Supplementary Information to ”Critical mineral requirements for the Paris Agreement will depend on the future we end up in”

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This Supplementary Information describes the scenario assumptions, clean-technology deployment trajectories and technology coverage used to estimate future demand for copper, cobalt, graphite, lithium, nickel and rare-earth elements. Results are presented for five Shared Socioeconomic Pathways, SSP1–SSP5, evaluated under baseline and Paris-aligned futures. Supplementary Figures 1 and 2 document the technology-deployment and socioeconomic assumptions, Supplementary Figure 3 disaggregates global annual mineral demand by end-use technology, and Supplementary Figure 4 reports the regional battery-chemistry assumptions. The complete set of technologies and modelling units is provided in Supplementary Table 1

1 Technology projections and assumptions

The deployment trajectories shown in Supplementary Figure 1 provide the annual technology activity outputs (for the 4 dominant clean energy technologies: solar PV, onshore and offshore wind, battery storage and electric vehicles) from the integrated assessment model which are subsequently used in the stock-flow calculations. The annual demand is broken down by technology and pathway and shown for both the baseline and Paris-aligned futures.

While Paris alignment requires faster or greater deployment than the corresponding baseline future across all technologies and pathways, both the timing and magnitude of deployment vary substantially among the five socioeconomic pathways. Several trajectories are non-monotonic, illustrating that pathways with comparable climate ambition can generate different annual peaks and different compositions of material demand.

Figure 1: Clean technology deployment under baseline and Paris futures for potential Shared Socioeconomic Pathways.
Annual deployment trajectories from 2026 to 2050 are shown for solar photovoltaic capacity, offshore wind capacity, onshore wind capacity, battery storage energy capacity and battery electric vehicles. Columns correspond to SSP1–SSP5 and rows correspond to the five technology groups. Dashed blue lines denote the baseline future and solid orange lines denote the Paris-aligned future. Deployment is expressed as GW yr^{-1} for solar and wind technologies, TWh yr^{-1} for battery-storage energy capacity and million vehicles yr^{-1} for battery-electric vehicles. These trajectories are used to calculate the annual technology specific material requirements in each scenario. SSP, Shared Socioeconomic Pathway.

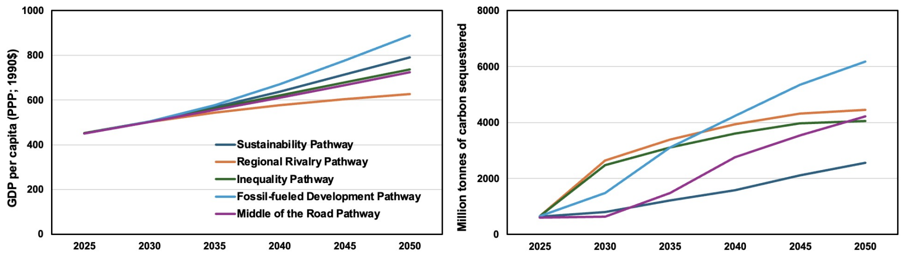

Figure 2: Left, assumed GDP per capita, expressed in purchasing-power-parity-adjusted 1990 dollars. Right, assumed carbon sequestration, expressed as Mt $CO2\ yr^{-1}$. Lines represent SSP1 (Sustainability), SSP2 (Middle of the Road), SSP3 (Regional Rivalry), SSP4 (Inequality) and SSP5 (Fossil-fuelled Development). The trajectories provide scenario-specific socioeconomic and carbon-management conditions for the Paris-aligned technology-deployment pathways.

Supplementary Figure 2 presents the socioeconomic and carbon-management assumptions that underpin the Shared Socio-economci pathways. The pathways begin from similar GDP-per-capita values but diverge increasingly after 2030. By 2050, GDP per capita is highest in SSP5 and lowest in SSP3. The assumed level of carbon sequestration also varies markedly, with the largest 2050 value in SSP5 and the smallest in SSP1. The IAM assumes that GDP is unchanged by the required emission mitigation in the different futures (i.e., GDP per capita under SSP1 is the same in both the baseline and the Paris-aligned future). In the baseline material demand results we see that demand for each mineral under the different pathways correlated with the GDP in each pathway. Under the Paris-aligned future pathways GDP is a less good predictor of future material demand. The required carbon sequestration in each (Paris-aligned) pathway highlights the additional technology requirements for delivering the Paris Agreement beyond critical mineral demand. Specifically, SSP5 requires fewer minerals than other pathways, but this is traded off against the increased requirement for carbon sequestration technology after 2040.

2 Technology contributions to critical mineral demand

Supplementary Figure 3 attributes global annual mineral demand to the technologies responsible for that demand. The six minerals have distinct temporal and technological profiles because their demand depends on both the scale of technology deployment and the material intensity of each technology. Battery related applications account for a substantial share of cobalt, graphite, lithium and nickel demand, whereas copper and rare-earth-element demand is distributed across both transport and power sector technologies. Several scenarios exhibit temporary peaks rather than monotonic growth, demonstrating that pressures on annual mineral supply can differ substantially from cumulative or end of period requirements.

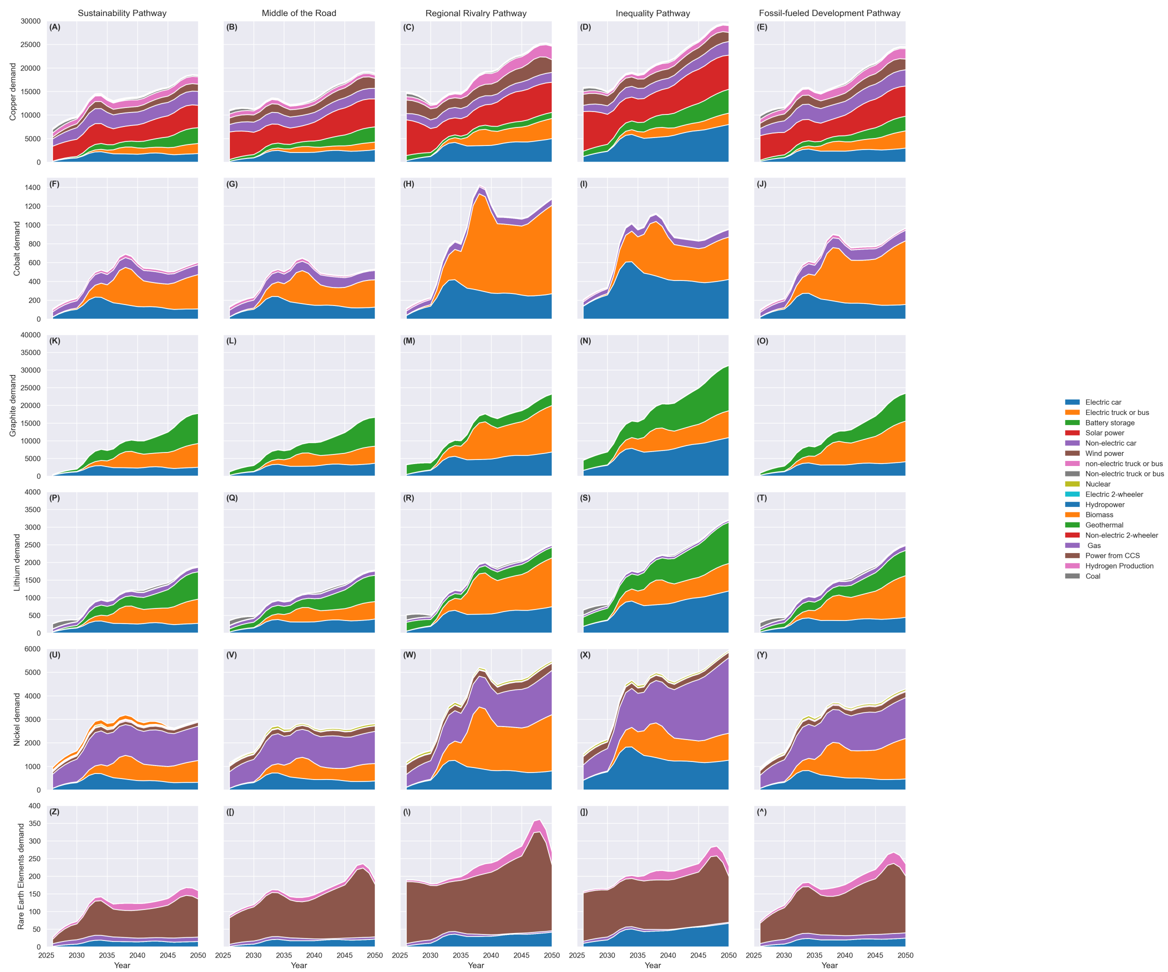

Figure 3: Rows show annual demand for copper, cobalt, graphite, lithium, nickel and rare-earth elements, and columns show SSP1–SSP5. Stacked areas indicate the contribution of each end-use technology to total global demand from 2026 to 2050; colours are held constant across panels. The height of each stack equals total annual demand for the corresponding mineral, scenario and year. Y-axis scales differ among minerals and should therefore not be compared directly across rows. Demand is expressed as million tonnes per year and represents annual primary material demand.

3 Technology coverage and modelling units

Supplementary Table 1 defines the technology boundary of the material demand model. The analysis includes passenger, bus and freight transport; renewable, nuclear and fossil electricity generation; carbon capture and storage; stationary power storage; and hydrogen production. Deployment is represented per vehicle for transport technologies, per MW of installed capacity for electricity-generation, carbon-capture and hydrogen technologies, and per kWh of energy capacity for battery storage. These deployment units are combined with the corresponding technology level material intensities to calculate annual mineral demand.

Technology Category	**End use technology**	**Power system**	**Unit of analysis**
Passenger transport	Car	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
	Large Car or Truck	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
	Mini Car	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
	2 and 3 wheelers	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
Bus	Bus	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
Freight transport	Heavy truck	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
	Medium Truck	BEV	vehicle
		FCEV	vehicle
		Liquids	vehicle
		Hybrid Liquids	vehicle
	Light Truck	BEV	vehicle
		FCEV	vehicle

Technology Category	End use technology	Power system	Unit of analysis
		Liquids	vehicle
		Hybrid Liquids	vehicle
Renewable energy generation	Offshore wind turbine	Wind	MW
	Onshore wind turbine	Wind	MW
	Solar PV	Solar	MW
	Solar CSP	Solar	MW
	Hydro-dam (small)	Hydropower	MW
	Geothermal	Geothermal	MW
	Biomass	Biomass	MW
Other	Nuclear Power	Nuclear	MW
Fossil fuel energy generation	Gas fired power plant	natural gas	MW
	Oil fired energy generation	Oil	MW
	Coal power plant	Coal	MW
Carbon capture and storage	Biomass + CCS	Biomass	MW
	Coal + CCS	Coal	MW
	Gas + CCS	Natural gas	MW
Power storage	NMC Battery		KWh
	LFP Battery		KWh
Hydrogen production	Electrolysis	Green hydrogen	MW
	Steam Methan Reforming + CCS	Blue hydrogen	MW

Table 1: The table lists the technology category, end-use technology, powertrain or energy system and unit of analysis used in the model. “Liquid-fuel vehicle” refers to a petrol- or diesel-fuelled vehicle, and “hybrid liquid-fuel vehicle” refers to a hybrid vehicle retaining a liquid-fuel powertrain. BEV, battery-electric vehicle; FCEV, fuel-cell electric vehicle; CCS, carbon capture and storage; CSP, concentrated solar power; NMC, nickel–manganese–cobalt; LFP, lithium iron phosphate; SMR, steam methane reforming.

4 Regional battery-chemistry assumptions

Supplementary Figure 4 reports the assumed regional evolution of nickel–manganese–cobalt and lithium iron phosphate battery chemistries. All seven regions move towards a greater share of lithium iron phosphate by 2050, but their initial technology mixes and rates of transition differ. East Asia and the Pacific is already lithium-iron-phosphate-dominant at the beginning of the analysis,

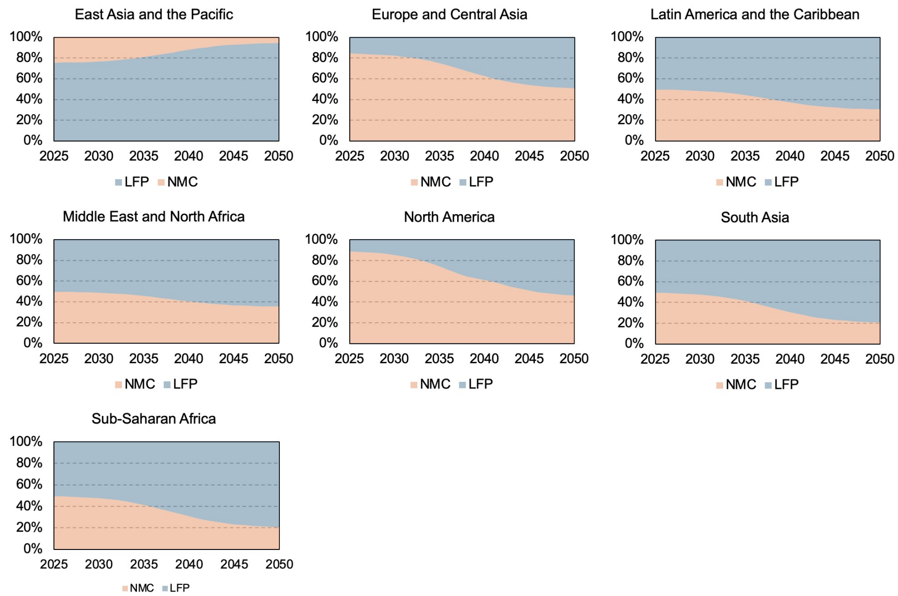

Figure 4: Projected change in battery technologies split by region (2026-2050)

whereas Europe and Central Asia and North America begin with predominantly nickel–manganese–cobalt chemistries and move towards more balanced shares. These assumptions translate regional battery deployment into chemistry-specific mineral requirements and are consequently an important determinant of the temporal and regional demand for nickel, cobalt and lithium. Future adoption of LFP batteries is based on projections by the IEA [1]

References

[1] IEA. Global Critical Minerals Outlook. Technical report, 2025. URL `www.iea.org`.