Future environmental impacts of metals: recent insights and emerging challenges

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1. Research goal

Literature Review:
- future environmental impacts
- future metal production

Metals studied

Cu Fe Al
Ni Pb Zn
Co Li REEs
Au Mn Ti

Scenario variables, modelling approaches, data sources

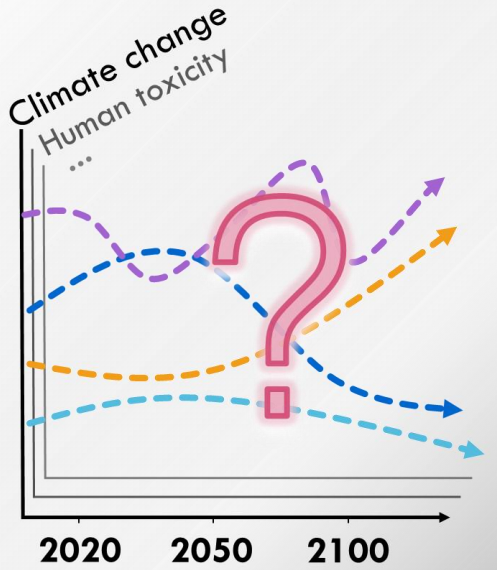
Background scenarios

Mining locations → Mining → Ore grade %

Fuel input → Processing → Processing technology

Efficiency → Metal production → Recycling share

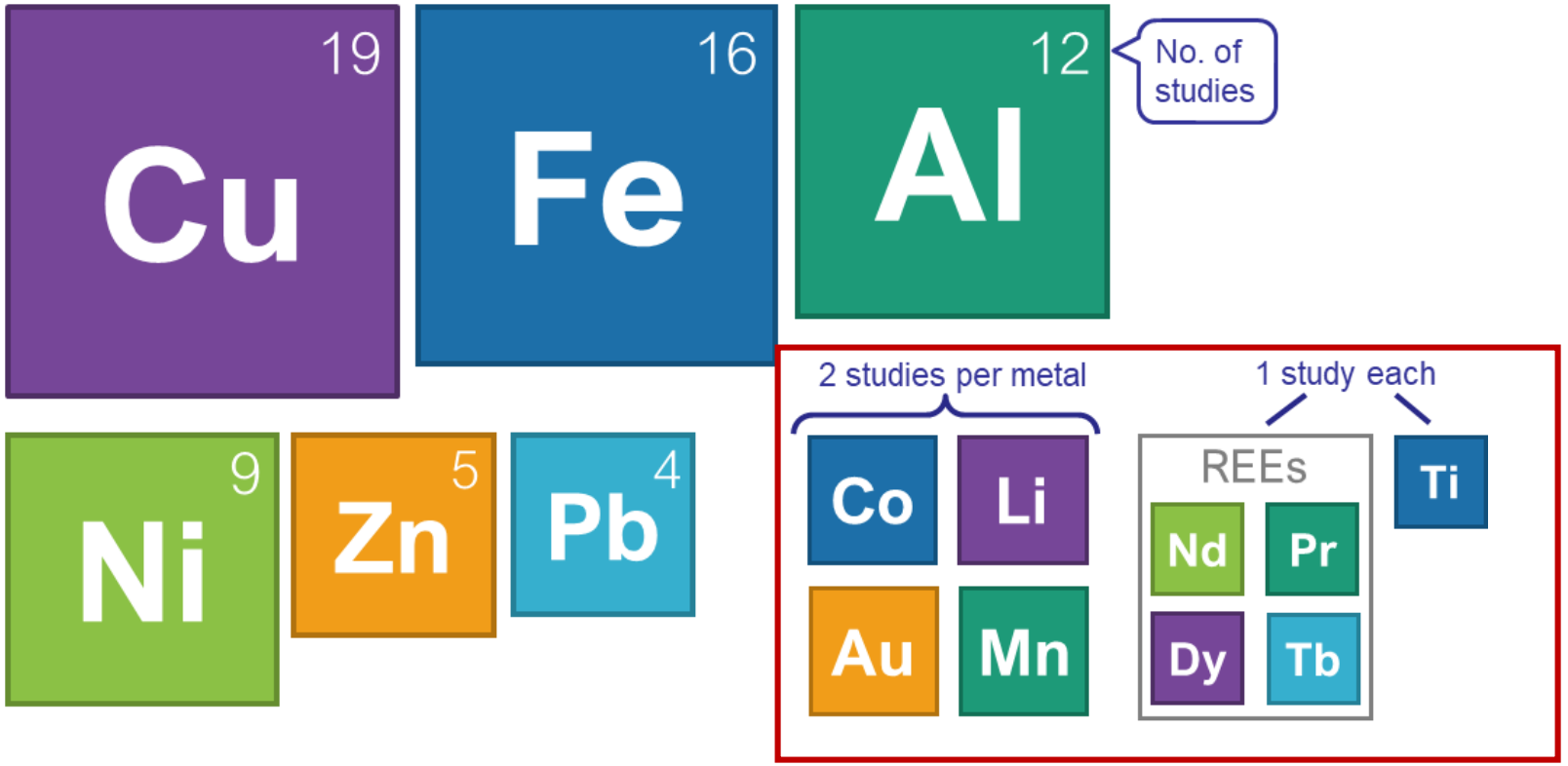
Trends of future impacts



Disclosure of data

2.1. Metals covered

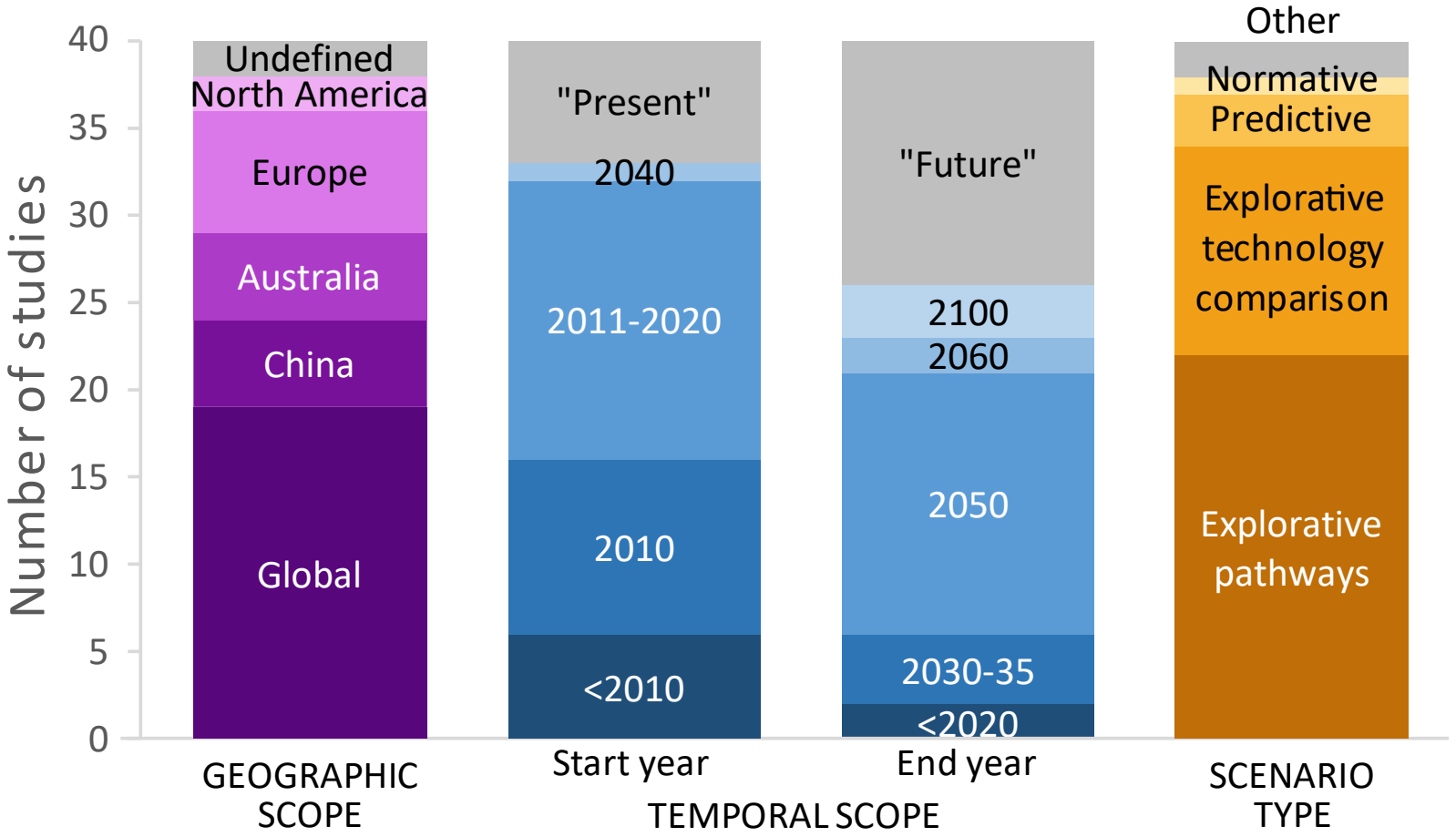
40 studies



Lack of studies for minor metals

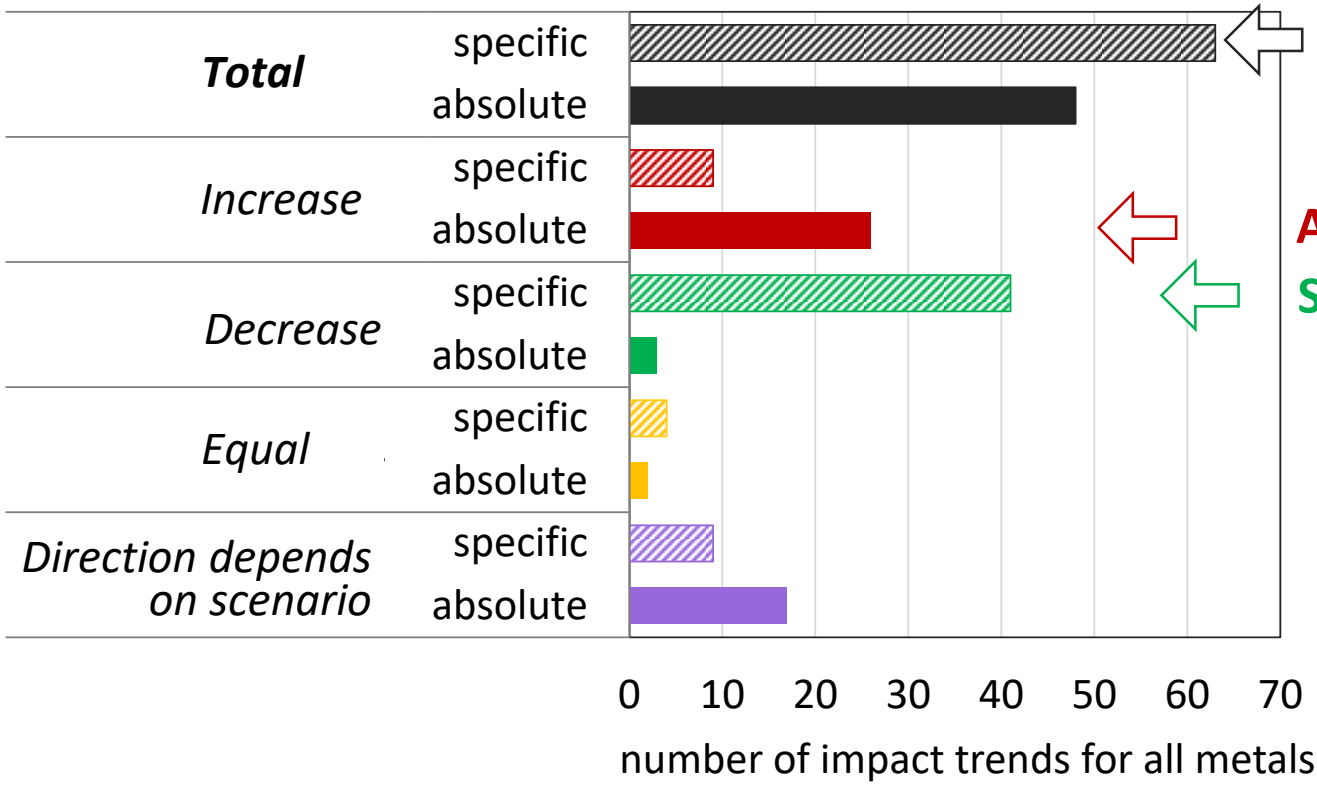
! Relevant for energy transition

2.1. Research scopes



Highly heterogeneous ⇒ **Difficult to compare results**

2.2. Trends of future impacts: GHG emissions



Most studied: specific impacts and GHG emissions

Absolute impacts still likely to increase

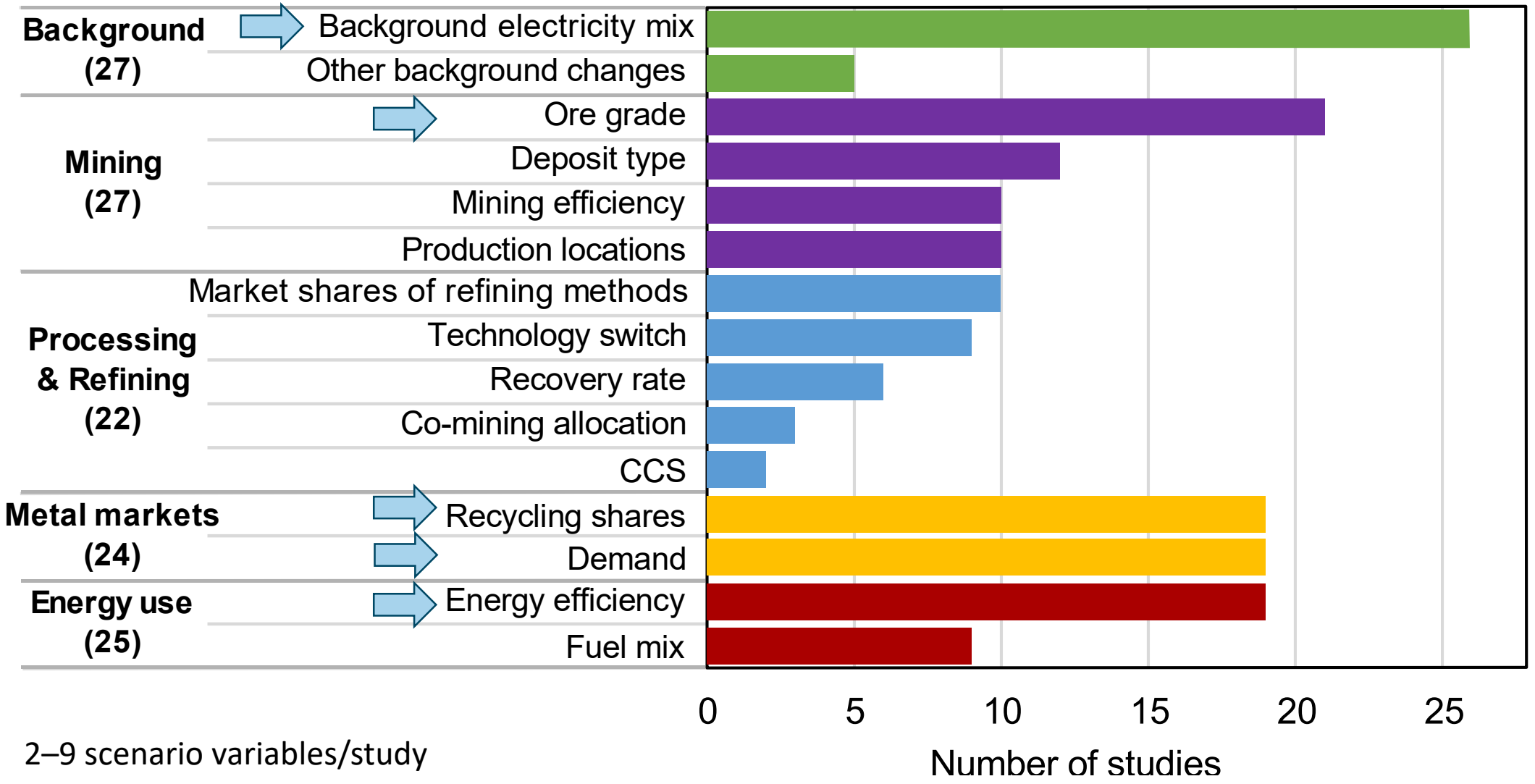
Specific impacts (per kg) may decrease

✓ Cu, Al, Pb

! Exceptions, e.g. Li

No clear consensus on future impact trends:
Results depend on scopes, metal and scenario variables

2.3. Scenario variables (15)



2.4. Scenario modelling approaches & data sources

- High diversity
  - 229 data sources
- Documentation: inconsistent

	Top 3	Variables				
		BG elec-tricity	Ore grade	Recycling share	Demand	Energy efficiency
Modelling approaches	**What-if scenarios**	■	■	■	■	■
	Extrapolation of historic trends		■	■	■	■
	Scenarios from IAMs/energy models	■		■	■	■
Data sources	**Scientific literature** (incl. IAMs/energy models)		■	■	■	■
	Derived within the publication	■		■	■	
	Governmental data	■	■	■		

⇨ **Highly heterogeneous** ⇨ **Difficult to compare results**

2.5 Disclosure of scenario data

- **Data not published: 25% studies**
- Large variety of:
  - data formats
  - documentation

Adherence to FAIR data principles:

Keyword	Repository	Zenodo	GitHub
Yields*	7.5%	5.0%	2.5%

Keywords never mentioned: machine readable; interop*; reus*; FAIR data; reproduc*; product system model; complete model

3. Challenges & recommendations

Challenges	Recommendations
Lack of studies addressing: • metals for energy transition (Nd, Dy, …) • impacts other than GHG emissions • future absolute impacts **Comparing impacts quantitatively:** • depend on scope and assumptions	**More prospective LCAs on metals needed:** • couple demand and supply scenarios **Harmonize assessments:** • identify & harmonize key scenario variables • shared scenario narratives
Reusing existing work: • Documentation and data format not standardized • Publishing scenario data in a transparent & reproducible way is uncommon	**Improve accessibility + reusability of scenario data:** • common format for scenario data and documentation • FAIR data principles

4. Database of reviewed studies

Reviewed studies: Scope

Article	Metal(s)	Temporal scope	Geographical scope
		Years or time range	*Country or region*
Alexander et al. (2021)	Cu	NA	Global
Ambrose & Kendall (2020)	Li	2018-2100	Global
Chisalita et al. (2019)	Fe	present + emergent t	The Netherland
Ciacci et al. (2020)	Cu	2010-2050	EU-28
Dong et al. (2020)	Cu	2010-2050	China
Eckelman (2010)	Ni	2005	Global
Elshkaki, Graedel, Ciacci, Reck (2016)	Cu	2010-2050	Global
Elshkaki, Reck, Graedel (2017)	Ni	2010-2050	Global
Fariana and Li (2021)	Au	NA	Sweden

…

Modelling approaches

Background		Mining	
Background energy mix		Ore grade	
Modelling approach	*Data source*	*Modelling approach*	*Data source*
NA	NA	three different c	No reference,
Regional differen	Ecoinvent 3.3	Depending on de	Ambrose & K
NA	NA	NA	NA
IEA scenarios extr	IEA (2012); derived w	NA	NA
China Renewable	CNREC(2017); IEA(20	extrapolation of	Northey et al.
IEA and company	IEA, 2007a,b; unspeci	Refer to referen	Brook (2007);
NA	NA	Function of cum	based on Muc
NA	NA	from literature	Norgate and J
NA	NA	NA	NA

List of all data sources:

Data source	Metal	Publication year	Title
Adelhardt et al. (1998)	Ni	1998	Stoffmengenflusse und Ener
Ahtola et al. (2015)	Li	2015	Overview of Lithium Pegmat
Albanese (2008)	Al, Cu	2008	Presentation to merrill lynch
Allwood et al. (2010)	Al, Cu, Fe	2010	Options for achieving a 50%

- **Impact trends**
- **…**

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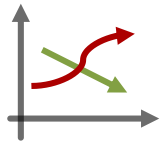
Repository zenodo

5. Conclusions



Specific impacts (per kg) likely to decrease, but absolute impacts may increase

! Exceptions depending on metal

High diversity of scopes and scenario assumptions

⇨ ultimate impacts unclear

Further research needed

⇨ Quantitative impact assessment with harmonized models

⇨ Community effort

Improve research practices

⇨ Harmonize methods & models

⇨ Standardize documentation and data formats (FAIR data principles)

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Publication

Future environmental impacts of metals: A systematic review of impact trends, modelling approaches, and challenges.
Resources, Conservation and Recycling

image: flaticon.com