

Supporting Information

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The Criticality of Non-Fuel Minerals: A Review of Major Approaches and Analyses

Number of total pages: 9 (including title page)

Number of figures: 0

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Table S1: List of main dimensions and indicators applied in 10 principal studies.

DOE study ^{S1}	EU study ^{S2}	GE approach ^{S3}	IDA study ^{S4}	IW study ^{S5}	Consult	NEDO study ^{S6}	NRC study ^{S7}	Oakdene Hollins study ^{S8}	Öko-Institut study ^{S9}	RWI / ISI / BGR study ^{S10}
Supply Risk: Future supply-to-demand ratio Competing technology demand Co-production Country and company concentration (production) Country risk (production) Importance to clean energy: Clean energy demand Substitutability	Supply risk: Substitutability Recycling rate Country concentration (production) Country risk (production) Economic importance: Consumption share of sectors Gross Value added of sectors	Supply and price risk: Market substitutability Country concentration and risk (production) Co-Production Demand risk by emerging technologies Price volatility Earth's abundance Impact of supply restriction on GE: GE share of supply Impact on GE revenue GE ability to substitute GE ability to pass through costs	Supply: US supplies Foreign supplies (including decrements and delays) Demand: Defense Investment Civilian Stockpile balance: Shortfalls Inventories	Quantitative indicators: Country concentration (production) Country risk (production) Company concentration (production) Reserve-to-production ratio Qualitative indicators: Substitutability Emerging technologies Strategic industry policy (production)		Supply and demand risk: Reserve-to-production ratio Country concentration (reserves) Country concentration (production) Country concentration (imports) Change rate of import price Variability of import price Change rate of world demand Change rate of domestic demand Change rate of specific demand Existence of stockpiling Existence of recycling Potential risk: Future regulation risk	Supply risk: Geologic availability, Technical availability, Environmental and social availability, Political availability Economic availability Impact of supply restriction: Consumption share of sectors Specific impact on sectors	Supply risk: Future supply-to-demand ratio Country concentration (production) Country risk (production) Vulnerability to climate change Material risk: Global consumption Substitutability Greenhouse Warming Potential Total Material Requirement	Supply risk: Country concentration (production) Reserve-to-production ratio Supply-to-demand time lag Co-Production Demand growth Change rate of global demand Recycling restrictions: Recycling technology and infrastructure Price incentives for recycling Technical limitations Dissipative usage share	Risk filter: Import value Country concentration (production) Country risk (production) Supply: Projection Demand: Technology factor projection Growth factor projections

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Table S2: Criticality designations in 7 selected studies.

	EU study ^{S2}	IDA study ^{S4}	IW study ^{S5}	NEDO study ^{S6}	NRC study ^{S7}	Oakedene Hollins study ^{S8}	South Korea approach ^{S11}	Formatted
Li	not critical	no shortfalls	high risk	critical	not critical	-	critical	Formatted
Be / beryl ore / beryllium copper	critical	shortfalls / shortfalls / no shortfalls ¹	-	not critical	-	not insecure	not critical	Formatted
B / borate	not critical	no shortfalls	-	not critical	-	not insecure / not insecure	not critical	Formatted
C (diamond)	-	-	-	-	-	not insecure	-	Formatted
C (graphite)	critical	-	medium risk	-	-	not insecure	-	Formatted
N (ammonia)	-	-	-	-	-	not insecure	-	Formatted
F (fluorspar)	critical	(no) shortfalls ^{1,2}	medium risk	-	-	not insecure	-	Formatted
Na (soda ash)	-	-	-	-	-	not insecure	-	Formatted
Mg / magnesite	critical / not critical ¹	-	medium risk	-	-	not insecure	critical	Formatted
Al / bauxite / Al₂O₃ (fused crude)	not critical / not critical / -	no shortfalls / (no) shortfalls ³ / shortfalls ¹	medium risk	-	-	-	-	Formatted
Si (metal)	-	-	-	-	-	not insecure	critical	Formatted
Si (andalusite)	-	-	-	-	-	not insecure	-	Formatted
Si (asbestos)	-	-	-	-	-	not insecure	-	Formatted
Si (bentonite)	not critical	-	low risk	-	-	not insecure	-	Formatted
Si (clays)	not critical	-	-	-	-	-	-	Formatted
Si (diatomite)	not critical	-	-	-	-	-	-	Formatted
Si (feldspar)	not critical	-	low risk	-	-	not insecure	-	Formatted
Si (kaolin)	-	-	low risk	-	-	-	-	Formatted
Si (kyanite)	-	-	-	-	-	not insecure	-	Formatted
Si (mica)	-	-	low risk	-	-	not insecure	-	Formatted
Si (perlite)	not critical	-	-	-	-	not insecure	-	Formatted
Si (silica)	not critical	-	-	-	-	-	-	Formatted
Si (talc)	not critical	-	-	-	-	not insecure	-	Formatted
Si (vermiculite)	-	-	-	-	-	-	-	Formatted

P (phosphate)	-	-	high risk	-	-	-	-
K (potash)	-	-	low risk	-	-	-	-
Ca (limestone)	not critical	-	-	-	-	-	-
Ca (gypsum)	not critical	-	low risk ⁴	-	-	-	-
Sc	critical ⁵	-	high risk	-	-	-	critical ⁵
Ti	not critical	no shortfalls	medium risk	not critical	not critical	-	critical
V	not critical	no shortfalls	-	not critical	not critical	-	not critical
Cr / chromite / ferrochrome	not critical	shortfalls / no shortfalls / no shortfalls ¹	high risk	not critical	-	not insecure	not critical
Mn / manganese ore / ferromanganese / manganese dioxide	not critical	shortfalls / no shortfalls / no shortfalls / no shortfalls ¹	medium risk	not critical	critical	not insecure	not critical
Fe	not critical	-	low risk	-	-	not insecure	-
Co	critical	shortfalls	high risk	not critical	-	not insecure	not critical
Ni	not critical	no shortfalls	low risk	not critical	-	not insecure	critical
Cu	not critical	no shortfalls	medium risk	-	not critical	not insecure	-
Zn	not critical	no shortfalls	medium risk	-	-	not insecure	-
Ga	critical	shortfalls	medium risk	not critical	not critical	not insecure	critical
Ge	critical	shortfalls	high risk	not critical	-	not insecure	not critical
As	-	-	-	-	-	not insecure	-
Se	-	-	high risk	not critical	-	not insecure	not critical
Br (bromine)	-	-	-	-	-	not insecure	-
Rb	-	-	-	not critical	-	-	not critical
Sr	-	-	-	not critical	-	insecure	not critical
Y	critical ⁵	shortfalls	high risk	critical	critical ⁵	-	critical ⁵
Zr / zirconium ore and concentrates	-	no shortfalls / no shortfalls	-	not critical	-	not insecure	critical
Nb	critical	shortfalls	high risk	critical	critical	not insecure	not critical
Mo	not critical	no shortfalls	high risk	not critical	-	not insecure	not critical
Ru	critical ⁶	shortfalls	-	-	-	not insecure	critical ⁶
Rh	critical ⁶	shortfalls	high risk ⁶	not critical	critical	insecure	critical ⁶

Pd	critical ⁶	no shortfalls	high risk ⁶	not critical	not critical	not insecure	critical ⁶
Ag	not critical	no shortfalls	medium risk	-	-	insecure	-
Cd	-	no shortfalls	-	-	-	-	not critical
In	critical	no shortfalls	high risk	critical	critical	not insecure	critical
Sn	-	shortfalls	medium risk	-	-	insecure	not critical
Sb	-	shortfalls	-	critical	-	insecure	not critical
Te	not critical	no shortfalls	-	not critical	-	-	not critical
I (iodine)	-	-	-	-	-	not insecure	-
Cs	-	-	-	not critical	-	-	not critical
Ba (barite)	not critical	-	medium risk	not critical	-	not insecure	not critical
Hf	-	no shortfalls	-	not critical	-	-	not critical
Ta	critical	shortfalls	medium risk	not critical	not critical	-	not critical
W	critical	shortfalls	high risk	critical	-	not insecure	critical
Re	not critical	shortfalls	-	not critical	-	not insecure	not critical
Os	critical ⁶	-	-	-	-	not insecure	critical ⁶
Ir	critical ⁶	no shortfalls	-	-	-	-	critical ⁶
Pt	critical ⁶	no shortfalls	high risk ⁶	critical ⁷	critical	insecure	critical ⁶
Au	-	-	medium risk	-	-	insecure	-
Hg	-	no shortfalls	-	-	-	insecure ⁸	-
Tl	-	-	-	not critical	-	-	not critical
Pb	-	no shortfalls	low risk	-	-	not insecure	-
Bi	-	shortfalls	-	critical	-	not insecure	not critical
La	critical ⁵	-	-	critical	critical ⁵	-	critical ⁵
Ce	critical ⁵	-	-	critical ⁷	critical ⁵	-	critical ⁵
Pr	critical ⁵	-	-	-	critical ⁵	-	critical ⁵
Nd	critical ⁵	shortfalls	high risk	critical	critical ⁵	-	critical ⁵
Sm	critical ⁵	shortfalls	-	not critical	critical ⁵	-	critical ⁵
Eu	critical ⁵	shortfalls	-	critical ⁶	critical ⁷	not insecure	critical ⁵
Gd	critical ⁵	-	-	-	critical ⁵	not insecure	critical ⁵
Tb	critical ⁵	shortfalls	-	critical ⁶	critical ⁷	not insecure	critical ⁵
Dy	critical ⁵	-	-	critical	critical ⁵	-	critical ⁵

Ho	critical ⁵	-	-	-	critical ⁵	not insecure	critical ⁵
Er	critical ⁵	-	-	-	critical ⁵	-	critical ⁵
Tm	critical ⁵	-	-	-	critical ⁵	-	critical ⁵
Yb	critical ⁵	-	-	-	critical ⁵	-	critical ⁵
Lu	critical ⁵	-	-	-	critical ⁵	not insecure	critical ⁵
other	Pm (indirectly as rare earth) ⁵ : critical	rubber (natural), specialty steels (300M, Armor, M50), carbon fiber (AS-4, IM-7, T-300, T-700), Kevlar, Nomex, High purity quartz fiber: no shortfalls carbon fiber (IM-6), silicon carbide: shortfalls S-2 glass fiber: withheld			Pm (indirectly as rare earth) ⁵ : critical	-	Pm (indirectly as rare earth) ⁵ : critical

Note: 1 = in case of ambiguity classified as critical in figure 1; 2 = metallurgical grade (no) and acid grade; 3 = metal grade (no) and refractory grade; 4 = includes anhydrite; 5 = rare earth elements as a group; 6 = platinum group metals as a group; 7 = special high risk minerals; 8 = finally not considered as insecure because of declining demand.

Table S3: Methodological comparison of the NRC and EU studies.

	NRC study ^{S7}	EU study ^{S2}
Vulnerability	Impact of supply restriction (ISR): $ISR = \sum_i isr_i \times \mu_i \quad (S1.)$ μ_i = share of use by application group i [0-1] isr_i = impact of supply restriction by application group [1, 2, 3, 4; depending on the value of consumption, substitutability, and emerging uses]	Economic importance (EI): $EI = \frac{1}{GDP} \times \sum_j GVA_j \times \mu_j \quad (S2.)$ μ_j = share of use by megasector j [0-1] GVA_j of each megasector j [€]
Supply risk	One discrete supply risk estimate covering five raw material availabilities [1, 2, 3, 4]: Geologic availability (depending on mineral deposits, import dependence) Technical availability (depending on by-product share, secondary production share) Political availability (depending on policies, stability, regulatory environment) Environmental and social availability (depending on local permission, public attitudes) Economic availability (depending on reserve/reserve base to production ratios, price, diversity of producers)	Supply risk (SR): $SR = S \times (1 - R) \times HHI_{WGI} \quad (S3.)$ Substitutability (S): $S = \sum_j s_j \times \mu_j \quad (S4.)$ μ_j = share of use by megasector [0-1] s_j = substitutability in application [0.0, 0.3, 0.7, 1] Recycling rate (R) defined as secondary scrap recycling rate in the EU as a share of total raw material production [0-1] Herfindahl-Hirschmann Index for country governance (HHI_{WGI}): $HHI_{WGI} = \sum_c \alpha_c^2 \times WGI_c \quad (S5.)$ α_c = share of country c in production [0-1] WGI_c = World Governance Indicator for country c

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