SUPPLEMENTARY INFORMATION

Schools in the footprint of transition mineral extraction

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This Supplementary Information contains:

Supplementary Note 1 | Indicative interval for the global exposed-child estimate.

The central estimate of 3.91 million primary-school-aged children whose schools fall within 10 km of an active ETM operation derives from the country-stratified proxy described in Methods. For each host country, the national primary-school-aged population is divided by the total Giga school count to obtain an implicit children-per-school ratio, which is then multiplied by the country's count of mine-proximate schools and adjusted by the primary net enrolment rate. The point estimate is reported in the main text. The 3 to 6 million range reflects plausible variation around this value, dominated by three sources of uncertainty.

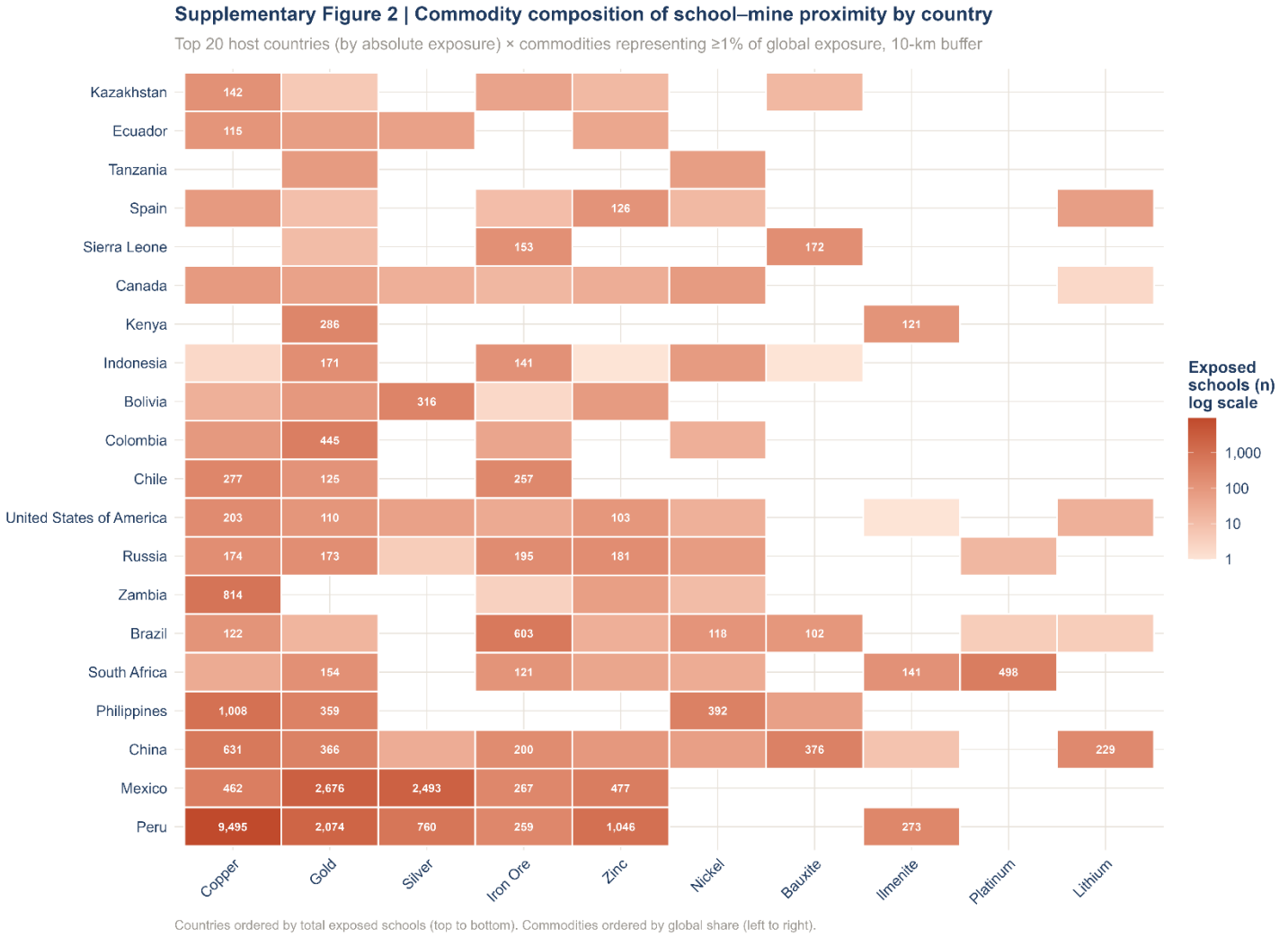
Average school size varies substantially within countries. In many Andean and sub-Saharan contexts, small rural unidocente schools coexist with large urban institutions, and the proxy collapses this variation into a single national mean. A ±30% perturbation of the country-level children-per-school ratio shifts the global estimate to approximately 2.7–5.1 million.

A second source is uneven Giga school coverage. Coverage relative to UNESCO institute for Statistics national totals exceeds 90% in some countries (Senegal, Liberia, several Latin American cases) and falls below 25% in others (Indonesia, Democratic Republic of the Congo). Under-coverage inflates the implicit children-per-school ratio, which partially compensates the under-count of exposed schools. The net direction of bias at global aggregation is uncertain. A correction that assumes proportional under-counting in low-coverage countries lifts the central estimate toward 4.6 million.

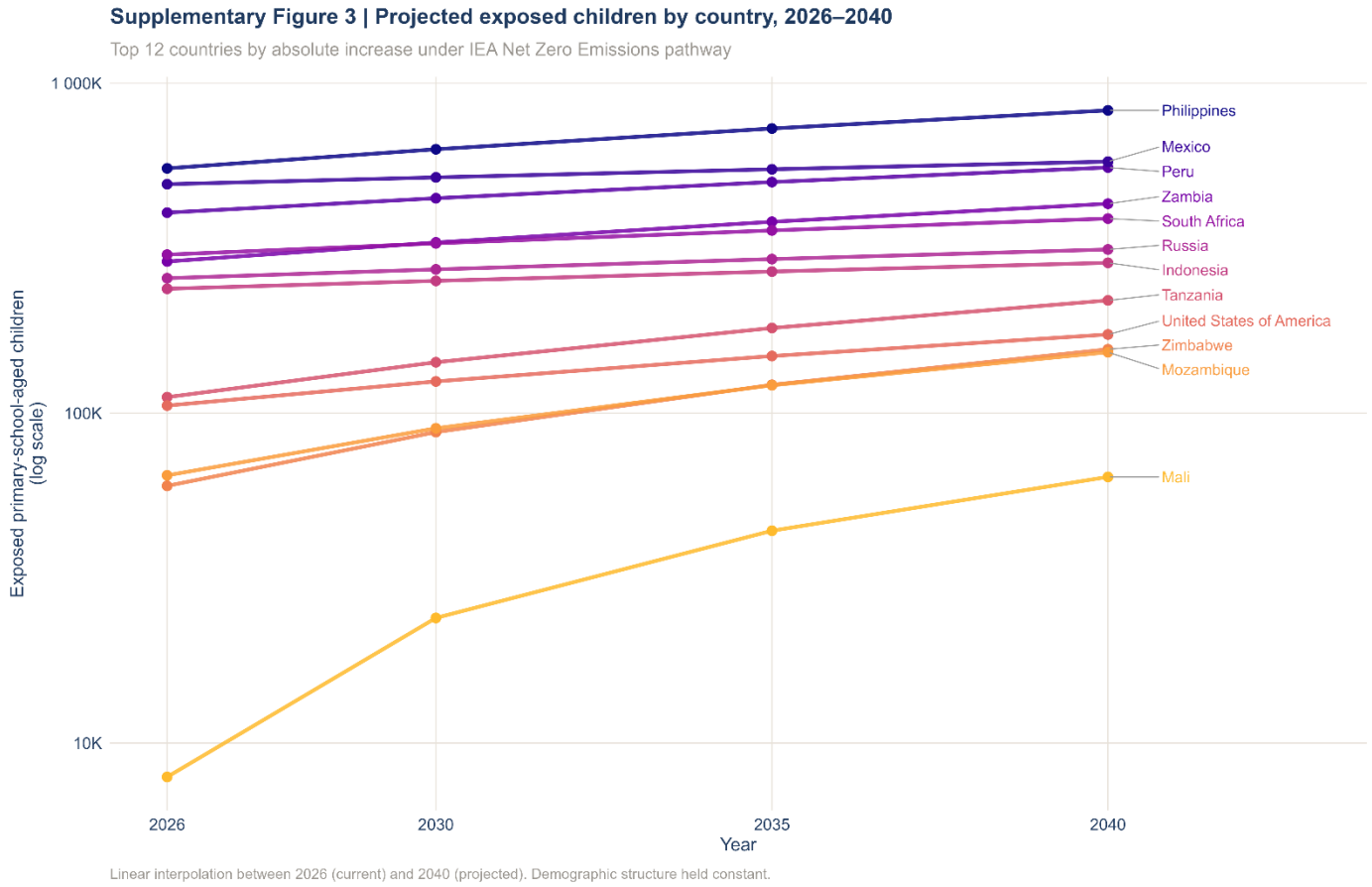
Net enrolment ratios introduce a third source of variation, ranging from 44% to 99% across the sample. The proxy applies the country-level value uniformly to all exposed schools in that country. In several high-exposure countries with above-average rural school participation (Peru, Zambia, Mexico), this approach may slightly understate exposure; in others (Liberia, Mali) it may overstate it.

Combining these three sources non-redundantly yields a plausible range of 3.0 to 6.0 million exposed children. The central estimate of 3.91 million represents the most defensible point value under the stated assumptions. The interval is indicative rather than a formal confidence interval, reflecting parametric uncertainty in the proxy rather than sampling variance.

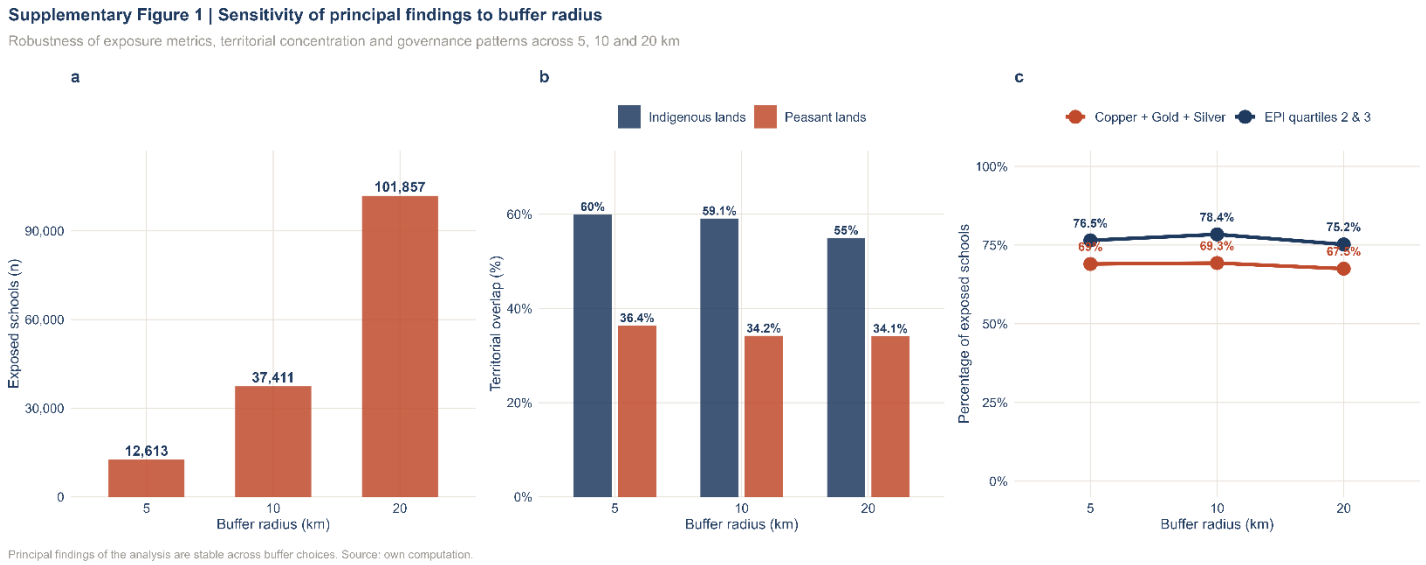
Supplementary Figure 1 | Commodity composition of school–mine proximity by country. Distribution of mine-proximate schools (10-km buffer) by the primary commodity of the nearest active operation, for the top 20 host countries by absolute exposure. Commodities representing at least 1% of global exposure are shown. Cell colour scales logarithmically with the number of exposed schools; numerical labels are shown for cells containing 100 or more schools. Countries are ordered from top to bottom by total exposed schools, and commodities from left to right by global share. National commodity profiles vary substantially: copper-associated operations dominate exposure in Peru (9,495 schools), gold and silver together account for most exposure in Mexico (2,676 and 2,493 schools), nickel drives the Philippine pattern (392 schools), and iron ore shapes exposure in Brazil (603 schools).



Supplementary Figure 2 | Projected exposed children by country, 2026–2040. Projected number of primary-school-aged children whose schools lie within 10 km of an active energy transition mineral operation, for the top 12 countries by absolute increase under the International Energy Agency Net Zero Emissions scenario. Trajectories are computed by linear interpolation between the 2026 baseline (current exposure) and the 2040 projection (current exposure scaled by commodity-specific demand multipliers; Supplementary Table 5). Demographic structure is held constant. The y-axis uses a logarithmic scale to improve visual separation across the full range of country values. The Philippines shows the largest absolute increase under the NZE pathway, reflecting projected nickel demand growth. Mali registers a smaller absolute change but the steepest proportional trajectory, anchored in expanding lithium and graphite operations.



Supplementary Figure 3 | Sensitivity of principal findings to buffer radius. Robustness of the principal findings across alternative buffer radii of 5, 10 and 20 km around each active energy transition mineral operation. a, Absolute number of schools located within each buffer radius (n). b, Proportion of exposed schools located within recognised Indigenous territories and peasant territories at each buffer radius. c, Proportion of exposed schools located in countries within Environmental Performance Index quartiles 2 and 3 (the middle-tier governance trap) and proportion of exposed schools whose nearest mining operation extracts copper, gold or silver. Territorial concentration on Indigenous and peasant lands, middle-tier governance concentration and commodity composition remain stable across buffer choices.



Supplementary Table 1 | Global distribution of school–mine proximity across buffer radii. Number and percentage of schools located within 5, 10 and 20 km of an active energy transition mineral (ETM) operation, proportional overlap on Indigenous and peasant territories at each buffer, and estimated exposed primary-school-aged children at the 10-km buffer. Total sample: 1,291,773 schools across 49 countries.

Buffer radius	Schools (total)	Schools (exposed)	Exposed (%)	Countries with exposure	Indigenous lands (%)	Peasant lands (%)	Children exposed (millions)	Notes
5 km	1,291,773	12,613	1.0	46	60.0	36.4	—	Primary radius lower bound (sensitivity)
10 km	1,291,773	37,411	2.9	48	59.1	34.2	3.91	Primary 10-km buffer used throughout main text
20 km	1,291,773	101,857	7.9	48	55.0	34.1	—	Primary radius upper bound (sensitivity)

Supplementary Table 2 | Country-level school–mine proximity at the 10-km buffer. Total schools, schools within 10 km of an active ETM operation, percentage exposed, estimated exposed primary-school-aged children, estimated exposed children living below the US$6.85-per-day poverty line, Environmental Performance Index (EPI) 2024 score and quartile, ND-GAIN climate vulnerability, double-vulnerability status, and mineral rents as percentage of GDP, reported for each country. Sorted by absolute number of exposed schools.

Country	ISO3	Total schools	Exposed schools (10 km)	Exposed (%)	Estimated children exposed	Estimated children below US$6.85/day	EPI score (2024)	EPI quartile	ND-GAIN vulnerability	Double vulnerable	Mineral rents (% GDP)
Peru	PER	108,515	14,015	12.9	405,307	146,721	46.50	3	0.409	No	12.1
Mexico	MEX	159,541	6,450	4.0	494,297	105,780	44.20	2	0.387	No	1.4
China	CHN	61,224	2,494	4.1	—	—	35.40	1	0.382	No	0.5
Philippines	PHL	39,913	1,820	4.6	552,187	324,134	32.10	1	0.444	Yes	1.5
South Africa	ZAF	25,539	1,339	5.2	302,326	180,186	42.70	2	0.395	No	3.8
Brazil	BRA	165,952	1,257	0.8	121,637	25,057	53	3	0.369	No	4.5
Zambia	ZMB	12,177	1,194	9.8	288,246	270,951	46.70	3	0.485	Yes	28.3
Russia	RUS	36,926	1,004	2.7	256,496	2,308	46.70	3	0.324	No	2.0
United States of America	USA	143,404	678	0.5	105,444	1,898	57.20	4	0.312	No	0.1
Chile	CHL	12,826	663	5.2	65,689	2,956	49.60	3	0.332	No	16.2
Colombia	COL	46,645	636	1.4	54,333	20,103	49.70	3	0.405	No	0.9
Bolivia	BOL	15,660	570	3.6	49,985	8,697	45.30	2	0.451	Yes	5.9
Indonesia	IDN	48,378	442	0.9	238,265	155,349	33.60	1	0.430	No	1.9
Kenya	KEN	29,700	439	1.5	98,285	88,555	36.90	1	0.500	Yes	0.0
Canada	CAN	15,313	378	2.5	61,534	369	61.10	4	0.282	No	1.2
Sierra Leone	SLE	11,941	363	3.0	39,270	35,932	39.90	2	0.597	Yes	0.2
Spain	ESP	34,441	342	1.0	24,388	561	64	4	0.305	No	0.1
Tanzania	TZA	27,826	328	1.2	111,830	102,325	43.60	2	0.516	Yes	4.0
Ecuador	ECU	9,188	277	3.0	48,640	14,641	51.30	3	0.461	Yes	0.0
Kazakhstan	KAZ	6,913	244	3.5	74,173	11,274	47.80	3	0.316	No	9.1
Sweden	SWE	10,578	231	2.2	15,554	233	70.30	4	0.317	No	1.0
Uzbekistan	UZB	10,438	210	2.0	86,098	10,676	42.60	2	0.359	No	8.5
Turkiye	TUR	16,694	204	1.2	78,811	3,231	37.20	1	0.375	No	0.6
Australia	AUS	10,338	194	1.9	35,105	527	63.10	4	0.316	No	10.5
Zimbabwe	ZWE	7,913	186	2.4	60,187	51,881	51.60	3	0.498	Yes	4.2
Portugal	PRT	8,259	184	2.2	11,903	262	61.90	4	0.318	No	0.1
Ghana	GHA	34,709	151	0.4	18,488	—	36.90	1	0.448	Yes	5.2

Country	ISO3	Total schools	Exposed schools (10 km)	Exposed (%)	Estimated children exposed	Estimated children below US$6.85/day	EPI score (2024)	EPI quartile	ND-GAIN vulnerability	Double vulnerable	Mineral rents (% GDP)
Dem. Rep. Congo	COD	7,291	145	2.0	—	—	39.50	2	0.561	Yes	28.8
Mozambique	MOZ	12,865	144	1.1	64,781	62,384	39	2	0.493	Yes	0.1
Argentina	ARG	47,558	117	0.3	9,636	1,465	47	3	0.383	No	0.6
Serbia	SRB	3,887	111	2.9	10,180	916	49.80	3	0.422	No	0.7
Liberia	LBR	4,962	96	1.9	7,599	—	34.30	1	0.538	Yes	5.4
Finland	FIN	2,505	95	3.8	12,304	49	73.80	4	0.280	No	0.1
Romania	ROU	18,142	78	0.4	4,234	216	57.30	4	0.412	No	0.0
Greece	GRC	12,100	55	0.5	2,456	79	67.30	4	0.337	No	0.1
Bulgaria	BGR	3,843	42	1.1	3,523	155	56.20	4	0.354	No	0.6
Senegal	SEN	14,696	38	0.3	5,508	4,329	43.80	2	0.535	Yes	2.9
Mali	MLI	11,810	35	0.3	7,892	6,992	34.50	1	0.576	Yes	16.2
Norway	NOR	3,600	35	1.0	3,504	14	69.90	4	0.256	No	0.0
Madagascar	MDG	3,488	29	0.8	39,898	38,541	30.10	1	0.558	Yes	0.0
Mongolia	MNG	863	25	2.9	12,846	3,134	37.20	1	0.365	No	26.6
Guinea	GIN	15,284	20	0.1	2,401	1,839	36.50	1	0.529	Yes	0.0
Burkina Faso	BFA	5,379	17	0.3	9,787	8,847	42.20	2	0.521	Yes	15.4
New Caledonia	NCL	326	13	4.0	—	—	—	—	—	No	16.8
Cote d'Ivoire	CIV	3,120	8	0.3	12,092	9,782	42.90	2	0.489	Yes	2.5
Mauritania	MRT	2,739	6	0.2	1,539	1,096	34.60	1	0.578	Yes	9.6
Venezuela	VEN	4,099	5	0.1	3,092	—	53.30	3	0.373	No	0.1
Kyrgyzstan	KGZ	2,080	4	0.2	1,614	1,053	42.80	2	0.311	No	11.2
Suriname	SUR	185	0	0.0	0	0	56.90	4	0.404	No	0.0

Suriname (SUR) hosts ETM project entries in the Owen et al. catalogue but no schools fell within any buffer radius. Em dashes (—) indicate countries lacking complete World Bank demographic data.

Supplementary Table 3 | Commodity composition of school–mine proximity at the 10-km buffer. Distribution of 37,411 mine-proximate schools by primary commodity of the nearest active operation, ranked by absolute number of exposed schools. The table also reports cumulative percentages and the subtotal corresponding to the seven energy transition minerals identified by the International Energy Agency: copper, nickel, lithium, lanthanides and rare earth elements, manganese, cobalt, and graphite.

Commodity	Exposed schools	Share of total (%)	Cumulative (%)
Copper	14,253	38.1	38.1
Gold	7,748	20.7	58.8
Silver	3,929	10.5	69.3
Iron Ore	2,550	6.8	76.1
Zinc	2,441	6.5	82.7
Nickel	1,135	3.0	85.7
Bauxite	749	2.0	87.7
Ilmenite	652	1.7	89.4
Platinum	554	1.5	90.9
Lithium	464	1.2	92.1
Lanthanides	369	1.0	93.1
Manganese	359	1.0	94.1
Lead	352	0.9	95.0
Tin	348	0.9	96.0
Chromite	219	0.6	96.5
Cobalt	205	0.6	97.1
Tungsten	203	0.5	97.6
Graphite	191	0.5	98.2
Molybdenum	155	0.4	98.6
Vanadium	131	0.3	98.9
Heavy Mineral Sands	101	0.3	99.2
Niobium	96	0.3	99.4
Phosphate	71	0.2	99.6
U3O8	60	0.2	99.8
Rutile	29	0.1	99.9
Tantalum	28	0.1	99.9
Titanium	9	0.0	100.0
Palladium	7	0.0	100.0
Potash	2	0.0	100.0

Commodity	Exposed schools	Share of total (%)	Cumulative (%)
Antimony	1	0.0	100.0
ETM-classified subtotal*	**16,976**	**45.4**	**—**

**ETM = energy transition minerals as identified by the International Energy Agency.*

Supplementary Table 4 | Spearman rank correlations between exposure metrics and country covariates. Spearman correlation coefficients (ρ), two-tailed p-values, and sample sizes for associations between the proportion of schools within 10 km of an active ETM operation (% exposed) and the estimated number of exposed primary-school-aged children, and 15 country-level covariates. Sample: up to n = 49 host countries (n varies with covariate availability).

Covariate	ρ (% exposed)	p (% exposed)	n (% exposed)	ρ (children exposed)	p (children exposed)	n (children exposed)
EPI overall score (2024)	0.033	0.823	48	-0.180	0.232	46
EPI Air Quality sub-score	-0.403	0.004	48	-0.517	<0.001	46
EPI Heavy Metals sub-score	0.264	0.070	48	0.147	0.328	46
EPI Health sub-score	-0.192	0.190	48	-0.373	0.011	46
EPI Waste Management sub-score	0.151	0.306	48	-0.073	0.628	46
Mineral rents (% of GDP)	0.287	0.045	49	0.246	0.100	46
ND-GAIN overall index	0.217	0.139	48	0.041	0.787	46
ND-GAIN vulnerability	-0.154	0.295	48	-0.043	0.775	46
ND-GAIN readiness	0.243	0.096	48	0.037	0.808	46
Primary net enrolment rate	0.329	0.026	46	0.176	0.241	46
Poverty headcount US$2.15/day (%)	-0.185	0.223	45	0.136	0.385	43
Poverty headcount US$6.85/day (%)	-0.127	0.408	45	0.098	0.531	43
GDP per capita (USD)	0.198	0.174	49	0.025	0.870	46
Population aged 0-14 (%)	-0.214	0.140	49	0.011	0.940	46
Rural population (%)	-0.168	0.247	49	-0.082	0.587	46

Bold associations (EPI Air Quality, Mineral rents) are statistically significant at p < 0.05. No multiple-comparison correction applied (see Methods).

Supplementary Table 5 | Commodity-specific demand multipliers under the IEA Net Zero Emissions scenario (2040). Multipliers used to project 2040 school–mine proximity by commodity under the IEA Net Zero Emissions pathway, derived from the Global Critical Minerals Outlook 2024. Commodities with documented clean-energy demand pathways that the IEA does not report individually (silver, platinum, vanadium) received conservative scaled multipliers; those without a transition-driven demand pathway received a multiplier of 1.0. The table reports the resulting projected schools and absolute growth.

Commodity	Current exposed schools	NZE 2040 multiplier	Projected 2040 exposed schools	Absolute growth	Growth (%)
Copper	14,253	1.5	21,380	7,127	50
Lithium	464	9.0	4,176	3,712	800
Silver	3,929	1.3	5,108	1,179	30
Nickel	1,135	2.0	2,270	1,135	100
Graphite	191	4.0	764	573	300
Zinc	2,441	1.2	2,929	488	20
Lanthanides	369	2.0	738	369	100
Platinum	554	1.5	831	277	50
Cobalt	205	2.0	410	205	100
Bauxite	749	1.2	899	150	20
Manganese	359	1.4	503	144	40
Vanadium	131	1.5	196	65	50
Tin	348	1.1	383	35	10
Phosphate	71	1.5	106	35	50
Tungsten	203	1.1	223	20	10
Niobium	96	1.2	115	19	20
U3O8	60	1.3	78	18	30
Tantalum	28	1.1	31	3	10
Titanium	9	1.2	11	2	20
Gold	7,748	1.0	7,748	0	0
Iron Ore	2,550	1.0	2,550	0	0
Ilmenite	652	1.0	652	0	0
Lead	352	1.0	352	0	0
Chromite	219	1.0	219	0	0
Molybdenum	155	1.0	155	0	0
Heavy Mineral Sands	101	1.0	101	0	0
Rutile	29	1.0	29	0	0
Palladium	7	1.0	7	0	0
Potash	2	1.0	2	0	0

Commodity	Current exposed schools	NZE 2040 multiplier	Projected 2040 exposed schools	Absolute growth	Growth (%)
Antimony	1	1.2	1	0	20

Supplementary Table 6 | Country-level projected school–mine proximity in 2040 (IEA NZE scenario). Projected mine-proximate schools and exposed primary-school-aged children in 2040 under the IEA Net Zero Emissions pathway, computed by applying commodity-specific demand multipliers (Supplementary Table 5) to currently exposed schools at the 10-km buffer, reported for each country. Sorted by absolute additional exposed children. China, the Democratic Republic of the Congo and New Caledonia appear in the school projections but lack the complete World Bank demographic data required to project exposed children.

Country	ISO3	Schools (current)	Schools (projected 2040)	Growth factor	Children (current)	Children (projected 2040)	Additional children by 2040
Philippines	PHL	1,820	2,728	1.5	552,187	827,552	275,365
Peru	PER	14,015	19,206	1.4	405,307	555,440	150,133
Zambia	ZMB	1,194	1,787	1.5	288,246	431,355	143,109
Tanzania	TZA	328	644	2.0	111,830	219,705	107,875
Zimbabwe	ZWE	186	483	2.6	60,187	156,161	95,975
Mozambique	MOZ	144	340	2.4	64,781	152,999	88,218
South Africa	ZAF	1,339	1,722	1.3	302,326	388,869	86,543
Mexico	MEX	6,450	7,552	1.2	494,297	578,741	84,444
United States of America	USA	678	1,113	1.6	105,444	173,159	67,715
Russia	RUS	1,004	1,227	1.2	256,496	313,416	56,920
Mali	MLI	35	284	8.1	7,892	64,083	56,191
Indonesia	IDN	442	530	1.2	238,265	285,594	47,329
Spain	ESP	342	954	2.8	24,388	68,036	43,648
Canada	CAN	378	630	1.7	61,534	102,491	40,957
Brazil	BRA	1,257	1,646	1.3	121,637	159,241	37,604
Ghana	GHA	151	391	2.6	18,488	47,849	29,361
Uzbekistan	UZB	210	274	1.3	86,098	112,420	26,321
Turkiye	TUR	204	266	1.3	78,811	102,570	23,759
Kazakhstan	KAZ	244	322	1.3	74,173	97,823	23,650
Serbia	SRB	111	353	3.2	10,180	32,375	22,195
Ecuador	ECU	277	359	1.3	48,640	63,004	14,364
Chile	CHL	663	805	1.2	65,689	79,749	14,059
Australia	AUS	194	270	1.4	35,105	48,768	13,662
Portugal	PRT	184	382	2.1	11,903	24,693	12,790
Madagascar	MDG	29	38	1.3	39,898	52,280	12,382
Bolivia	BOL	570	697	1.2	49,985	61,148	11,163
Finland	FIN	95	179	1.9	12,304	23,235	10,931
Colombia	COL	636	714	1.1	54,333	61,039	6,706

Country	ISO3	Schools (current)	Schools (projected 2040)	Growth factor	Children (current)	Children (projected 2040)	Additional children by 2040
Mongolia	MNG	25	38	1.5	12,846	19,526	6,680
Sierra Leone	SLE	363	397	1.1	39,270	42,991	3,721
Argentina	ARG	117	159	1.4	9,636	13,062	3,426
Cote d'Ivoire	CIV	8	10	1.3	12,092	15,115	3,023
Sweden	SWE	231	273	1.2	15,554	18,362	2,808
Guinea	GIN	20	34	1.7	2,401	4,130	1,729
Norway	NOR	35	51	1.4	3,504	5,066	1,562
Kenya	KEN	439	445	1.0	98,285	99,718	1,433
Romania	ROU	78	94	1.2	4,234	5,103	869
Mauritania	MRT	6	9	1.5	1,539	2,309	770
Burkina Faso	BFA	17	18	1.1	9,787	10,478	691
Venezuela	VEN	5	6	1.2	3,092	3,710	618
Greece	GRC	55	66	1.2	2,456	2,966	509
Kyrgyzstan	KGZ	4	5	1.3	1,614	2,018	404
Senegal	SEN	38	38	1.0	5,508	5,508	0
Liberia	LBR	96	96	1.0	7,599	7,599	0
Bulgaria	BGR	42	42	1.0	3,523	3,523	0
China	CHN	2,494	5,046	2.0	—	—	—
Dem. Rep. Congo	COD	145	220	1.5	—	—	—
New Caledonia	NCL	13	25	1.9	—	—	—

Supplementary Table 7 | Sensitivity of principal findings to buffer radius selection. Robustness of the principal findings across alternative buffer radii of 5, 10 and 20 km. The table reports total exposed schools, percentage of the global sample exposed, proportion of exposed schools within recognised Indigenous and peasant territories, and the combined share of copper-, gold- and silver-associated operations. These metrics remain consistent across buffer choices.

Buffer radius	Exposed schools	Exposed (%)	Indigenous lands (%)	Peasant lands (%)	Copper+Gold+Silver (%)
5 km	12,613	1.0	60.0	36.4	67.5
10 km (primary)	37,411	2.9	59.1	34.2	69.3
20 km	101,857	7.9	55.0	34.1	67.4

Supplementary Table 8 | Sensitivity of principal findings to Giga dataset coverage. Comparison of principal findings across four Giga coverage thresholds, retaining countries whose Giga school count meets or exceeds the stated percentage of UNESCO Institute for Statistics national totals. The middle-tier governance pattern is not attenuated by restricting to high-coverage countries. It intensifies. The positive correlation with mineral rents strengthens monotonically from ρ = 0.29 to ρ = 0.48, the negative correlation with EPI Air Quality deepens from ρ = −0.35 to ρ = −0.49, and the composite EPI overall score remains uncorrelated across all thresholds.

Coverage threshold	n countries	Exposed schools	Children (M)	Q2+Q3 (%)	ρ Mineral rents	p Mineral rents	ρ EPI Air Quality	p EPI Air Quality	ρ EPI overall	p EPI overall
Full sample (0%)	49	37,411	3.91	78.4	0.290	0.045	-0.350	0.013	0.030	0.823
≥30%	45	34,735	3.86	83.7	0.320	0.032	-0.370	0.013	0.030	0.830
≥50%	41	34,246	3.60	83.8	0.340	0.032	-0.410	0.008	0.040	0.829
≥70%	35	33,321	3.25	82.6	0.480	0.004	-0.490	0.004	-0.130	0.478

The ≥70% threshold (n = 35) is the restricted sample reported in the main text Results.