

# Journal Club - Sustainability in my research

ENG-650

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Margaux Roulet

RESEARCH ARTICLE

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**INDUSTRIAL ECOLOGY**

## **By-product metals are technologically essential but have problematic supply**

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# How to invite Batman to your party?



Well, it's easy. You do the bat signal, just like the Police Commissioner of Gotham City.

But then, let's say you want to invite Robin.



Because it's only Batman that can bring him

# Host-Companion Problem

- Modern technologies (PV, wind, EVs, electronics) rely on a **broad set of metals – *Metals like Robin.***
- Many of these are **not mined on purpose** → they come out of the ground as **by-products**.
- Raises a new **supply risk**: availability tied to *host metals*.
- Key question: *Can demand for companion metals be met sustainably?*



# Periodic Table of Companionality

**Definition:** The degree to which a metal is produced as a **by-product** of one or more host metals (Cu, Zn, Ni, Pb, Au, Pt).

- Authors quantified **62 metals** (2008 snapshot).
- **61% (38/62)** are primarily by-products.
- Companion cluster includes:
  - **Indium, Gallium, Tellurium, Selenium** → solar PV.
  - **REEs (Dy, Tb, Nd, etc.)** → wind, EVs.
  - **Cobalt, Rhenium** → superalloys, batteries.

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57-71	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89-103	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Uut Ununtrium	114 Fl Flerovium	115 Uup Ununpentium	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium

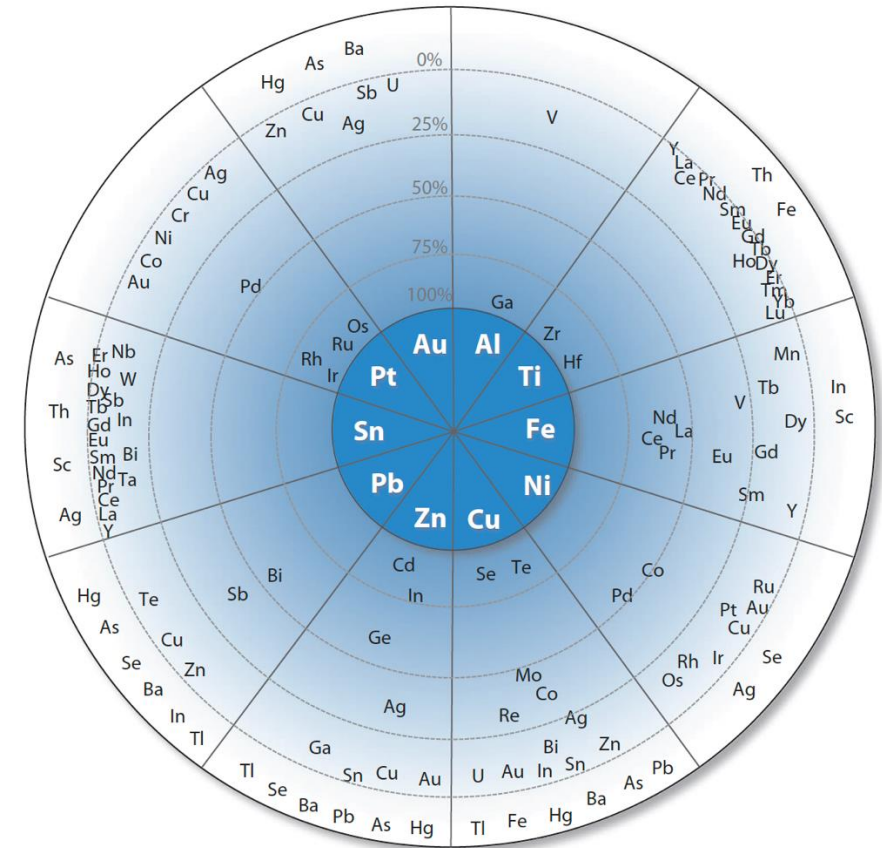
<b>Lanthanide series</b>	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
<b>Actinide series</b>	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

% of metal's global primary production obtained as companion



# The wheel of metal companionship

- Shows host–companion relationships.
- Examples:
  - **Cu** hosts Se, Te, Mo, Ag.
  - **Zn** hosts In, Ge, Cd.
  - **Ni/Pt** host Co, Ru, Rh, Ir.
- Most companions are tied to **1 or 2 key hosts**.



**Fig. 2. The wheel of metal companionship.** The principal host metals form the inner circle. Companion elements appear in the outer circle at distances proportional to the percentage of their primary production (from 100 to 0%) that originates with the host metal indicated. The companion elements in the white region of the outer circle are elements for which the percentage of their production that originates with the host metal indicated has not been determined. Data sources and assumptions for the assessment are given in the Supplementary Materials. Inspired by a diagram developed by (10).

# Companionality Dynamics

- Shows how different metals' dependence on hosts has evolved over decades.

- Stable companions:**

- Rhenium → ~70-90% from Mo.
- Silver → ~70% companion, little change.

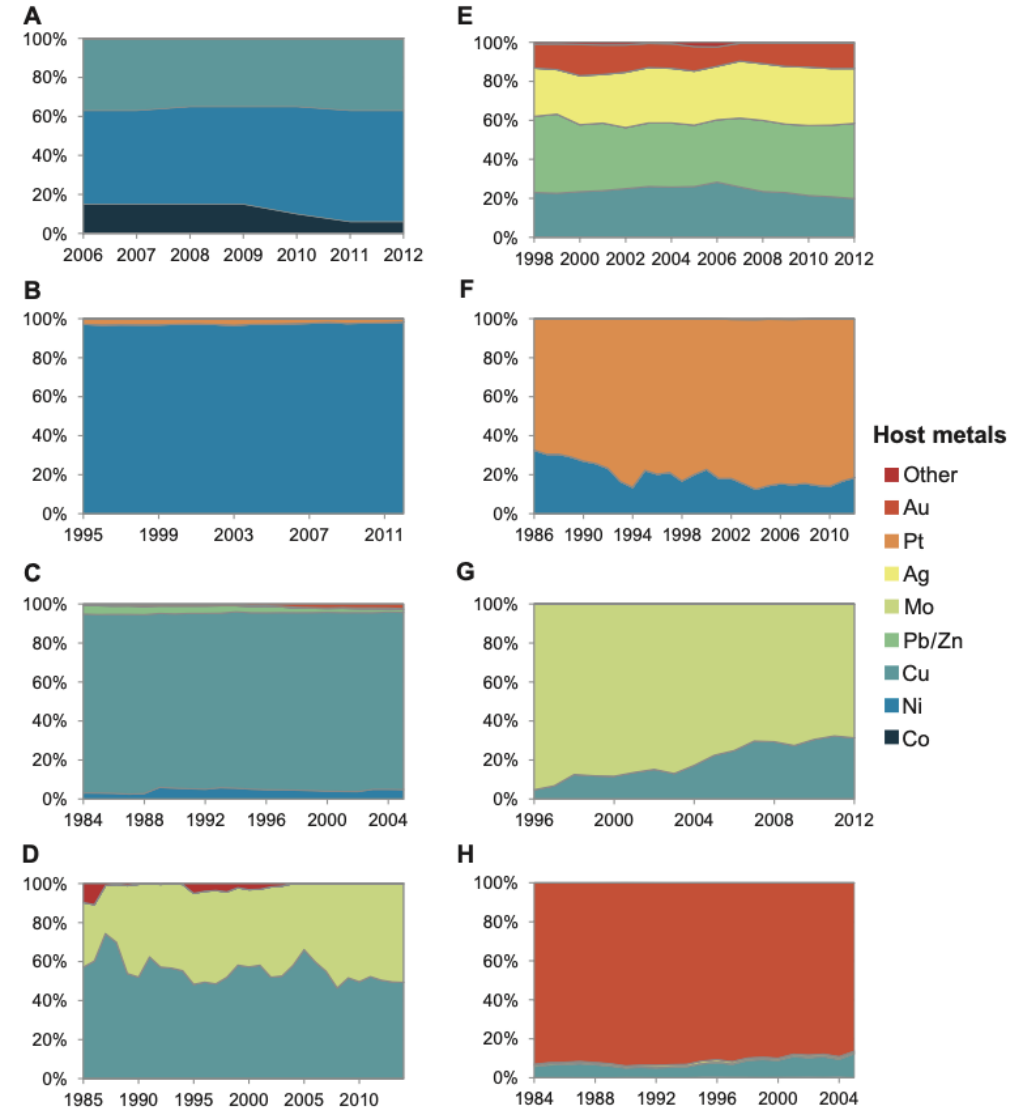
- Dynamic companions:**

- Molybdenum → fell from ~75% (Cu) to ~47% (primary mines).
- Cobalt → mix of Co, Ni, Cu ores shifts over time.

- Hosts:**

- Copper, Nickel, Platinum, Gold → mainly mined directly.

- Key insight:** Companionality isn't static → supply risks can change with new mines, demand shifts, and technology.



**Fig. 3. Companionality dynamics.** (A to H) Variations in host metal contributions (vertical axis) for cobalt (A), nickel (B), copper (C), molybdenum (D), silver (E), platinum (F), rhenium (G), and gold (H) as a percentage of total primary production over several years (horizontal axis). Data are from (5, 37–39).

# Other systemic risk in metals supply



## Geopolitical risk factors

- Market concentration
- Recycling Rate

# HHI to measure market concentration risk factors

Economic measure of market concentration to understand how competitive a market is

Sum the Market Shares (MS) of all firms

$$HHI = \sum_{i=1}^N (MS_i)^2$$

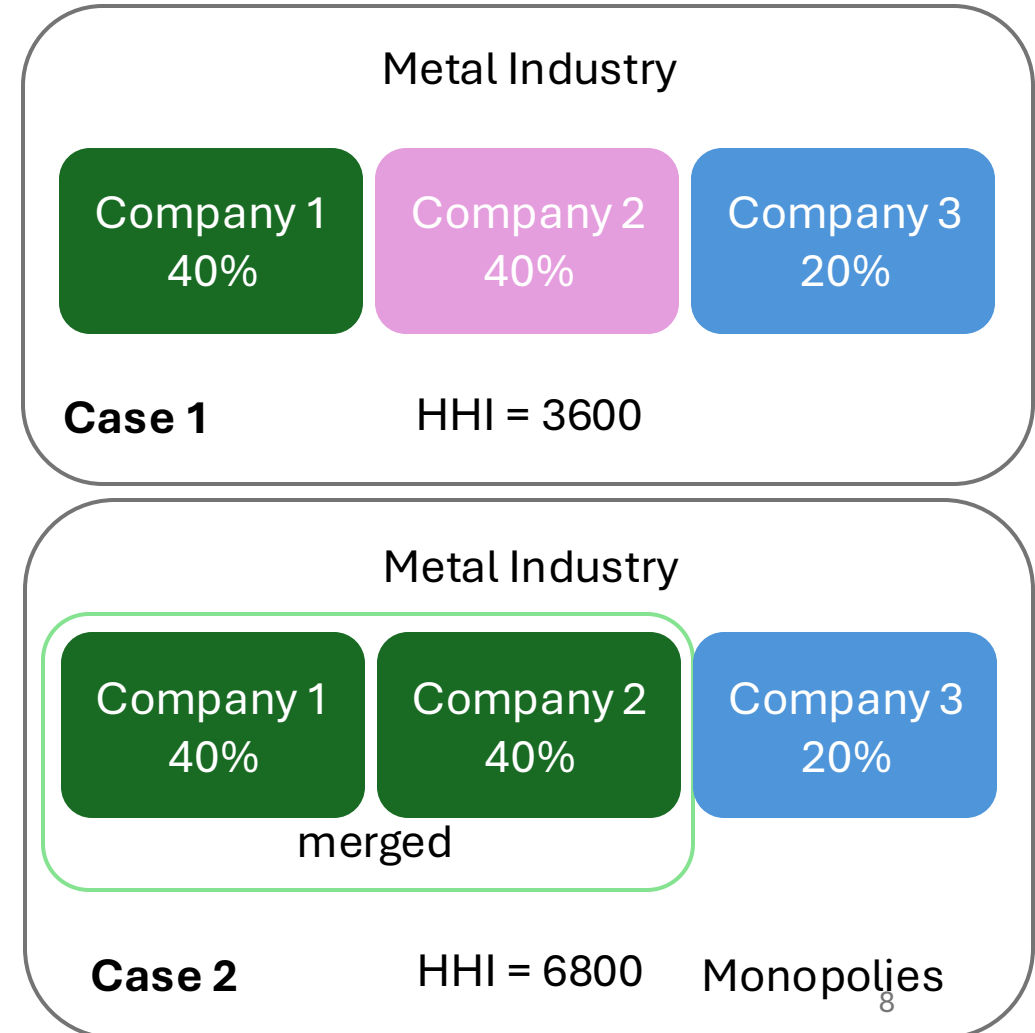
**Close to 0** → market is very competitive (lots of tiny players).

**Below 1500** → unconcentrated market.

**1500–2500** → moderately concentrated.

**Above 2500** → highly concentrated. (risk of monopoly/oligopoly)

**>5000** → extremely concentrated



# 2D Matrix market concentration vs companionality

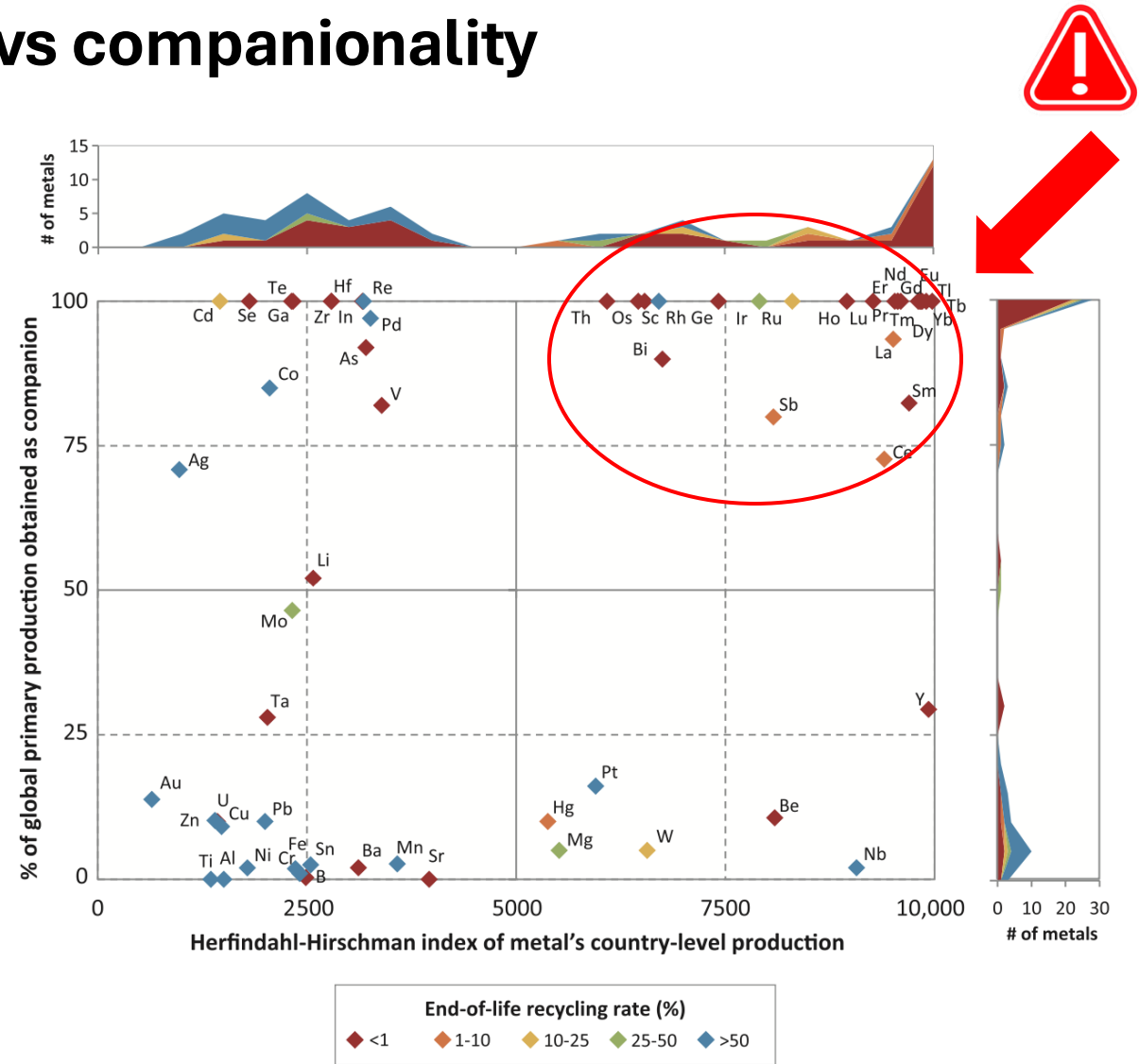
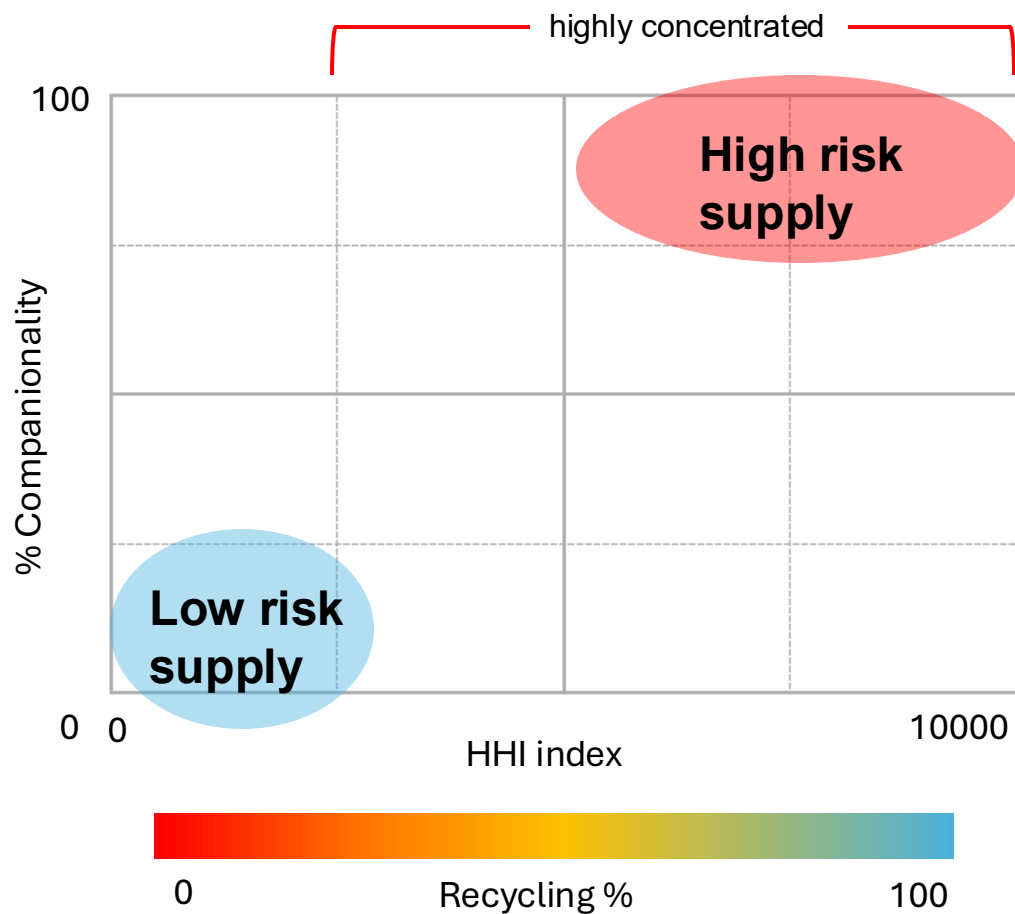


Fig. 4. Companionality, primary production concentration, and end-of-life recycling for 62 metals.

# 2D Matrix market concentration vs companionability

45/63 metals production is highly concentrated (production in < 3-4 countries)

20/31 metals with extremely high concentration are not recycled

27/38 metals obtained as companions are not recycled

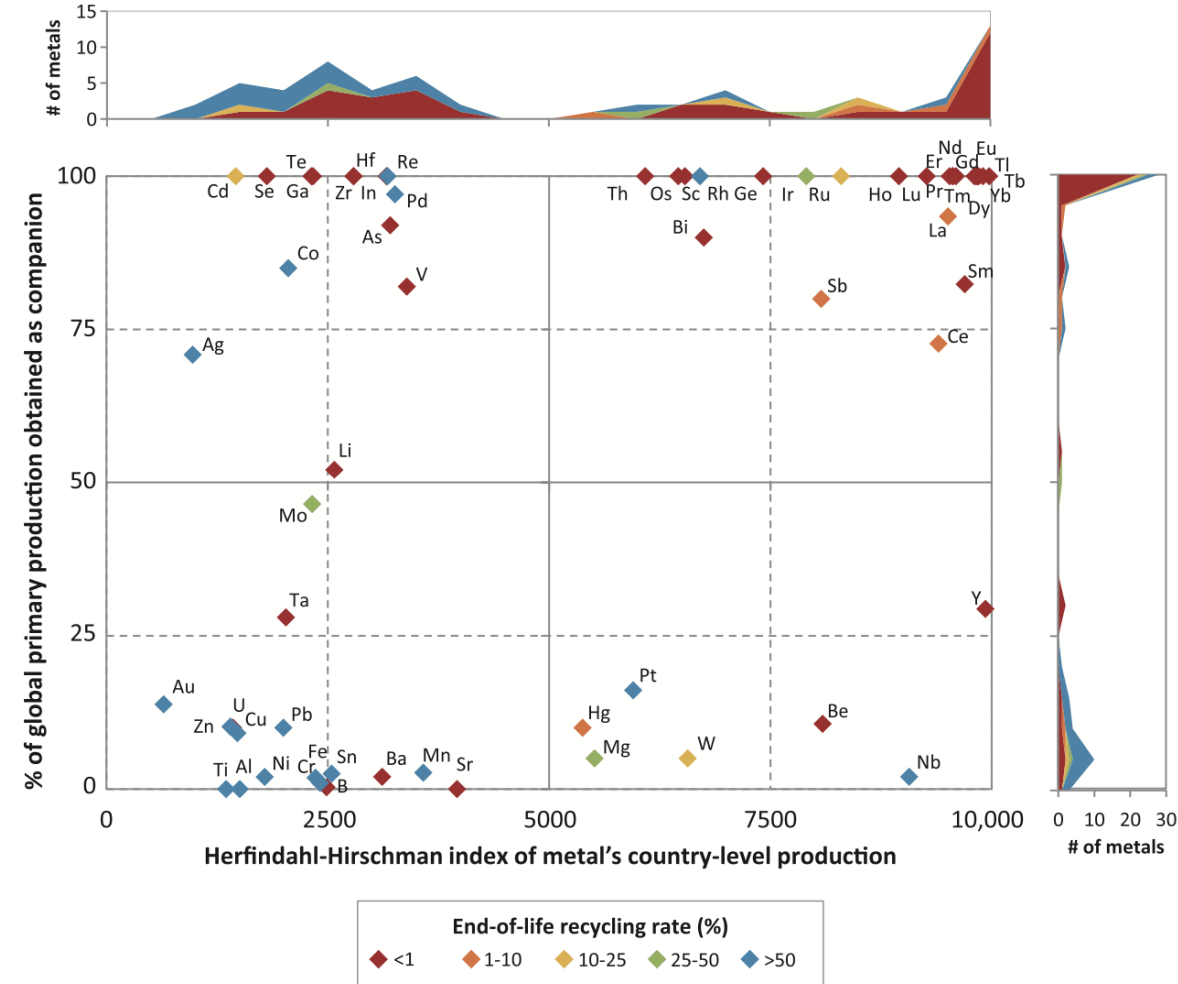
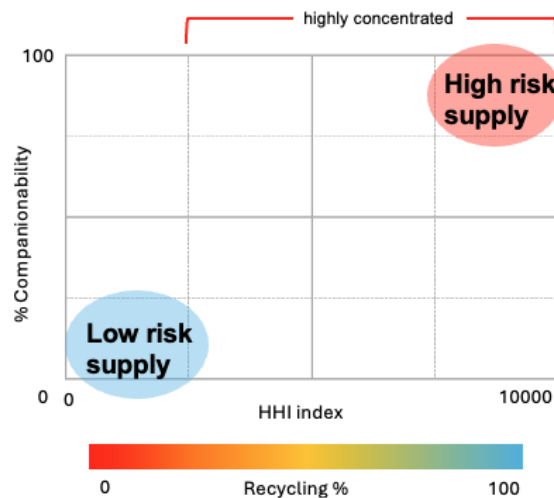
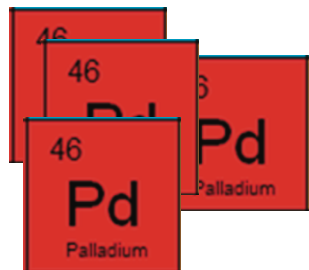
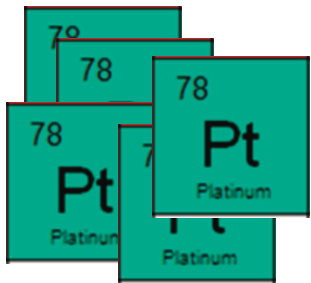


Fig. 4. Companionability, primary production concentration, and end-of-life recycling for 62 metals.

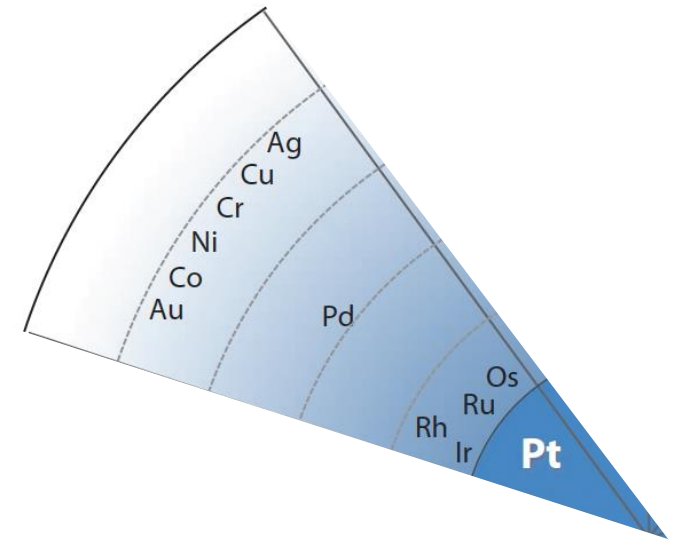
# Economic evaluation of companionability

Who's the real companion ?

Host

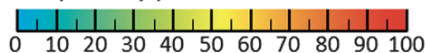


Companion



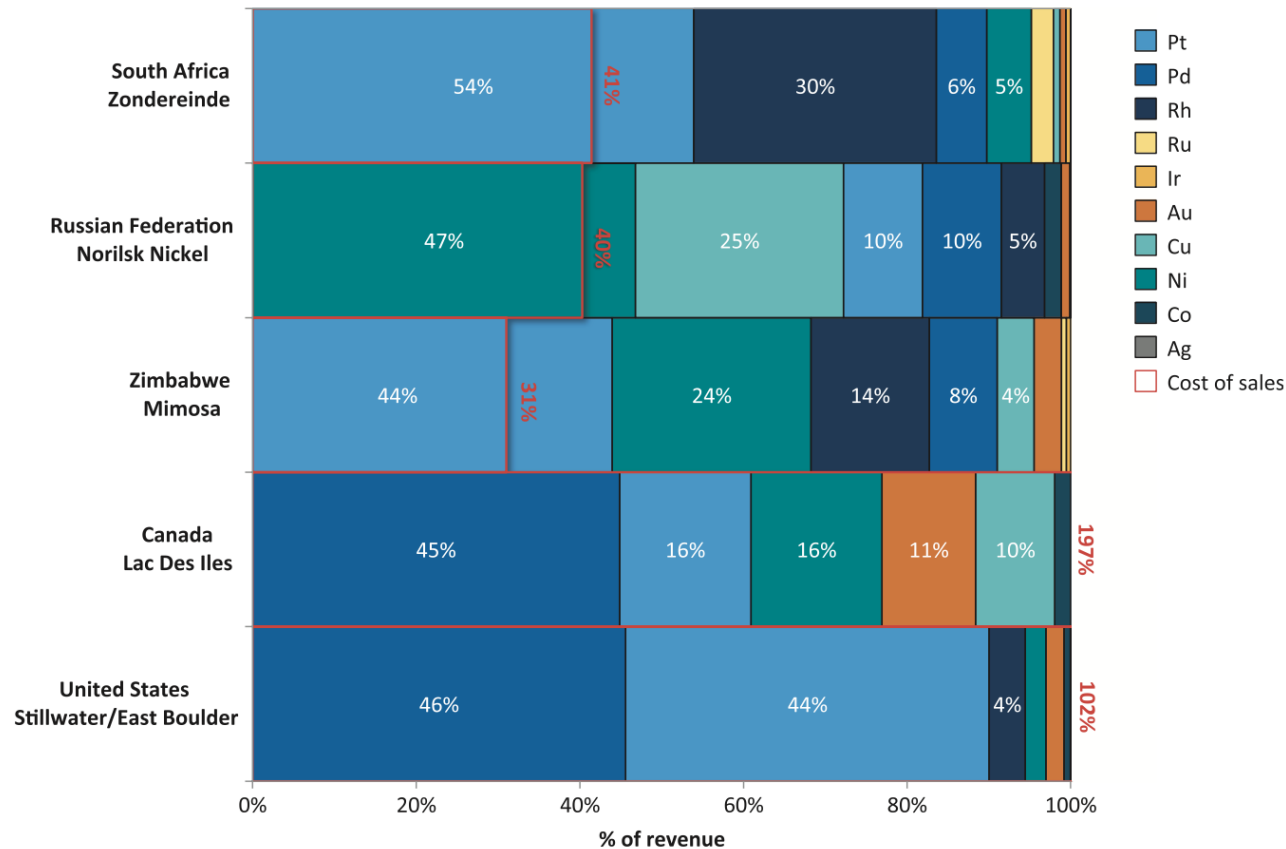
a companion metal is one that is **financially dependent** on other metals for recovery rather than merely co-occurring with the host.

% of metal's global primary production obtained as companion



# Economic evaluation of companionality

Who's the real companion ?



**Pt is a self-sufficient host**

**Ni is a self-sufficient host**

**Pt is a self-sufficient host**

**Pt is a by-product. Pd is a host.**

**Pt and Pd are co-products**

Fig. 5. Revenue contribution by metal (in descending order) for five mines producing platinum

# Economic companionship assessment

## Evaluation of metal economical self-sufficiency

$$\text{Companionality}_i = \frac{\sum_j \left( \left( 100 \cdot \left( 1 - \min \left( \frac{\text{Revenue}_{i,j}}{\text{Cost of sales}_j}, 1 \right) \right) \right) \cdot \text{Sales volume}_{i,j} \right)}{\text{Sales volume}_i}$$

0 → entirely self-sufficient  
 100 → entirely dependent

*To quantify a metal's companionship, the authors weight-averaged the ratio of the metal's revenue contribution relative to cost of sales for each mine by each mine's sales volume of that metal relative to its global sales across all operations.*

	production companionship	economic companionship
Pt	16	17
Pd	97	80
<b>Rh</b>	100	48
Ru	100	95
Ir	100	99

Authors find minor changes to generalized companionship except for Rhodium.

Companions likely provide only a small contribution to the overall revenue and are unlikely to cover a significant portion of the cost of sales.

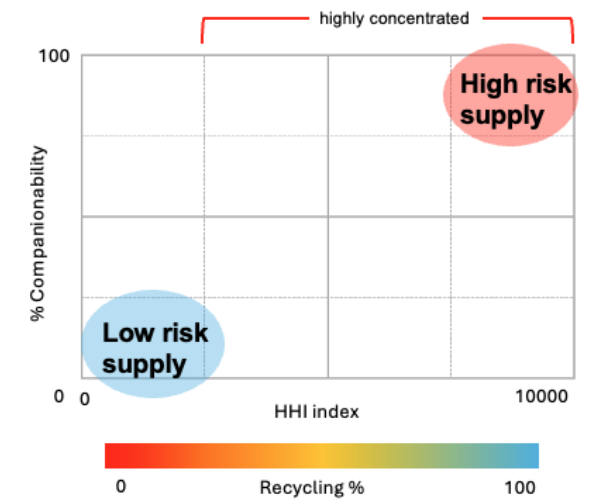
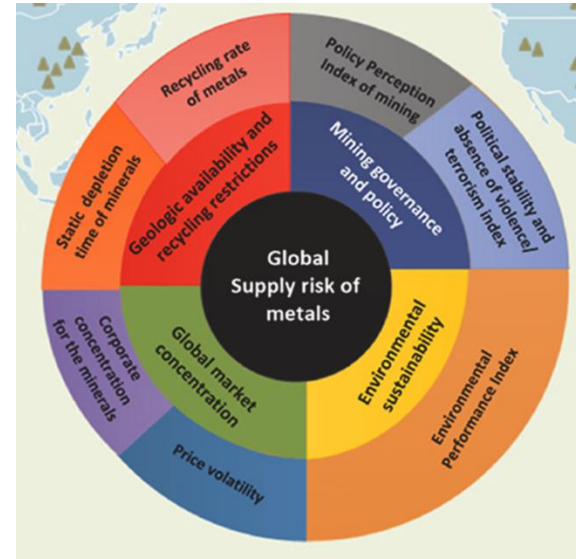
# Take aways

Modern technology makes use of companion metals which supply depends on the host metal.

Market for metal is highly concentrated which increase the metal supply volatility

Companion metals are merely not recycled

Companion metals are economically dependent on host metals



# Discussion

«It is undeniable that the widespread use of companion metals has resulted in markedly improved performance in many product sectors. Sustaining those uses may become a challenge going forward because of the ***dependence of companion metal supplies on the production of host metals***. [...] much of ***modern technology*** depends on metals whose ***supplies are uncertain*** and whose ***market transactions are largely opaque***; in concert, this produces a supply situation that may prove difficult to sustain.»

**If primary production of companion metals becomes constrained, what levers for action exist?**

# Other systemic risk in metals supply

Can you think of any ?

- **Ukraine Invasion:** Russia's position as a major producer of nickel and cobalt led to market volatility and concerns about supply availability following the 2022 events.
- **COVID-19 Pandemic:** Lockdown policies in countries like Peru disrupted copper mining, while disruptions in South Africa's platinum output demonstrated the impact of regional lockdowns on global supply chains.
- **Environmental Policies:** Policies aimed at mitigating climate change have increased the demand for critical metals like lithium, raising systemic risk for companies producing these and other important metals.

