Assessing Resource Criticality of Metals and Its Relationship to Life Cycle Assessment

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LCA Discussion Forum, ETH Zurich

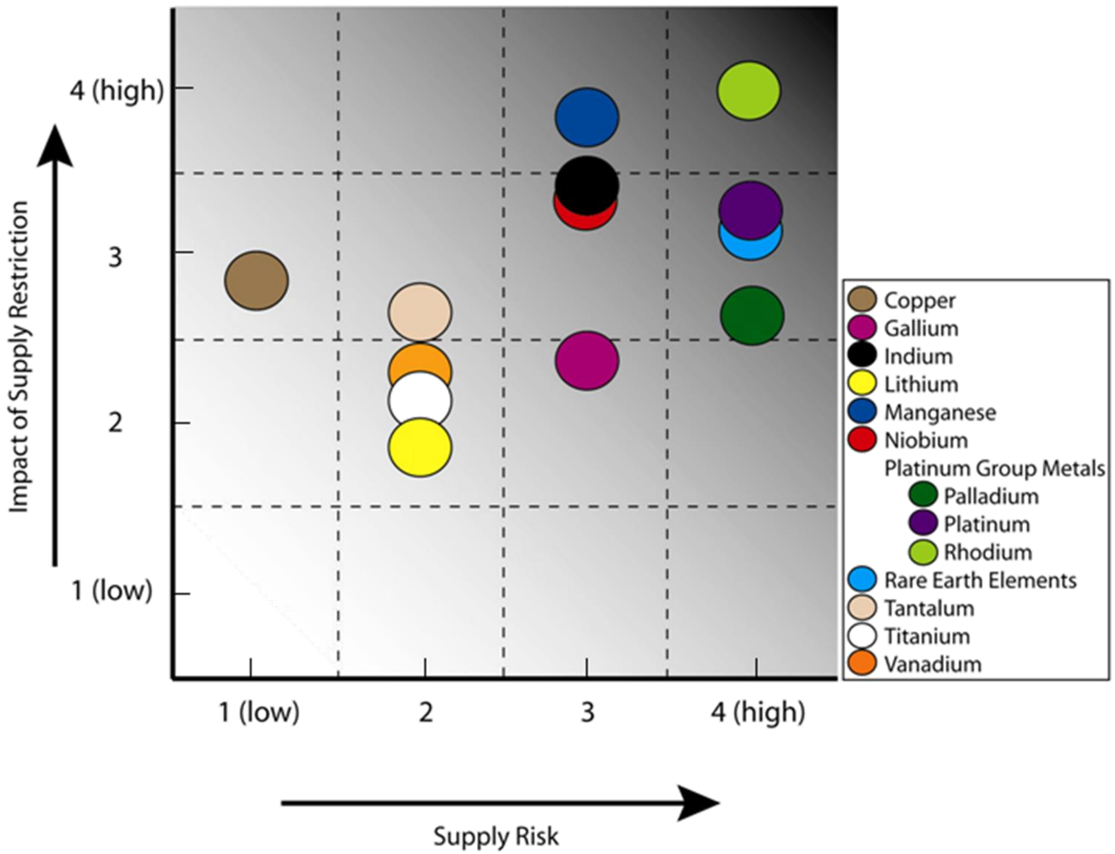
April 11, 2014

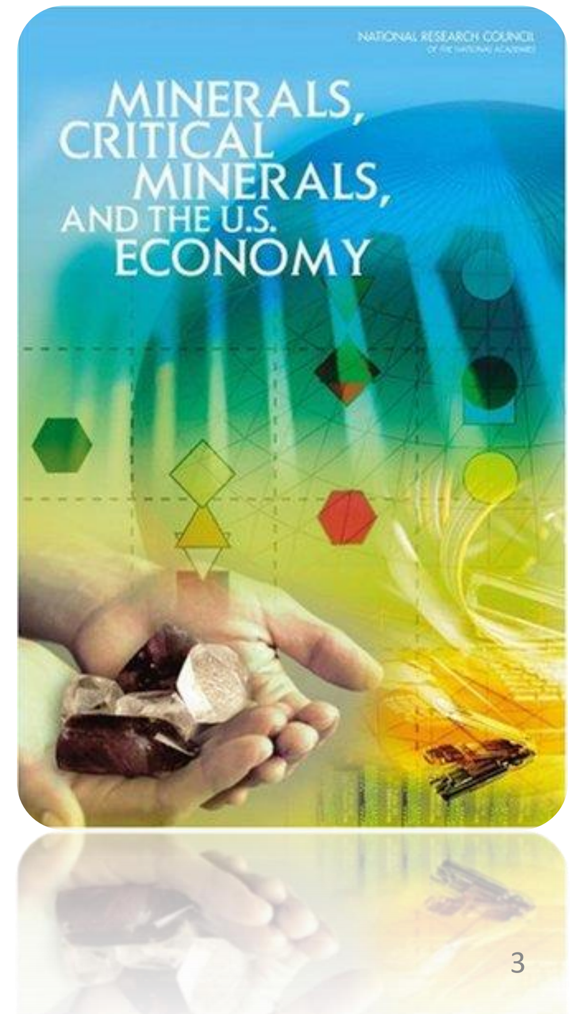
“Criticality” of a material

- “The condition of being the highest importance” (Free Dictionary, 2014)

- “Combining a comparatively high economic importance with a comparatively high risk of supply” (Buijs et al., 2012)

National Research Council report provides basis for assessing *Metal Criticality*





Source: NRC (2008) Minerals, Critical Minerals, and the U.S. Economy. Washington D.C.: U.S. National Research Council, National Academies Press.

Goals of the Yale Criticality Project

- Developing a defendable and workable methodology for evaluating the degree to which a metal is "critical"

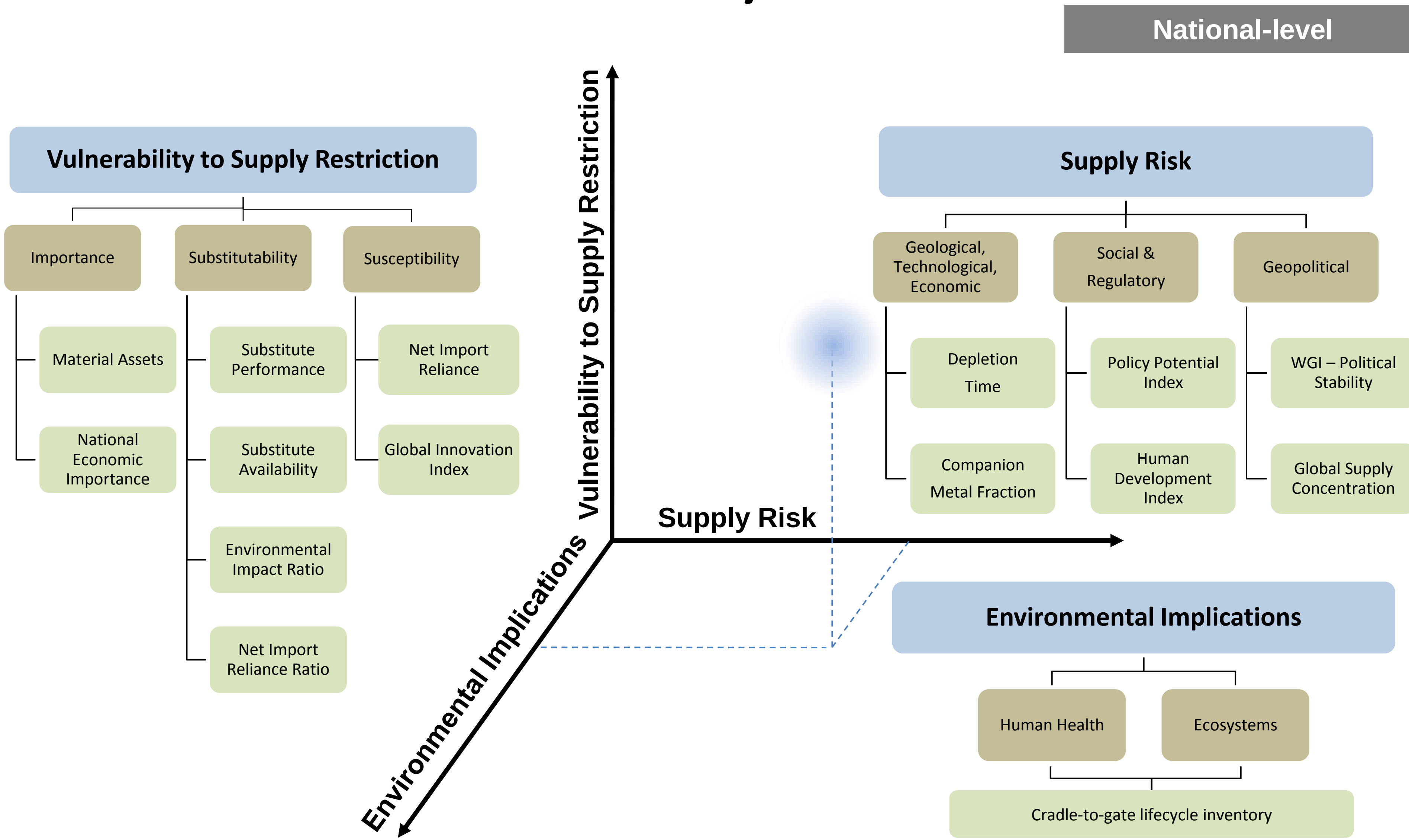
Criteria

Comprehensive	Balance analytical rigor and data availability	Of interest to multiple stakeholders

- Applying the methodology to evaluate the criticality of a number of different metals

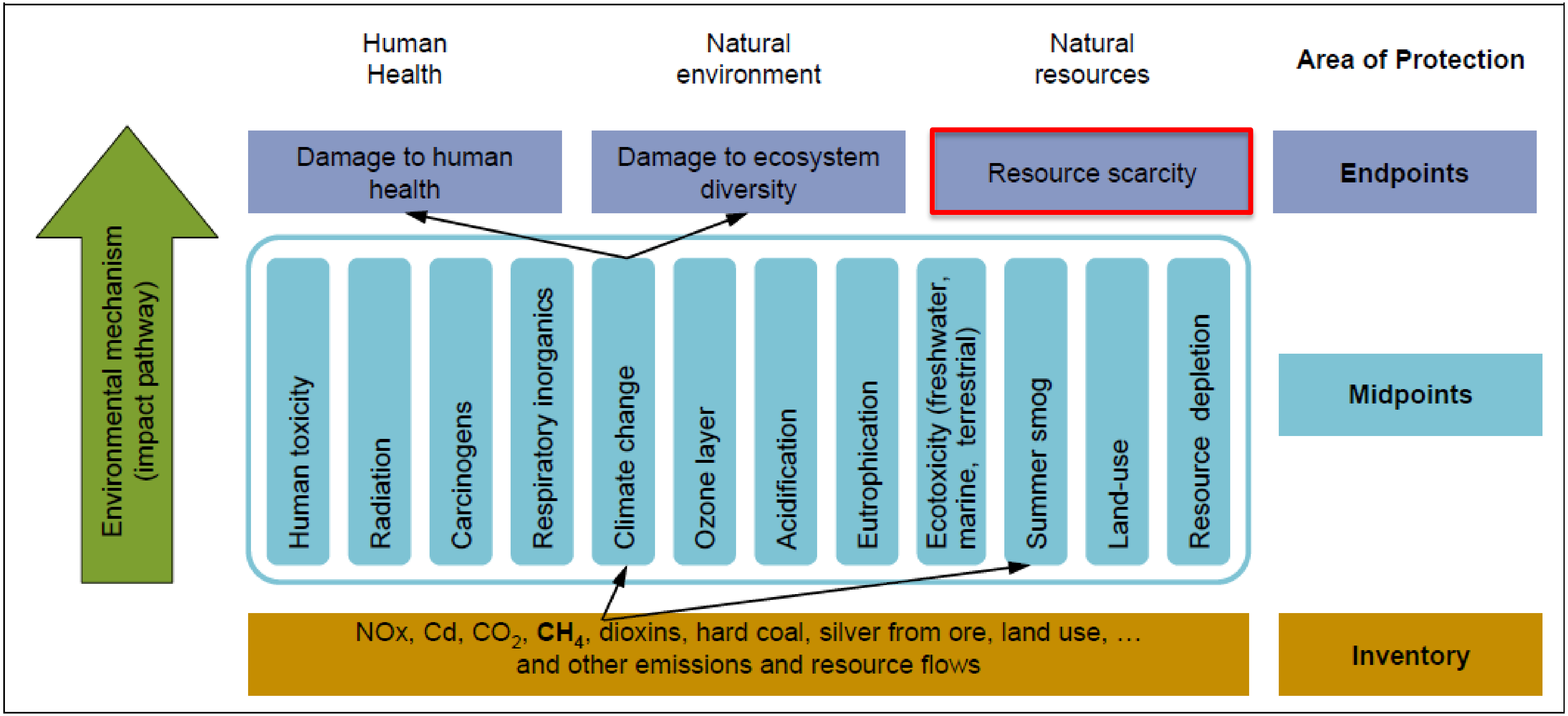
- Creating a family of scenarios to study the possible evolution of metal criticality

Criticality Axis



Source: Graedel, et al. Methodology of Metal Criticality Determination *Environ. Sci. Technol.*, 2012, 46 (2), pp 1063–1070

Areas of Protection (AoP) in LCA



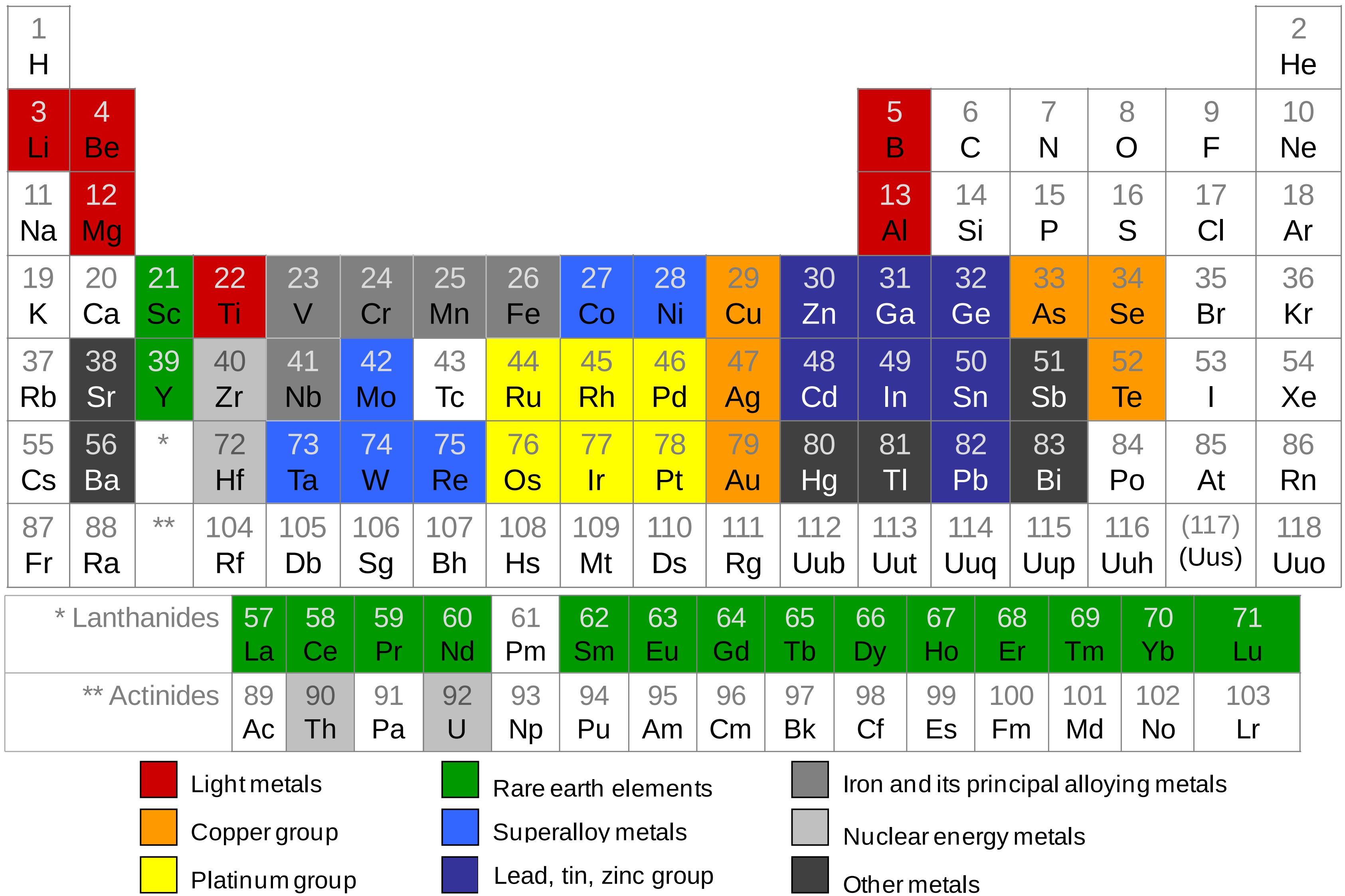
Source: EC - JRC. ILCD Handbook – International Reference Life Cycle Data System, 1st edition, *European Commission - Joint Research Centre*, 2010.

Assessing Resources in LCA

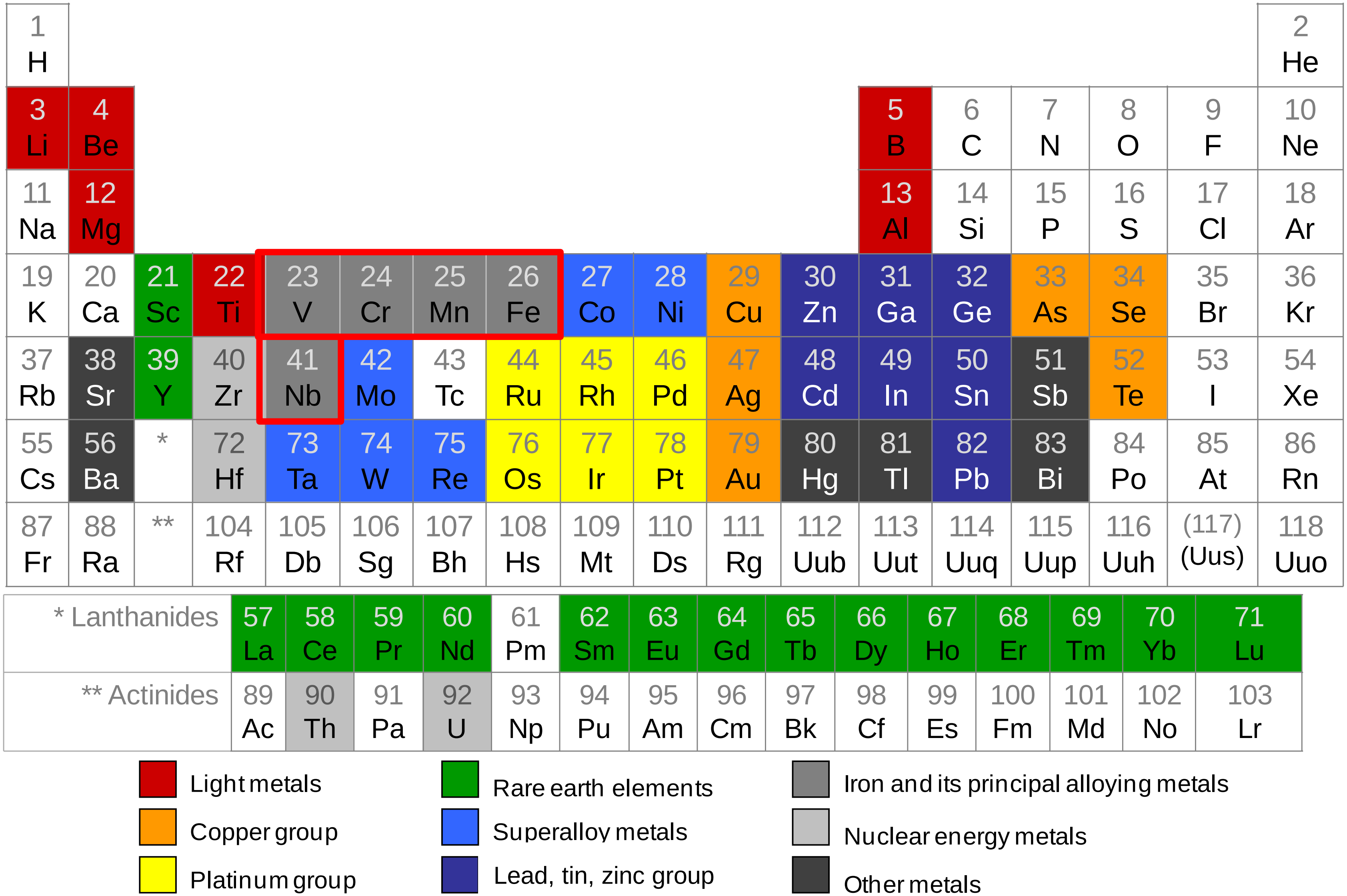
- Different approaches to assess resource in Life Cycle Impact Assessment
  – Scarcity / mass extracted
  – Exergy consumption
  – Future consequences of resource extraction
  – Marginal cost of resource extraction
  – Distance to target
  – Willingness to pay

Source: Kinglmair et al. (2013) *Assessing resource depletion in LCA: a review of methods and methodological issues;* International Journal of LCA

Metal Criticality Grouping (Yale Project)



Metal Criticality Grouping (Yale Project)



Iron Group: Uses

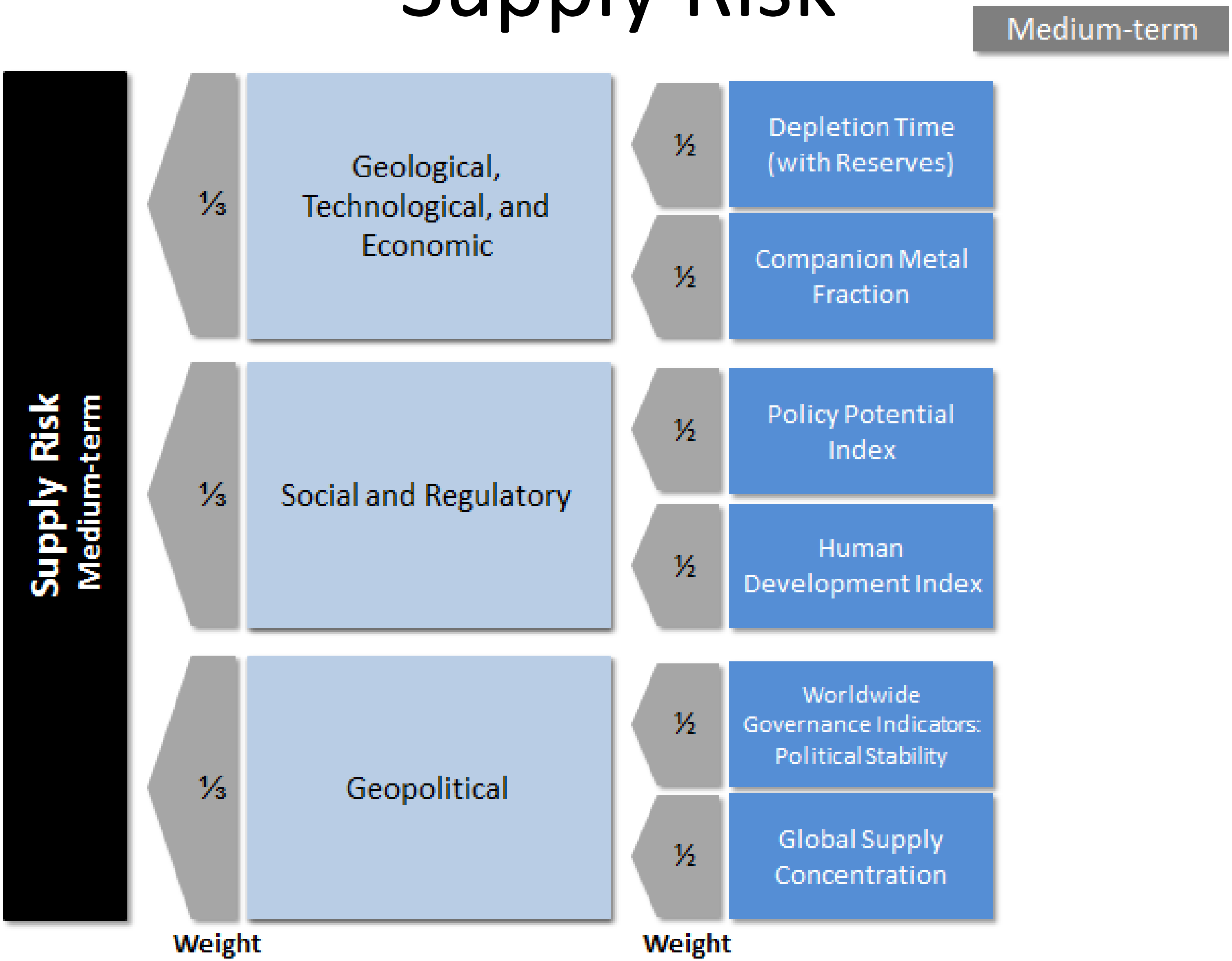
- Iron and steel are the basic metals of any industrial society

- Steel used together with alloying elements to obtain specific properties (heat and corrosion resistance, high strength, etc.)

- Alloyed steels used in more than 3500 steel products (Fenton, 2005)
  - Iron: construction, transportation, machinery, other
  - Chromium: stainless and alloy steels, chemicals, refractory materials
  - Niobium: HSLA steels, stainless steels, superalloys
  - Manganese and Vanadium: Iron-based steels, superalloys, chemicals, batteries

Supply Risk

Supply Risk



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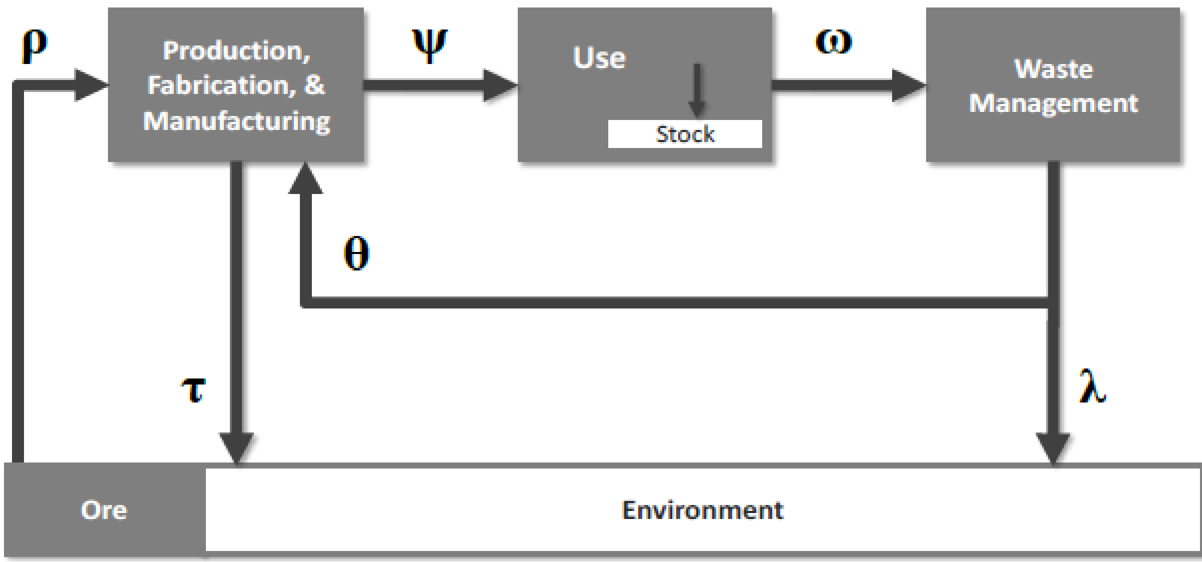
Depletion time model: In-use Stocks estimates



ρ: Mining production
ψ: Demand
ω: Output from use phase
λ: Landfilled
θ: Scrap
τ: Net loss to tailings, slag and from other processing

$$S_t = \sum_{T_o}^{T} (Inflow_t - Outflow_t) + S_o$$

Source: Graedel, et al. Methodology of Metal Criticality Determination *Environ. Sci. Technol.*, 2012, 46 (2), pp 1063–1070

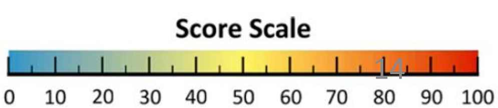
- For some metals, anthropogenic materials stocks represent a significant source and should be included in resource assessment in LCA (see also Schneider et al (2011)*).

*Schneider et al (2011) The anthropogenic stock extended abiotic depletion potential (AADP) as a new parameterisation to model the depletion of abiotic resources. Int J Life Cycle Assess 16: 929–936.

Supply Risk (Medium-Term)

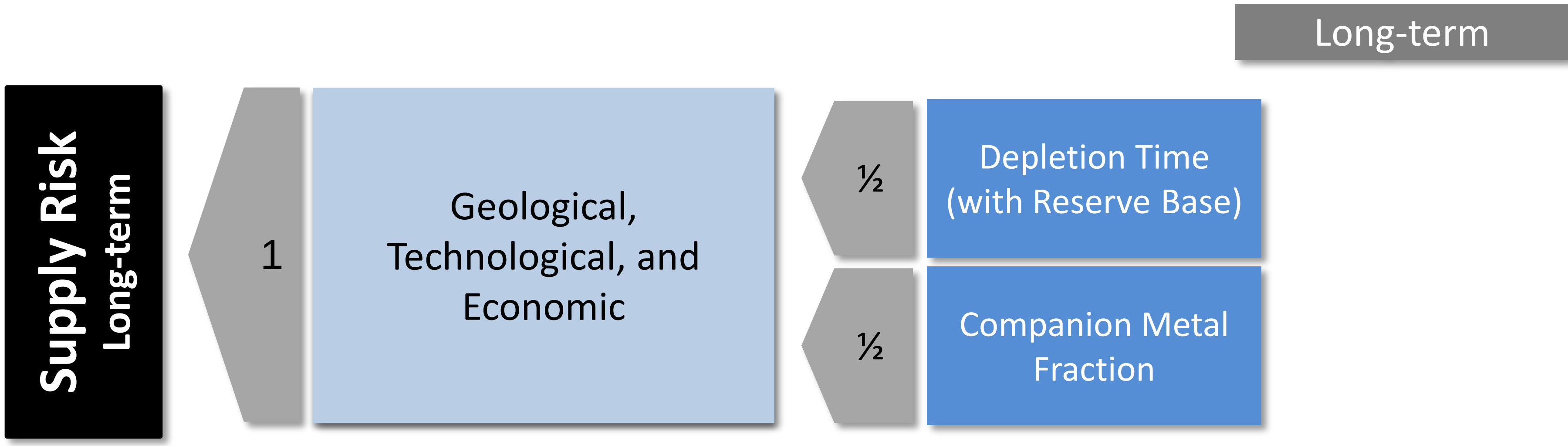
Element	Geological, Technological, and Economic				Social and Regulatory				Geopolitical				Supply Risk	
	DT_M		CF		PPI		HDI		WGI-PV		GSC		SR_M	
V	0	0	82	73	59	51	67	59	66	58	80	80	**59**	**56**
		0		82		59		67		65		80		**59**
		0		93		69		77		72		81		**62**
Cr	96	95	0	0	63	56	65	59	58	51	75	73	**60**	**58**
		96		0		64		66		58		75		**60**
		97		0		72		73		65		77		**62**
Mn	89	85	4	3	54	47	72	66	66	59	82	80	**61**	**59**
		89		4		54		72		66		82		**61**
		92		5		62		80		72		84		**63**
Fe	0	0	0	0	54	48	73	68	60	55	75	72	**44**	**42**
		0		0		54		74		60		75		**44**
		20		0		60		82		65		78		**47**
Nb	80	71	13	10	49	38	73	59	62	48	97	97	**62**	**58**
		81		12		49		73		60		97		**62**
		87		15		64		89		72		98		**66**

DT_M = Depletion Time, CF = Companion Metal Fraction, PPI = Policy Potential Index, HDI = Human Development Index, WGI-PV = Worldwide Governance Indicator: Political Stability, GSC = Global Supply Concentration, SR_M = Supply Risk



Nuss et al. (2014) Criticality of Iron and Its Principal Alloying Elements. Environ Sci Technol 48: 4171–4177.

Supply Risk



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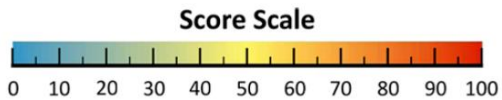
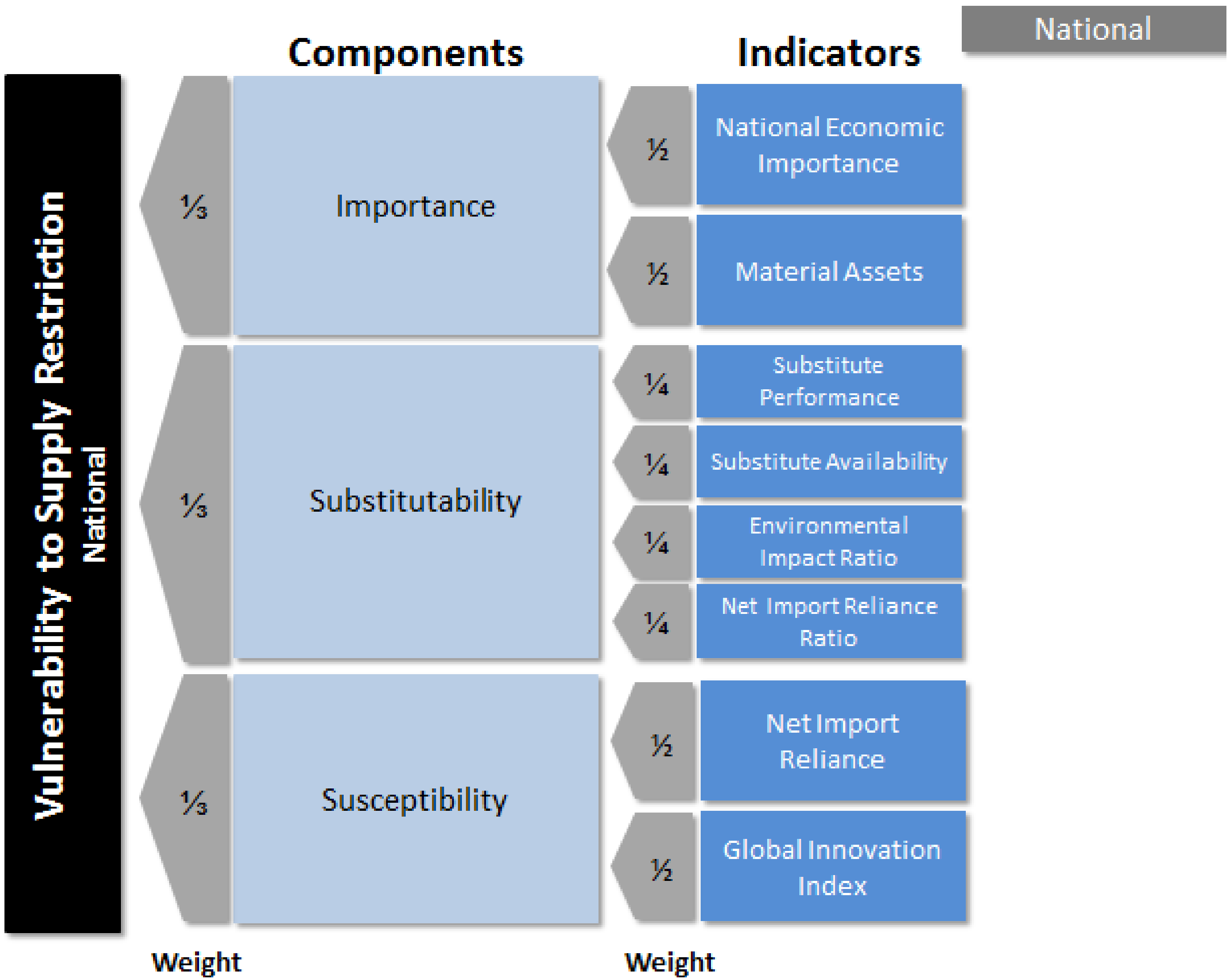
Supply Risk (Long-term)

Element	DT_L		CF		SR_L	
V	0	0	82	73	**41**	**36**
		0		82		**41**
		0		93		**46**
Cr	86	80	9	0	**43**	**40**
		86		0		**43**
		91		0		**45**
Mn	0	0	4	3	**2**	**2**
		0		4		**2**
		0		5		**2**
Fe	0	0	0	0	**0**	**0**
		0		0		**0**
		0		0		**0**
Nb	76	65	13	10	**44**	**39**
		76		12		**44**
		83		15		**48**



Vulnerability to Supply Restrictions

Vulnerability to Supply Restriction



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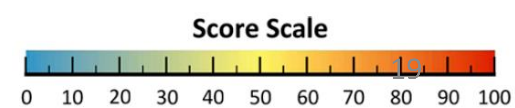
Vulnerability to Supply Restriction (USA)

Element	Importance				Substitutability								Susceptibility				VSR	
	MA_N		NE		SP		SA_M		ER		IRR		IR		GII		VSR_N	
V	67	60	1	1	65	58	64	60	34	28	57	47	91	76	29	23	50	47
		67		1		64		64		35		55		91		29		49
		73		1		71		68		44		66		100		36		52
Cr	100	100	11	9	65	48	59	43	60	43	50	33	66	55	29	23	58	54
		100		11		65		59		60		49		66		29		58
		100		14		80		75		77		66		79		36		61
Mn	99	94	28	21	89	85	92	89	96	93	88	85	100	84	29	23	73	70
		99		28		89		92		96		88		100		29		72
		100		36		92		94		98		91		100		36		75
Fe	92	87	51	39	52	44	43	42	100	99	10	8	13	11	29	23	48	45
		92		51		50		43		100		10		13		29		48
		98		66		59		44		100		12		16		36		51
Nb	89	83	2	2	49	42	59	57	92	79	35	31	100	84	29	23	56	53
		89		2		47		59		90		36		100		29		55
		95		3		53		62		99		42		100		36		58

MA_N = Material Assets, NE = National Economic Importance, SP = Substitute Performance, SA = Substitute Availability, ER = Environmental Impact Ratio, IRR = Net Import Reliance Ratio, IR = Net Import Reliance, GII = Global Innovation Index, VSR = Vulnerability to Supply Restriction



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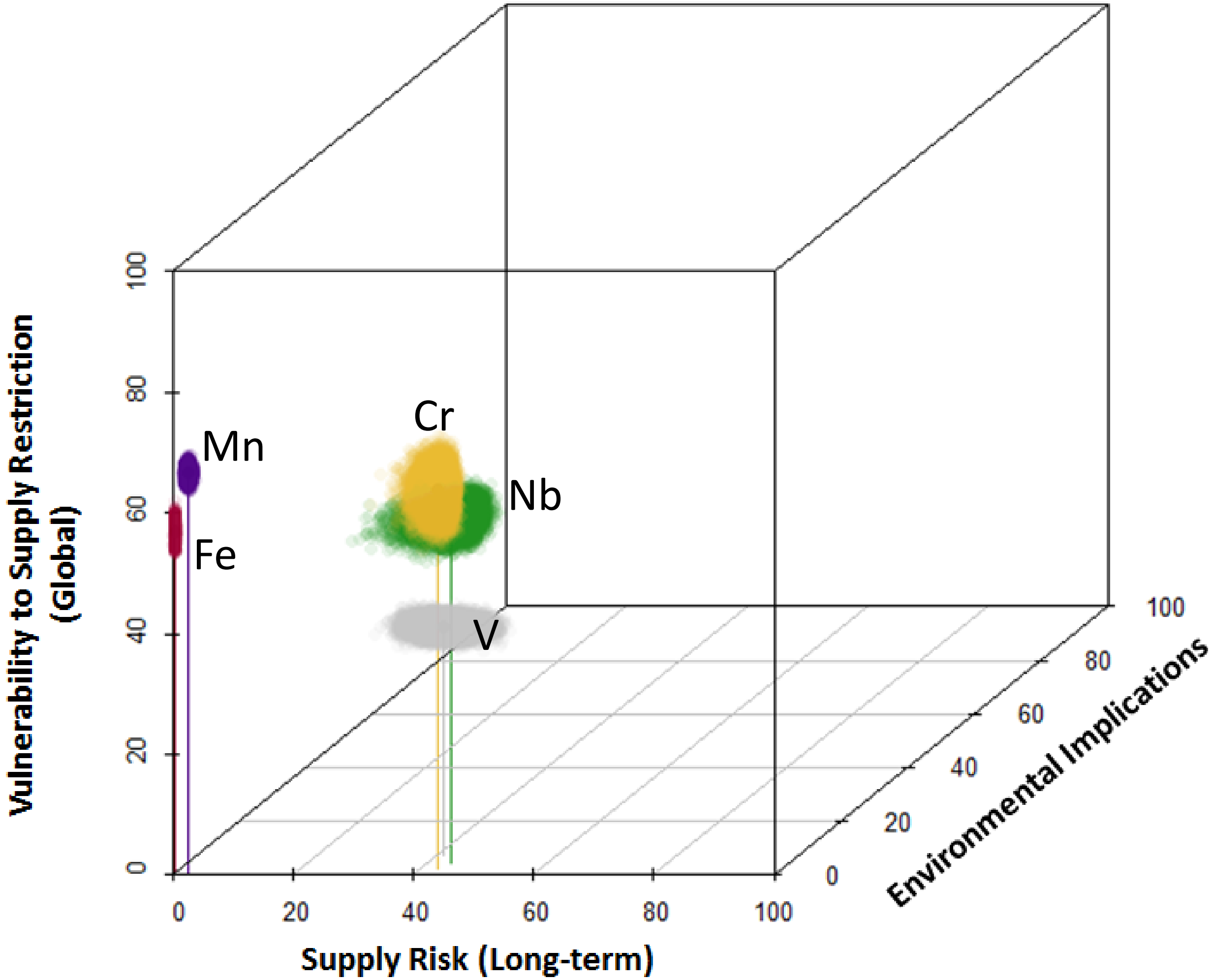
Iron Group Criticality Assessment (Global)



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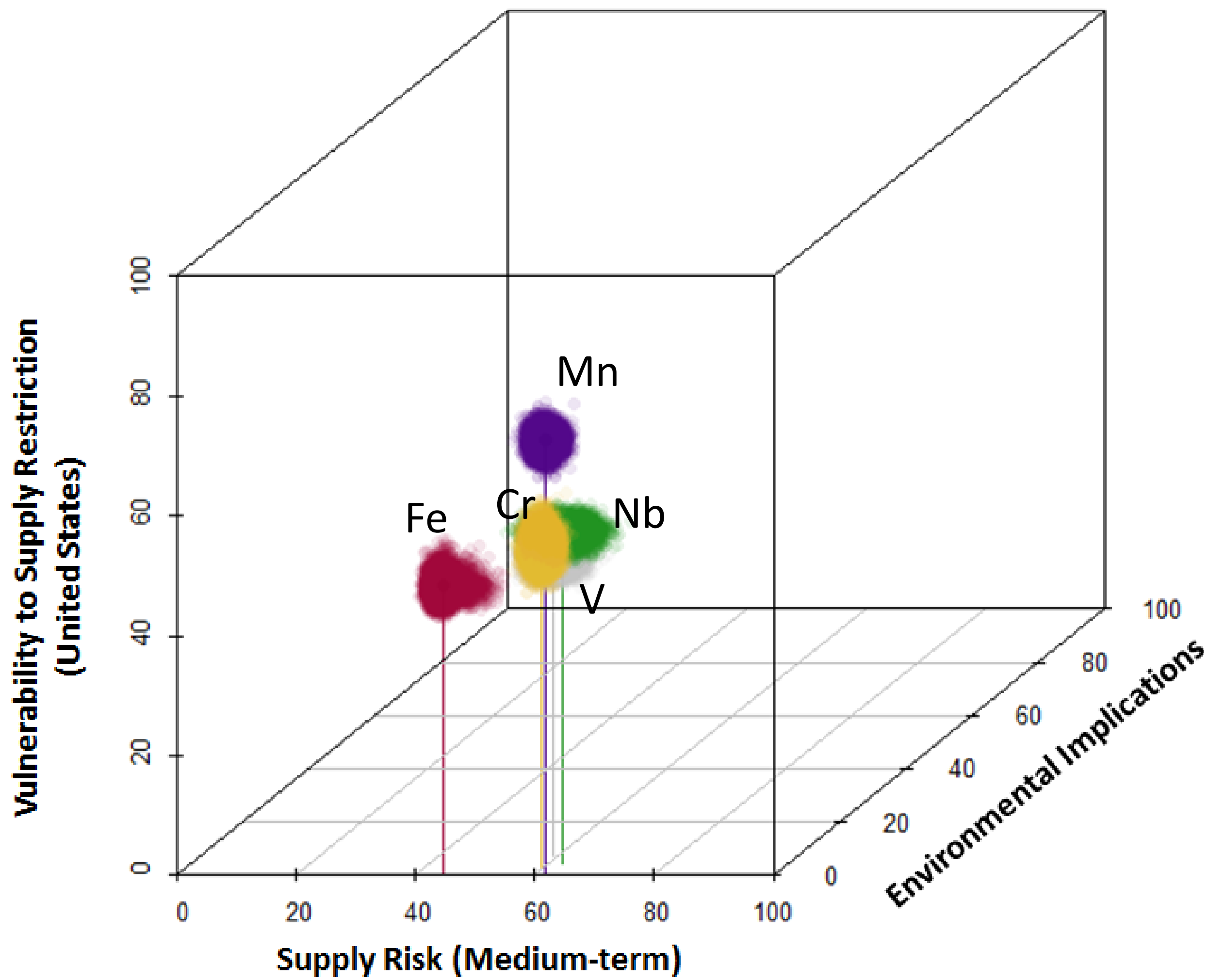
Iron Group Criticality Assessment (U.S.)



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Resource Criticality

- Criticality approach includes factors relevant to raw materials' supply risk (e.g. ,geological, social, geopolitical, recycling)
- No ideal choice for indicators included
- Highly dependent on "user" perspective (global, national, corporate)
- Matter of degree, not a state of being (thresholds)
- Dynamic (e.g., demand, reserves, loss rates, technology development)
- Methodology should be applicable to wide range of metals/resource (data availability)

Thank You!

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