.45	12.65	0.00	16.67	16135.5	81.21
103	0.3	0.18	94	7.74	602.50	963.05	1.55	2157.31	277.96	38011.6	245.71	169.27	1228.08	0.06	8.93	11.94	12.13	0.00	16.08	15956.5	79.57
104	0.4	0.18	94	7.52	590.11	952.12	1.54	2093.65	260.97	37498.7	243.44	165.17	1213.02	0.06	8.85	11.60	11.79	0.00	15.69	15856.2	78.18

105	0.5	0.18	94	7.35	580.68	945.51	1.53	2008.24	250.56	37189.7	242.00	161.53	1203.91	0.06	8.80	11.35	11.53	0.00	15.37	15788.1	76.93
106	0.6	0.18	94	7.20	572.84	941.07	1.53	1947.28	243.46	36982.8	240.98	158.19	1197.79	0.06	8.76	11.13	11.31	0.00	15.10	15736.5	75.77
107	0.7	0.18	94	7.07	566.00	937.87	1.52	1900.53	238.26	36834.3	240.20	155.08	1193.37	0.06	8.72	10.94	11.11	0.00	14.86	15694.8	74.68
108	0.8	0.18	94	6.95	559.87	935.45	1.52	1862.85	234.25	36722.3	239.57	152.15	1190.02	0.06	8.69	10.77	10.94	0.00	14.64	15659.6	73.65
109	0.9	0.18	94	6.84	554.27	933.54	1.52	1831.39	231.05	36634.7	239.05	149.39	1187.39	0.06	8.66	10.61	10.78	0.00	14.44	15628.9	72.68
110	1.0	0.18	94	6.74	549.10	932.00	1.52	1804.41	228.41	36564.1	238.60	146.77	1185.26	0.06	8.63	10.47	10.63	0.00	14.25	15601.5	71.76
111	0.1	0.29	94	8.70	645.62	986.81	1.56	3093.16	395.32	40949.2	200.92	3964.26	1265.69	0.06	5.12	13.06	13.26	0.00	17.89	9122.29	78.75
112	0.2	0.29	94	7.93	599.32	921.85	1.51	2364	296.31	37888.8	188.47	3956.16	1176.25	0.06	4.83	11.85	12.03	0.00	16.58	8631.6	76.29
113	0.3	0.29	94	7.59	579.98	900.11	1.49	2110.77	262.89	36866.3	184.16	3951.16	1146.30	0.06	4.72	11.34	11.51	0.00	15.99	8452.53	74.65
114	0.4	0.29	94	7.37	567.59	889.17	1.48	1977.11	245.90	36353.5	181.90	3947.06	1131.24	0.06	4.65	11.00	11.17	0.00	15.59	8352.26	73.26
115	0.5	0.29	94	7.20	558.16	882.57	1.48	1891.7	235.49	36044.5	180.46	3943.42	1122.13	0.06	4.59	10.74	10.91	0.00	15.28	8284.15	72.01
116	0.6	0.29	94	7.05	550.32	878.13	1.47	1830.74	228.39	35837.6	179.43	3940.08	1116.01	0.05	4.55	10.53	10.69	0.00	15.01	8232.60	70.85
117	0.7	0.29	94	6.92	543.48	874.93	1.47	1783.99	223.19	35689.1	178.65	3936.97	1111.59	0.05	4.51	10.34	10.50	0.00	14.77	8190.90	69.76
118	0.8	0.29	94	6.80	537.35	872.50	1.47	1746.31	219.18	35577	178.03	3934.04	1108.24	0.05	4.48	10.17	10.33	0.00	14.55	8155.65	68.73
119	0.9	0.29	94	6.69	531.75	870.60	1.46	1714.85	215.97	35489.4	177.51	3931.28	1105.61	0.05	4.45	10.01	10.17	0.00	14.35	8124.93	67.76
120	1.0	0.29	94	6.59	526.58	869.06	1.46	1687.87	213.34	35418.9	177.06	3928.66	1103.48	0.05	4.42	9.87	10.02	0.00	14.16	8097.60	66.83
121	0.1	0.75	143	13.57	996.50	1502.72	2.39	4394.2	594.06	60443.9	141.06	261.32	1928.56	0.09	12.8	21.32	21.62	0.00	27.71	22184	107.96
122	0.2	0.75	143	12.47	930.12	1409.58	2.31	3660.81	452.08	56055.8	123.21	249.71	1800.31	0.09	12.4	19.59	19.87	0.00	25.82	21480.4	104.44
123	0.3	0.75	143	11.98	902.38	1378.40	2.28	3211.2	404.17	54589.6	117.03	242.53	1757.37	0.08	12.3	18.85	19.12	0.00	24.98	21223.6	102.09
124	0.4	0.75	143	11.67	884.62	1362.73	2.27	2806.62	379.80	53854.2	113.78	236.66	1735.77	0.08	12.2	18.37	18.63	0.00	24.41	21079.9	100.09
125	0.5	0.75	143	11.42	871.09	1353.25	2.26	2620.074	364.87	53411.2	111.71	231.44	1722.71	0.08	12.1	18.00	18.26	0.00	23.96	20982.2	98.30
126	0.6	0.75	143	11.20	859.84	1346.88	2.26	2487.464	354.69	53114.5	110.25	226.65	1713.93	0.08	12.0	17.69	17.94	0.00	23.57	20908.3	96.63
127	0.7	0.75	143	11.02	850.04	1342.29	2.25	2386.11	347.23	52901.5	109.13	222.19	1707.60	0.08	12.0	17.42	17.67	0.00	23.23	20848.5	95.07
128	0.8	0.75	143	10.85	841.26	1338.82	2.25	2304.68	341.49	52740.9	108.23	217.99	1702.80	0.08	11.9	17.18	17.42	0.00	22.91	20797.9	93.60
129	0.9	0.75	143	10.69	833.23	1336.09	2.24	2236.83	336.89	52615.3	107.48	214.03	1699.03	0.08	11.9	16.95	17.19	0.00	22.62	20753.9	92.20
130	1.0	0.75	143	10.55	825.80	1333.88	2.24	2178.77	333.11	52514.2	106.84	210.26	1695.97	0.08	11.9	16.75	16.98	0.00	22.35	20714.7	90.88
131	0.1	0.18	143	12.72	961.87	1505.43	2.32	4116.79	588.93	60365.6	376.55	262.14	1932.48	0.09	13.3	19.69	19.99	0.00	25.87	24023.3	120.00
132	0.2	0.18	143	11.61	895.49	1412.28	2.24	3367.37	446.95	55977.4	358.69	250.53	1804.23	0.09	12.9	17.95	18.23	0.00	23.99	23319.7	116.47
133	0.3	0.18	143	11.13	867.75	1381.11	2.22	2927.20	399.03	54511.3	352.51	243.36	1761.29	0.09	12.8	17.22	17.49	0.00	23.14	23062.9	114.12
134	0.4	0.18	143	10.81	850.00	1365.43	2.20	2544.09	374.67	53775.9	349.26	237.48	1739.69	0.09	12.7	16.74	17.00	0.00	22.57	22919.1	112.13
135	0.5	0.18	143	10.56	836.46	1355.95	2.20	2365.62	359.74	53332.9	347.20	232.26	1726.63	0.08	12.6	16.37	16.63	0.00	22.12	22821.5	110.33

136	0.6	0.18	143	10.35	825.22	1349.59	2.19	2239.11	349.56	53036.2	345.73	227.47	1717.85	0.08	12.5	16.06	16.31	0.00	21.73	22747.6	108.67
137	0.7	0.18	143	10.16	815.42	1345.00	2.19	2142.64	342.10	52823.2	344.61	223.01	1711.52	0.08	12.5	15.79	16.04	0.00	21.39	22687.8	107.11
138	0.8	0.18	143	10.00	806.63	1341.52	2.18	2065.27	336.35	52662.6	343.71	218.81	1706.72	0.08	12.4	15.54	15.79	0.00	21.08	22637.2	105.63
139	0.9	0.18	143	9.84	798.60	1338.79	2.18	2000.91	331.76	52537	342.97	214.85	1702.95	0.08	12.4	15.32	15.56	0.00	20.79	22593.2	104.24
140	1.0	0.18	143	9.48	929.55	1246.32	2.10	1909.82	310.31	51723.4	322.30	5684.96	1582.63	0.08	12.36	15.30	14.56	0.00	20.38	21793.2	95.86
141	0.1	0.29	143	12.50	863.17	1415.17	2.24	3967.58	425.33	54335.2	270.44	5673.35	1815.21	0.09	6.95	17.09	17.35	0.00	25.74	13262.5	112.94
142	0.2	0.29	143	11.40	835.42	1322.03	2.16	3209.5	377.42	52869.1	264.26	5666.18	1686.96	0.08	6.79	16.35	16.61	0.00	23.85	12558.9	109.42
143	0.3	0.29	143	10.92	817.67	1290.85	2.14	2774.48	353.05	52133.7	261.02	5660.30	1644.02	0.08	6.69	15.87	16.12	0.00	23.01	12302.1	107.07
144	0.4	0.29	143	10.60	804.13	1275.17	2.13	2402.92	338.12	51690.7	258.95	5655.08	1622.42	0.08	6.61	15.50	15.74	0.00	22.44	12158.3	105.08
145	0.5	0.29	143	10.35	792.89	1265.69	2.12	2228.79	327.94	51394	257.48	5650.29	1609.36	0.08	6.55	15.19	15.43	0.00	21.98	12060.7	103.28
146	0.6	0.29	143	10.14	783.09	1259.33	2.11	2105.5	320.48	51181	256.36	5645.83	1600.58	0.08	6.50	14.92	15.15	0.00	21.60	11986.7	101.61
147	0.7	0.29	143	9.95	774.30	1254.74	2.11	2011.71	314.73	51020.4	255.47	5641.63	1594.25	0.08	6.45	14.68	14.91	0.00	21.25	11926.9	100.05
148	0.8	0.29	143	9.78	766.28	1251.26	2.10	1936.52	310.14	50894.7	254.72	5637.67	1589.45	0.08	6.41	14.45	14.68	0.00	20.94	11876.4	98.58
149	0.9	0.29	143	9.63	791.18	1248.53	2.10	1874.0	327.98	52435.8	242.33	211.09	1585.68	0.08	6.37	15.11	15.35	0.00	20.65	11832.4	97.18
150	1.0	0.29	143	9.48	758.85	1246.32	2.10	1820.71	306.36	50793.6	234.08	5633.91	1582.63	0.08	6.37	14.25	14.47	0.00	20.38	11793.2	95.86

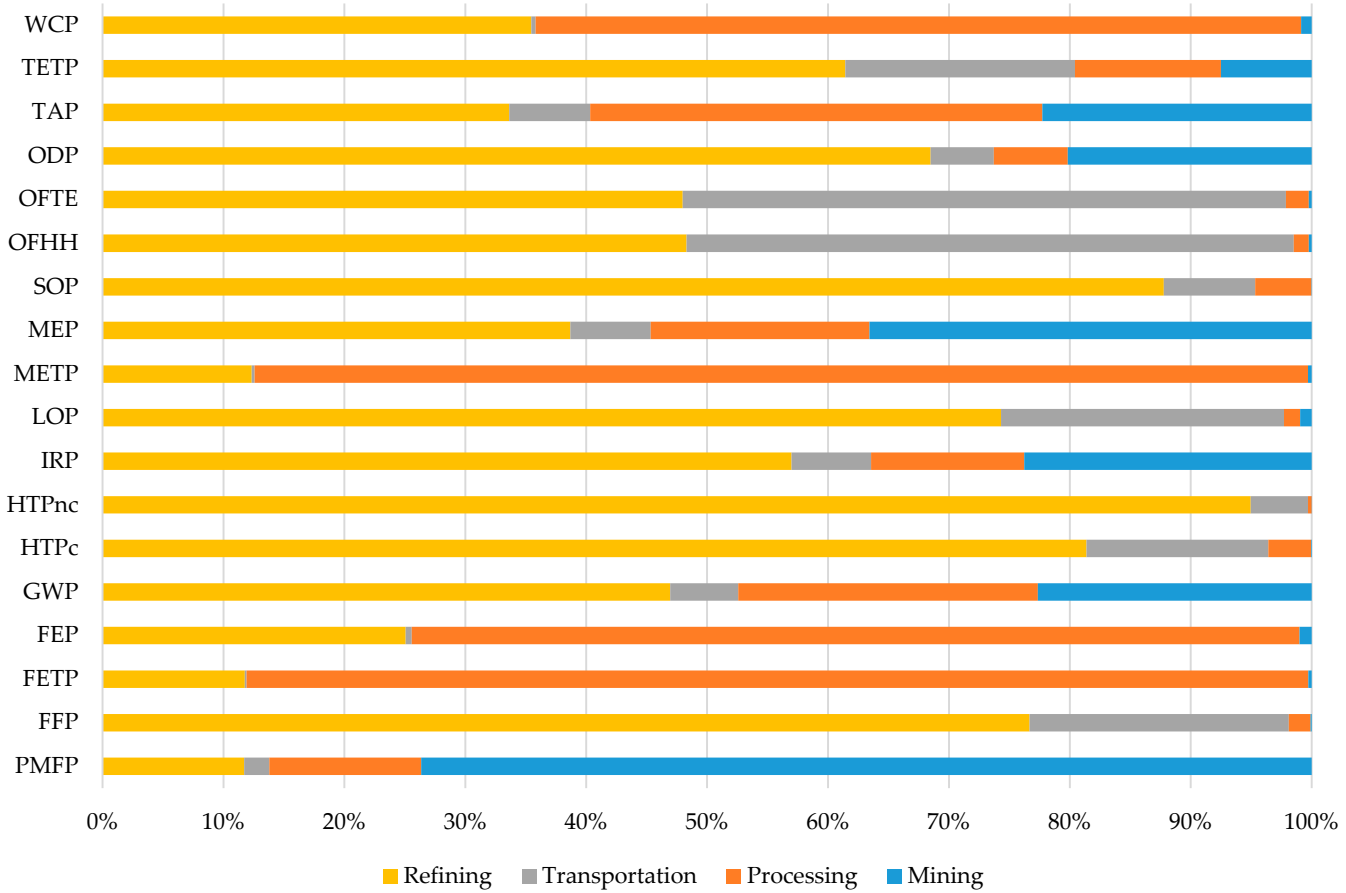

Figure S2: Relative proportion of environmental impacts per MWh of NMC111 storage, across all life cycle stages considered in the base case

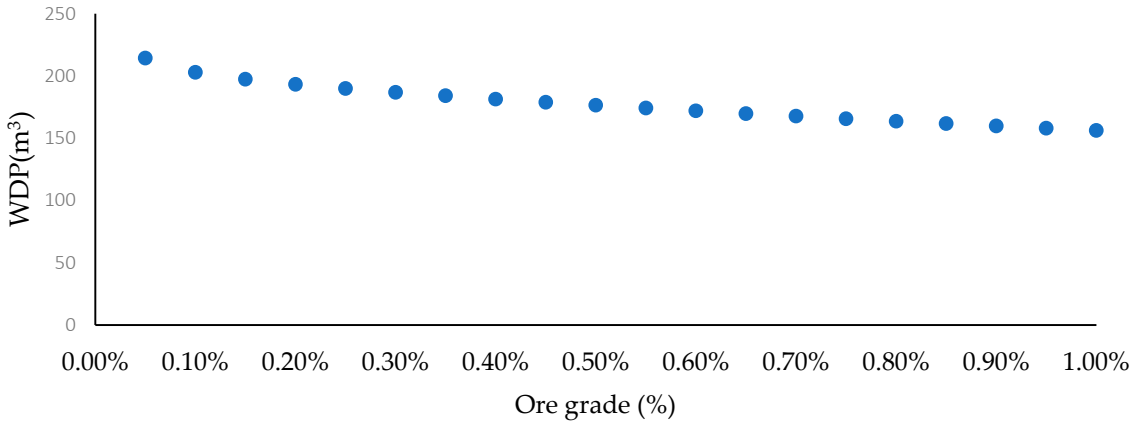

Figure S3: Impact of ore grade on water depletion of mining and processing of $Co(OH)_2$

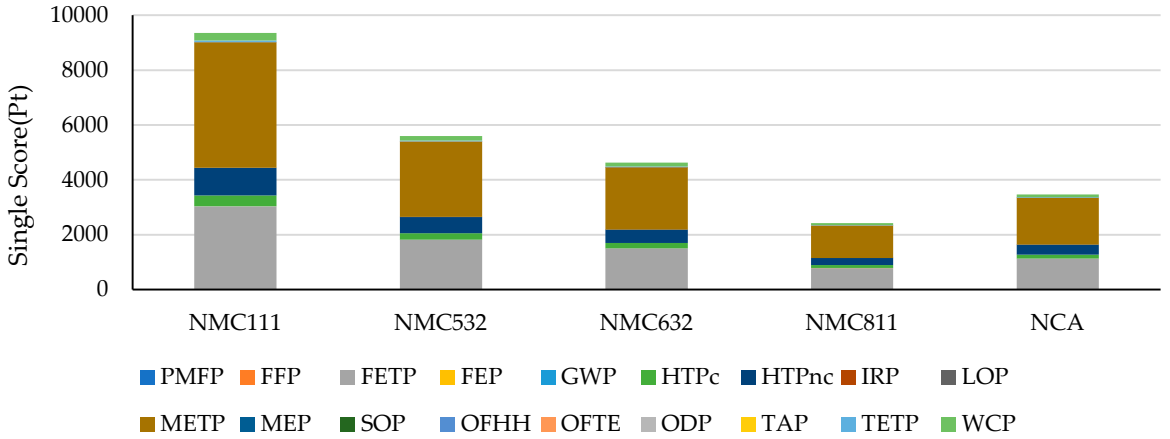

Figure S4: Single-score results for environmental impacts comparison of different battery chemistries (location—China and ore grade—0.3%)

Table S7: Single score results for battery chemistries and locations for an ore grade of 0.3%

		PMFP	FFP	FETP	FEP	GWP	HTPc	HTPnc	IRP	LOP	METP	MEP	SOP	OFHH	OFTE	ODP	TAP	TETP	WCP	Total
NMC111	Base Case (China)	1.23	2.43	3027.65	9.52	1.08	394.05	1000.17	0.66	0.11	4583.86	0.05	0.00	2.43	2.85	0.00	1.60	52.83	273.11	9353.62
	Canada (NA)	1.19	2.41	3076.06	9.33	1.04	393.20	999.60	2.00	0.11	4663.76	0.05	0.00	2.27	2.67	0.00	1.54	60.30	311.86	9527.40
	Finland (EU)	1.16	2.32	2875.00	8.99	1.01	371.87	969.48	1.50	2.51	4353.17	0.05	0.00	2.16	2.54	0.00	1.53	31.92	292.58	8917.79
NMC532	Base Case (China)	0.75	1.46	1814.25	5.68	0.65	234.17	592.13	0.39	0.06	2749.57	0.03	0.00	1.45	1.70	0.00	0.98	32.01	164.95	5600.03
	Canada (NA)	0.73	1.53	1824.63	5.71	0.62	238.14	593.47	0.40	0.06	2767.00	0.03	0.00	1.38	1.63	0.00	0.94	35.99	165.54	5637.61
	Finland (EU)	0.74	1.45	1815.01	5.68	0.61	233.75	592.31	0.39	0.06	2750.95	0.03	0.00	1.39	1.63	0.00	0.95	32.56	165.00	5602.31
NMC632	Base Case (China)	0.62	1.21	1499.68	4.70	0.54	193.89	489.31	0.32	0.05	2272.93	0.02	0.00	1.20	1.41	0.00	0.81	26.67	136.32	4629.70
	Canada (NA)	2.17	4.56	5426.25	16.94	0.49	708.18	1764.92	1.19	0.19	8228.78	0.09	0.00	4.11	4.84	0.17	2.79	107.03	492.30	16765.00
	Finland (EU)	2.19	4.32	5397.70	16.79	0.46	695.17	1761.48	1.16	0.19	8181.13	0.09	0.00	4.13	4.86	0.17	2.83	96.83	490.71	16660.19
NMC811	Base Case (China)	0.33	0.65	784.65	2.46	0.28	102.37	255.57	0.17	0.03	1189.50	0.01	0.00	0.65	0.76	0.00	0.43	14.55	71.25	2423.66
	Canada (NA)	0.30	0.61	784.89	2.39	0.27	100.34	255.06	0.51	0.03	1190.01	0.01	0.00	0.58	0.68	0.00	0.39	15.40	79.57	2431.05
	Finland (EU)	0.30	0.59	733.59	2.29	0.26	94.90	247.37	0.38	0.64	1110.76	0.01	0.00	0.55	0.65	0.00	0.39	8.16	74.65	2275.51
NCA	Base Case (China)	0.47	0.92	1123.40	3.51	0.40	145.91	366.30	0.24	0.04	1702.89	0.02	0.00	0.92	1.08	0.00	0.61	20.48	102.09	3469.26
	Canada (NA)	0.44	0.89	1125.60	3.42	0.37	144.05	365.77	0.73	0.04	1706.69	0.02	0.00	0.84	0.98	0.00	0.56	22.26	114.12	3486.78
	Finland (EU)	0.43	0.83	1052.04	3.30	0.35	127.45	349.82	0.54	0.92	1593.06	0.02	0.00	0.77	0.91	0.00	0.56	11.87	107.07	3249.93