

Supplementary Information: Reducing water stress from mining battery materials

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The PDF includes:

Supplementary Figures 1 to 8

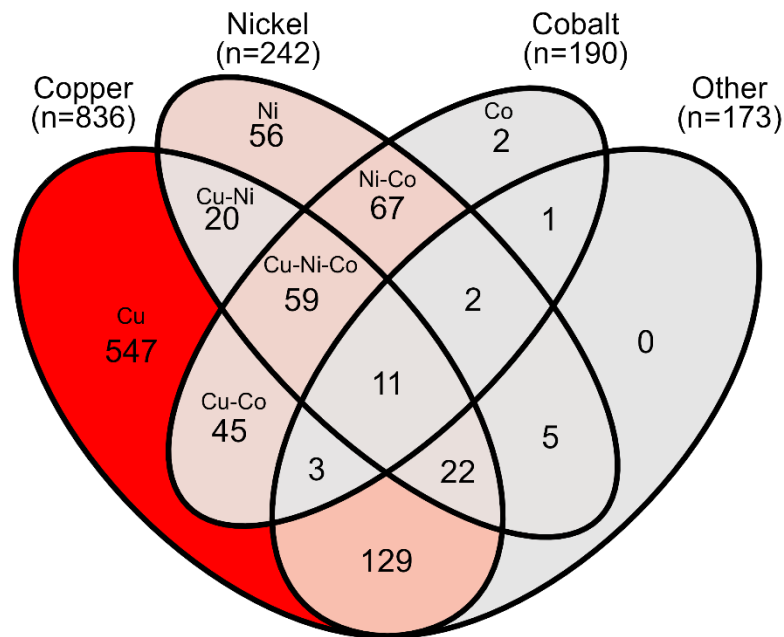
Supplementary Tables 1 to 2

Supplementary Text 1

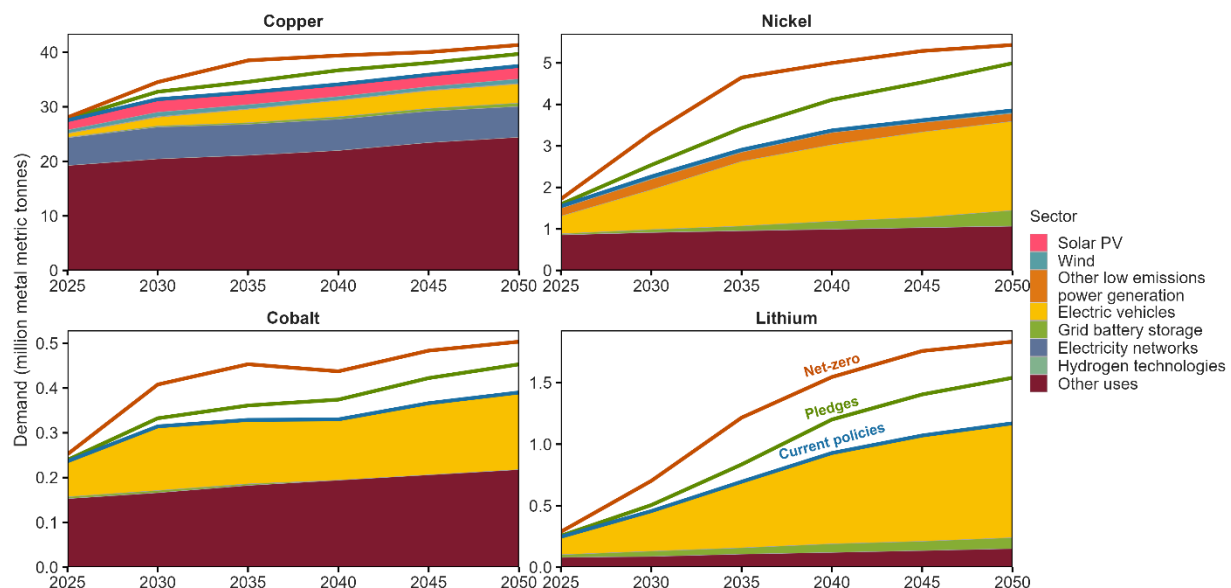
Other Supplementary Materials for this manuscript include the following:

Extended Data Figures 1 to 8

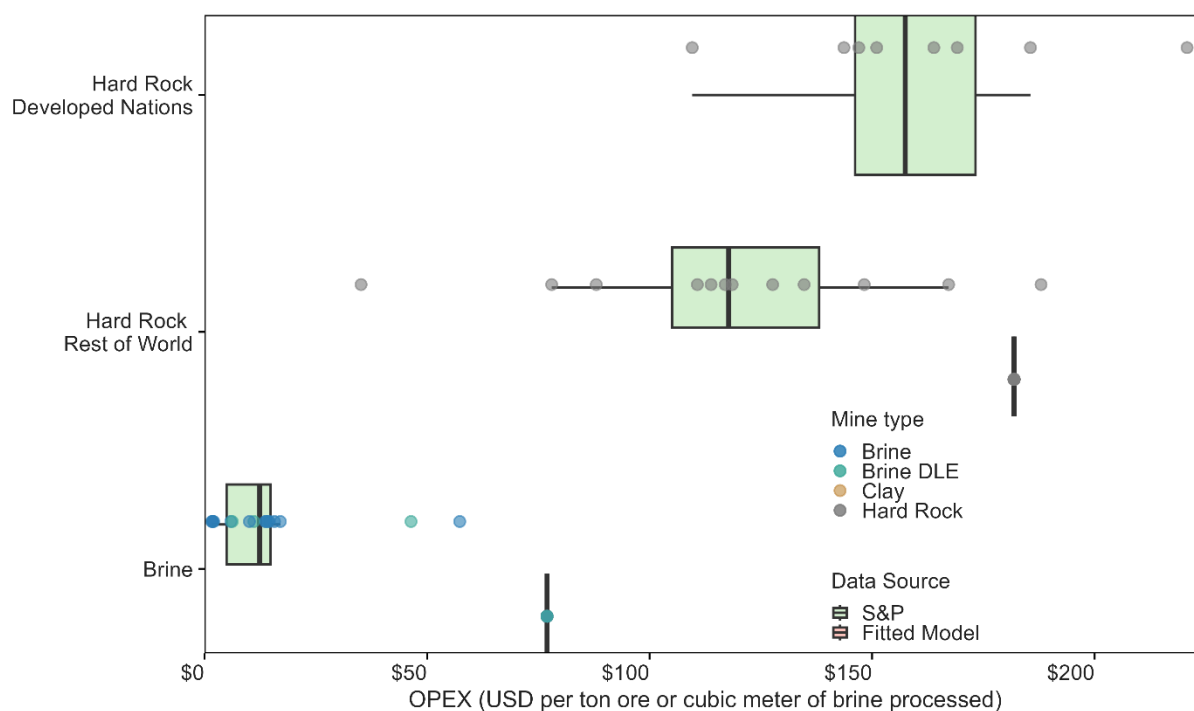
Supplementary Figures



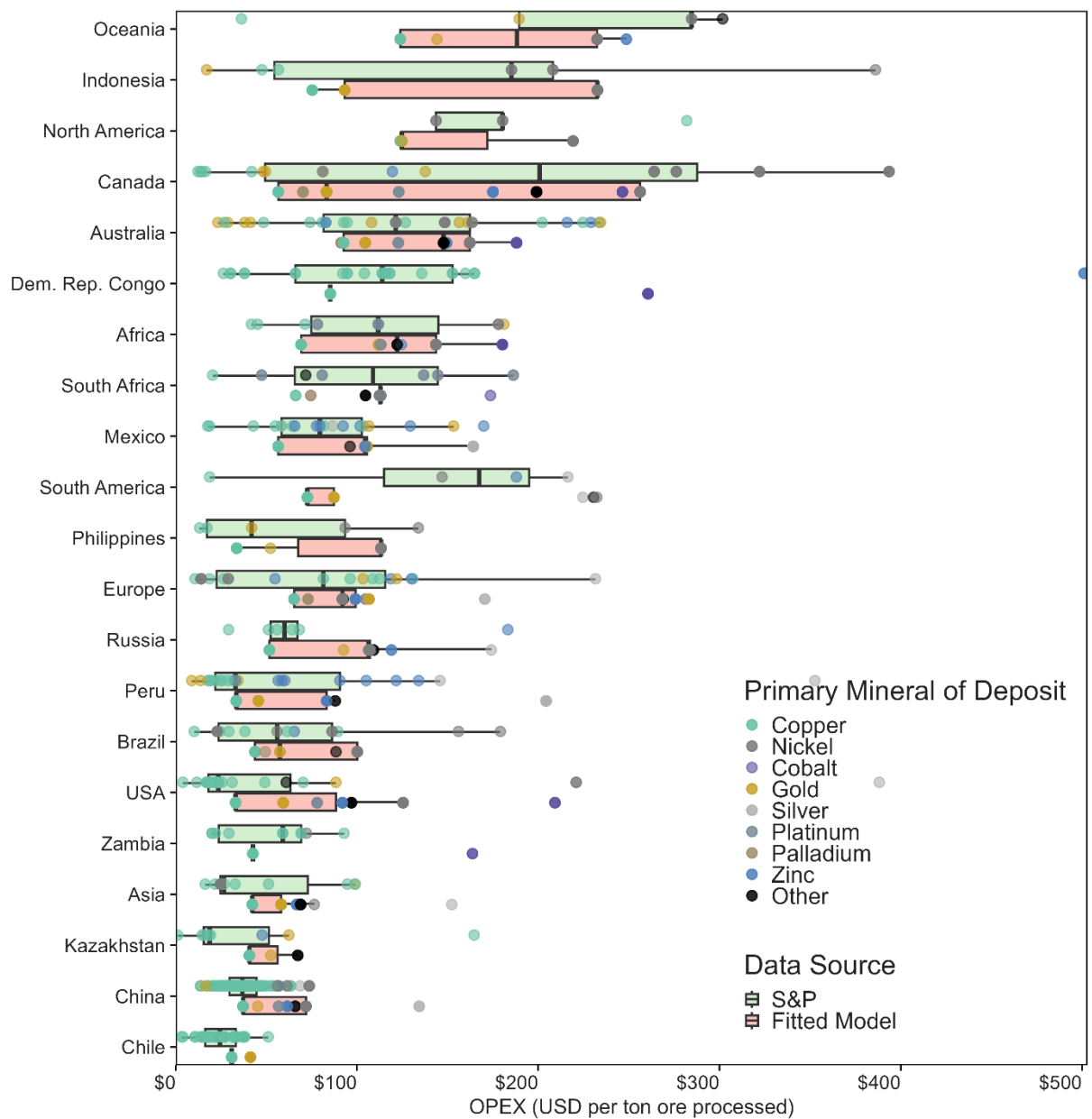
Supplementary Figure 1 | Co-production of copper, nickel and cobalt among model deposits inputs. Others indicate deposits where the primary commodity mineral of the deposit is no copper, nickel nor cobalt. Data source for deposit characteristics is Metals and Mining database from S&P¹.



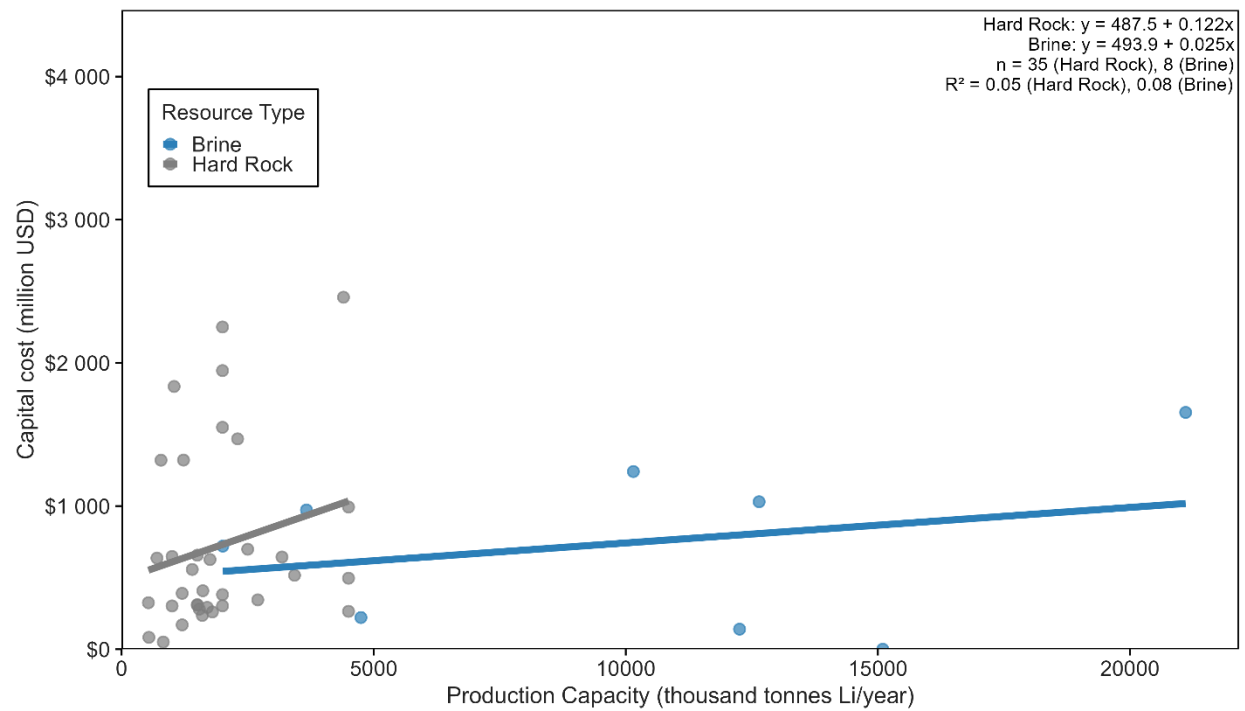
Supplementary Figure 2 Mineral demand forecast, in million metric tons, by the International Energy Agency (IEA). Scenarios are Stated Policy Scenarios (SPS), Announced Pledges Scenario (APS) and Net Zero Emissions (NZE). Sectors are divided into clean energy uses and other uses.



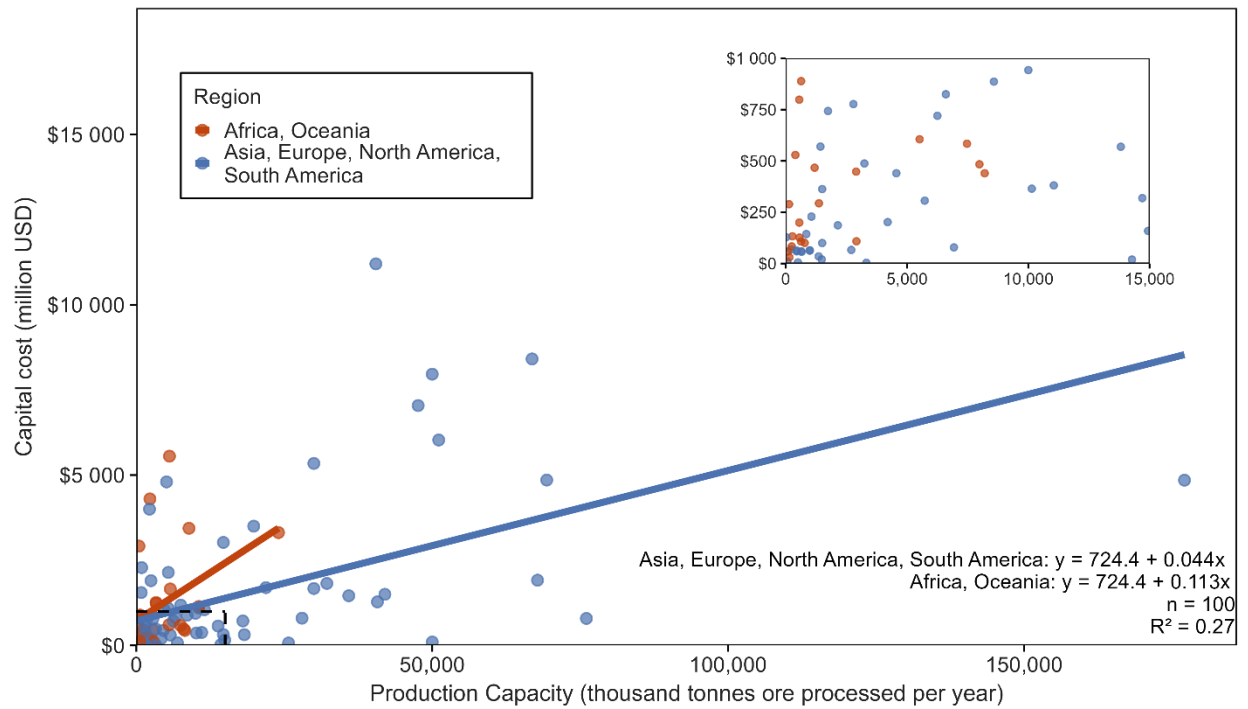
Supplementary Figure 3 | Operational cost (OPEX) for lithium extraction. Color of boxplot indicate whether cost was estimated by S&P Metals and Mining database¹ or by a linear regression model based regional aggregation and resource type. Color of points indicate resource type. Given the limited data on lithium deposits, we use the 95th prediction quantile to fill missing costs. The following countries are considered as developed nations: Australia, Germany, United Kingdom, Spain, France, Finland, Canada, Czechia, Austria, Portugal, Italy and the United States. Data for model fitting come from Metals and Mining database from S&P¹.



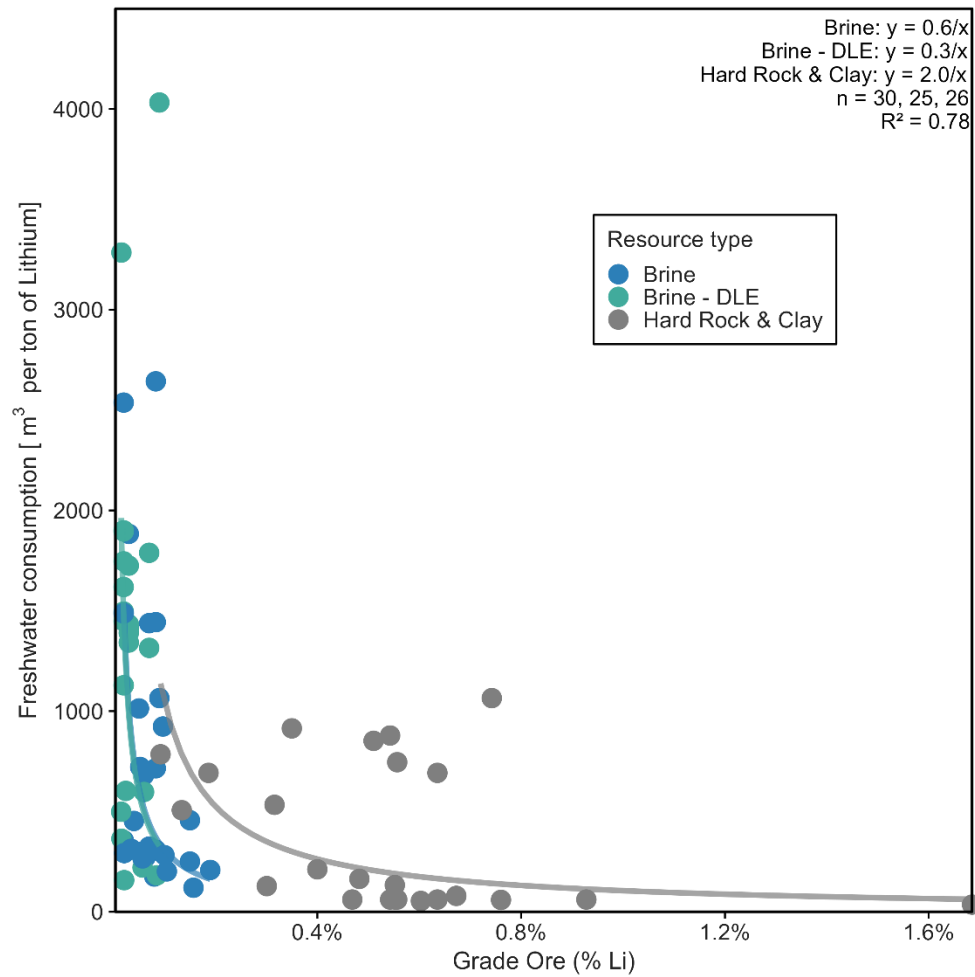
Supplementary Figure 4 | Operational cost (OPEX) for ore processing (copper, nickel and cobalt). Color of boxplot indicate whether cost was estimated by S&P Metals and Mining database¹ or by a random forest model based on country and primary mineral of the deposit. Color of points indicate primary mineral, and the countries or regions aggregation are sorted by decreasing OPEX. Data for model fitting come from Metals and Mining database from S&P¹.



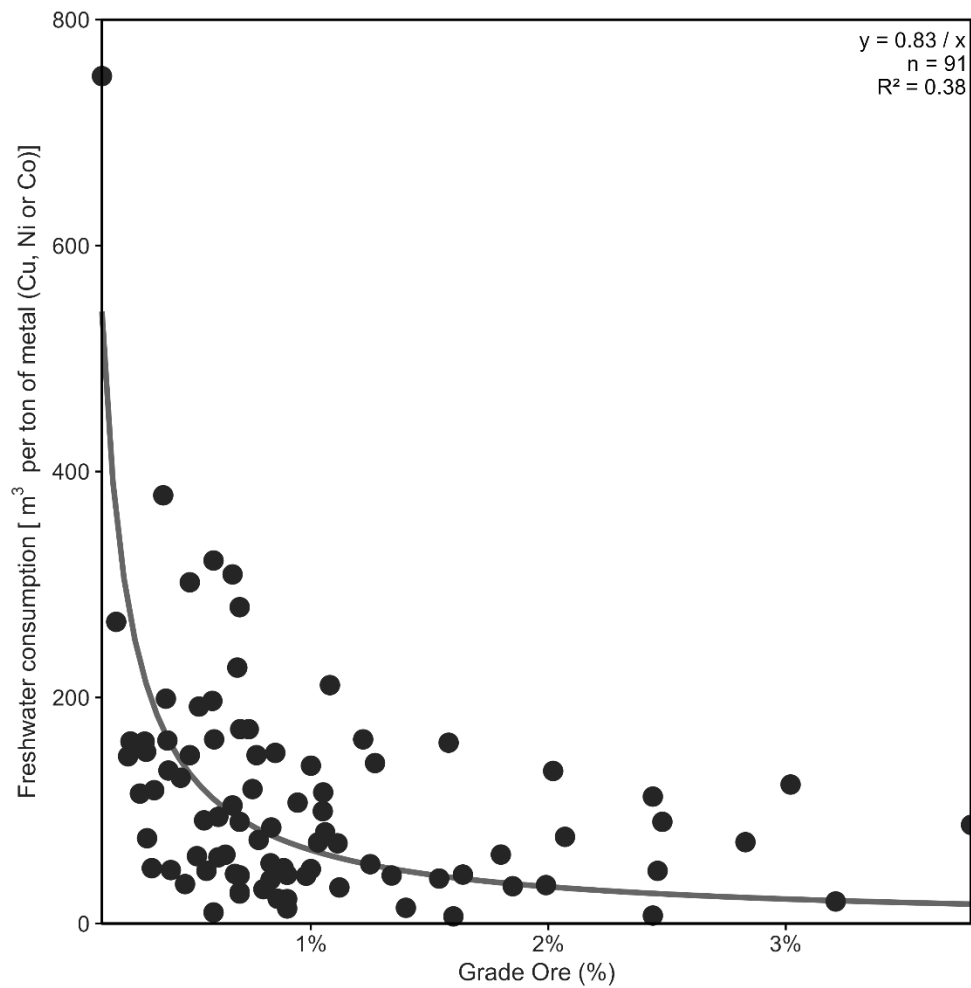
Supplementary Figure 5 | Capital expenditure estimation for lithium projects. Two linear models were fitted, one for brine resources and one for other resources (hard rock). Each dot shows cumulative capital expenditure on investment or expansion projects along current production capacity. The intercept of the line provides the estimate for initial cost for opening, and the slope provides the estimate of capacity expansion cost. Data for model fitting come from Metals and Mining database from S&P¹.



Supplementary Figure 6 | Capital expenditure estimation for copper, nickel and cobalt projects. One model was fitted for all ore resources. Each dot shows cumulative capital expenditure on investment or expansion projects along current production capacity. The intercept of the line provides the estimate for initial cost for opening, and the slope provides the estimate of capacity expansion cost. Data for model fitting come from Metals and Mining database from S&P¹.



Supplementary Figure 7 | Freshwater consumption per ton of lithium and ore grade of lithium. Each dot is a reported value by scientific literature. Color indicates resource type. Fitted model is by ore grade and resource type. An extra cubic meter of water consumption is added to the fitted model for brines, to account for brine water depletion,



Supplementary Figure 8 | Freshwater consumption per ton of ore and ore grade for copper, nickel or cobalt. Each dot is a reported value by scientific literature. Fitted model is by ore grade.

Supplementary Tables

Supplementary Table 1 | Literature reported freshwater consumption values by mineral and ore grade.

Mineral	Deposit	Type	Ore grade (%)	Water use (m³/ton mineral)	Ref.
Copper	Cadia-Ridgeway	Combined	0.33%	49.0	²
Copper	Ernest Henry	Open Pit	0.98%	42.3	²
Copper	Golden Grove	Underground	1.85%	33.0	²
Copper	Mount Isa	Underground	3.21%	19.5	²
Copper	Northparkes	Combined	0.78%	74.0	²
Copper	Olympic Dam	Underground	2.46%	46.6	²
Copper	Prominent Hill	Open Pit	1.54%	39.8	²
Copper	Rosebery	Underground	0.36%	1,046.9	²
Copper	Telfer	Combined	0.24%	161.1	²
Copper	Alumbrera	Open Pit	0.55%	91.3	²
Copper	Highland Valley	Underground	0.40%	135.4	²

Mineral	Deposit	Type	Ore grade (%)	Water use (m ³ /ton mineral)	Ref.
Copper	Kidd Creek	Open Pit	2.07%	76.7	²
Copper	Andina	Combined	1.05%	99.4	²
Copper	Codelco Norte	Open Pit	0.83%	53.3	²
Copper	Collahuasi	Open Pit	1.12%	31.9	²
Copper	El Soldado	Combined	1.00%	48.2	²
Copper	El Teniente	Underground	1.00%	139.7	²
Copper	Escondida	Open Pit	1.25%	52.5	²
Copper	Lomas Bayas	Open Pit	0.31%	75.5	²
Copper	Los Bronces	Open Pit	1.06%	80.7	²
Copper	Mantos Blancos	Open Pit	0.69%	226.5	²
Copper	Mantoverde	Open Pit	0.56%	46.6	²
Copper	Salvador	Combined	0.59%	321.3	²
Copper	Quebrada Blanca	Open Pit	0.86%	21.9	²
Copper	Pyhasalmi	Underground	1.08%	211.0	²
Copper	Sepon	Open Pit	1.99%	34.0	²
Copper	Palabora	Underground	0.61%	94.4	²
Copper	Cayeli	Underground	3.78%	87.3	²
Copper	Tintaya	Open Pit	1.34%	42.5	²
Copper	Ok Tedi	Open Pit	0.83%	38.8	²
Copper	Kennecott Utah	Open Pit	0.59%	9.8	²
Copper	Trident - Sentinel	Open Pit	0.49%	302.0	³
Copper	Kansanshi	Combined	0.58%	197.0	³
Copper	Lumwana	Open Pit	0.49%	149.0	³
Copper	Kamoto	Combined	0.89%	49.0	³
Copper	Tenke Fungurume	Open Pit	2.83%	72.0	³
Copper	Grasberg	Combined	1.22%	163.0	³
Copper	Erdenet	Open Pit	0.53%	192.0	³
Copper	Dexing Complex	Combined	0.40%	162.0	³
Copper	Letpadaung Mountain	Open Pit	0.39%	199.0	³
Copper	Batu Hijau	Open Pit	0.45%	129.0	³
Copper	Rudna	Underground	2.02%	135.0	³
Copper	Aitik	Open Pit	0.18%	267.0	³
Copper	Zhezkazgan Complex	Combined	1.27%	142.0	³
Copper	Cobre Panama	Open Pit	0.47%	826.0	³
Copper	Escondida	Open Pit	0.83%	85.0	³
Copper	El Teniente	Combined	0.85%	151.0	³
Copper	Chuquicamata	Open Pit	0.59%	163.0	³
Copper	Cerro Verde	Open Pit	0.34%	118.0	³
Copper	Morenci	Open Pit	0.28%	115.0	³
Copper	Kennecott	Combined	3.02%	123.0	³
Copper	Highland Valley	Open Pit	0.30%	161.0	³
Copper	Mission	Combined	0.38%	379.0	³
Copper	Bagdad	Open Pit	0.31%	152.0	³
Copper	Boddington	Combined	0.12%	750.0	³
Copper	Telfer	Combined	1.70%	1,181.0	³
Copper	Mt Isa Copper	Combined	1.80%	61.0	³
Copper	Cadia East	Combined	0.23%	148.0	³
Copper	Ok Tedi	Combined	0.75%	119.0	³
Copper	Sarcheshmeh	Open Pit	0.70%	172.0	³
Copper	Sungun	Open Pit	0.77%	149.0	³
Copper	Jabal Sayid	Combined	2.48%	90.0	³
Copper	Malanjkhand	Combined	1.11%	71.0	³
Copper	Saindak	Open Pit	1.58%	160.0	³
Copper	Phu Kam	Open Pit	0.54%	1,110.1	⁴

Mineral	Deposit	Type	Ore grade (%)	Water use (m ³ /ton mineral)	Ref.
Copper	Cerro Colorado	Open Pit	0.68%	43.9	⁵
Copper	Quebrada Blanca	Open Pit	0.90%	21.6	⁵
Copper	Inés de Collahuasi	Open Pit	0.90%	13.3	⁵
Copper	El Abra	Open Pit	0.47%	34.9	⁵
Copper	Codelco Norte	Open Pit	0.80%	30.4	⁵
Copper	Sence	Open Pit	1.40%	13.9	⁵
Copper	El Tesoro	Open Pit	0.90%	43.1	⁵
Copper	Codelco Gabi	Open Pit	0.41%	47.3	⁵
Copper	Zaldivar	Open Pit	0.70%	27.7	⁵
Copper	Escondida	Open Pit	1.60%	6.3	⁵
Copper	Mantos Blancos	Open Pit	0.70%	26.5	⁵
Copper	Codelco Salvador	Open Pit	0.61%	58.6	⁵
Copper	Manto Verde	Open Pit	0.70%	42.6	⁵
Copper	Inés de Collahuasi	Open Pit	0.67%	104.5	⁵
Copper	Codelco Norte	Open Pit	1.03%	71.8	⁵
Copper	Escondida	Open Pit	1.64%	43.3	⁵
Copper	Mantos Blancos	Open Pit	0.70%	90.0	⁵
Copper	Codelco Salvador	Open Pit	0.67%	309.0	⁵
Copper	Minera Candelaria	Open Pit	0.52%	59.6	⁵
Copper	Minera Ojos del Salado	Open Pit	0.70%	280.0	⁵
Copper	Los Pelambres	Open Pit	0.64%	60.9	⁵
Copper	Global avg.	Combined	0.74%	172.0	⁶
Copper	Copper-gold avg.	Combined	1.05%	116.0	⁶
Copper	Copper-cobalt avg.	Open Pit	2.44%	7.0	⁷
Copper	Copper-cobalt avg.	Underground	2.44%	112.3	⁷
Nickel	Global avg.	Combined	0.94%	107.0	⁶
Lithium	Atacama	Brine	0.15%	250	⁸
Lithium	Tres Quebradas	Brine	0.10%	282	⁸
Lithium	Maricunga	Brine	0.09%	1,065	⁸
Lithium	Sal de Vida	Brine	0.08%	176	⁸
Lithium	Hombre Muerto North	Brine	0.07%	325	⁸
Lithium	Cauchari-Olaroz	Brine	0.05%	298	⁸
Lithium	Pastos Grandes	Brine	0.04%	452	⁸
Lithium	Olaroz	Brine	0.06%	681	⁸
Lithium	Silver Peak	Brine	0.02%	357	⁸
Lithium	Uyuni	Brine	0.07%	1,789	⁸
Lithium	Fenix	Brine	0.07%	1,315	⁸
Lithium	Rio Grande	Brine	0.03%	1,389	⁸
Lithium	Centenario	Brine	0.03%	1,411	⁸
Lithium	Rincon	Brine	0.03%	1,432	⁸
Lithium	Tolillar	Brine	0.03%	1,432	⁸
Lithium	Arizaro	Brine	0.03%	1,725	⁸
Lithium	Antofalla	Brine	0.03%	1,341	⁸
Lithium	Salinas Grandes	Brine	0.02%	1,448	⁸
Lithium	Kachi	Brine	0.02%	1,618	⁸
Lithium	Los Angeles	Brine	0.02%	1,496	⁸
Lithium	Pozuelos	Brine	0.02%	1,746	⁸
Lithium	Chaerhan	Brine	0.02%	1,128	⁸
Lithium	Qinghai Yiliping	Brine	0.02%	1,128	⁸
Lithium	Atacama	Brine	0.19%	208	⁹
Lithium	Qarhan	Brine	0.016%	3,285	¹⁰
Lithium	Silver Peak	Brine	0.083%	2,643	¹⁰
Lithium	Olaroz	Brine	0.083%	1,443	¹⁰
Lithium	Cauchari-Olaroz	Brine	0.083%	715	¹⁰

Mineral	Deposit	Type	Ore grade (%)	Water use (m ³ /ton mineral)	Ref.
Lithium	Da Qaidam	Brine	0.02%	602	¹⁰
Lithium	Hombre Muerto	Brine	0.06%	597	¹⁰
Lithium	Yiliping	Brine	0.02%	498	¹⁰
Lithium	Barunma Sea	Brine	0.016%	364	¹⁰
Lithium	Atacama	Brine	0.083%	309	¹⁰
Lithium	West Tajinar	Brine	0.02%	292	¹⁰
Lithium	East Tajinar	Brine	0.09%	182	¹⁰
Lithium	Olaroz	Brine	0.06%	271	¹¹
Lithium	Fenix	Brine	0.05%	721	¹¹
Lithium	Brine high grade	Brine	0.1048%	201	¹²
Lithium	Brine medium grade	Brine	0.0347%	313	¹²
Lithium	Brine low grade	Brine	0.0038%	17,991	¹²
Lithium	Hombre Muerto	Brine	0.07%	1,438	¹³
Lithium	Olaroz	Brine	0.05%	1,013	¹³
Lithium	Silver Peak	Brine	0.03%	1,883	¹³
Lithium	Atacama	Brine	0.15%	456	¹³
Lithium	Qarhan	Brine	0.02%	2,537	¹³
Lithium	Xitai Jinaier	Brine	0.02%	1,487	¹³
Lithium	Dongtai Jinaier	Brine	0.02%	1,487	¹³
Lithium	Zabuye	Brine	0.10%	923	¹³
Lithium	Atacama	Brine	0.16%	120	¹⁴
Lithium	Salar de Olaroz	Brine - DLE	0.06%	220	¹⁴
Lithium	Salar de Olaroz	Brine	0.06%	266	¹⁴
Lithium	Hombre Muerto	Brine - DLE	0.09%	4,032	¹⁴
Lithium	Tajinar	Brine - DLE	0.02%	158	¹⁴
Lithium	Upper Rhine Graben	Brine - DLE	0.02%	1,895	⁸
Lithium	Salton Sea	Brine - DLE	0.02%	1,900	⁸
Lithium	Greenbushes	Hard Rock	0.74%	1,065	¹⁵
Lithium	Mt Cattlin	Hard Rock	0.56%	745	¹⁵
Lithium	Mt Marion	Hard Rock	0.64%	692	¹⁵
Lithium	Mt Wodgina	Hard Rock	0.54%	878	¹⁵
Lithium	Pilgangoora	Hard Rock	0.51%	852	¹⁵
Lithium	Keliber-Syvajarvi	Hard Rock	0.40%	212	¹⁶
Lithium	Hard rock - high grade	Hard Rock	1.6850%	36	¹²
Lithium	Hard rock - medium grade	Hard Rock	0.7605%	59	¹²
Lithium	Hard rock - low grade	Hard Rock	0.3008%	128	¹²
Lithium	Greenbushes	Hard Rock	0.93%	61	¹³
Lithium	Mt Marion	Hard Rock	0.64%	61	¹³
Lithium	Wodgina	Hard Rock	0.54%	61	¹³
Lithium	Mt Cattlin	Hard Rock	0.56%	61	¹³
Lithium	Pilgangoora	Hard Rock	0.55%	61	¹³
Lithium	Bald Hill	Hard Rock	0.47%	61	¹³
Lithium	Nemaska Lithium	Hard Rock	0.60%	54	¹³
Lithium	Grota do Cirilo	Hard Rock	0.67%	79	¹³
Lithium	Mina do Barroso	Hard Rock	0.48%	164	¹³
Lithium	Arcadia	Hard Rock	0.55%	133	¹³
Lithium	Tonopah lithium	Volcano-Sedimentary	0.092%	785	¹⁷
Lithium	Sonora	Volcano-Sedimentary	0.35%	914	¹⁸
Lithium	Falchani	Volcano-Sedimentary	0.33%	5,385	¹⁸
Lithium	Thacker Pass	Volcano-Sedimentary	0.32%	4,511	¹⁸
Lithium	Nevada sedimentary projects	Volcano-Sedimentary	0.19%	692	¹⁹
Lithium	Mc Dermitt Caldera	Volcano-Sedimentary	0.13%	506	²⁰
Lithium	Thacker Pass	Volcano-Sedimentary	0.316%	533	²⁰

Supplementary Table 2 | Parameter random sampling bounds. All parameters were either sample with a uniform distribution with the indicated bounds, or Bernoulli for binary variables (0 or 1).

Variable	Uncertainty bounds
Water consumption (m³) per ton ore	From 95% prediction intervals (2.5 th and 97.5 th) from fitted regression models (see Supplementary Figure 7 and 8). For deposits with specific values estimated by the literature (Supplementary Table 1), we assume a variation of -25% to 50%.
Stress-weighted characterization factors	Values drawn from the 5,000 Monte Carlo results generated by sampling from the AWARE 2.0 parametric input data ²¹ .
Water desalination available	Binary (whether available to use or not).
Water desalination costs	\$0.25 to \$1.5 per m ³ (ref. ²²).
Protect fish-biodiversity	Binary (whether mineral extraction in certain basins (see below) was allowed or not).
Threshold fish biodiversity protection	60 to 100 fish biodiversity index.
Mineral demand	-25% SPS to +25% NZE (interpolation of IEA demand scenarios, including APS in the middle) ²³ .
LFP share (electric vehicle demand)	30% to 90% (we estimate that IEA demand scenarios ²³ assume a growth of LFP share from 55% in 2025 to 65% by 2050, see Supplementary Text 1).
Ni-Co ratio (electric vehicle demand)	6 to 12 (ref. ²³) (IEA electric vehicle demand projections shows an increasing Ni-Co ratio from 5.5 to 12 by 2040, see Supplementary Text 1).
Max. depletion rate	Evaporative Brine: 1% to 3% per year. Rest: 2% to 5% per year.
Recovery rate	S&P deposit level data 5 th and 95 th quantiles (weighted by 2025 production or reserves in case of lithium). Cu: 60 to 95%; Ni: 50% to 90%; Co: 55% to 85%; Li: 60% to 90%.
Operational costs (OPEX)	From 90% prediction intervals (5 th and 95 th) from fitted regression models (see Supplementary Figure 3 and 4). Due to less lithium deposits on production, we use the 50 th and 99 th prediction quantiles for the lower and upper bounds. For deposits with S&P cost ¹ estimations we assume a variation of -10% to 10%.
Opening and capacity expansion costs (CAPEX)	From 80% prediction intervals (10 th and 90 th) from fitted regression models (see Supplementary Figure 5 and 6). Due to uncertain fit on lithium capacity expansion coefficient, we assume variation of -30% to 30%.

Supplementary Text 1 | LFP share and Ni-Co ratio estimation

IEA demand scenarios do not indicate the main assumptions in their modeling, so we have to reverse-engineer an estimation for LFP (Lithium Iron Phosphate) battery chemistry share in their mineral demand for electric vehicles lithium-ion batteries.

We assume only two major lithium-ion chemistries in the electric vehicle forecast: LFP and NMC (Nickel Manganese Cobalt). We further assume a 6.6 Ni-Li ratio for NMC, which roughly equals the ratio for NMC811 and NCA (Nickel Cobalt Aluminum), two widely used battery nickel chemistries, using default mineral content (in kg per kWh of storage) from BatPaC 5.2 model²⁴. Under these assumptions we can estimate the share of LFP (α) at each year and scenario using the IEA mineral demand projections for nickel and lithium, as:

$$\frac{IEA\ Nickel_t}{IEA\ Lithium_t} = \frac{Q[kWh] \times ((1 - \alpha)NMC_{Ni} + \alpha LFP_{Ni})}{Q[kWh] \times ((1 - \alpha)NMC_{Li} + \alpha LFP_{Li})}$$

Taking into advantage that LFP has no nickel (LFP_{Ni}=0) and that the lithium content in NMC and LFP are roughly equal at 90 grams per kWh²⁴, the equation becomes:

$$\frac{IEA\ Nickel_t}{IEA\ Lithium_t} = \frac{(1 - \alpha)NMC_{Ni}}{NMC_{Li}}$$

Assuming a Ni-Li ratio content of 6.6:

$$\alpha = 1 - \frac{\frac{IEA\ Ni_t}{IEA\ Li_t}}{\frac{NMC_{Ni}}{NMC_{Li}}} = 1 - \frac{IEA\ Ni_t / IEA\ Li_t}{6.6}$$

The results indicate that all three IEA scenarios assume a roughly static share of LFP around 55% from 2025 to 2035, and then a linear increase to 65% by 2050.

The Ni-Co ratio assumption from IEA can be simply calculated as electric vehicle nickel demand divided by cobalt demand. Results indicate that IEA assumes a Ni-Co ratio of around 5.5 in 2025, with a linear increase towards 12 by 2040, and static until 2050. This reflects the shifts of nickel battery chemistries towards higher nickel content (e.g. NMC811 over NMC532 or NMC111).

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