Supporting Information

Potential impact of abiotic resource use considering country-specific supply chain: consumption-based characterization and normalization utilizing a multi-regional input-output model

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Table S1. Classification of disaggregated 51 mining sectors.

Commodities
Coal and peat
Crude petroleum
Bituminous or oil shale and tar sands
Natural gas
Uranium and Thorium ores and concentrates
Iron ores and concentrates; Natural micaceous iron oxides
Copper ores and concentrates
Nickel and Cobalt ores and concentrates
Aluminium ores and concentrates
Silver ores and concentrates
Precious metal ores and concentrates nes
Manganese ores and concentrates etc
Lead ores and concentrates
Zinc ores and concentrates
Tin ores and concentrates
Chromium ores and concentrates
Tungsten ores and concentrates
Molybdenum ores and concentrates
Titanium ores and concentrates
Zirconium ores and concentrates
Niobium, tantalum and vanadium ores and concentrates
Antimony ores and concentrates
ores and concentrates nes
Slag and ash nes, including seaweed ash (kelp)
Sand and stones
Natural calcium phosphates, aluminum calcium phosphates etc; Gypsum; Fluorspar
Macadam of slag, dross or similar industrial waste etc
Granules, chippings & powder nes
Bitumen and asphalt; asphaltites and asphaltic rocks
Kaolin; Fire clay; other clays
Bentonite
Decolourising earths and fuller's earth
Andalusite; kyanite and sillimanite
Mullite
Chamotte or dinas earths

Table S1. (continued).

Commodities
Mica; Natural steatite
Unroasted iron pyrites
Emery, Natural Corundum; Natural Garnet and other Natural Abrasives
Natural barium sulphate (barytes); Natural barium carbonate (witherite)
Tarred macadam
Natural sodium borates; Natural borates etc nes
Kieserite, epsomite (natural magnesium sulphates)
Natural cryolite; natural chiolite
Salt
Natural graphite
Natural magnesium carbonate (magnesite)
Magnesia, fused, dead burned etc & magnesium oxide
Asbestos
Felspar
Vermiculite, perlite and chlorites
Mineral substances, nes

Table S2. Correspondence between the target 32 abiotic resources and disaggregated mining sectors.

Abiotic resource	Corresponding mining sector
Silver (Ag)	Silver ores and concentrates
Aluminum (Al)	Aluminium ores and concentrates
Gold (Au)	Precious metal ores and concentrates nes
Boron (B)	ores and concentrates nes
Barium (Ba)	Natural barium sulphate (barytes); Natural barium carbonate (witherite)
Cobalt (Co)	Nickel and Cobalt ores and concentrates
Chromium (Cr)	Chromium ores and concentrates
Copper (Cu)	Copper ores and concentrates
Fluorine (F)	Natural calcium phosphates, aluminum calcium phosphates etc; Gypsum; Fluorspar
Iron (Fe)	Iron ores and concentrates; Natural micaceous iron oxides
Lithium (Li)	ores and concentrates nes
Magnesium (Mg)	Natural magnesium carbonate (magnesite)
Manganese (Mn)	Manganese ores and concentrates etc
Molybdenum (Mo)	Molybdenum ores and concentrates
Niobium (Nb)	Niobium, tantalum and vanadium ores and concentrates
Nickel (Ni)	Nickel and Cobalt ores and concentrates
Phosphorus (P)	Natural calcium phosphates, aluminum calcium phosphates etc; Gypsum; Fluorspar
Lead (Pb)	Lead ores and concentrates
Palladium (Pd)	Precious metal ores and concentrates nes
Platinum (Pt)	Precious metal ores and concentrates nes
Rhenium (Re)	ores and concentrates nes
Antimony (Sb)	Antimony ores and concentrates
Tin (Sn)	Tin ores and concentrates
Tantalum (Ta)	Niobium, tantalum and vanadium ores and concentrates
Titanium, (Ti)	Titanium ores and concentrates
Uranium (U)	Uranium and Thorium ores and concentrates
Vanadium (V)	Niobium, tantalum and vanadium ores and concentrates
Tungsten (W)	Tungsten ores and concentrates
Zinc (Zn)	Zinc ores and concentrates
Oil	Crude petroleum
Natural gas (NG)	Natural gas
Coal	Coal and peat

Table S3. Coefficients of variation for the consumption- and mine production-based characterization factors (CFs) and the share of inducing mine production.

	Coefficient of variation		
	Consumption-based CF	Mine production-based CF	Share of inducing mine production*
Ag	0.09	0.17	0.76
Al	0.30	0.71	0.61
Au	0.06	0.11	0.78
B	0.15	0.82	0.89
Ba	0.32	0.49	0.56
Co	0.17	0.62	0.93
Cr	0.10	0.16	0.56
Cu	0.07	0.21	0.80
F	0.30	0.40	0.47
Fe	0.25	0.37	0.55
Li	0.66	2.29	0.33
Mg	0.47	0.88	0.49
Mn	0.18	0.33	0.75
Mo	0.27	0.78	0.61
Nb	0.12	0.38	1.25
Ni	0.16	0.38	0.67
P	0.45	0.68	0.41
Pb	0.06	0.19	0.72
Pd	0.35	0.54	0.60
Pt	0.65	0.97	0.91
Re	0.14	0.56	0.38
Sb	0.10	0.30	1.08
Sn	0.07	0.39	0.67
Ta	0.38	1.24	0.51
Ti	0.46	1.20	0.57
U	0.26	1.12	0.55
V	0.40	0.60	0.66
W	0.07	0.41	0.96
Zn	0.05	0.12	0.63
oil	0.34	0.63	0.62
NG	0.36	0.52	0.60
coal	0.43	0.93	0.52

* The coefficients of variation were calculated for the Euclidean distance between the share of global mine production (i.e., average share) and that of inducing mine production of each consuming country.

Table S4. Abiotic resource use associated with the production of 1 kWh of the three lithium-ion batteries (LIBs) (Yokoi et al. 2024). NMC: $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$-Graphite LIB, LTO: $LiFePO_4$-$Li_4Ti_5O_{12}$ LIB, LFP: $LiFePO_4$-Graphite LIB (LFP).

	NMC [kg/kWh]	LTO [kg/kWh]	LFP [kg/kWh]
Ag	7.27E-05	1.12E-04	7.34E-05
Al	3.10E-01	1.39E+00	3.63E-01
Au	6.51E-05	1.01E-04	6.57E-05
Ba	8.61E-04	1.33E-03	8.69E-04
Co	2.88E-01	0	0
Cr	6.42E-07	9.94E-07	6.48E-07
Cu	7.72E-01	2.18E-01	8.91E-01
Fe	1.34E+00	3.08E+00	2.23E+00
Li	2.70E-01	5.78E-01	3.21E-01
Mn	2.82E-01	2.20E-02	1.44E-02
Mo	1.67E-05	2.58E-05	1.69E-05
Ni	8.68E-01	1.21E-02	7.92E-03
Pb	2.52E-04	3.89E-04	2.54E-04
Pd	2.07E-06	3.20E-06	2.09E-06
Sn	4.26E-04	6.60E-04	4.30E-04
Ti	2.88E-04	1.79E+00	2.91E-04
Zn	3.38E-05	5.22E-05	3.41E-05

Table S5. Top 20 countries by consumption-based normalization value (NV) per GDP.

	Country	Consumption-based NV [2015$]	GDP [2015$]	Consumption-based NV per GDP (-)
1	Guyana	9.5E+09	3.2E+09	2.97
2	Gabon	6.3E+09	1.4E+10	0.44
3	Oman	2.3E+10	6.8E+10	0.34
4	Aruba	5.7E+08	2.9E+09	0.20
5	Mozambique	2.9E+09	1.6E+10	0.18
6	Trinidad and Tobago	4.2E+09	2.5E+10	0.17
7	Congo	1.2E+09	8.6E+09	0.14
8	Ghana	6.8E+09	4.9E+10	0.14
9	Sierra Leone	5.5E+08	4.2E+09	0.13
10	Uzbekistan	9.5E+09	8.2E+10	0.12
11	Bahamas	1.2E+09	1.2E+10	0.10
12	Papua New Guinea	2.2E+09	2.2E+10	0.10
13	Ukraine	8.6E+09	9.1E+10	0.09
14	Tanzania	4.3E+09	4.7E+10	0.09
15	Colombia	2.6E+10	2.9E+11	0.09
16	Suriname	4.2E+08	4.8E+09	0.09
17	Viet Nam	1.6E+10	1.9E+11	0.08
18	Burkina Faso	9.4E+08	1.2E+10	0.08
19	Kyrgyzstan	5.1E+08	6.7E+09	0.08
20	Hong Kong	2.3E+10	3.1E+11	0.07
	World	2.3E+12	7.4E+13	0.03

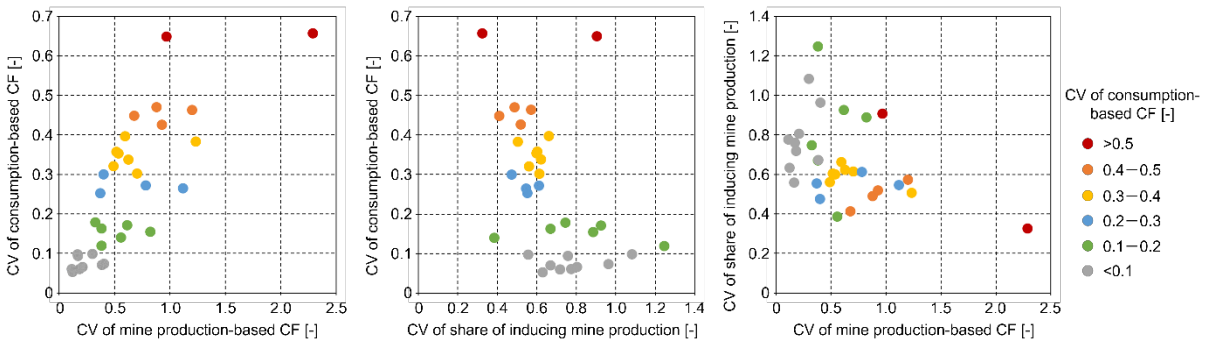

Figure S1. Relationships among the coefficients of variation (CV) for the consumption- and mine production-based characterization factors (CFs) and the share of inducing mine production. The colors of the plots represent CV for the consumption-based CFs.

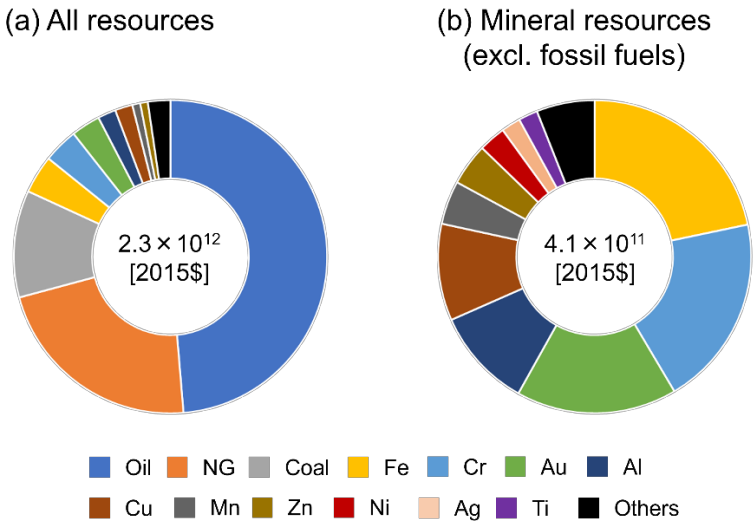

Figure S2. Share of global normalization values (NVs) of abiotic resource use based on user cost (external costs) in 2015. (a) All target abiotic resources. (b) Target abiotic resources excluding fossil fuels. In the case of global NV, consumption- and mining-based accounting shows the same value and share of abiotic resources.

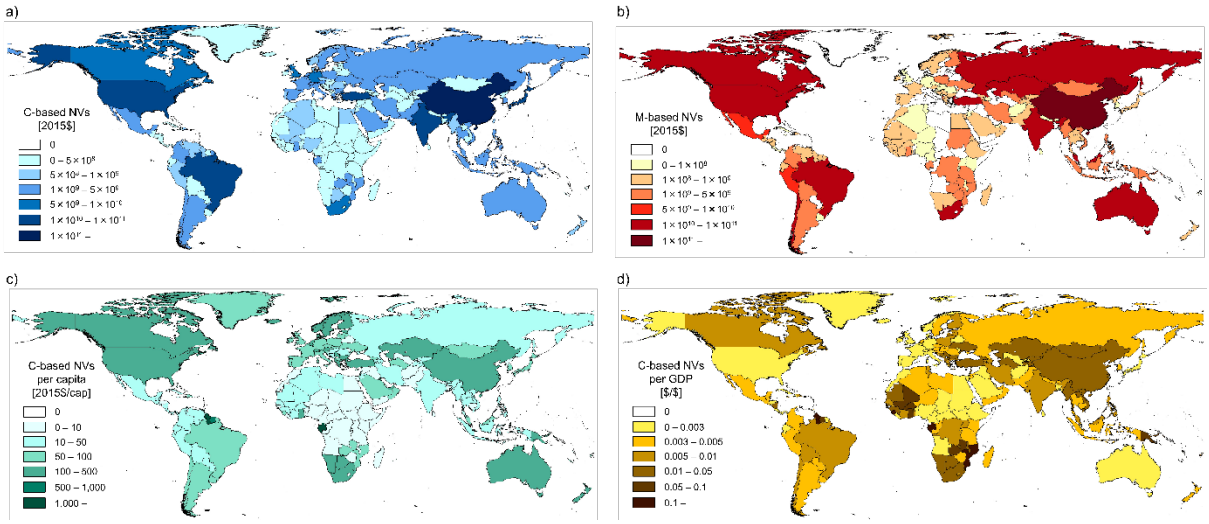

Figure S3. Geographical distributions of consumption-based normalization values (NVs) (a), mine production-based NVs (b), consumption-based NVs per capita (c), and consumption-based NVs per GDP (d) for mineral resource use in 2015. The values are the sum of NVs for the target mineral resources.

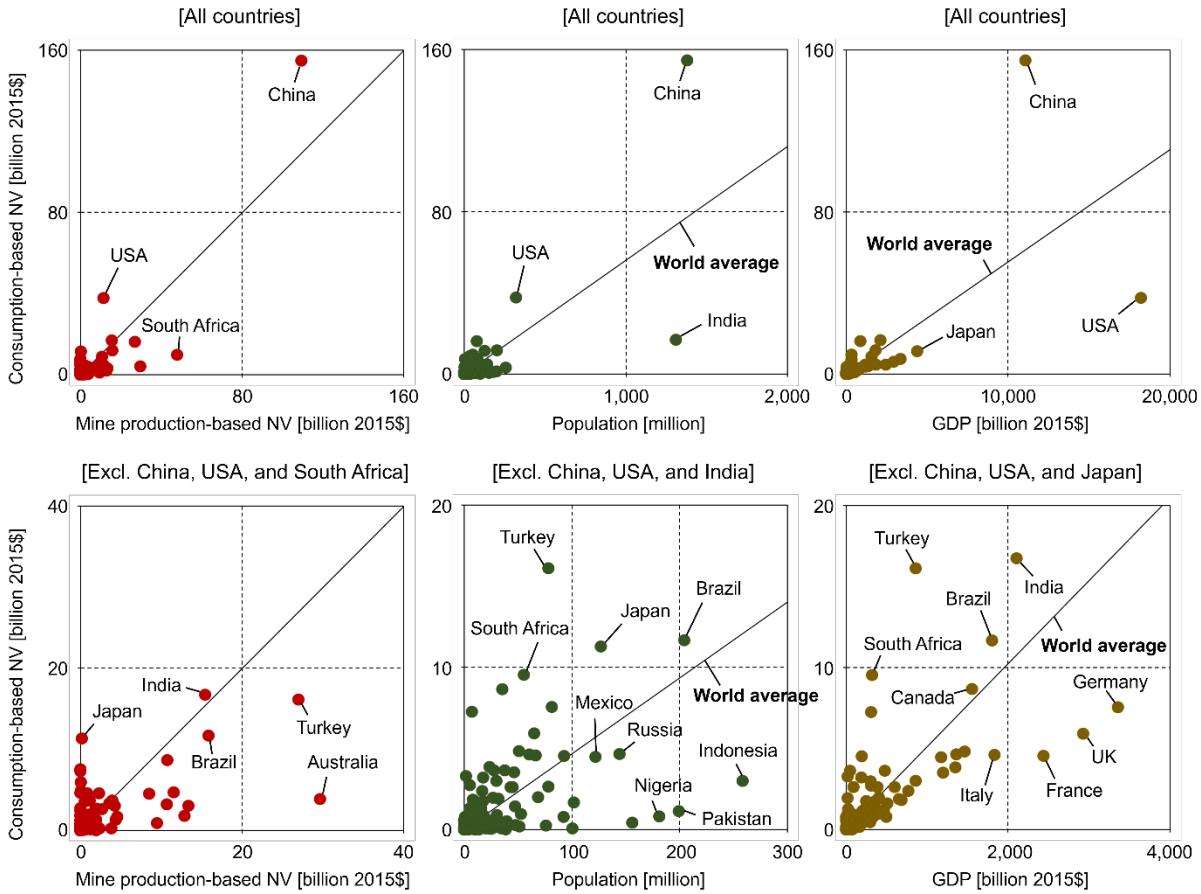

Figure S4. Scatter plots of consumption-based normalization values (NVs) and mine production-based NVs, population, and GDP for mineral resources. The black lines in the population and GDP scatter plots represent the global averages, i.e., ratios of the global NV and global population (or GDP).

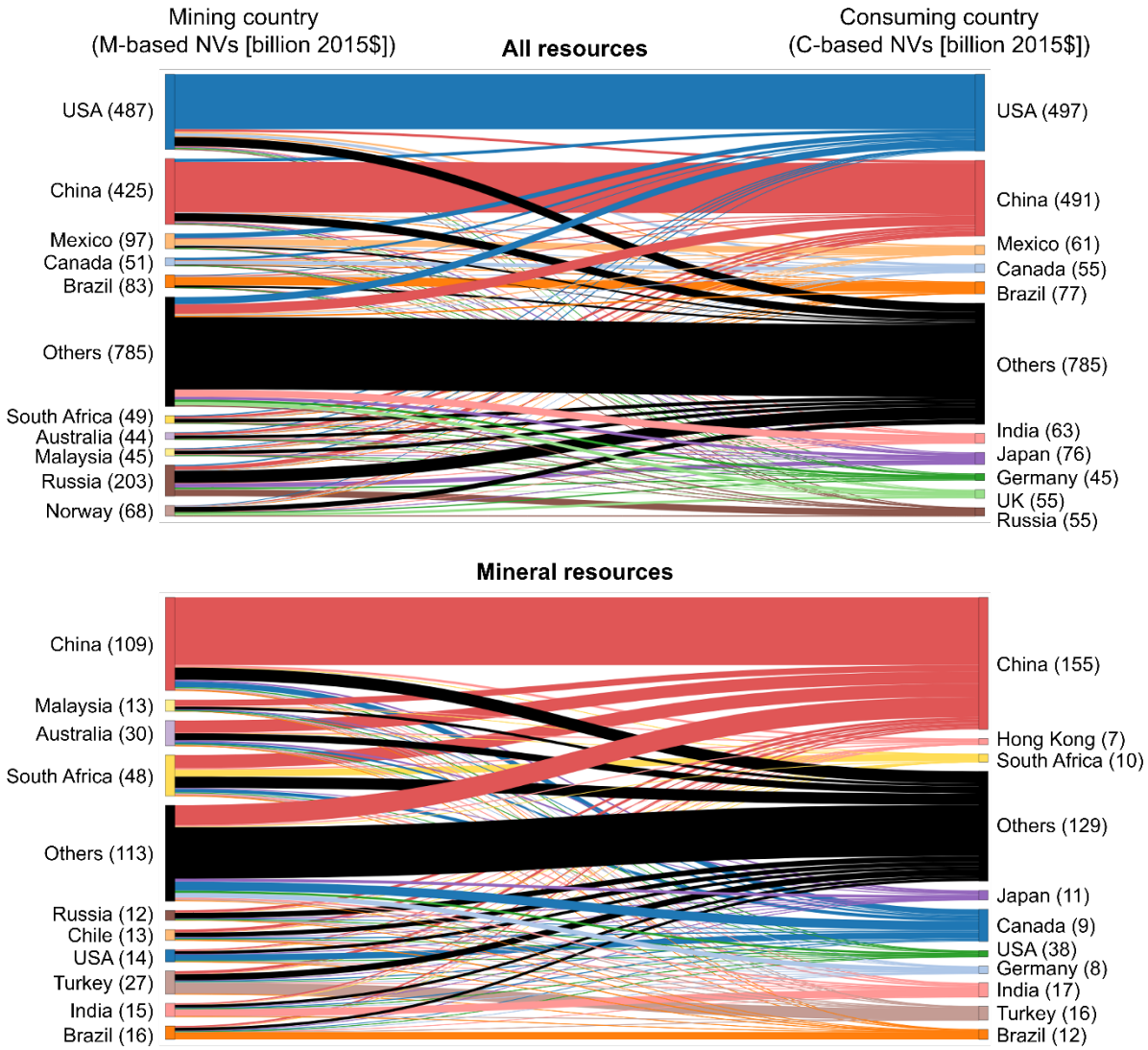

Figure S5. Sankey diagram showing the relationship between mining and consuming countries for normalization values of all abiotic (upper) and mineral (lower) resources. M-based NVs: Mine production-based normalization values; C-based NVs: Consumption-based normalization values.

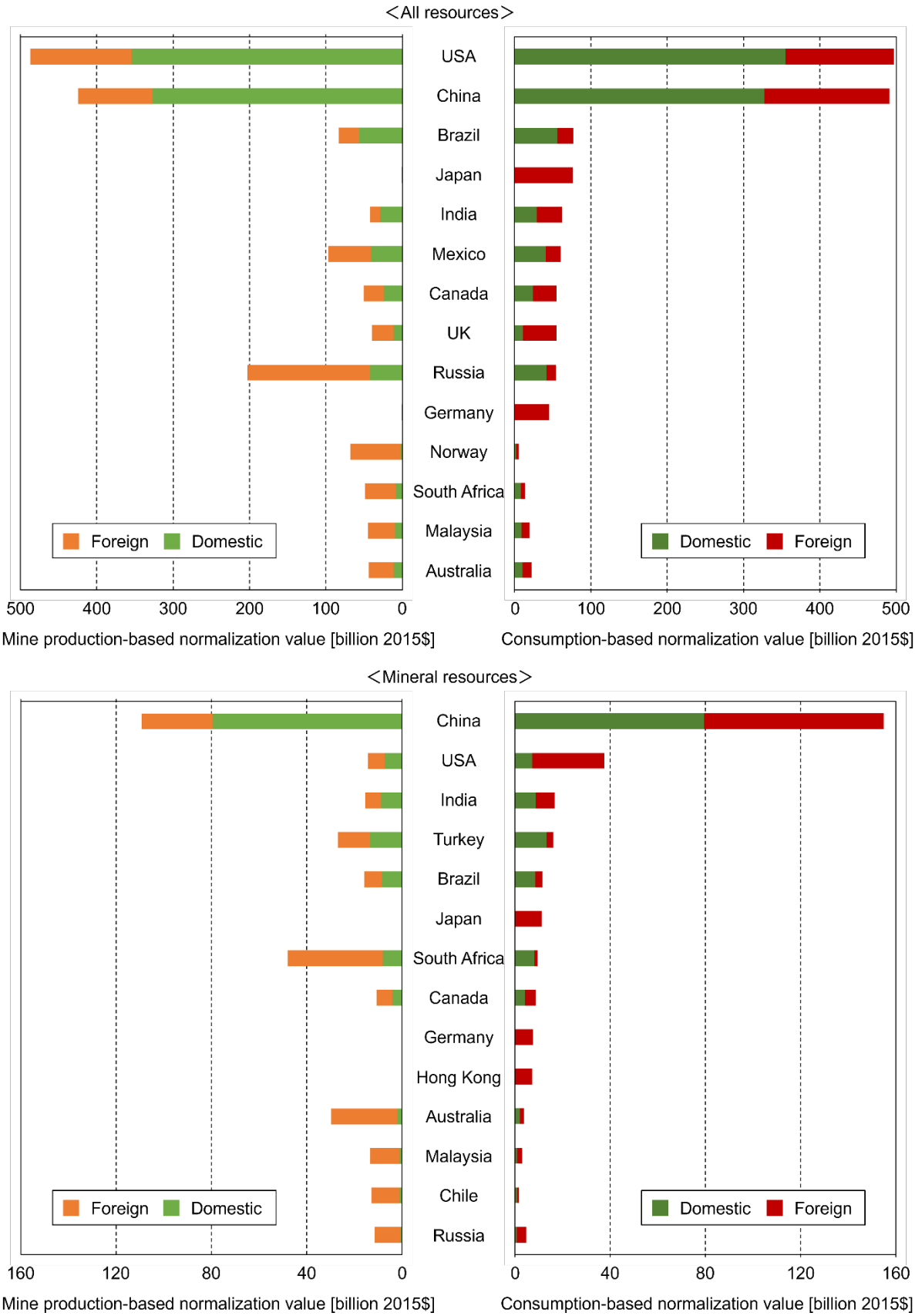

Figure S6. Share of induced impacts in-country and by foreign countries (left) and inducing impacts in-country and in foreign countries (right) covering the top 10 countries for each normalization value.

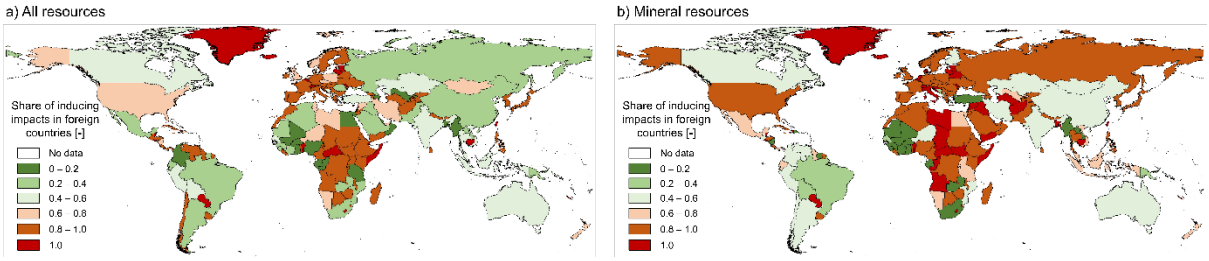

Figure S7. Geographical distributions of the share of inducing impacts in foreign countries.

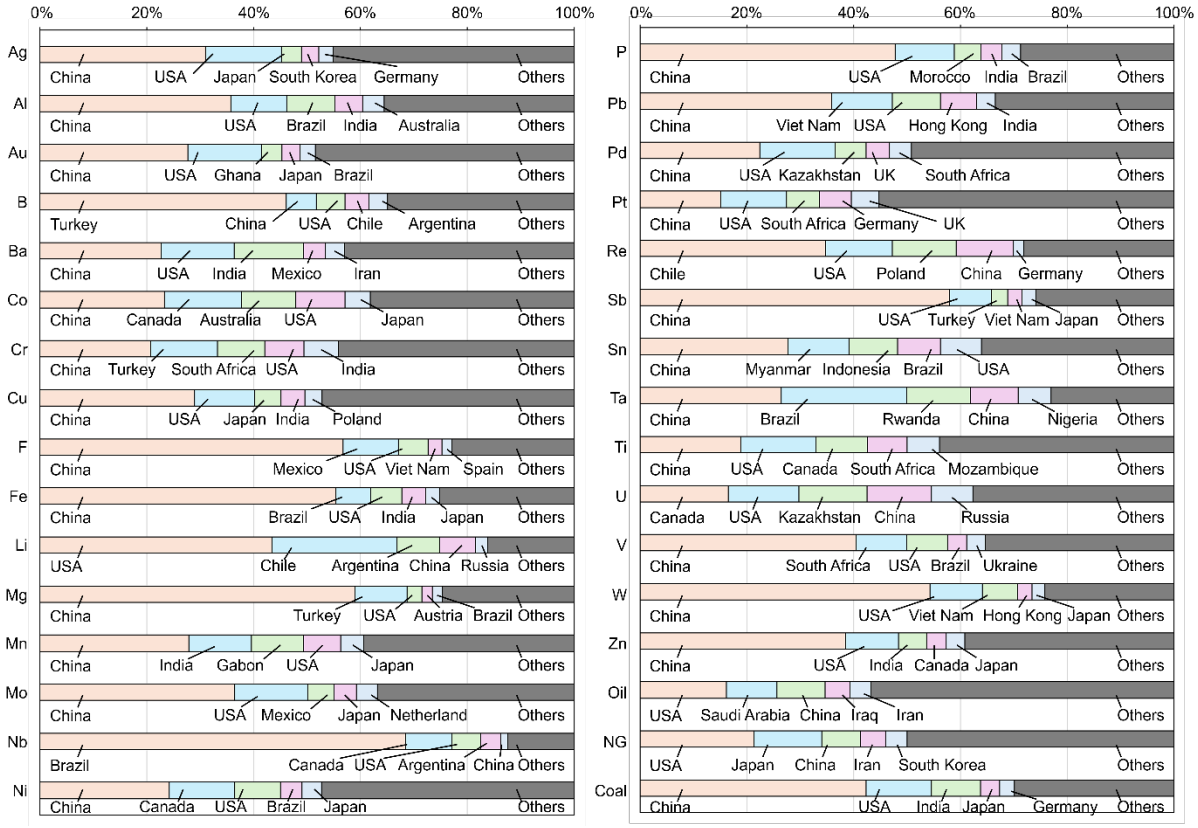

Figure S8. Share of inducing mine production in 2015.

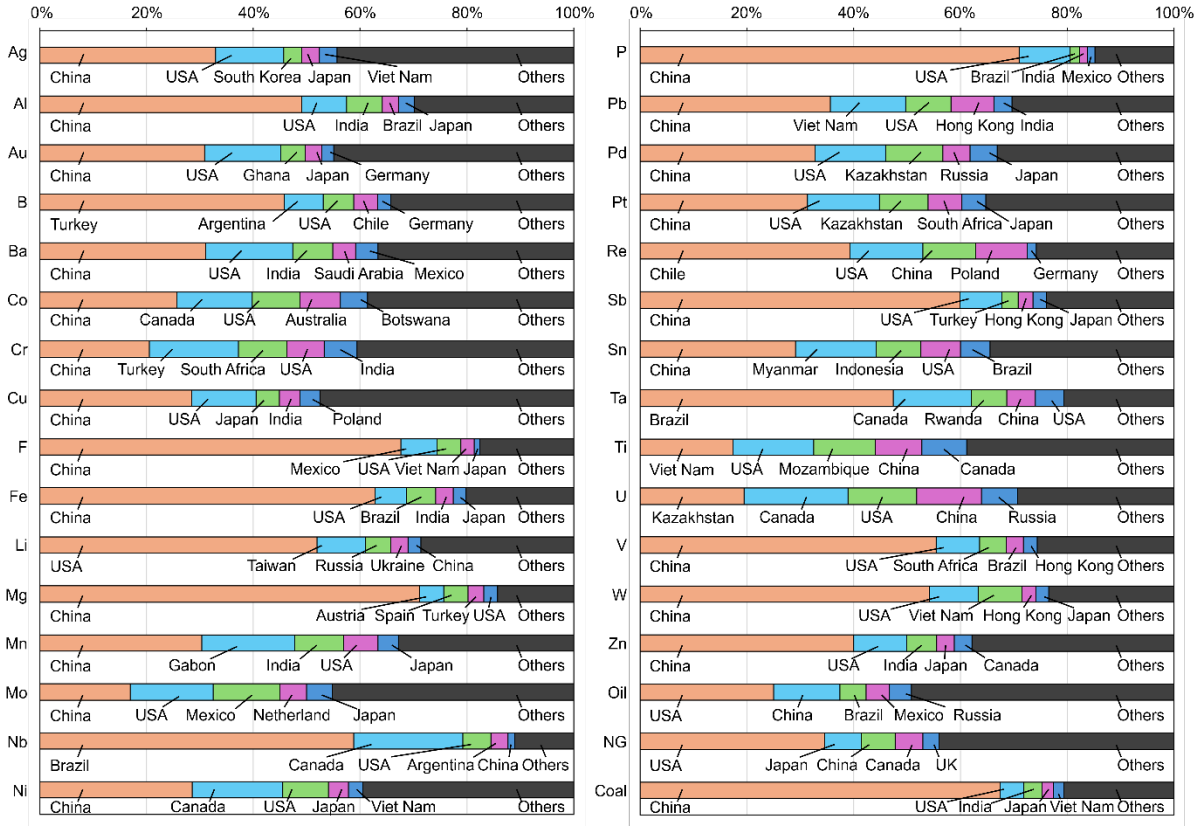

Figure S9. Share of inducing user cost in 2015.

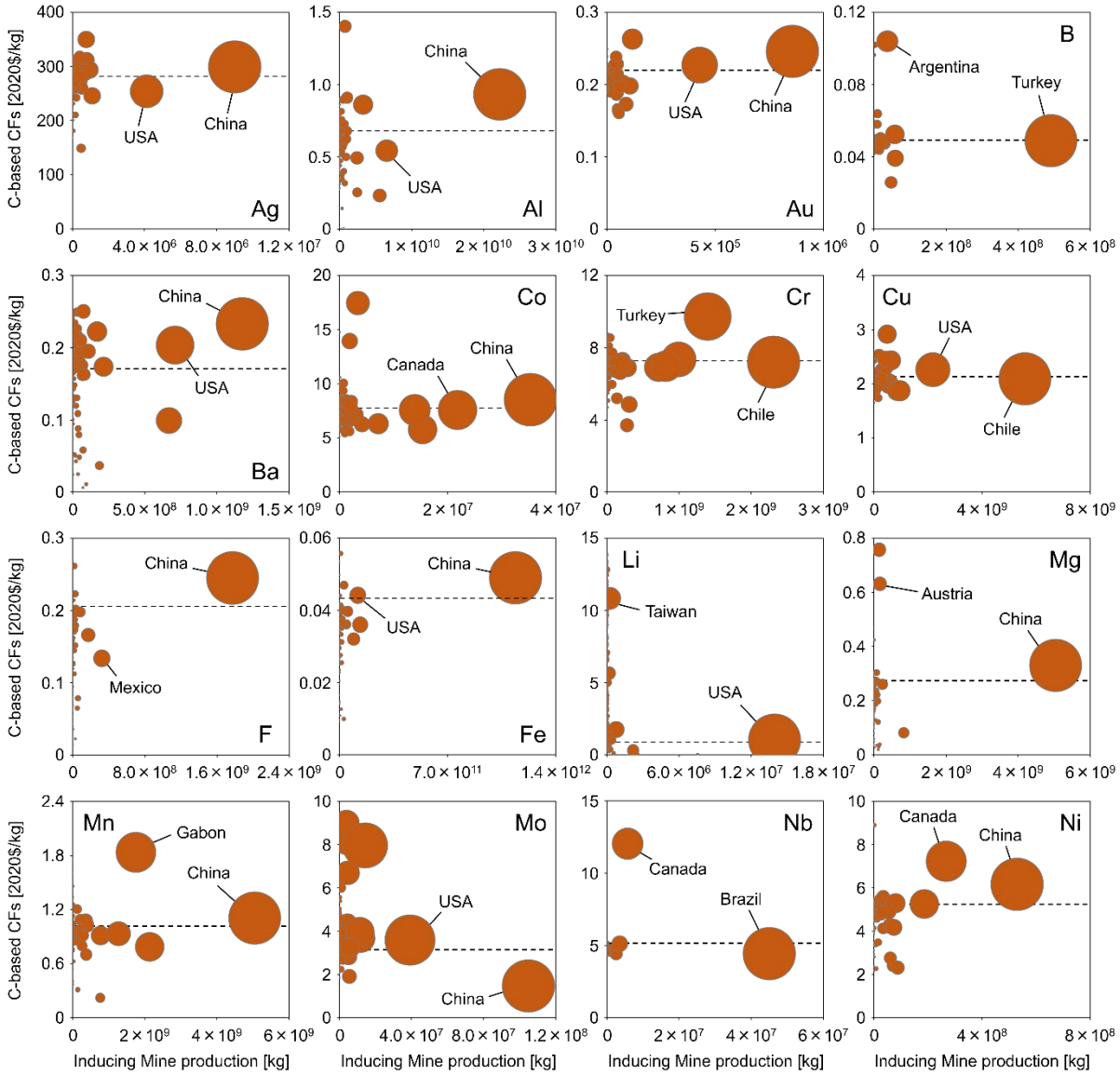

Figure S10. Relationships between inducing mine production and consumption-based characterization factors (C-based CFs) in 2015. The size of the circles represents the inducing external cost, which is calculated by multiplying the inducing mine production and C-based CFs. The weighted average of C-based CFs is shown by dotted lines.

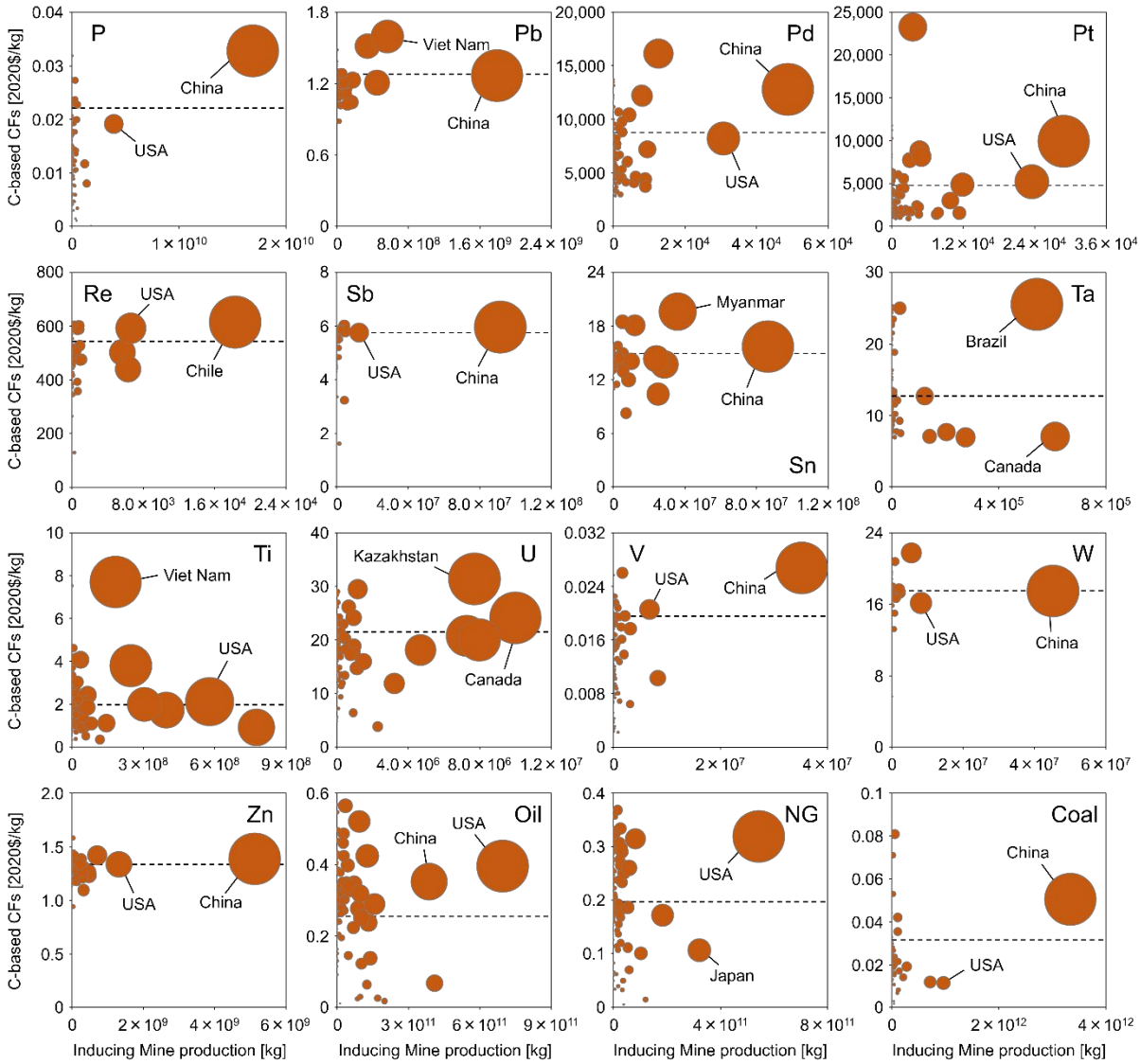

Figure S10. (continued)

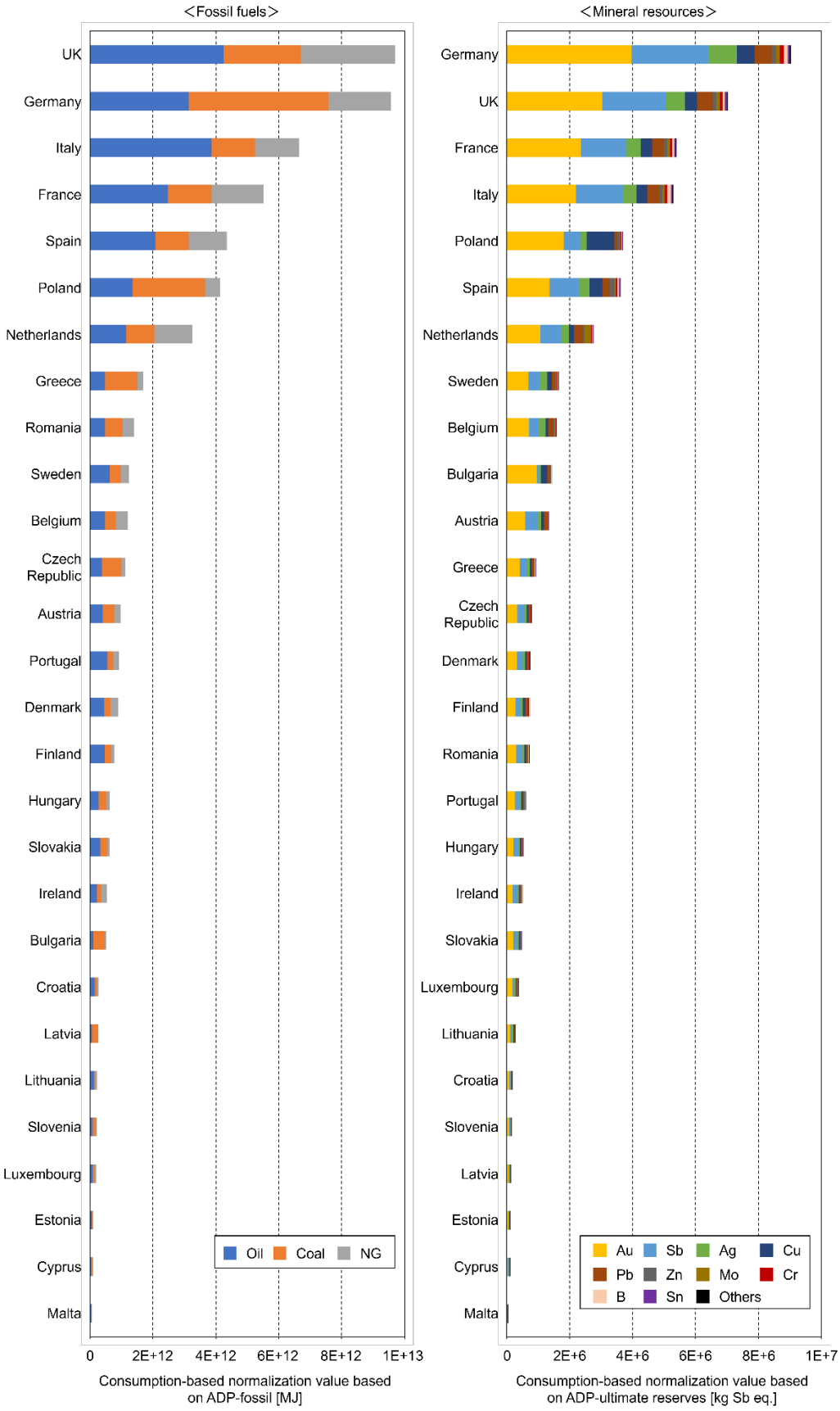

Figure S11. Share of fossil fuels (left) and mineral resources (right) in consumption-based normalization values in 28 EU countries based on the abiotic depletion potential (ADP) in this study.

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