



What is a Critical Material?

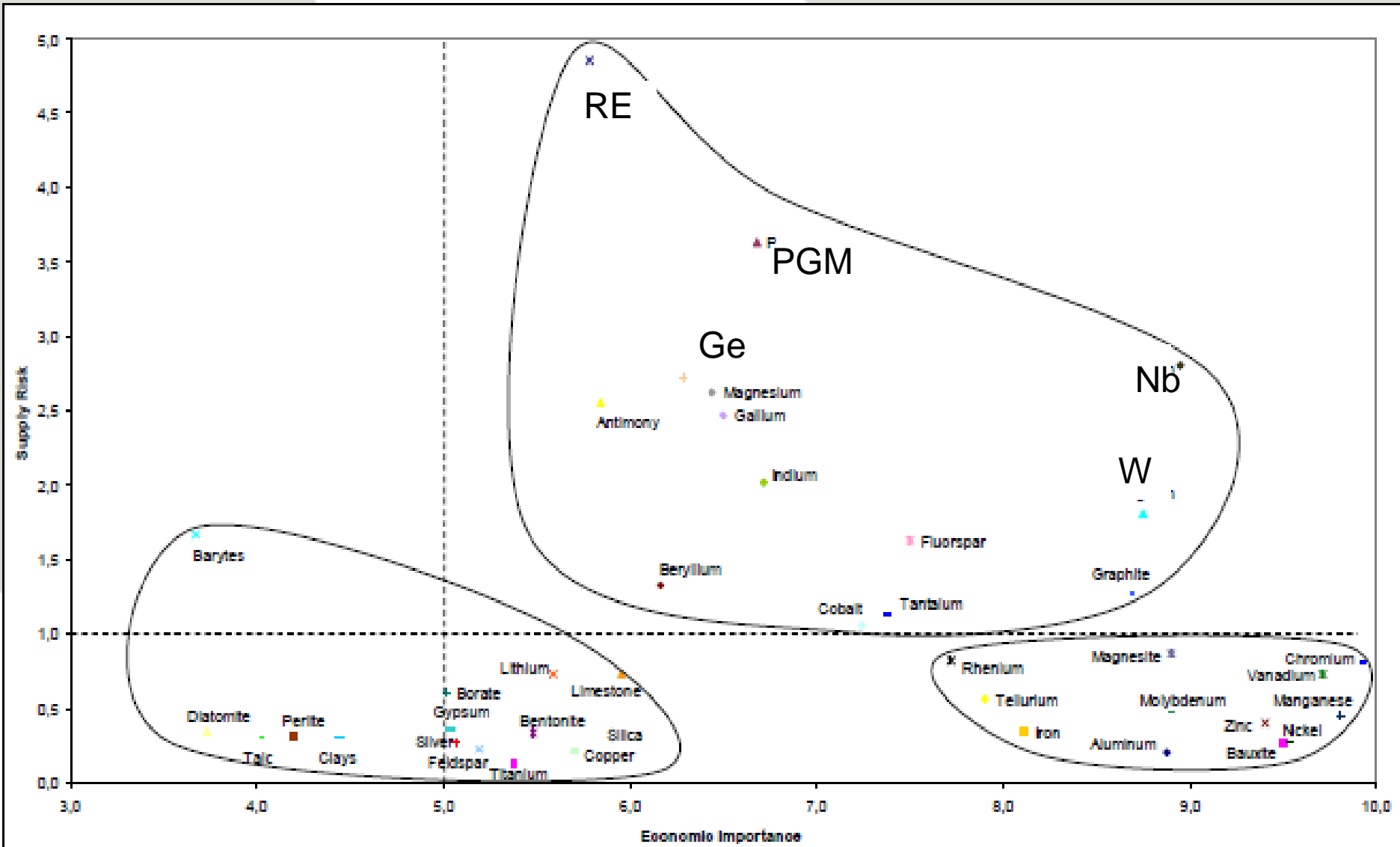
Thomas E. Graedel

Yale University

May 22, 2012



The European Commission Criticality Assessment, 2010

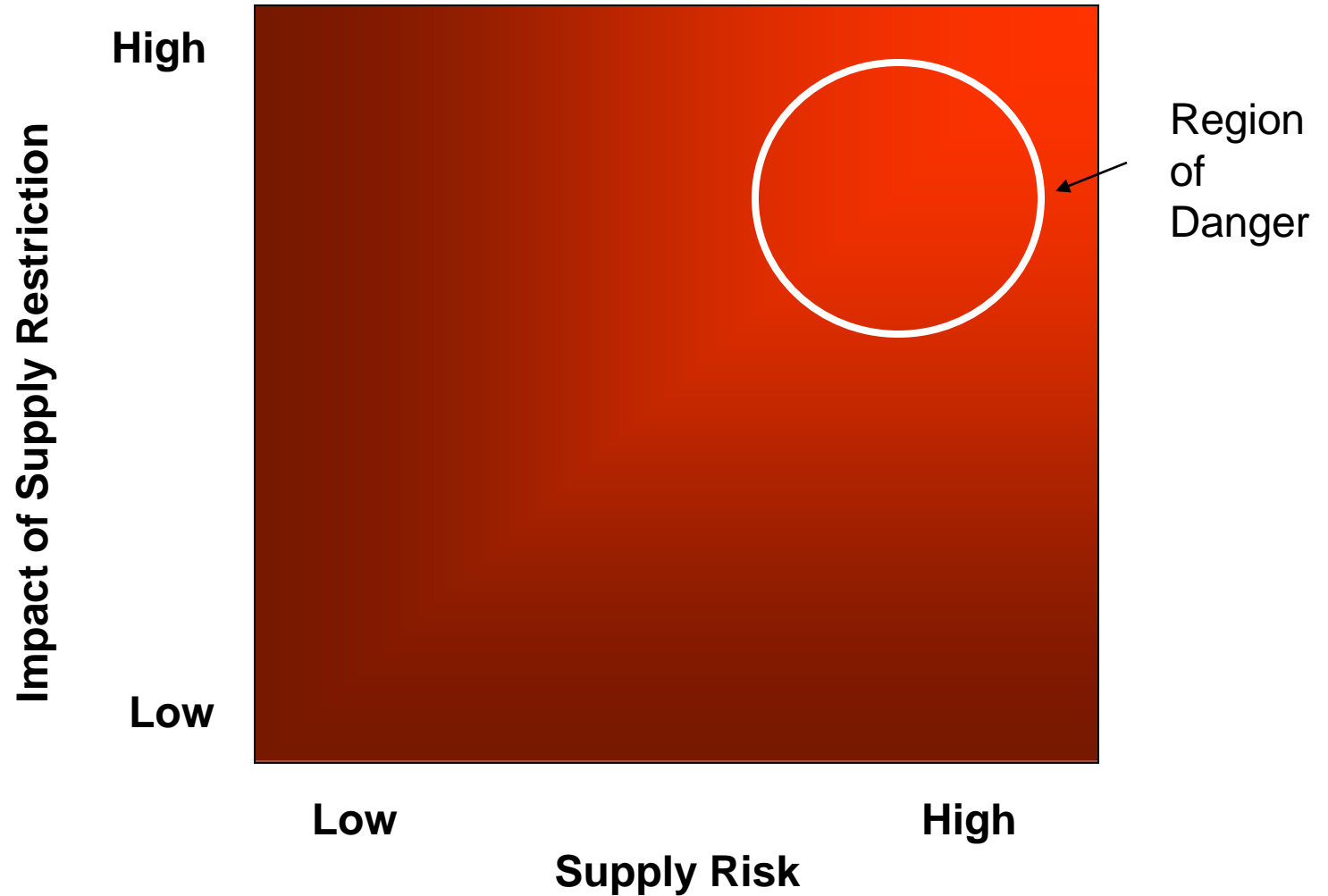


Random Results in Criticality Assessment

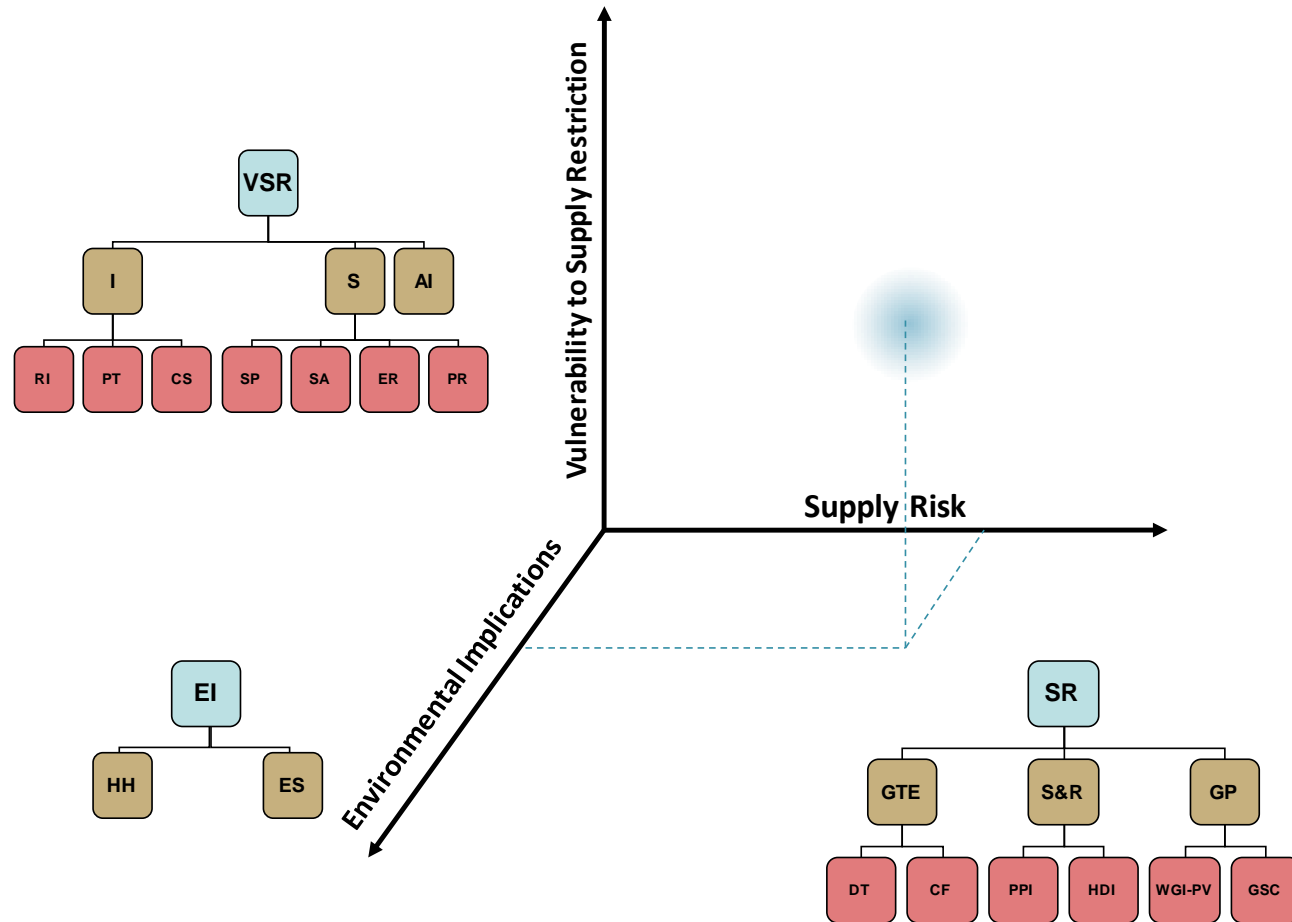
	EC	IDA	IW	NEDO	NRC	Oakd. Hollins	South Korea
Cu	No	No	Maybe	--	No	No	--
As	--	--	--	--	--	No	--
Se	--	--	Yes	No	--		No
Ag	No	No	Maybe	--	--	No	--
Te	No	No	--	No	--	Yes	No
Au	--	--	Maybe	--	--	No	--

The Yale Approach to Criticality

The Criticality Matrix and the “Region of Danger”



The Three-Axis Criticality Evaluation Concept

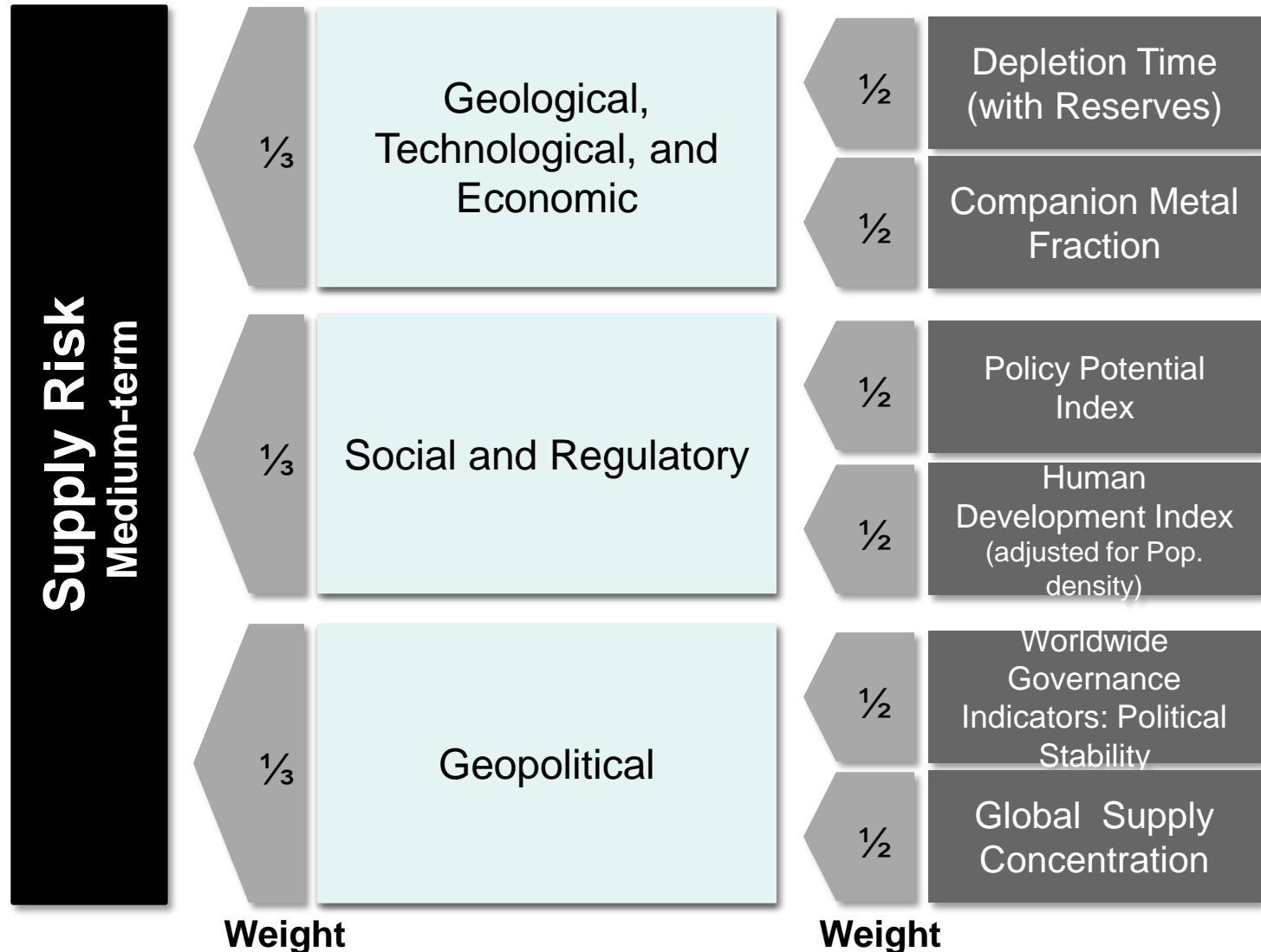


Elements to be Analyzed in the Criticality Project

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
	Lanthanide Series			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
	Actinide Series			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Supply Risk Axis – Corporate and National

Components

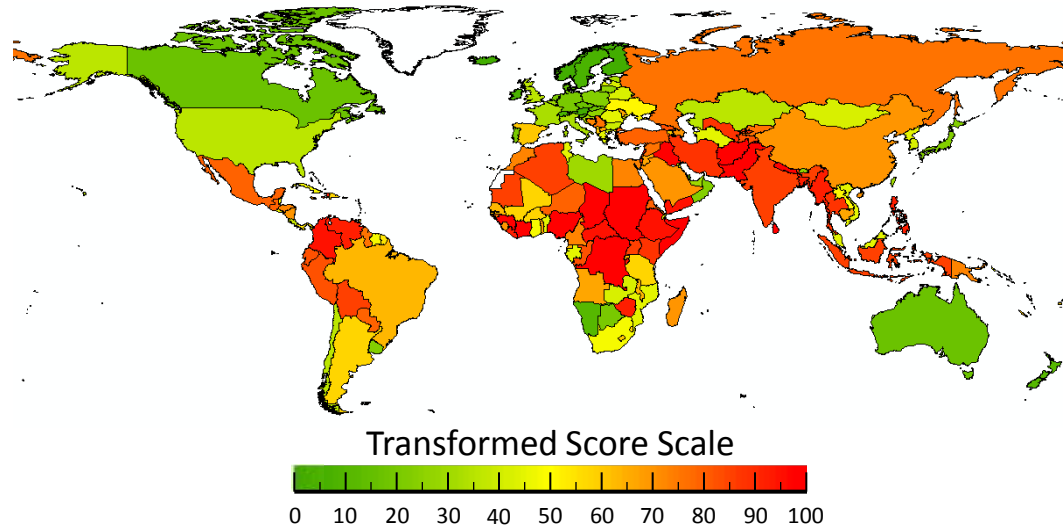


Politically unstable nations pose a higher risk of supply restriction

World Bank – WGI

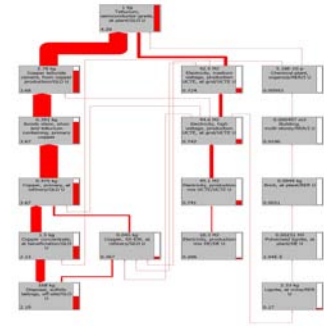
- Measures perceptions of the likelihood that a government will be destabilized or overthrown by unconstitutional or violent means
- Encompasses social, economic, and political factors associated with underlying vulnerability and economic distress

2008 Worldwide Governance Indicators – Political Stability & Absence of Violence/Terrorism



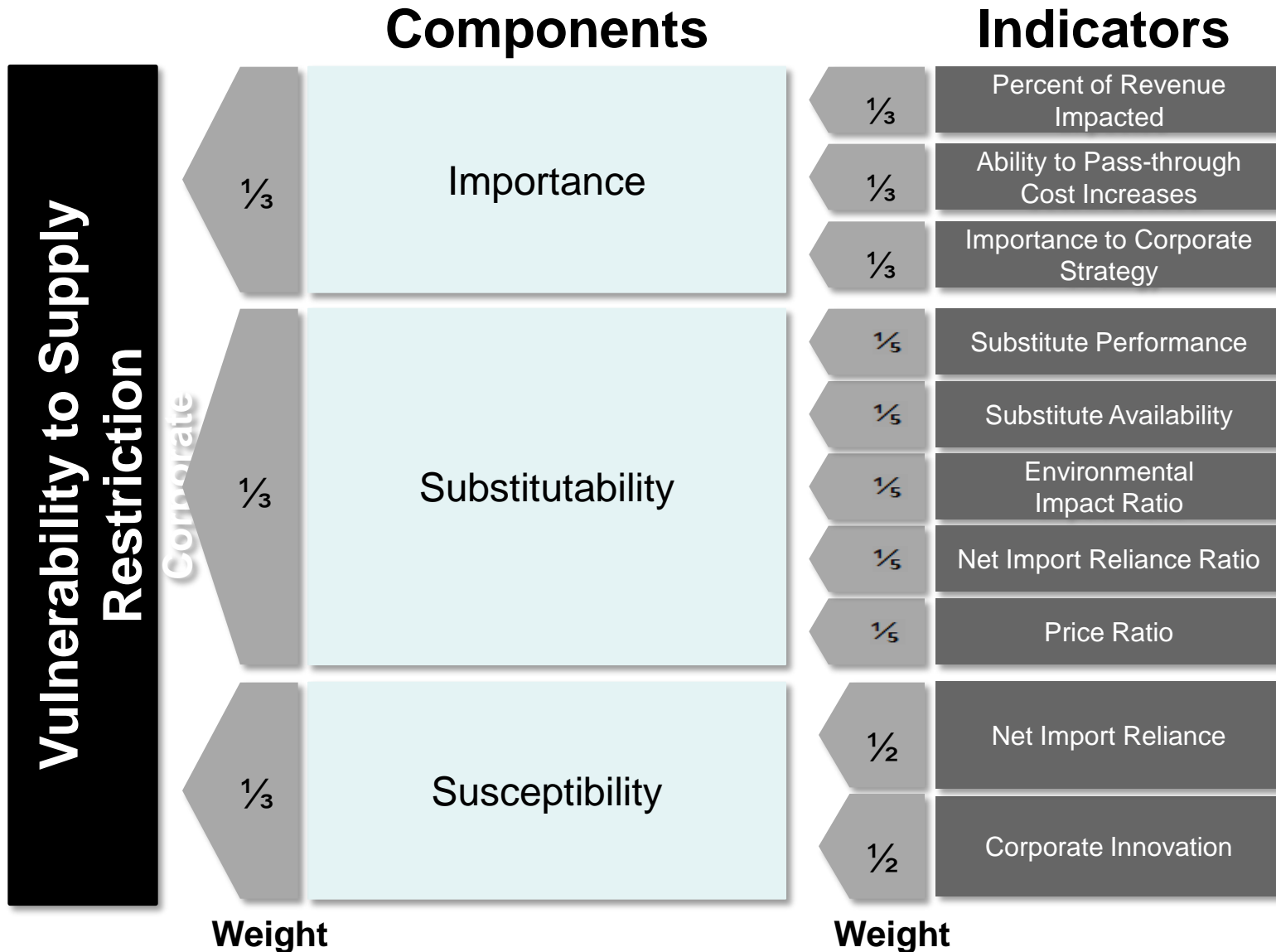
$$WGI_PV_j^{Trans.} = 100 - WGI_PV_j$$
$$WGI_PV_i = \sum w_{i,j} \times WGI_PV_j^{Trans.}$$

Environmental Impact



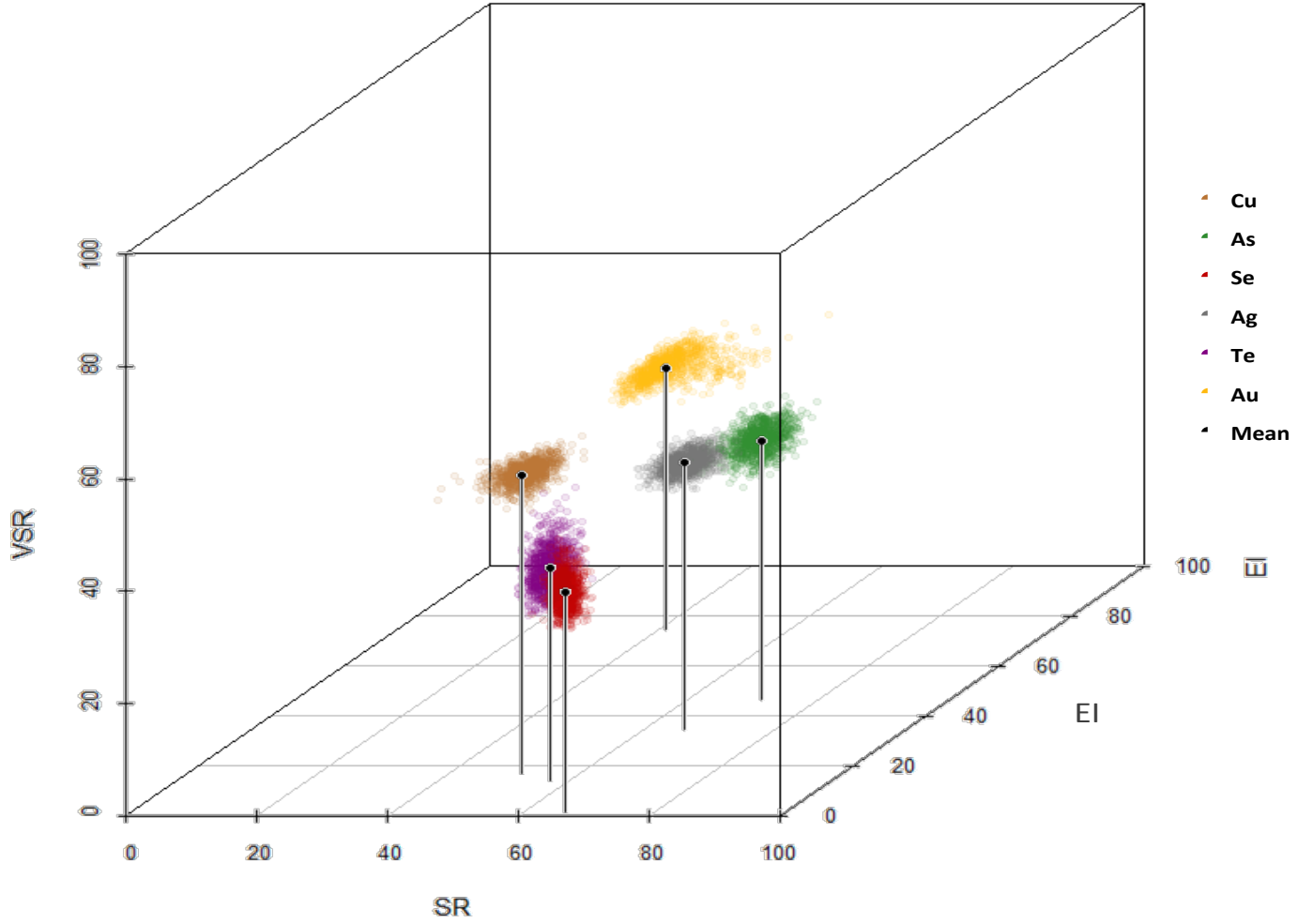
- Evaluates the potential environmental impact of using a metal in modern society
- Based on Ecoinvent database, ReCiPe (H) Endpoint impact methodology (world average normalization)
- Using the following impact category only:
 - Ecosystems
- Result is a single score for a cradle-to-gate environmental impact assessment

Vulnerability – Corporate Level



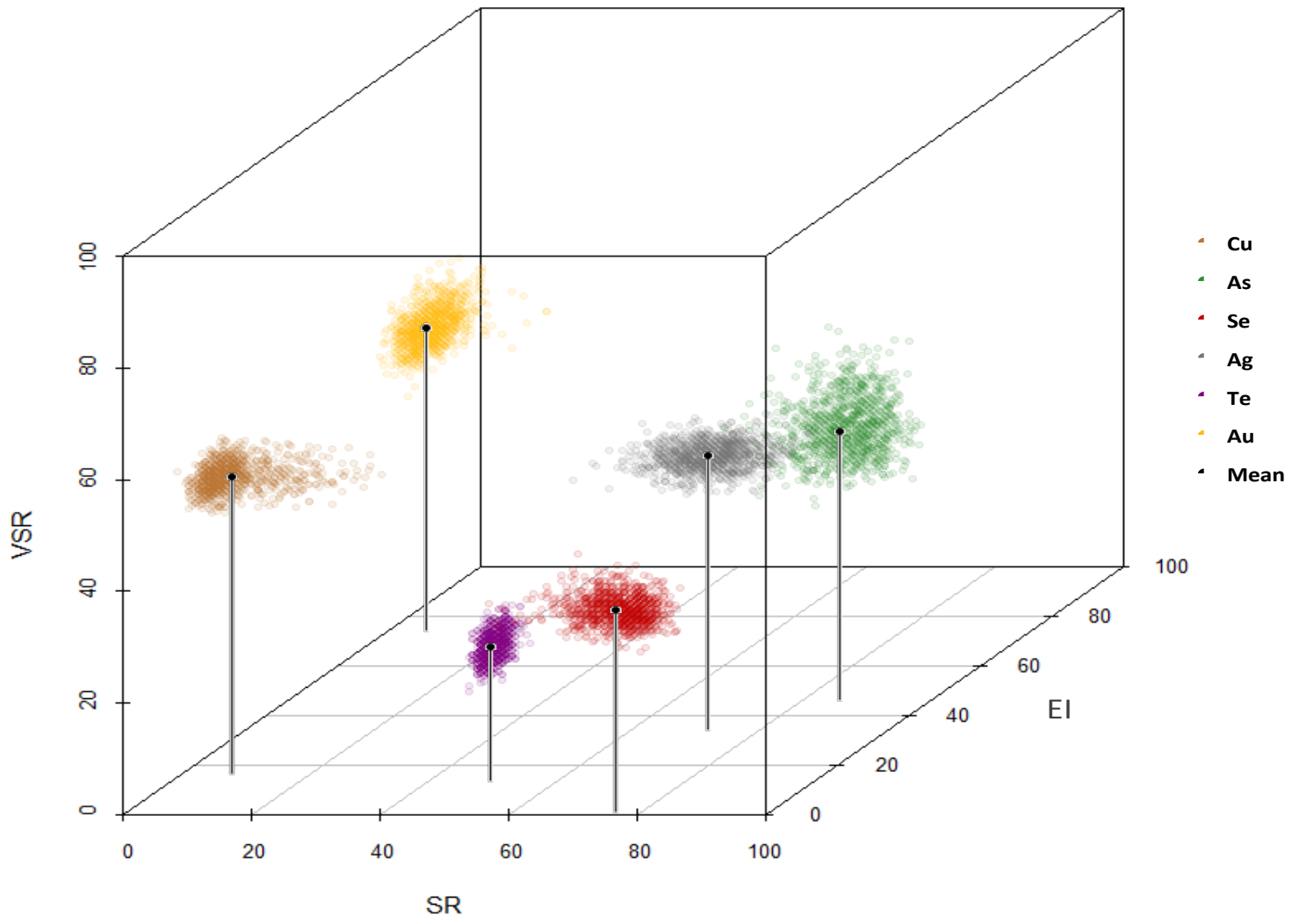
A Sampling of Criticality Results

Copper Family Criticality - US



Copper Family Criticality - Global

N. Nassar et al., *Env. Sci. Technol.*, 46, 1071-1078, 2012

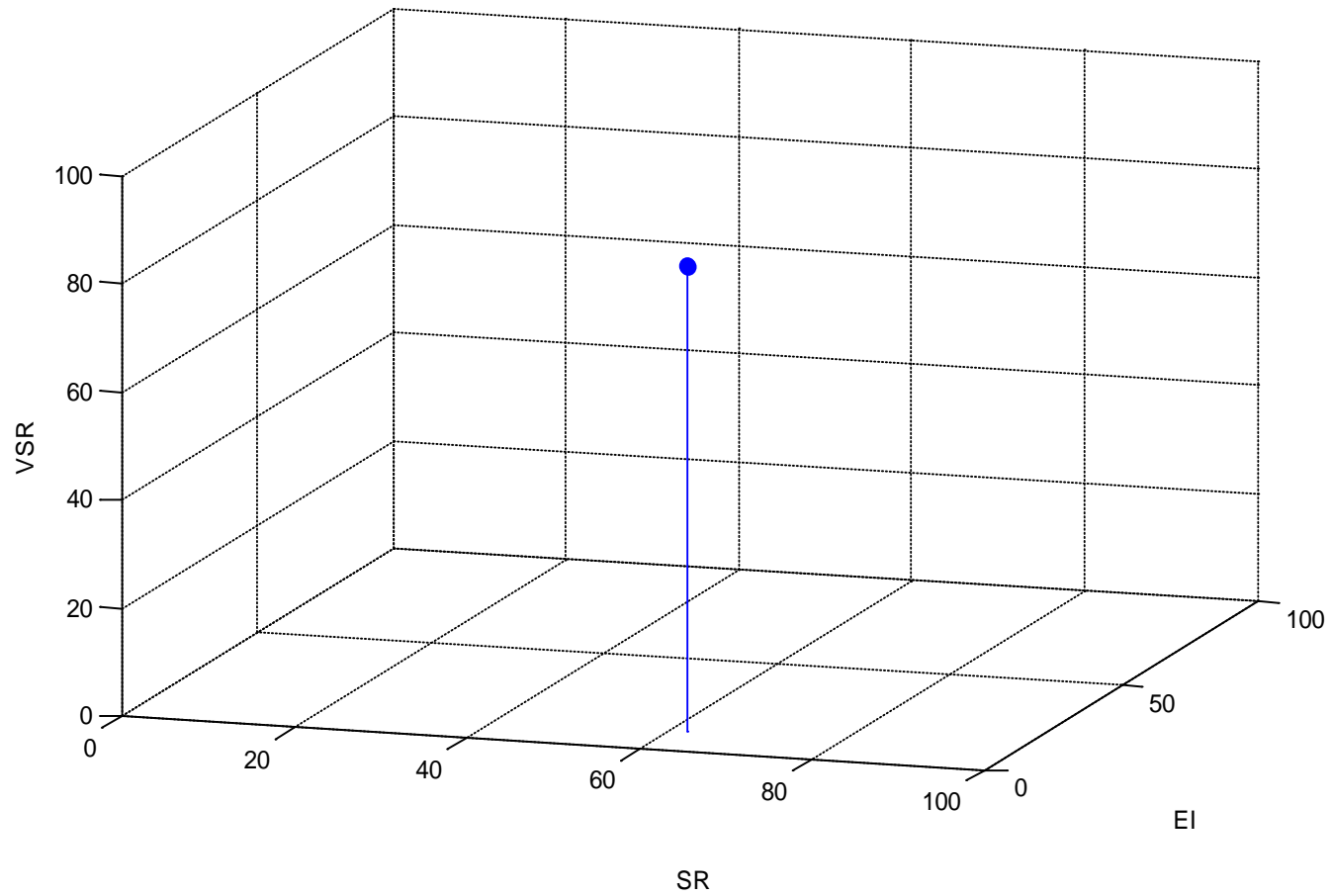


A Criticality Analysis for Tin

World Leading Countries in Tin Production

<i>Country</i>	<i>Mine production (tonnes)</i>	<i>% of global total</i>
China	115,000	44
Indonesia	60,000	23
Peru	38,000	15
Bolivia	16,000	6
Brazil	12,000	5
Total	261,000	100

Tin Criticality : Generic Methodology



Indicator Values

(utilizes generic substitutes for tin uses)

Supply Risk

Geological, Technological, and Economic			Social & Regulatory					Geopolitical					SR _M	SR _M alternative weighting*
DT _M	CF	GTE _M	PPI		HDI	S&R	WGI		GSC		GP			
91	0	46	Tin mining	60	Tin smelting	65	63	Tin mining	76	Tin mining	76	76	62	87

Vulnerability to Supply Restriction

Importance				Substitutability						Susceptibility			VSR _C
RI	PT	CS	I	SP	SA _M	ER	IRR	PR	S	IR	CI	SU	
87.50	62.50	87.50	79.17	43.75	42.23	12.05	62.50	7.00	32.26	100.00	62.5	81.3	59.2

Indicator Values

(assumes no suitable substitutes exist for tin uses)

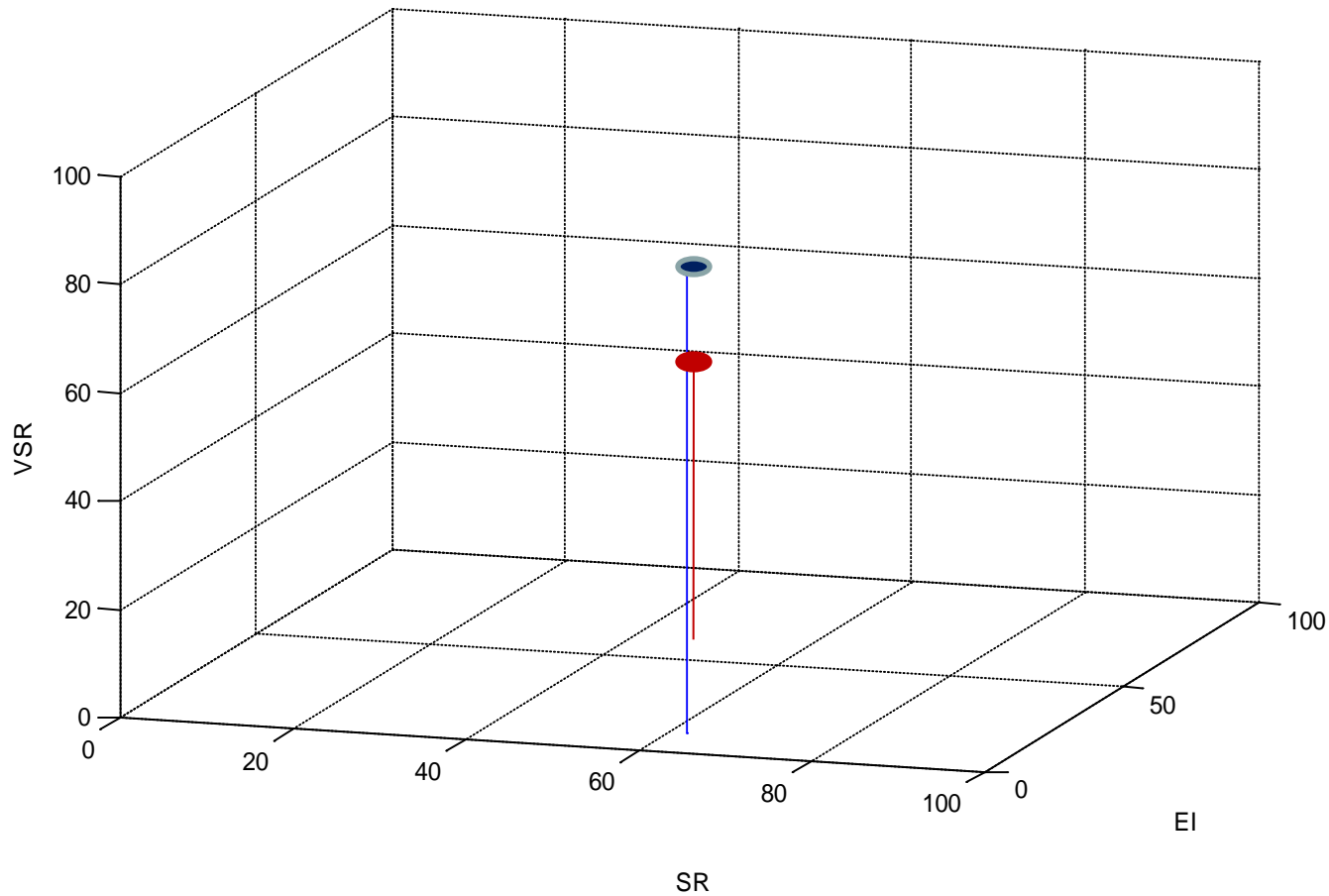
Supply Risk

Geological, Technological, and Economic			Social & Regulatory					Geopolitical					SR _M	SR _M alternative weighting*
DT _M	CF	GTE _M	PPI		HDI	S&R	WGI		GSC		GP			
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RI	PT	CS	I	SP	SA _M	ER	IRR	PR	S	IR	CI	SU	
87.50	62.50	87.50	79.17	100.00	100.00	100.00	100.00	100.00	100.00	100.0	62.5	81.3	85.8

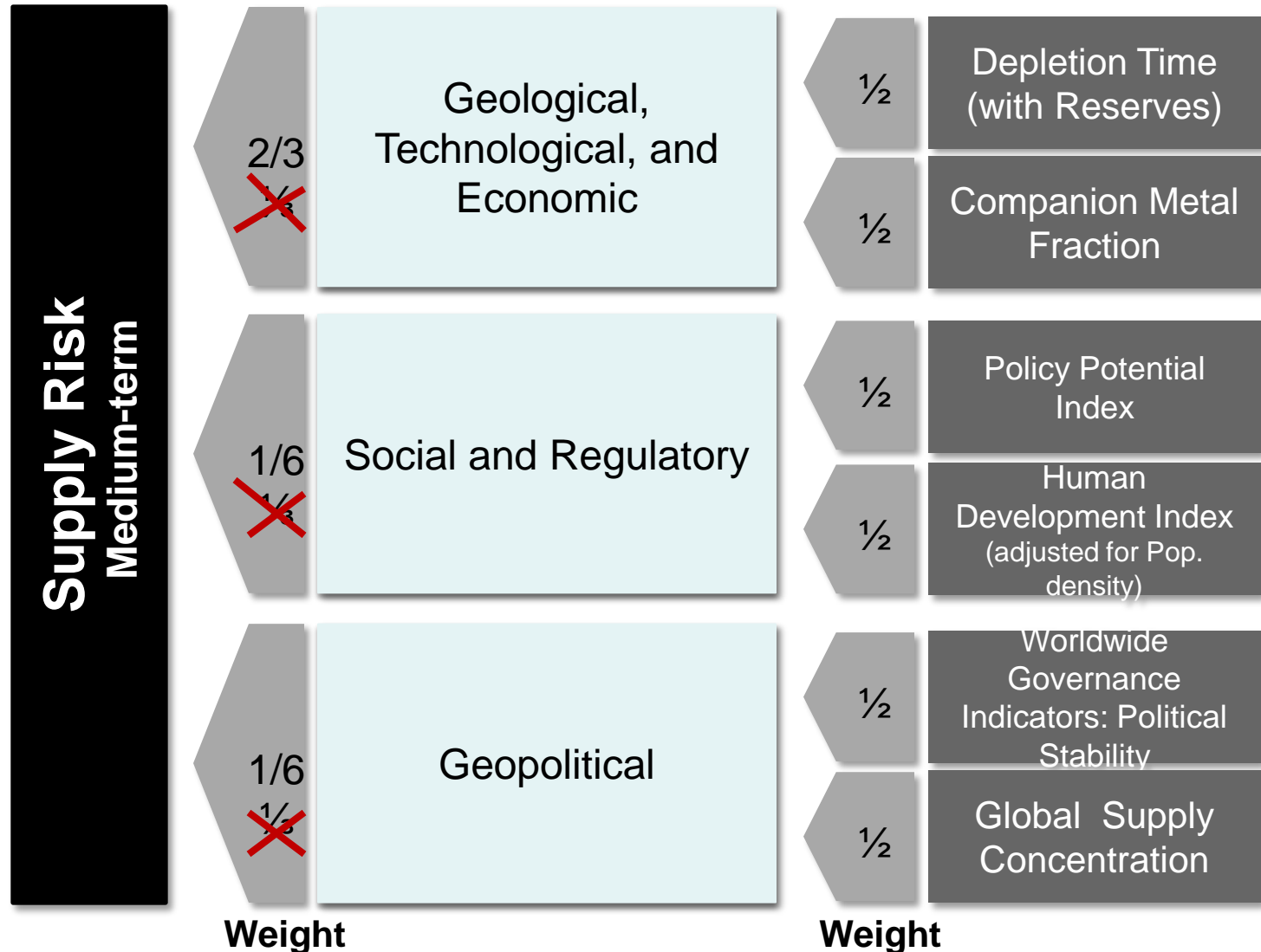
Tin Criticality as a Function of Substitutability



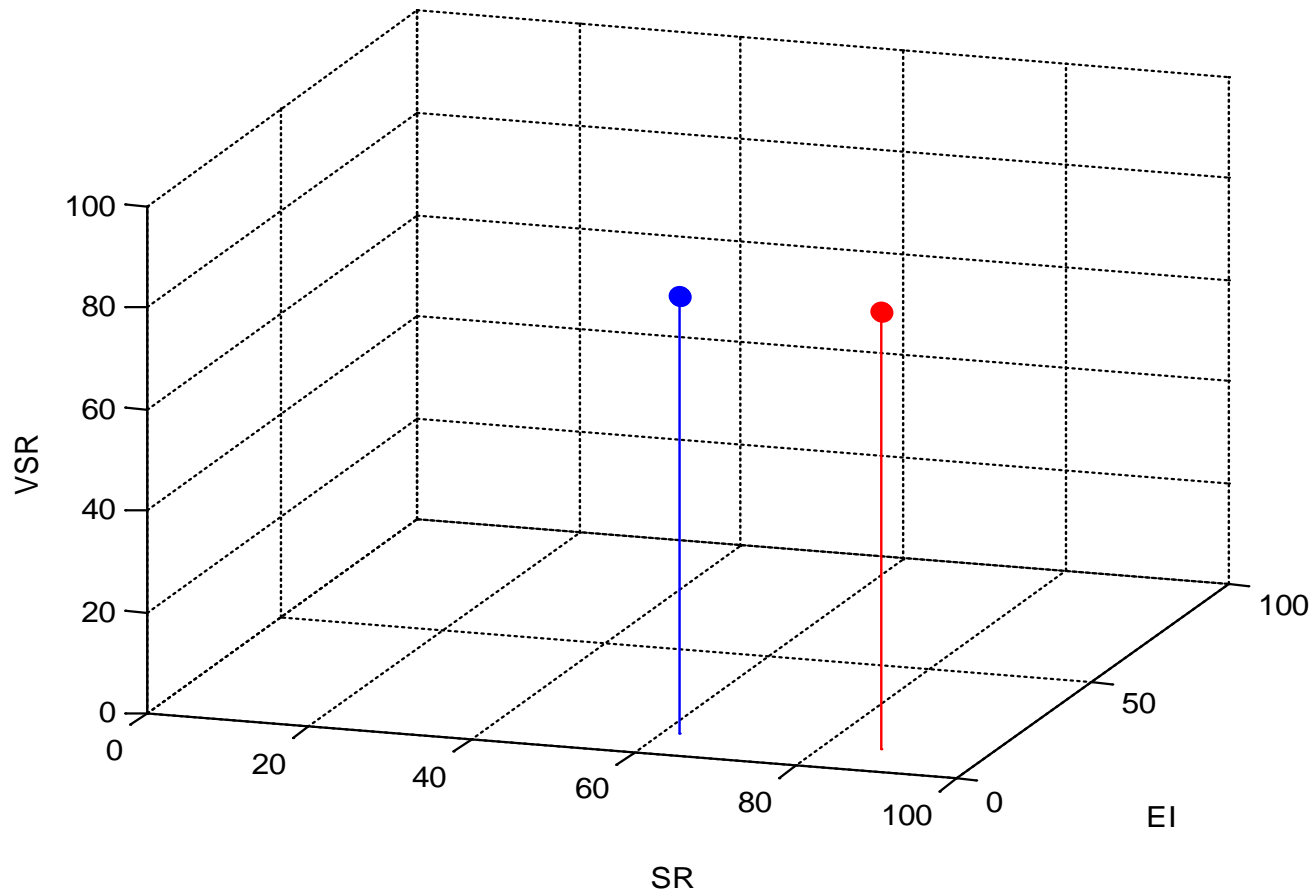
Red: generic substitutes; blue: no suitable substitutes

Supply Risk Axis – Corporate and National

Components




































































Tin Criticality – Alternative Weighting of Supply Risk Components



Blue: no weighting; Red: weighting GP 2/3, GTE 1/6, SR 1/6

Criticality Project Plan – May, 2012

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	1 H		 Published					 Completed											2 He
2	 3 Li	 4 Be											 5 B	6 C	7 N	8 O	9 F	10 Ne	
3	11 Na	 12 Mg	 In Progress					 Planned					13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
4	19 K	20 Ca	 21 Sc	 22 Ti	 23 V	 24 Cr	 25 Mn	 26 Fe	 27 Co	 28 Ni	 29 Cu	 30 Zn	 31 Ga	 32 Ge	 33 As	 34 Se	35 Br	36 Kr	
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Evaluating Criticality: A Summary

- What is critical to one organization may not be critical to another, and methodologies must take this into account
- Criticality is best regarded as an attribute of degree rather than as a state, and the important information is *why* a metal's criticality is what it is, not *whether* the metal is "critical" or not
- The Yale comprehensive critical metals assessment will be complete by the end of 2012