Supplementary Materials: Taking the Step towards a More Dynamic View on Raw Material Criticality: An Indicator Based Analysis for Germany and Japan

Simon Glöser-Chahoud, Luis Tercero Espinoza, Rainer Walz and Martin Faulstich

In the following supplementary data we provide supporting information regarding trade codes, production data and calculated indicator values as well as a rough overview of indicators used in previous criticality studies.

1. Data sources

Production data at the country level in order to calculate the concentration of production (Herfindahl-Hirschman-Index (HHI)) and the domestic consumption for the indicators in the corresponding paper are based on data from the US Geological Survey (USGS [1]). Table S1 summarizes the trade codes (Harmonized System) used for the trade data assessment based on UN Comtrade database (see UN Comtrade website http://comtrade.un.org/). The level of detail regarding trade statistics for specific high-tech metals is a major limitation of the approach introduced in the corresponding paper. For several high-tech metals (such as indium, gallium, hafnium, niobium or tantalum) a specific analysis of trade flows is not possible as the trade flows of these commodities are only reported in association with other substances. The same is true for specific substances from element groups such as specific Rare Earth Elements (REEs) or Platinum Group Metals (PGMs) for which only platinum and palladium are reported separately.

Table S1. HS codes (Harmonized System) relevant for the trade data analysis using the UN Comtrade database. The material contents, which are only needed for the calculation of the first indicator in the corresponding paper (Equation 1) due to the comparison to global production levels, were estimated from stoichiometric balances and literature data [2]. However, for some commodities a significant level of uncertainty remains regarding material contents.

Raw Material	H0-Code	Commodity Description UN Comtrade	Material Content in %
Antimony	261710	Antimony ores and concentrates	70
Antimony	282580	Antimony oxides	80
Antimony	811000	Antimony and articles thereof, including waste and scrap	100
Beryllium	811219	Beryllium, articles thereof, nes	100
Beryllium	811211	Beryllium, unwrought, waste or scrap/powders	100
Bismuth	283422	Bismuth nitrates	55
Bismuth	283693	Bismuth carbonate	82
Bismuth	810600	Bismuth, articles thereof, waste or scrap	100
Chromium	283323	Chromium sulphates	26
Chromium	261000	Chromium ores and concentrates	33
Chromium	281910	Chromium trioxide	68
Chromium	281990	Chromium oxides, hydroxides except chromium trioxide	62
Chromium	811220	Chromium, articles thereof, waste or scrap/powders	100
Cobalt	260500	Cobalt ores and concentrates	20
Cobalt	282200	Cobalt oxides and hydroxides; commercial cobalt oxides	74
Cobalt	810510	Cobalt mattes and other intermediate products of cobalt metallurgy;	95
Cobalt	291523	Cobalt acetates	25

Raw Material	H0-Code	Commodity Description UN Comtrade	Material content in %
Gallium, Indium, Hafnium	811291	Rare metals nes, unwrought/waste or scrap (incl. Gallium, but not exclusive)	100
Germanium	282560	Germanium oxides and zirconium dioxide	79
Gallium, Indium, Hafnium	811299	Articles of rare metals nes	100
Germanium	811230	Germanium, articles thereof, waste or scrap/powders	100
Lithium	282520	Lithium oxide and hydroxide	40
Lithium	283691	Lithium carbonates	19
Magnesium	251910	Natural magnesium carbonate (magnesite)	29
Magnesium	251990	Magnesia, fused, dead-burned etc and magnesium oxide	60
Magnesium	281610	Magnesium hydroxide and peroxide	50
Magnesium	810411	Magnesium unwrought >99.8% pure	100
Magnesium	810419	Magnesium unwrought nes	100
Manganese	260200	Manganese ores, concentrates, iron ores >20% Manganese	50
Manganese	282010	Manganese dioxide	63
Manganese	282090	Manganese oxides other than manganese dioxide	70
Molybdenum	261310	Molybdenum concentrates, roasted	67
Molybdenum	261390	Molybdenum ores and concentrates except roasted	54
Molybdenum	282570	Molybdenum oxides and hydroxides	70
Molybdenum	810210	Molybdenum, powder	100
Molybdenum	810291	Molybdenum, unwrought, bars/rods simply sintered,scra	100
Niobium and Tantalum	261590	Niobium, tantalum and vanadium ores and concentrates	10
Niobium and Tantalum	810310	Unwrought tantalum, including bars and rods obtained simply by sintering	100
Palladium	711021	Palladium unwrought or in powder form	100
Platinum	711011	Platinum unwrought or in powder form	100
Platinum-Group	711041	Iridium, osmium and ruthenium unwrought or powder for	100
Platinum-Group	711031	Rhodium unwrought or in powder form	100
Rare Earths	280530	Rare-earth metals, scandium and yttrium	100
Rare Earths	284610	Cerium compounds	75
Rare Earths	284690	Compounds, mixes of rare-earths, yttrium, scandium ne	80
Selenium	280490	Selenium	100
Silver	261610	Silver ores and concentrates	20
Silver	284321	Silver nitrate	65
Silver	284329	Silver compounds other than silver nitrate	70
Silver	710610	Silver powder	100
Silver	710691	Silver in unwrought forms	100
Tellurium	280450	Boron, Tellurium	100
Tin	260900	Tin ores and concentrates	30
Tin	800110	Tin not alloyed unwrought	100
Tin	800120	Tin alloys unwrought	10
Titanium	261400	Titanium ores and concentrates	50
Titanium	282300	Titanium oxides	65
Titanium	810810	Titanium, unwrought, waste or scrap, powders	100
Tungsten	261100	Tungsten ores and concentrates	68
Tungsten	810110	Powders, tungsten (wolfram)	100
Tungsten	810191	Tungsten unwrought, bars/rods simply sintered, scrap	100
Vanadium	282530	Vanadium oxides and hydroxides	60
Mercury	280540	Mercury	100
Gold	284330	Gold compounds	55
Gold	710811	Gold powder non-monetary	100
Gold	710812	Gold in unwrought forms non-monetary	100
Silicon	280461	Silicon, >99.99% pure	100
Silicon	280469	Silicon, <99.99% pure	98
Silicon	281122	Silicon dioxide	47
Silicon	284920	Silicon carbide	70
Vanadium	811240	Vanadium, articles thereof, waste or scrap/powders	100
Vanadium	261590	Niobium, tantalum and vanadium ores and concentrates	30

2. Supply risk indicators in previous criticality studies

As discussed in the corresponding paper, the supply risk dimension within the criticality analysis is calculated from the concentration of production and the concentration of imported materials at the country level (taking the Herfindahl-Hirschman-Index (HHI) as a concentration measure). These concentration measures are classical risk indicators that already were relevant when analyzing a region's dependence on strategic raw materials and geopolitical risks during the Cold War [3,4]. In current multi indicator based static criticality studies further subindicators are taken into account for the analysis of supply risk (see Table S2). However, the concentration of production at the country level still is the most important indicator for measuring supply risk and import dependency plays an important role in current criticality studies.

Table S2. Indicators applied to assess raw material supply risk in different recent static criticality assessments (cf. Achzet and Helbig (2013) [5]). Note that only metals are included in the listed critical raw materials while industrial minerals and organic materials which were also assessed in several studies are excluded.

Study \ Indicator	Concentration of production country level	Static depletion time	Byproduct Share	Conc. of Production Corporation Level	Alteration Rate of Demand	Recyclingrate	Substitutability	Import Dependency	Price Level	Price Volatility	Abundance	Alteration Rate of Supply	Metals Assigned Critical
"Minerals, Critical Minerals, and the U.S. Economy" [6]		⊗	⊗			⊗		⊗					Rh, Re, Mn, Sb, Ga, In, Pt, Pd, REE
"Design in an Era of Constrained Resources" [7]	⊗		⊗		⊗		⊗		⊗	⊗	⊗		REE, Ga, In, Pt, Pd
"Critical raw materials for the EU" [8,9]	⊗					⊗	⊗						REE, Mg, Nb, Ge, In, Ga, Co, Be, PGM, Cr, Si, Sb, W
"Critical Materials Strategy" [10,11]	⊗	⊗	⊗	⊗	⊗								Dy, Eu, Tb, Y, Nd
"Critical raw materials for Germany" [12]	⊗	⊗	⊗	⊗		⊗	⊗	⊗					Re, Ge, Sb, W, In, Bi, REE, Ga, Pd, Ag, Sn, Nb
"Criticality of metals and metalloids" [13]	⊗	⊗	⊗										Ga, Se, PGM, Au, Hg, Cr, Nb, W, Mo
"Criticality Assessment of Metals for Japan's Resource Strategy" [14]	⊗	⊗	⊗			⊗		⊗	⊗	⊗			Nd, Dy, Nb, In, Co, Mn, Ag, Zn, Ta, Pt, Pd
"Ensuring resource availability for the UK economy" [15]	⊗	⊗											Ag, Rh, Hg, Pt, Sr, Ag, Sb, Sn, Mg, W
"Critical Metals in Strategic Energy Technologies" [16,17]	⊗		⊗		⊗								Nd, Dy, Ge, Ga, In, Pt, Pd, Y, Tb
"Critical Metals for Future Sustainable Technologies" [18]	⊗	⊗	⊗										REE, Ga, In, Pt, Pd
"Raw Materials for Future Technologies" [19,20]					⊗								Li, Nd, Ge, Dy, Pt, Ta, Ag, In, Ga
Frequency of indicator application	9	7	7	2	4	4	3	3	2	2	1	0	

3. Additional results

Table S3 contains the calculated indicator values for the relative economic importance (Figure 5 in the corresponding paper) for Germany. The respective indicator values for Japan are listed in Table S4.

Table S3. Calculated values of Indicators 1–3 (cf. corresponding paper Figure 5) for Germany (only those commodities with values significantly > 1 are listed).

Year	Mg	W	Ti	REEs	Ge	Bi	Pt	Pd	PGMs
Indicator 1									
2004	1.08	1.54	1.79	0.97	1.02	2.92	0.33	0.42	0.78
2005	1.57	1.16	1.87	0.23	0.89	2.15	1.11	1.12	2.00
2006	1.59	0.65	1.82	1.11	1.09	2.41	0.95	1.70	0.91
2007	1.68	2.02	2.11	1.31	1.24	1.75	0.81	0.61	0.64
2008	1.81	2.24	2.30	1.72	1.80	2.32	0.22	2.34	1.28
2009	2.04	2.76	2.39	1.71	1.93	2.95	0.16	2.46	2.23
2010	1.95	4.02	2.28	1.52	1.70	2.77	1.39	2.34	2.75
2011	2.00	3.68	2.28	1.58	1.90	2.74	1.36	2.46	2.62
2012	1.90	3.40	2.36	1.33	1.74	2.66	1.40	2.28	2.60
Indicator 2									
2004	1.07	1.52	1.99	1.24	1.14	2.89	0.37	0.47	0.87
2005	1.75	1.29	2.10	0.30	0.99	2.39	1.24	1.26	2.24
2006	1.78	0.73	1.93	1.34	1.15	2.70	1.01	1.80	0.97
2007	1.78	2.14	2.20	1.57	1.29	1.85	0.84	0.64	0.66
2008	1.89	2.33	2.00	1.71	1.57	2.41	0.20	2.04	1.11
2009	1.78	2.40	2.48	2.03	2.01	2.57	0.17	2.56	2.32
2010	2.02	4.17	2.33	1.78	1.74	2.87	1.42	2.40	2.81
2011	2.10	3.70	2.50	1.80	2.00	2.86	1.50	2.45	2.75
2012	2.00	3.50	2.39	1.70	1.75	2.75	1.40	2.20	2.80
Indicator 3									
2004	1.64	2.33	2.48	1.54	1.42	4.42	0.46	0.58	1.08
2005	2.18	1.61	2.58	0.37	1.22	2.98	1.53	1.55	2.77
2006	2.20	0.90	2.63	1.83	1.57	3.33	1.37	2.44	1.31
2007	2.43	2.92	3.08	2.19	1.81	2.52	1.17	0.89	0.93
2008	2.64	3.26	3.74	3.20	2.93	3.38	0.36	3.81	2.08
2009	3.33	4.50	3.49	2.86	2.82	4.80	0.24	3.60	3.26
2010	2.85	5.88	3.38	2.57	2.52	4.05	2.05	3.47	4.07
2011	2.90	5.50	3.20	2.70	2.75	4.00	1.90	3.70	3.80
2012	2.75	5.00	3.50	2.10	2.60	3.90	2.10	3.50	3.70

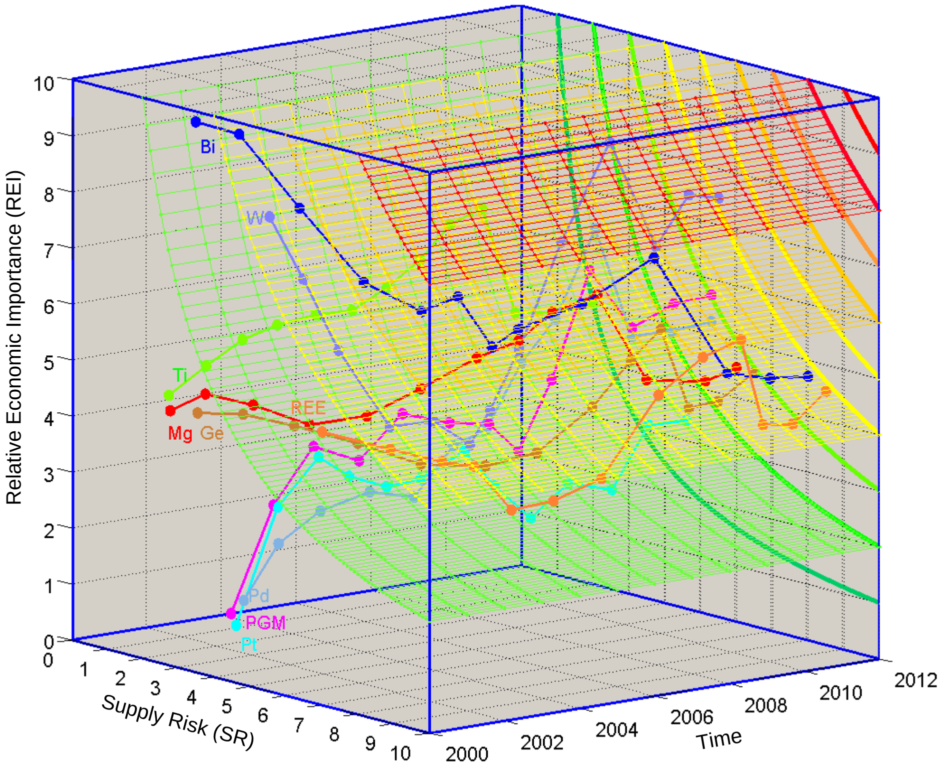
In addition to Figure 7 in the corresponding paper, Figure S1a displays the criticality matrix enhanced by the dimension of time with criticality levels included, while Figure S1b shows the criticality matrix with grey background which might increase the readability. Table S5 contains the normalized values of the relative economic importance and the supply risk, respectively.

Table S4. Calculated values of Indicators 1–3 (cf. corresponding paper Figure 5) for Japan (only those commodities with values significantly > 1 are listed).

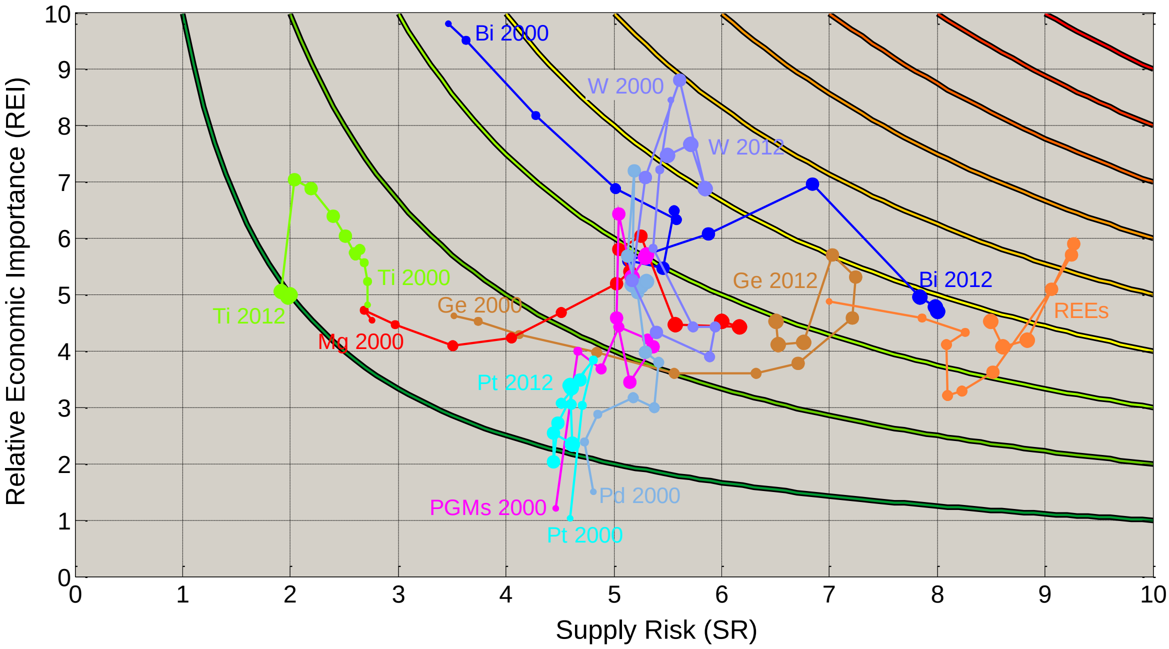
Year	REEs	Ge	Li	Pt	Pd	PGMs
Indicator 1						
2004	1.26	1.47	1.17	1.83	1.49	0.96
2005	1.57	1.49	0.96	0.71	1.31	1.69
2006	0.61	1.31	1.69	2.59	2.02	1.74
2007	2.22	2.02	1.74	2.73	2.62	1.94
2008	2.34	2.62	1.94	2.17	2.22	1.87
2009	1.86	2.22	1.87	2.66	2.12	2.29
2010	2.28	2.12	2.29	2.86	2.93	2.30
2011	2.28	2.31	2.21	2.85	2.84	2.42
2012	2.19	2.24	2.10	2.73	2.71	2.24
Indicator 2						
2004	1.94	1.93	1.55	2.54	2.07	1.34
2005	2.54	2.07	1.34	0.91	1.68	2.17
2006	0.91	1.68	2.17	3.49	2.72	2.34
2007	3.49	2.72	2.34	3.40	3.26	2.41
2008	3.40	3.26	2.41	2.41	2.47	2.08
2009	2.41	2.47	2.08	2.93	2.33	2.52
2010	2.93	2.33	2.52	2.79	2.86	2.24
2011	3.10	2.50	2.40	2.75	2.80	2.40
2012	3.00	2.40	2.30	2.60	2.65	2.20
Indicator 3						
2004	2.26	2.25	1.80	2.69	2.19	1.41
2005	2.69	2.19	1.41	1.12	2.06	2.67
2006	1.12	2.06	2.67	3.91	3.04	2.62
2007	3.91	3.04	2.62	4.42	4.24	3.14
2008	4.42	4.24	3.14	3.79	3.89	3.27
2009	3.79	3.89	3.27	4.68	3.72	4.02
2010	4.68	3.72	4.02	5.38	5.51	4.32
2011	4.50	4.10	3.90	5.40	5.30	4.50
2012	4.30	4.00	3.70	5.20	5.10	4.20

Table S5. Normalized values of the "Relative Economic Importance" and the "Supply Risk" (cf. corresponding paper Figure 7) for Germany.

Year	W	Bi	Pt	Pd	PGM	REE	Ge	Mg	Ti
Relative Economic Importance									
2004	4.22	4.43	5.80	3.22	3.61	6.34	3.06	3.00	4.43
2005	4.68	3.91	5.75	3.30	3.60	6.49	3.07	3.81	4.21
2006	5.20	4.33	6.03	3.63	3.79	5.47	3.48	3.98	4.08
2007	5.41	5.26	6.40	5.10	4.58	5.62	2.72	5.03	3.45
2008	5.80	7.09	6.89	5.70	5.31	6.08	2.03	5.69	4.60
2009	6.03	8.82	7.04	5.90	5.71	6.96	2.54	7.20	6.43
2010	4.46	6.88	5.05	4.20	4.15	4.95	2.34	5.17	5.32
2011	4.42	7.68	4.96	4.07	4.12	4.78	3.38	5.17	5.66
2012	4.53	7.47	5.00	4.53	4.53	4.71	3.35	5.24	5.71
Supply Risk									
2004	4.05	5.94	2.64	8.09	5.56	5.59	4.61	5.38	5.05
2005	4.51	5.89	2.60	8.22	6.32	5.55	4.51	5.42	5.32
2006	5.03	5.40	2.51	8.51	6.70	5.46	4.69	5.29	5.37
2007	5.15	5.16	2.40	9.06	7.21	5.14	4.48	5.22	5.14
2008	5.05	5.29	2.19	9.25	7.24	5.88	4.44	5.13	5.03
2009	5.25	5.61	2.04	9.27	7.03	6.84	4.44	5.19	5.04
2010	5.57	5.85	1.92	8.83	6.76	7.84	4.62	5.17	5.17
2011	6.17	5.71	1.97	8.61	6.53	7.98	4.59	5.25	5.30
2012	6.00	5.50	2.00	8.50	6.50	8.00	4.60	5.30	5.30



(**a**)



(**b**)

Figure S1. Results of the dynamic criticality assessment for Germany displayed as a variation of Figure 7 in the corresponding paper. (**a**) Criticality matrix in 3 dimensions assessing the values of supply risk and relative economic importance over time; (**b**) Criticality matrix with temporal movements in 2 dimensions (the larger the dots, the more present the value).

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