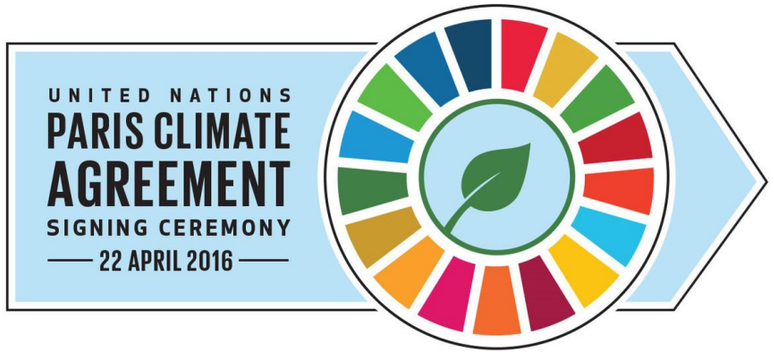
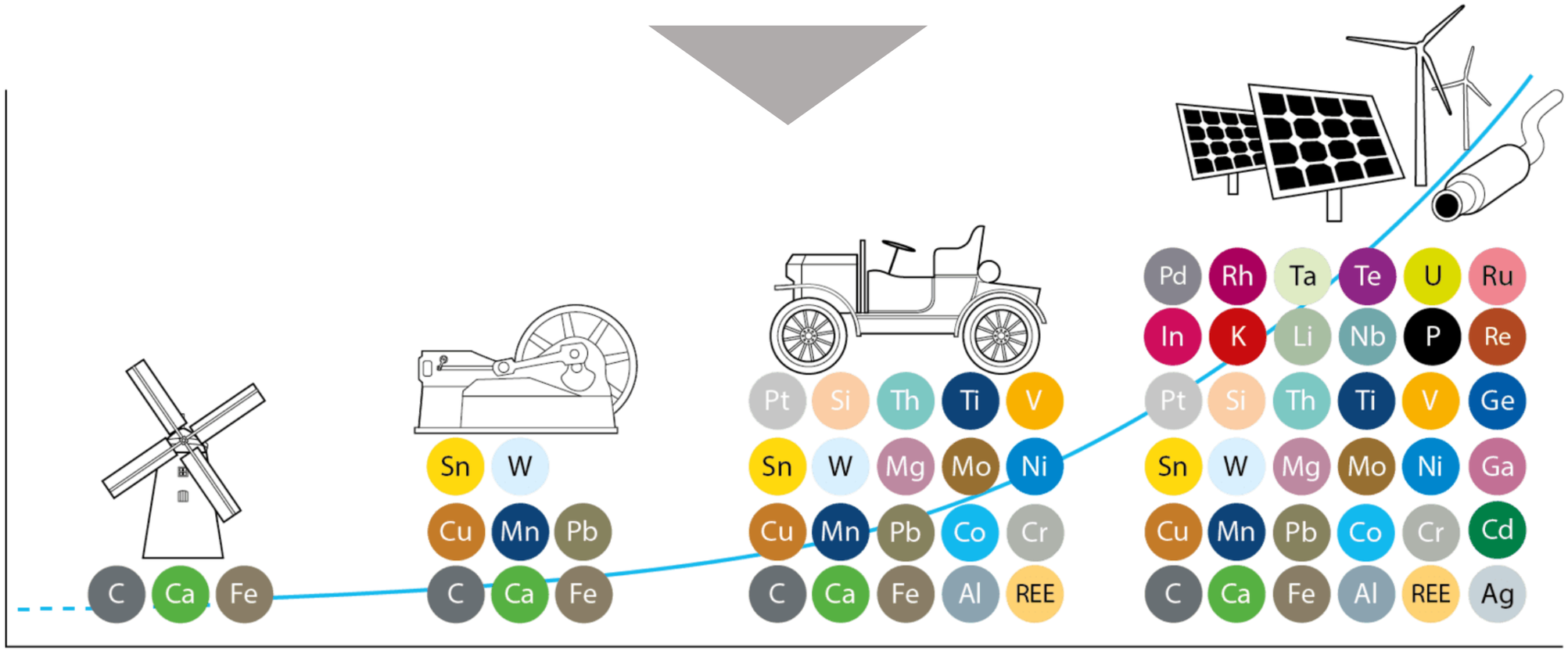
Critical materials demand in the green transition: a review

Takuma Watari

Researcher, National Institute for Environmental Studies
PhD candidate, The University of Tokyo

Energy-Metal Nexus

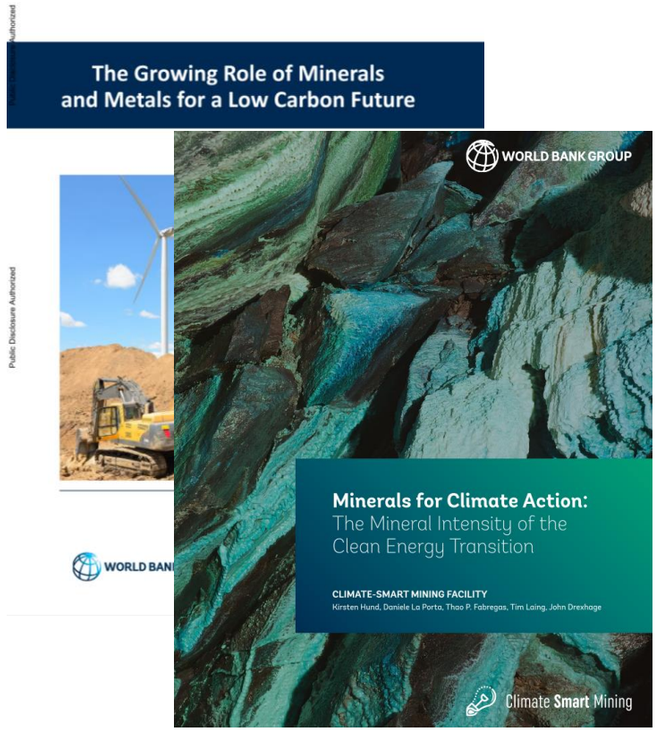




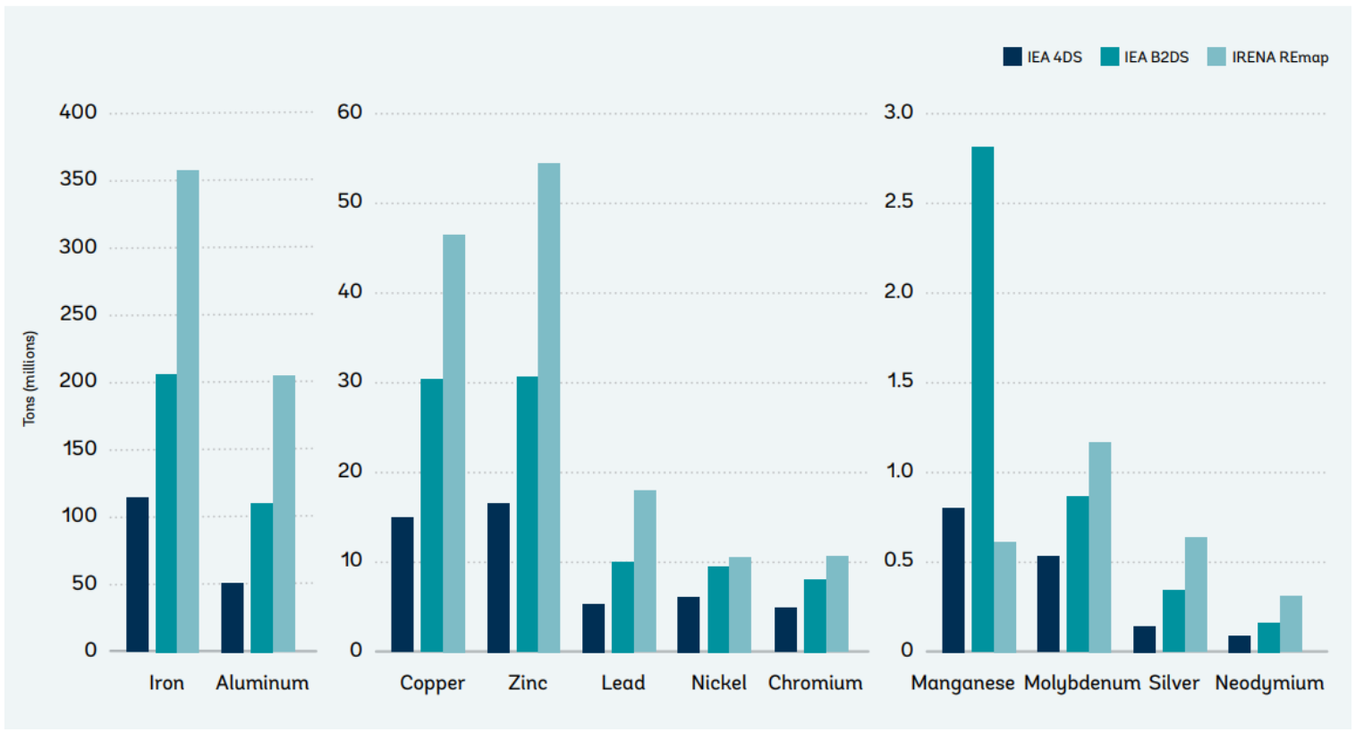
Achzet et al. (2009)

Energy-Metal Nexus

Growing number of studies are emerging



World Bank (2017, 2020)



What are the progress and limitations in existing studies?

Review of critical metal dynamics to 2050 for 48 elements

Takuma Watari, Keisuke Nansai and Kenichi Nakajima (2020)
"**Review of critical metal dynamics to 2050 for 48 elements**"
Resource Conservation and Recycling, 155, 104669
https://doi.org/10.1016/j.resconrec.2019.104669

Resources, Conservation & Recycling 155 (2020) 104669

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Review

Review of critical metal dynamics to 2050 for 48 elements

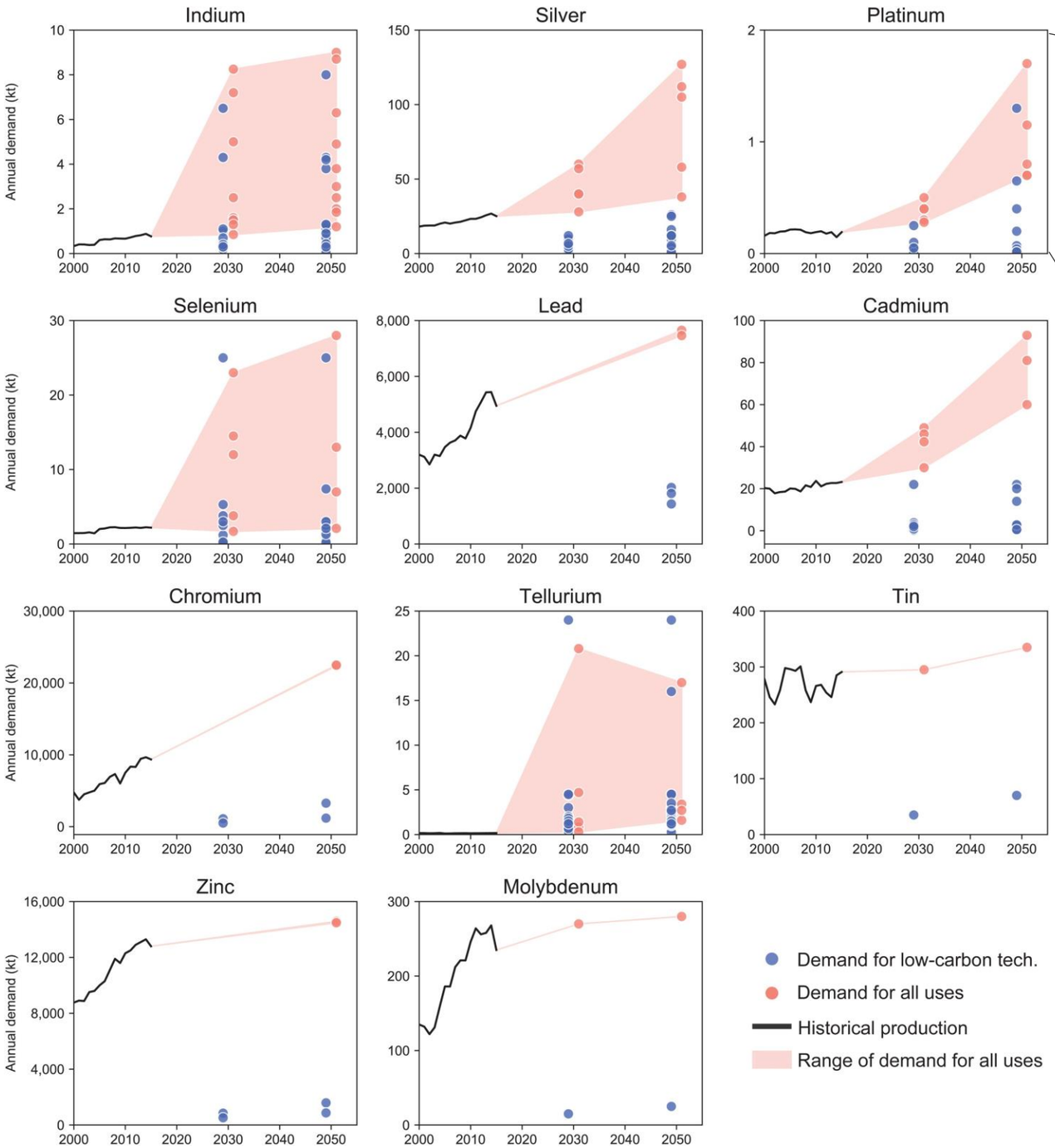
Takuma Watari[a,b,*], Keisuke Nansai[a,c], Kenichi Nakajima[a]

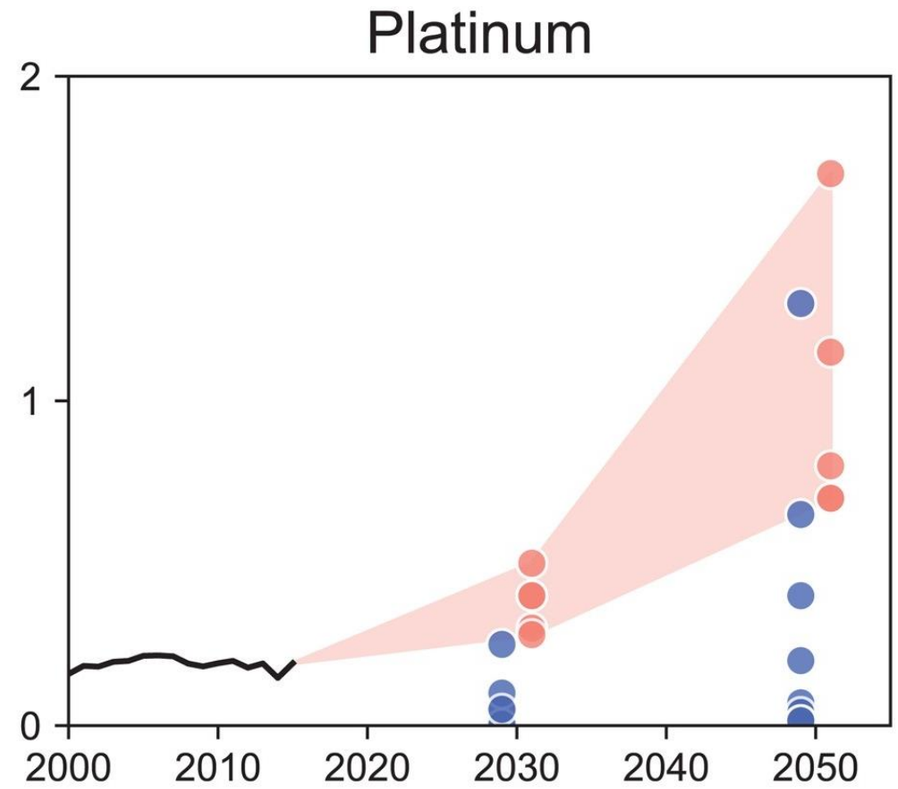
[a] Center for Material Cycles and Waste Management Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan
[b] Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, 277-8563, Japan
[c] ISA, School of Physics, Faculty of Science, The University of Sydney, Camperdown, 2006, NSW, Australia

This study provides;

- Critical review of 88 studies covering 48 metals
- Five unaddressed issues in existing studies
- Data set containing predicted global demand gathered from various relevant articles (546 data points)

Demand projection dataset

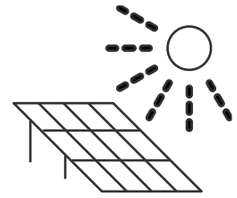


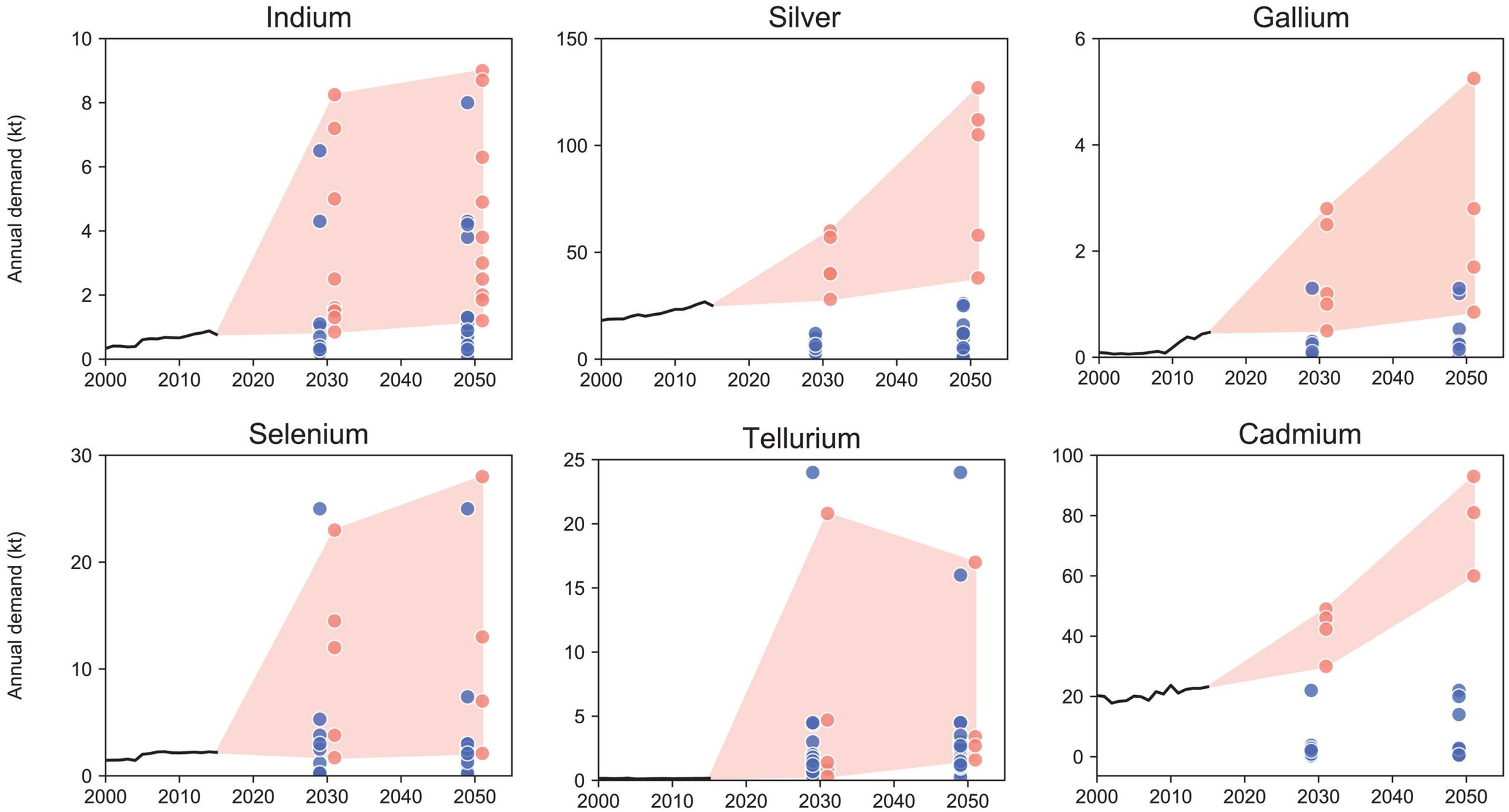


Dataset covers;

- 546 data points covering 22 metals
- Demand for both low-carbon tech. and all uses
- One-to-one reference to data points and original papers

Metals related to solar PV

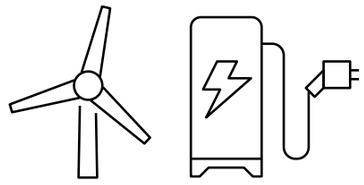


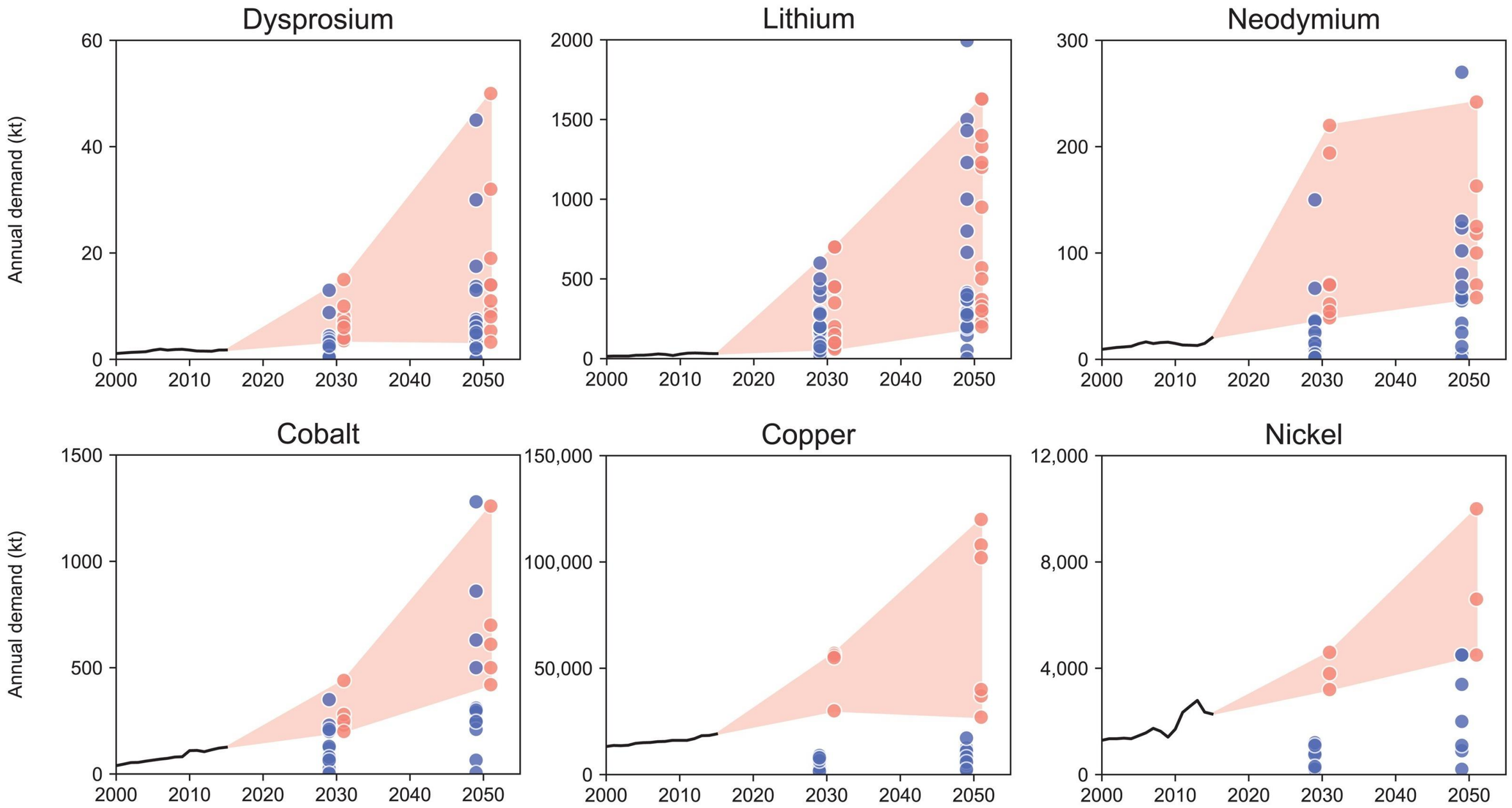


Takuma Watari et al. (2020) *Resource Conservation and Recycling*, 155, 104669

National Institute for Environmental Studies, Japan

Metals related to EVs and wind





Takuma Watari et al. (2020) *Resource Conservation and Recycling*, 155, 104669

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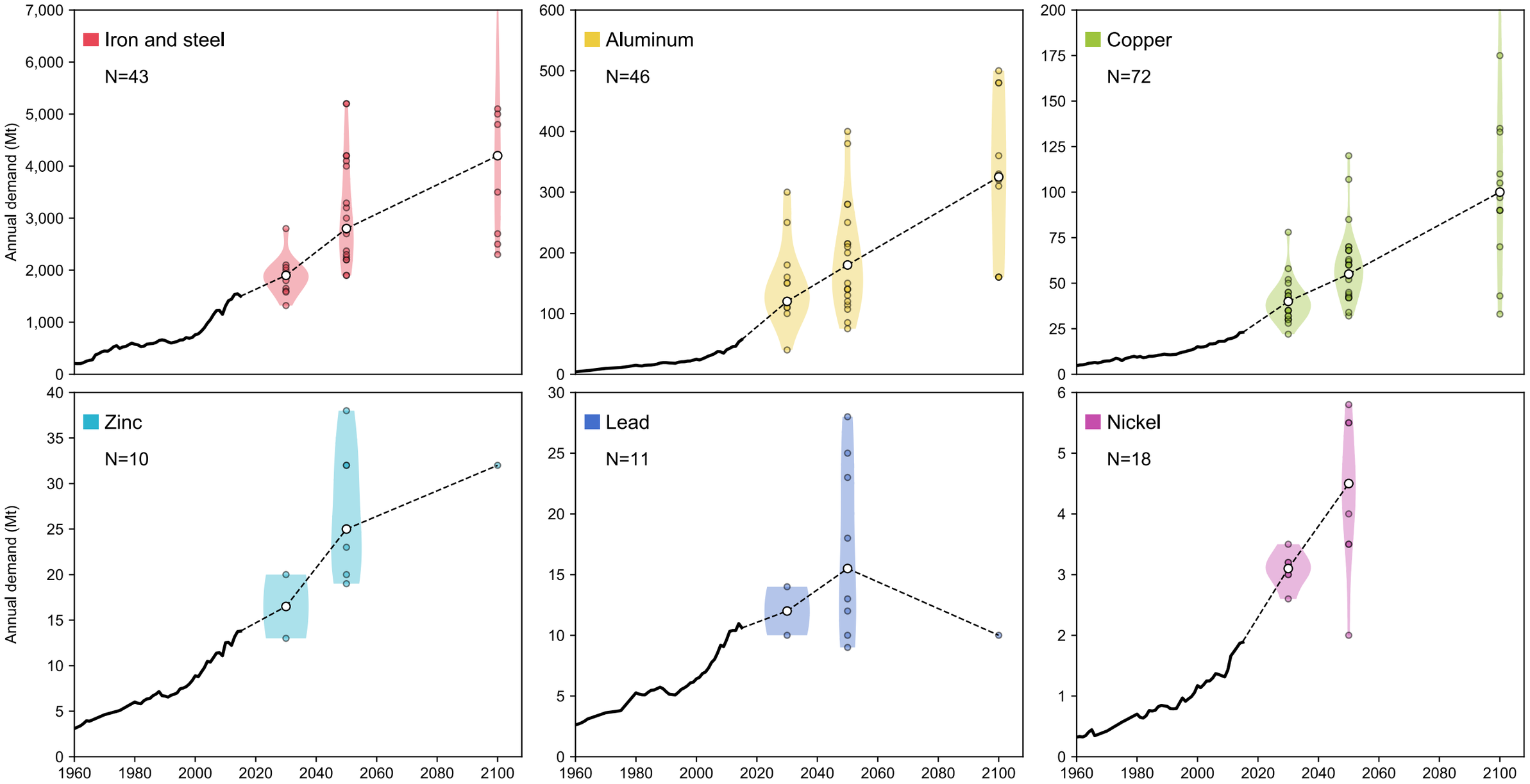
Future of major metals



https://doi.org/10.1016/j.resconrec.2020.105107

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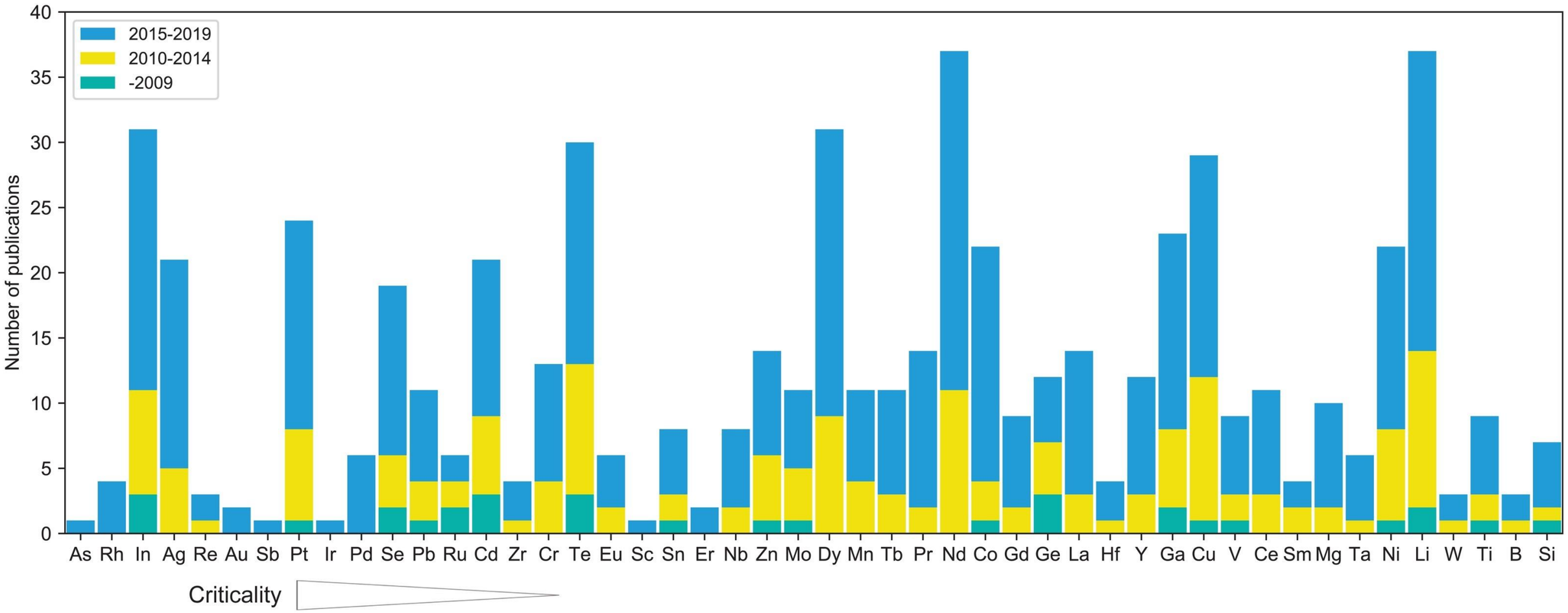
What are the limitations and unaddressed issues in previous studies?

Number of publications each element



No long-term demand outlook is available for some high criticality metals

Coverage of full life cycle

Criticality

	As	Rh	In	Ag	Re	Au	Sb	Pt	Ir	Pd	Se	Pb	Ru	Cd	Zr	Cr	Te	Eu	Sc	Sn	Er	Nb	Zn	Mo
Extraction/processing	0	2	21	15	2	2	1	15	1	3	12	6	3	13	3	7	21	6	0	5	1	5	7	5
Manufacturing	1	4	31	21	3	2	1	23	1	6	19	10	6	21	4	12	30	7	1	8	1	8	13	11
Waste management	1	2	18	15	1	2	1	16	1	4	10	6	2	11	2	7	18	2	0	5	1	5	7	5
Trade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Environment	0	0	1	1	0	0	0	2	0	0	1	1	0	0	1	1	1	1	0	2	1	1	2	1
Social	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Lowest — Highest

	Dy	Mn	Tb	Pr	Nd	Co	Gd	Ge	La	Hf	Y	Ga	Cu	V	Ce	Sm	Mg	Ta	Ni	Li	W	Ti	B	Si
Extraction/processing	21	9	11	10	23	15	5	7	9	2	10	14	15	5	8	3	4	3	13	26	2	6	2	3
Manufacturing	30	11	11	13	36	21	8	12	13	4	13	23	28	9	10	4	9	6	22	37	3	9	3	7
Waste management	18	6	6	8	20	13	3	7	5	1	5	12	14	5	4	0	5	3	10	24	1	6	1	3
Trade	2	1	2	2	2	1	1	0	1	0	2	0	0	0	1	1	0	0	1	4	0	0	0	0
Environment	3	1	1	2	3	1	1	0	2	1	2	1	4	1	2	0	1	0	1	1	1	1	1	1
Social	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The social and environmental implications induced by growth in metals demand have been barely quantified

Coverage of full life cycle

Criticality

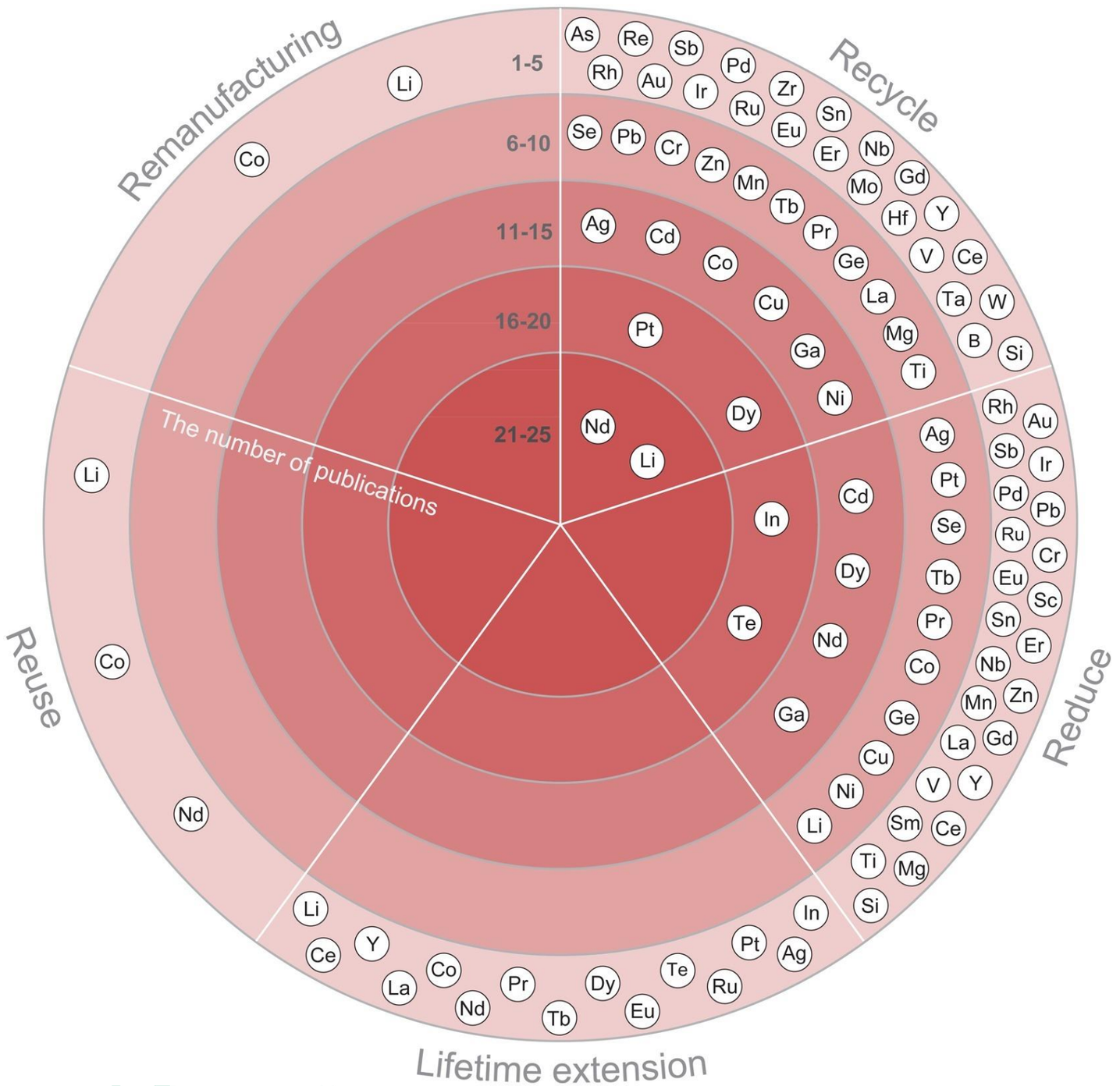
	As	Rh	In	Ag	Re	Au	Sb	Pt	Ir	Pd	Se	Pb	Ru	Cd	Zr	Cr	Te	Eu	Sc	Sn	Er	Nb	Zn	Mo
Extraction/processing	0	2	21	15	2	2	1	15	1	3	12	6	3	13	3	7	21	6	0	5	1	5	7	5
Manufacturing	1	4	31	21	3	2	1	23	1	6	19	10	6	21	4	12	30	7	1	8	1	8	13	11
Waste management	1	2	18	15	1	2	1	16	1	4	10	6	2	11	2	7	18	2	0	5	1	5	7	5
Trade	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Environment	0	0	1	1	0	0	0	2	0	0	1	1	0	0	1	1	1	1	0	2	1	1	2	1
Social	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Lowest — Highest

	Dy	Mn	Tb	Pr	Nd	Co	Gd	Ge	La	Hf	Y	Ga	Cu	V	Ce	Sm	Mg	Ta	Ni	Li	W	Ti	B	Si
Extraction/processing	21	9	11	10	23	15	5	7	9	2	10	14	15	5	8	3	4	3	13	26	2	6	2	3
Manufacturing	30	11	11	13	36	21	8	12	13	4	13	23	28	9	10	4	9	6	22	37	3	9	3	7
Waste management	18	6	6	8	20	13	3	7	5	1	5	12	14	5	4	0	5	3	10	24	1	6	1	3
Trade	2	1	2	2	2	1	1	0	1	0	2	0	0	0	1	1	0	0	1	4	0	0	0	0
Environment	3	1	1	2	3	1	1	0	2	1	2	1	4	1	2	0	1	0	1	1	1	1	1	1
Social	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Consideration of the spatial divergence between consuming and producing countries formed by international resource trade has been underemphasized

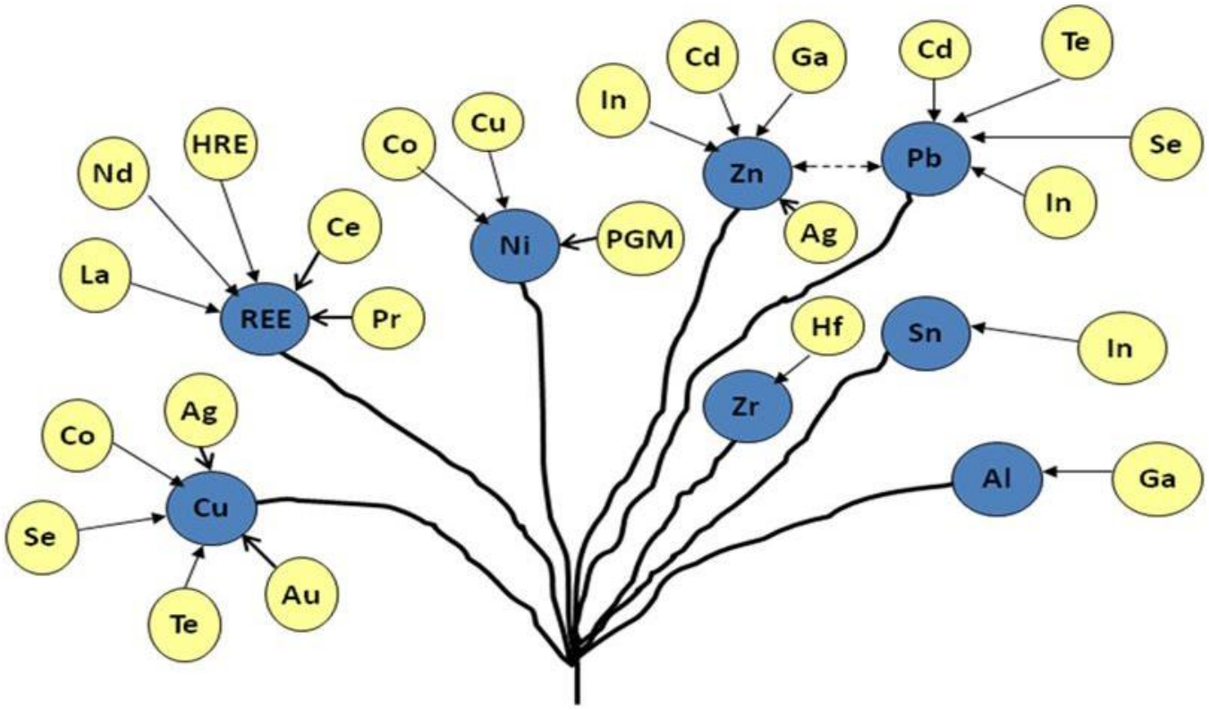
Progress in circular economy strategy



There has been little attention given to full array of circular economy strategies that include component reuse and remanufacturing

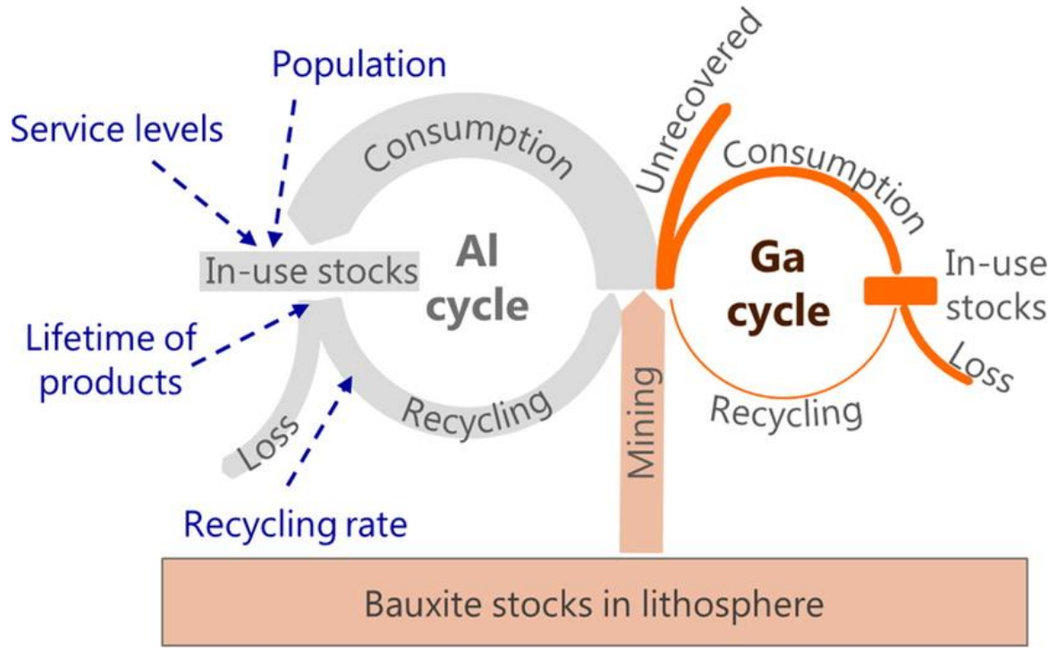
Metal linkages

The host-companion flower garden of metals



© Yale University, 2009,
after Meskers and Hagelüken

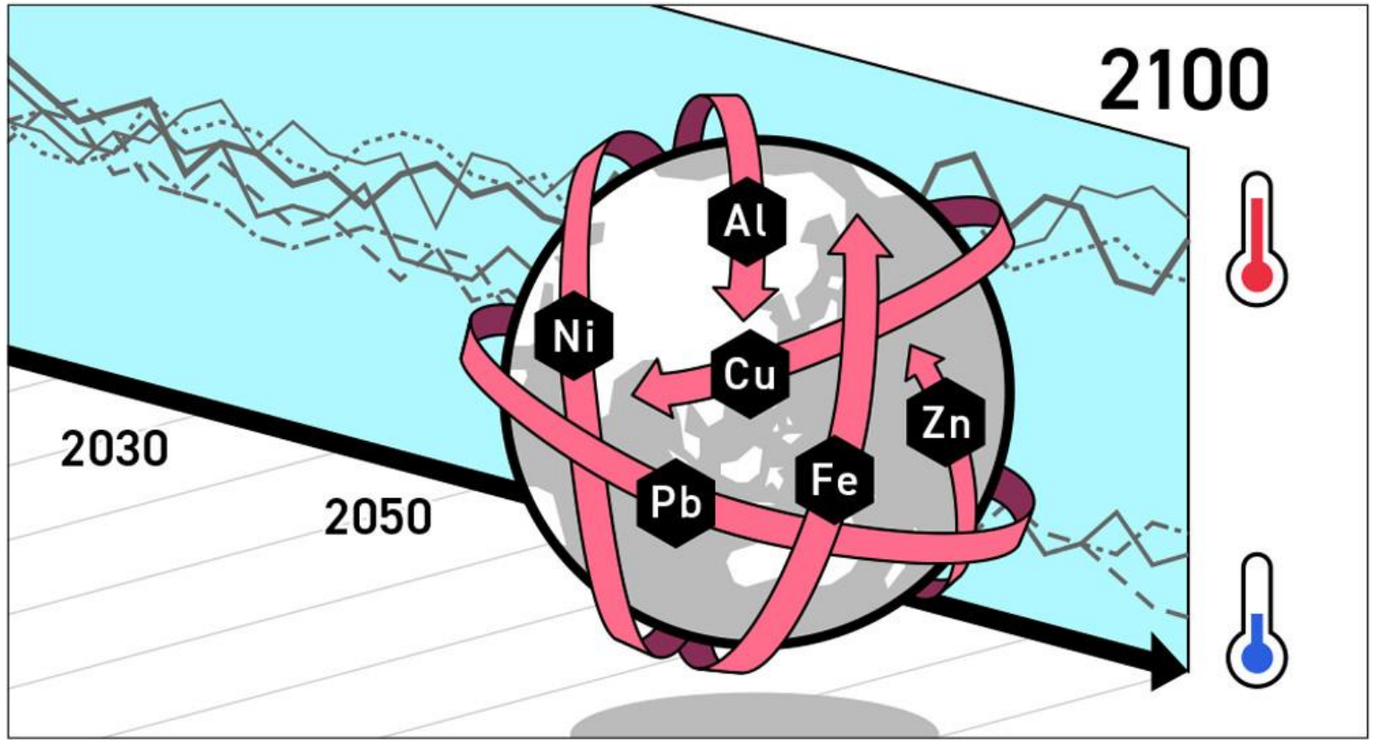
Linked metal cycles of aluminum and gallium



A. Løvik et al. (2016)

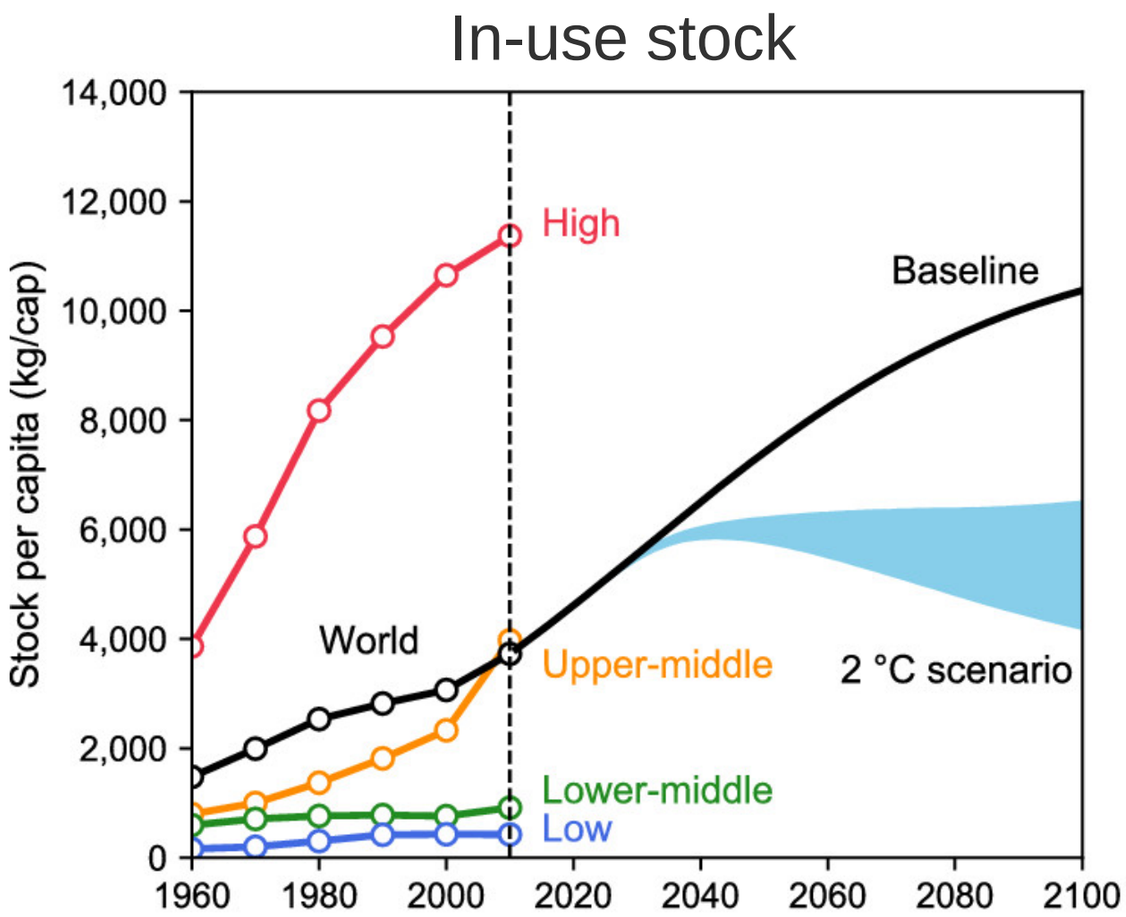
Only 13 % of the studies examined here (11 of 88) quantitatively consider metal linkages in their models.

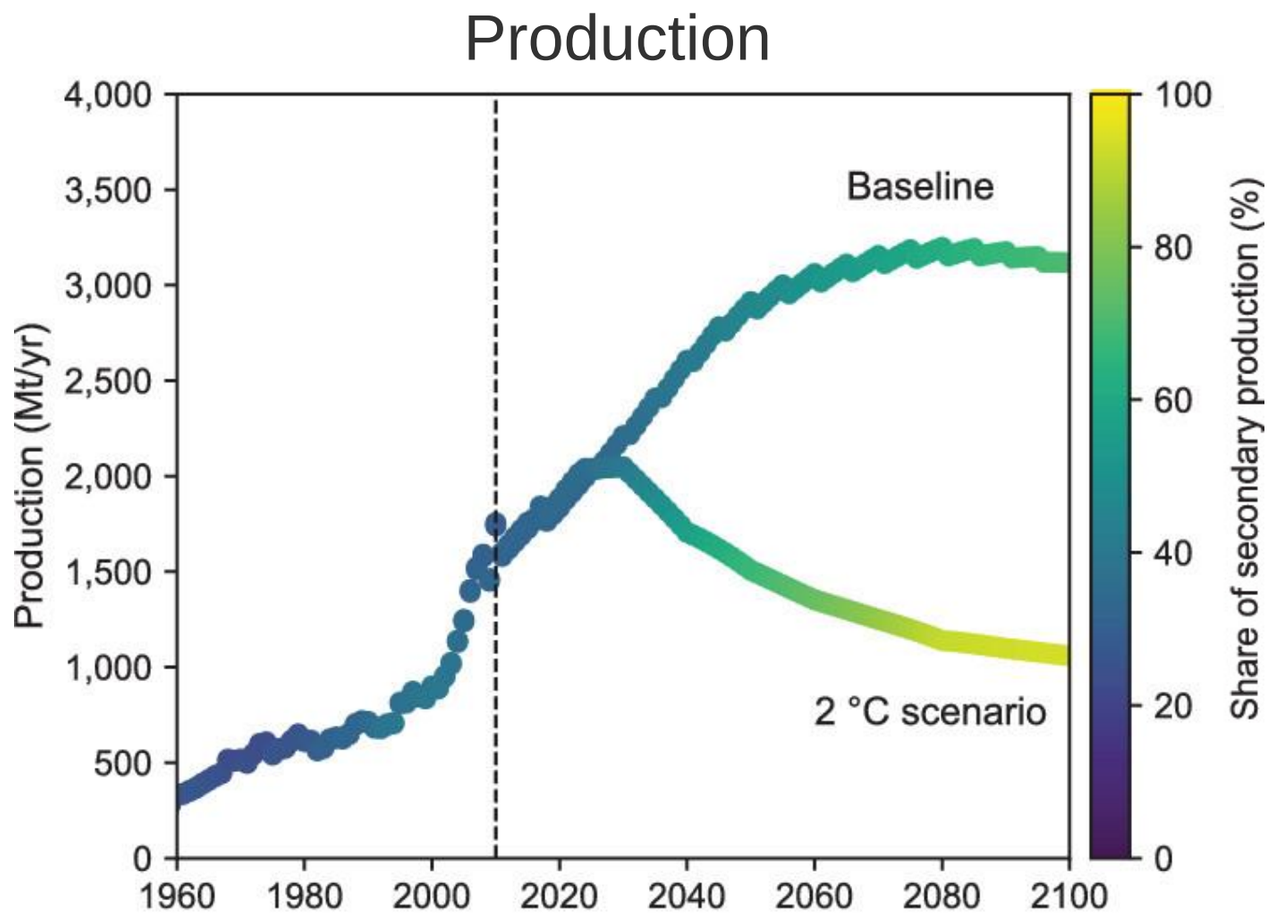
Major metal flows in a carbon-constrained world



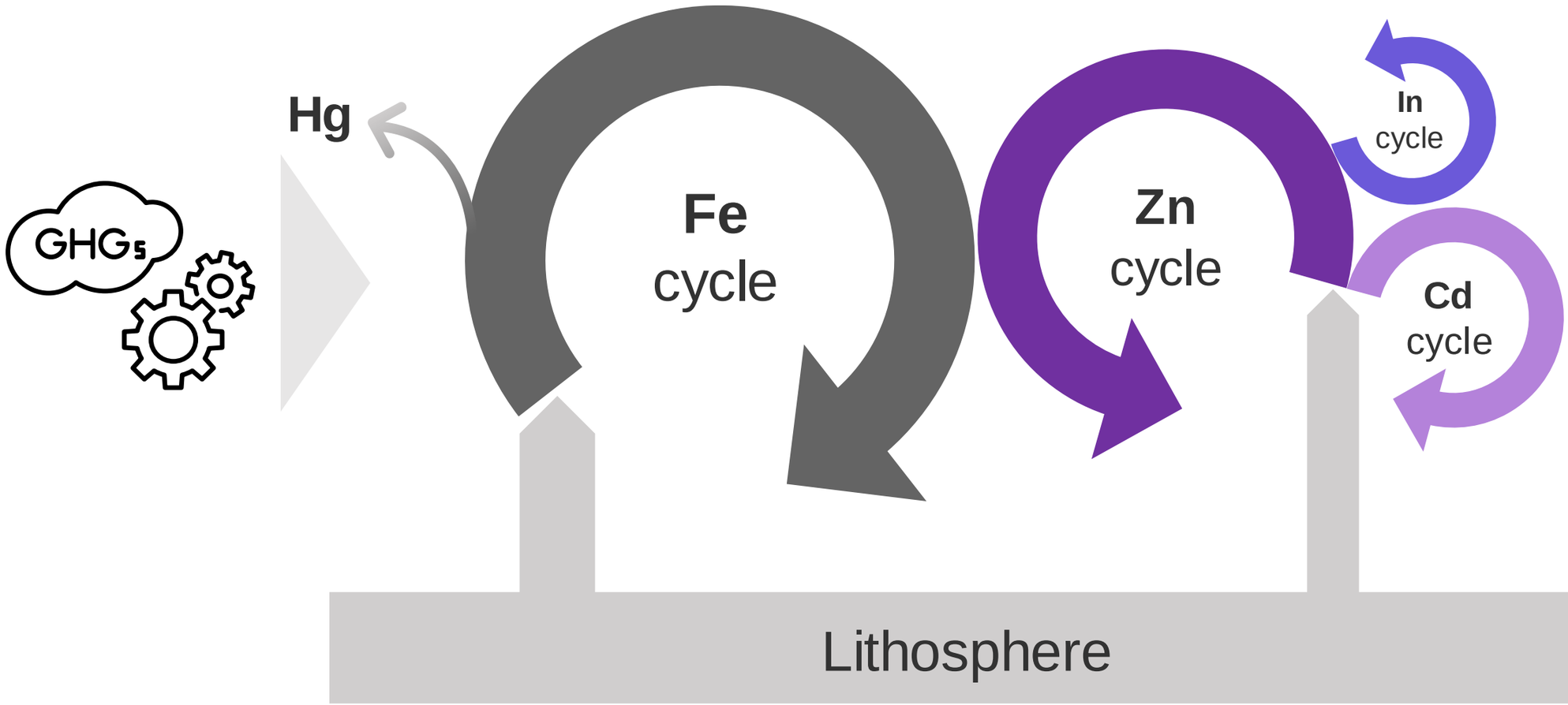
Takuma Watari, Keisuke Nansai, Damien Giurco, Kenichi Nakajima, Benjamin McLellan and Christoph Helbig (2020)
“**Global Metal Use Targets in Line with Climate Goals**”
Environmental Science and Technology
https://pubs.acs.org/doi/full/10.1021/acs.est.0c02471

Major metal flows in a carbon-constrained world



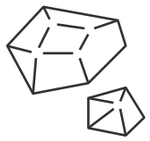


Major metal flows in a carbon-constrained world



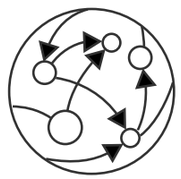
We need to better understand the anthropogenic metal cycles and future availability in a system where multiple cycles are closely linked

Summary of five unaddressed issues



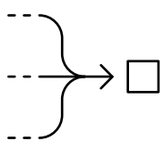
i. No long-term demand outlook is available for some high criticality metals

ii. The social and environmental implications induced by growth in metals demand have been barely quantified



iii. Consideration of the spatial divergence between consuming and producing countries formed by international resource trade has been underemphasized

iv. There has been little attention given to various circular economy strategies that include component reuse and remanufacturing



v. The linkage between host and by-product metals has been scarcely modelled

Thank you for your kind attention!

watari.takuma@nies.go.jp

For more information on our recent work on climate-metal nexus;

- Takuma Watari, Benjamin McLellan, Damien Giurco, Elsa Dominish, Eiji Yamasue and Keisuke Nansai (2019)
  “**Total Material Requirement for the Global Energy Transition to 2050: A Focus on Transport and Electricity**”
  Resource Conservation and Recycling, 148, 91-103
  https://doi.org/10.1016/j.resconrec.2019.05.015

- Takuma Watari, Keisuke Nansai and Kenichi Nakajima (2021)
  “**Major metals demand, supply, and environmental impacts to 2100: A critical review**”
  Resource Conservation and Recycling, 164, 105107
  https://doi.org/10.1016/j.resconrec.2020.105107