



Prospective, spatially-explicit LCA of global copper mining considering uncertainties in regional supply

Stephen Northey, Damien Giurco, Bernardo Mendonca

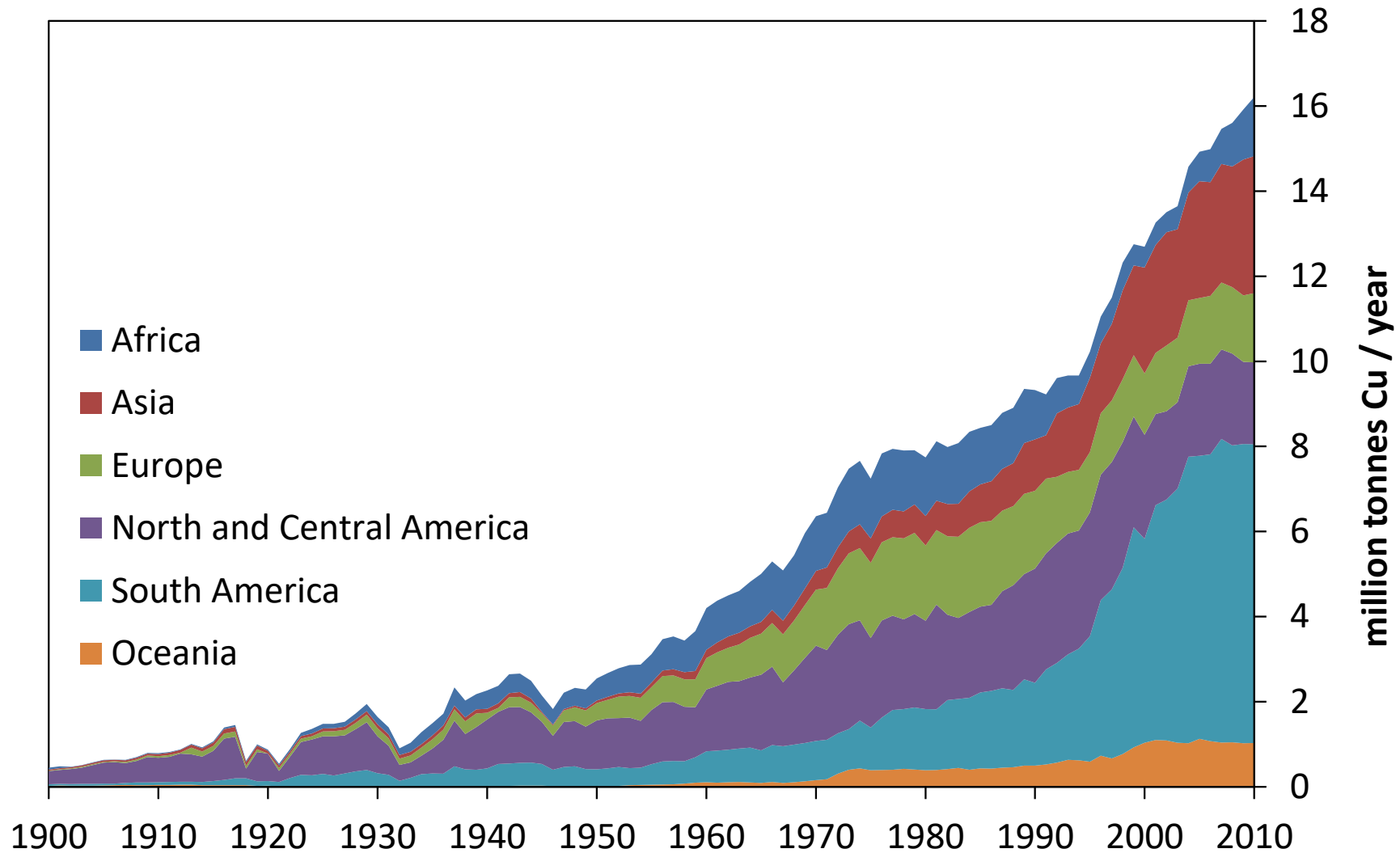
University of Technology Sydney, Institute for Sustainable Futures

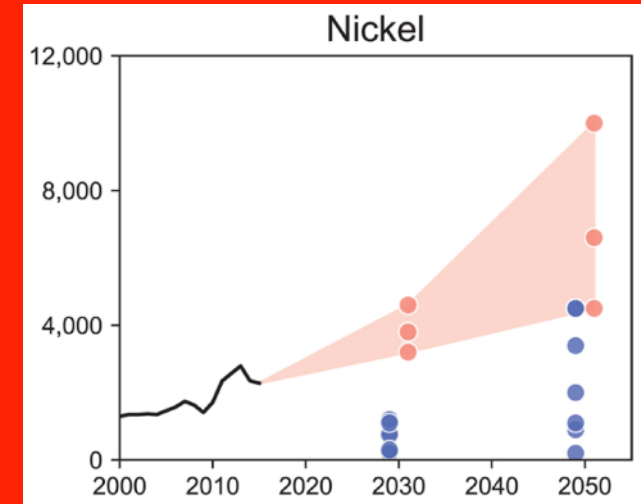
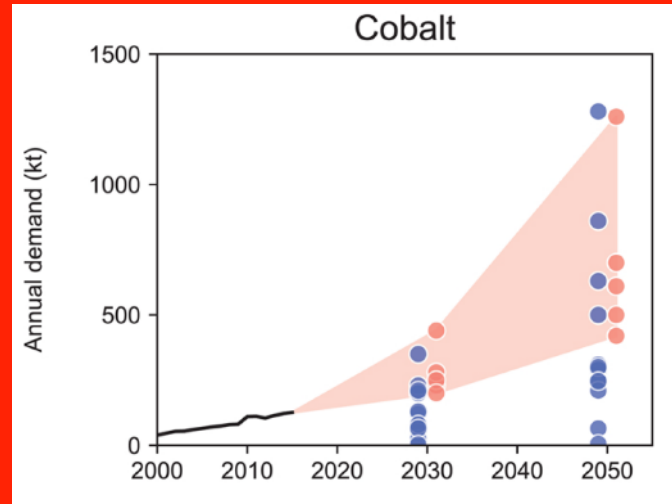
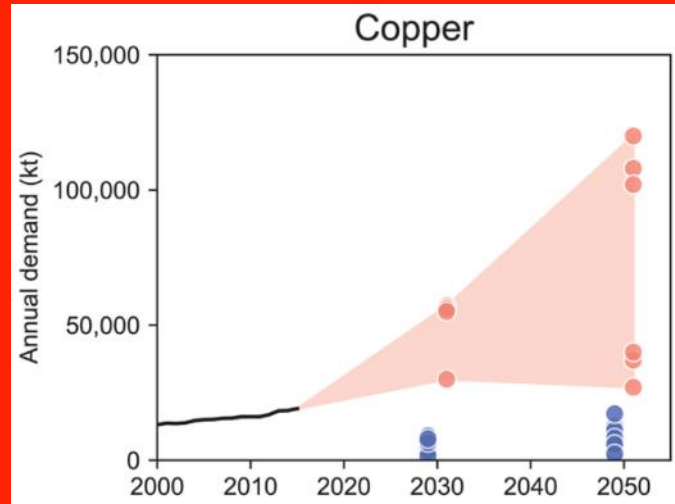
Laura Sonter

University of Queensland, School of the Environment

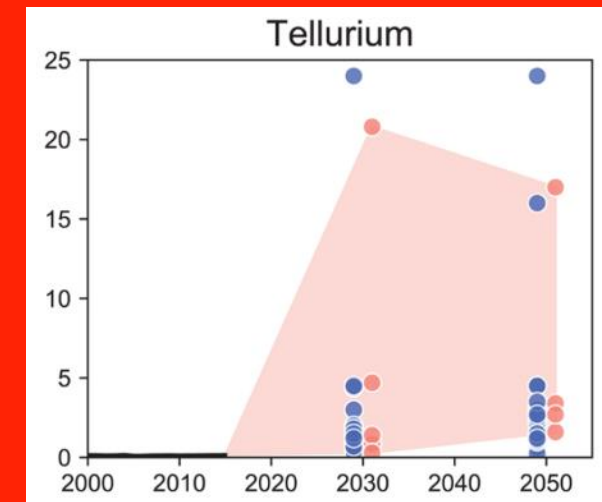
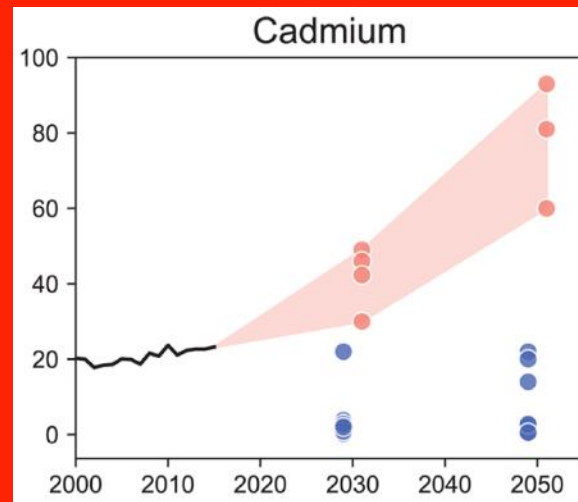
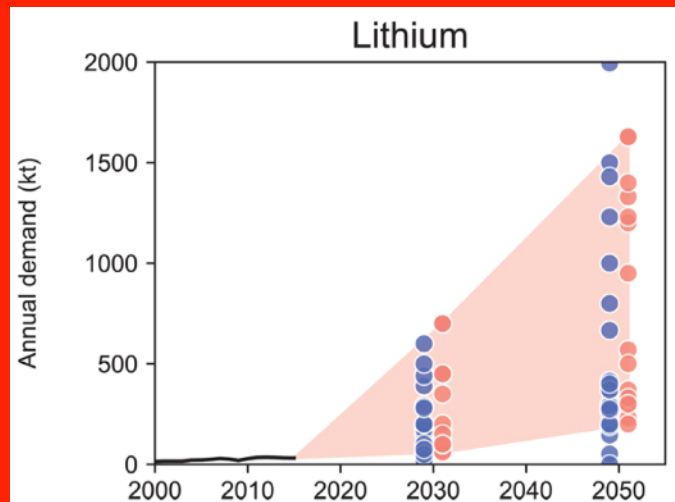
11th Australian Conference on Life Cycle Assessment, 20th July 2023

20th century saw large increases in copper mining





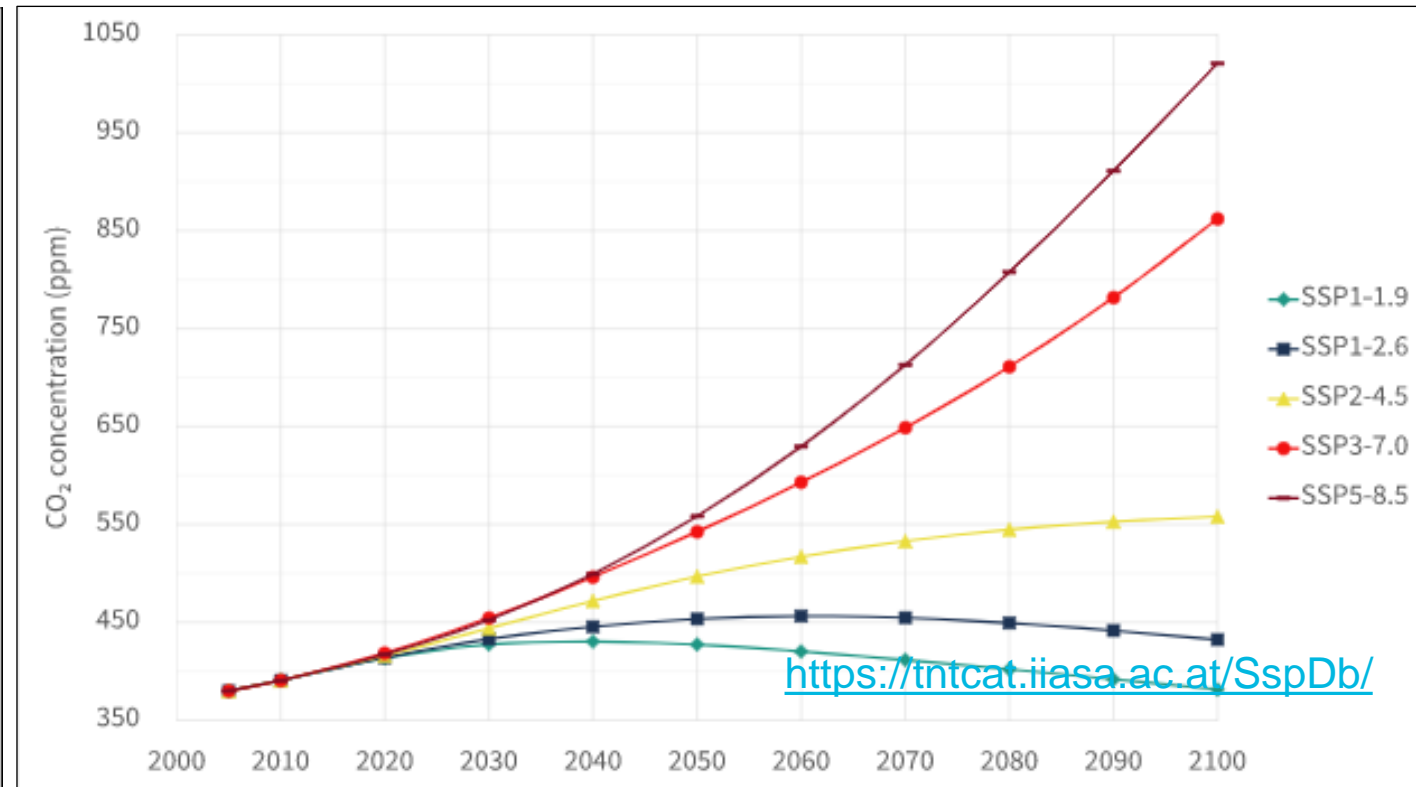
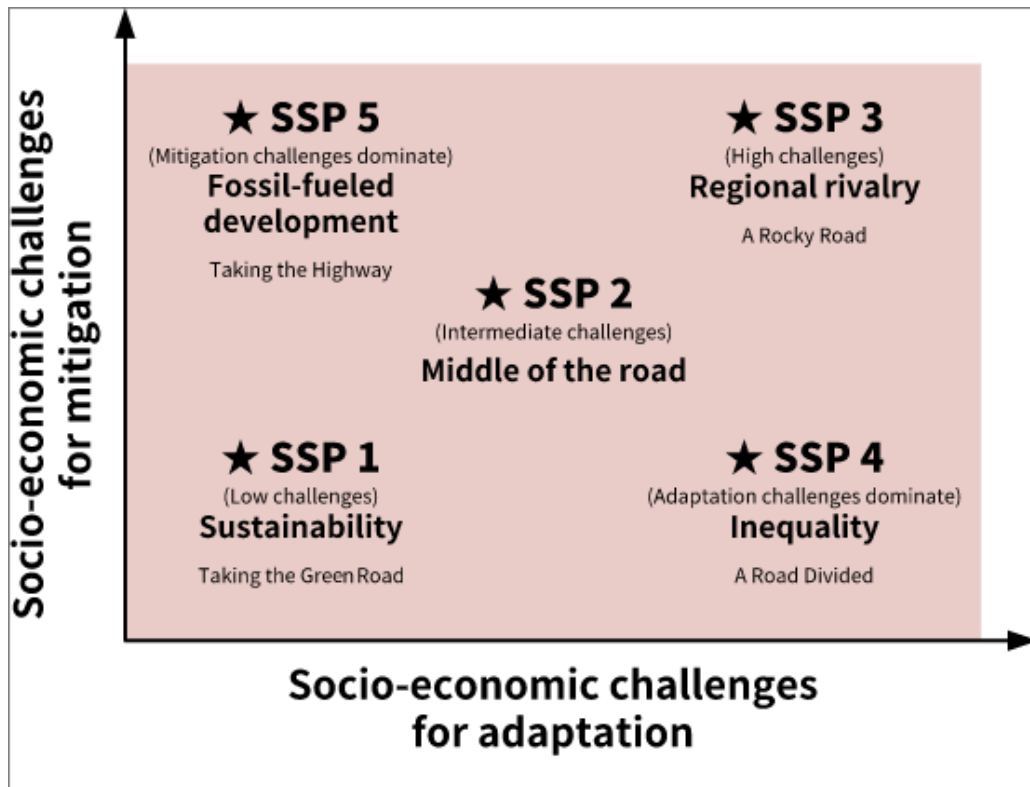
The Problem



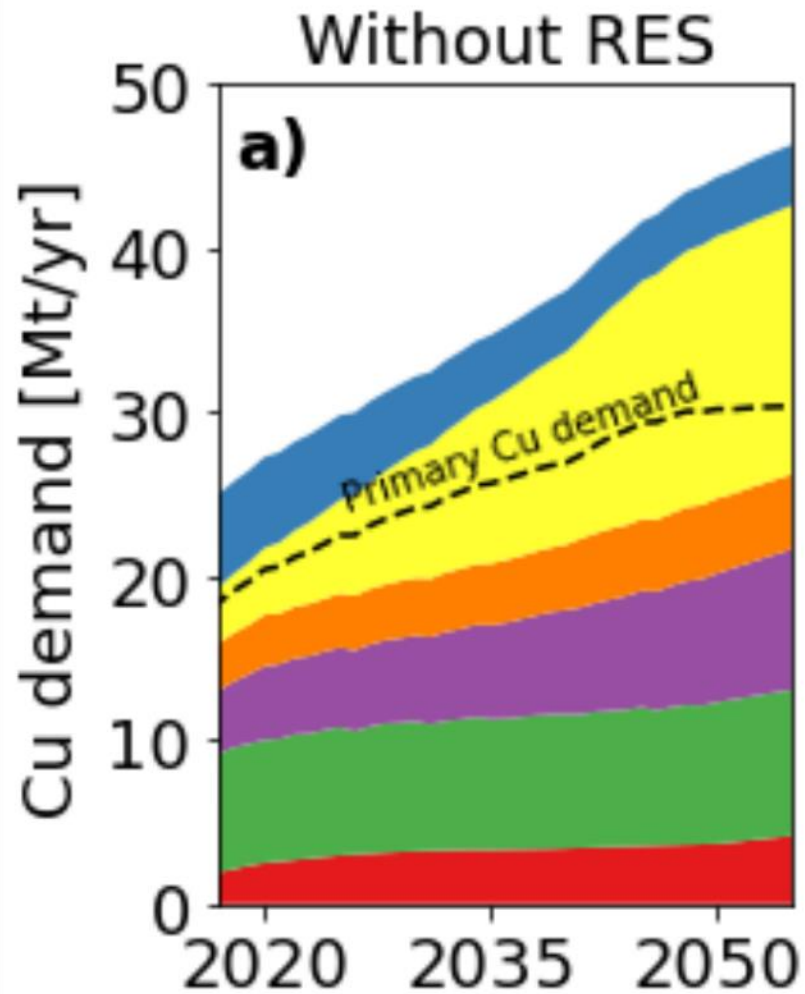


The future is uncertain, but it can be grappled with

e.g. Shared Socio-economic Pathways (SSPs)

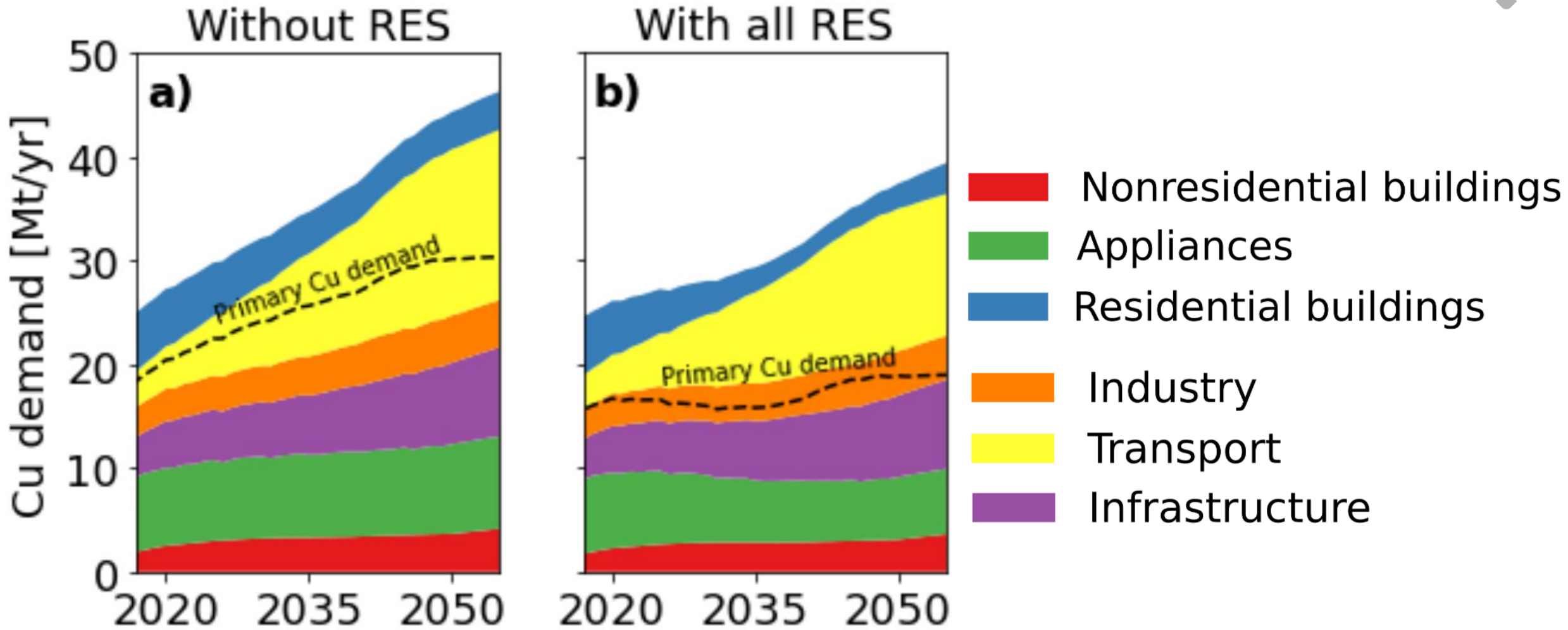


Growth in copper demand is expected under a 'middle of the road' pathway (SSP 2 RCP 2.6)



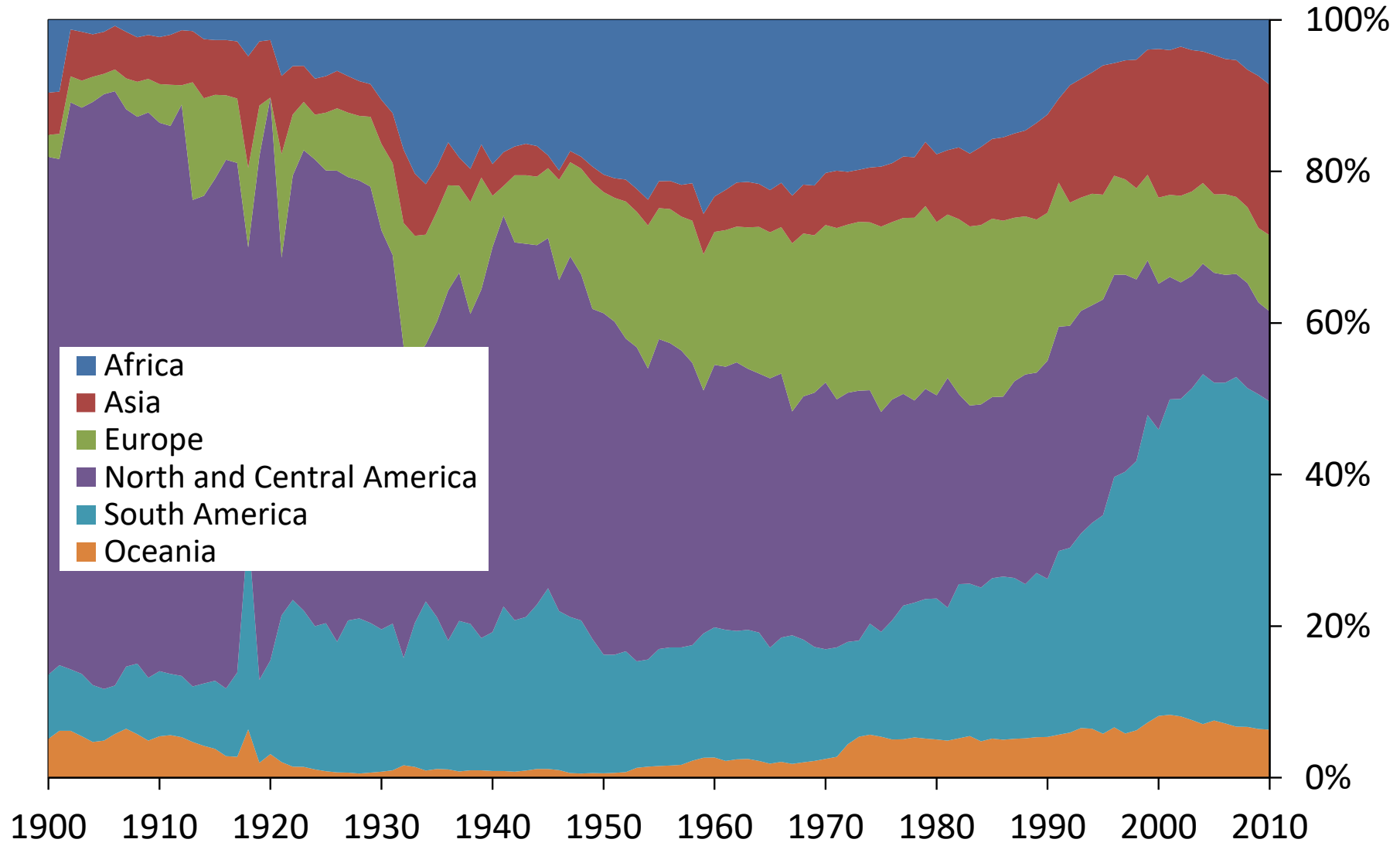
- Nonresidential buildings
- Appliances
- Residential buildings
- Industry
- Transport
- Infrastructure

Resource efficiency and circular economy related strategies have potential to substantially reduce copper demand overtime



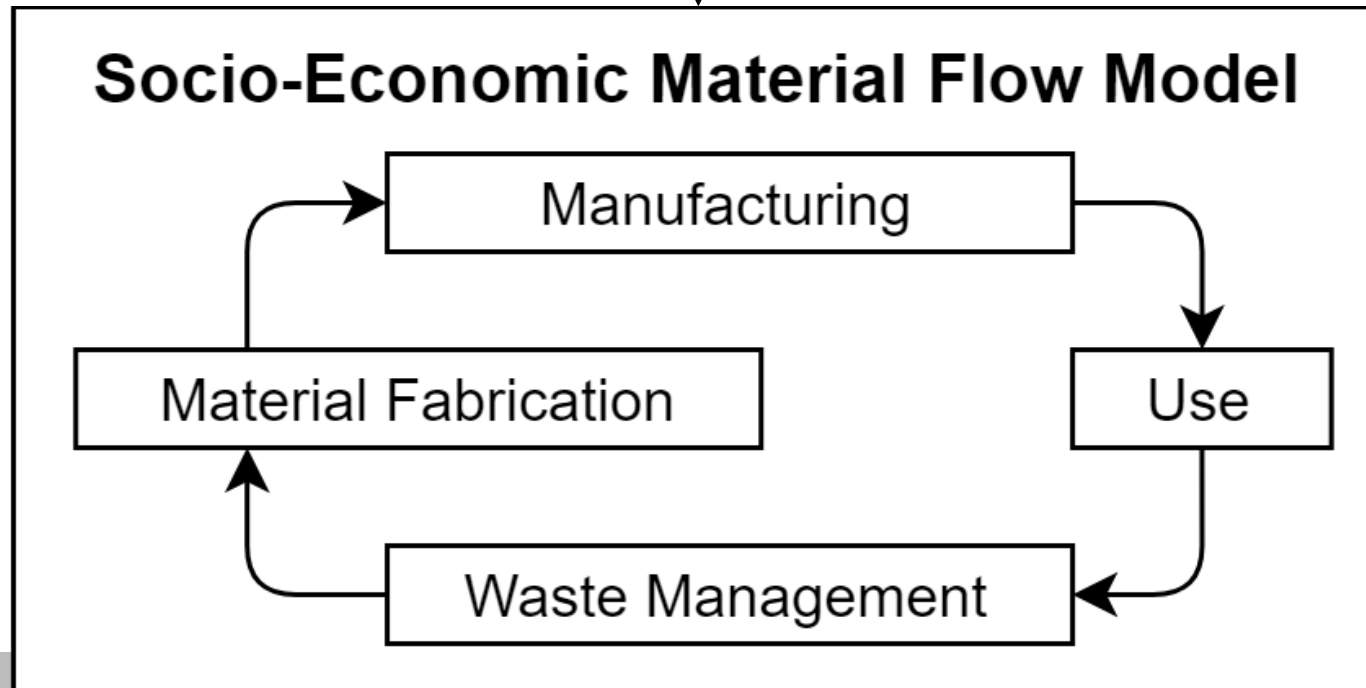


A key uncertainty is where the copper will
actually come from





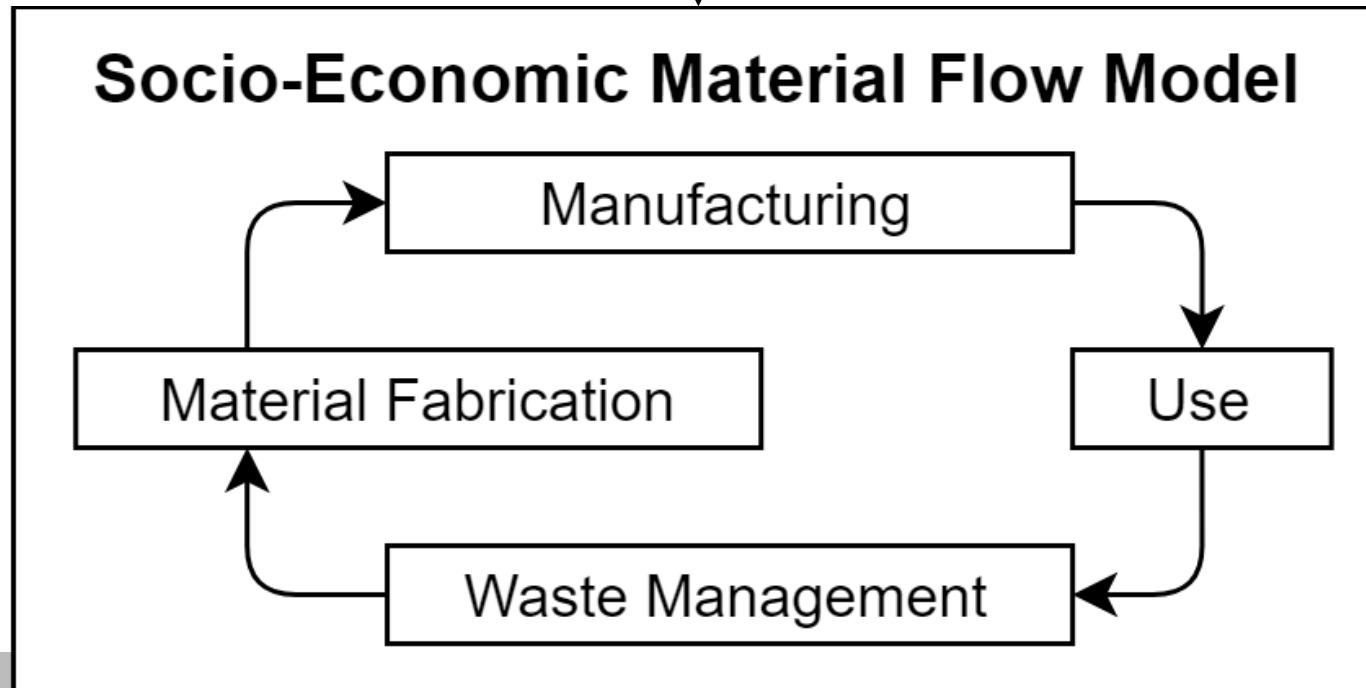
Primary Material Supply





'Black Box' model (it's very popular)

Primary Material Supply

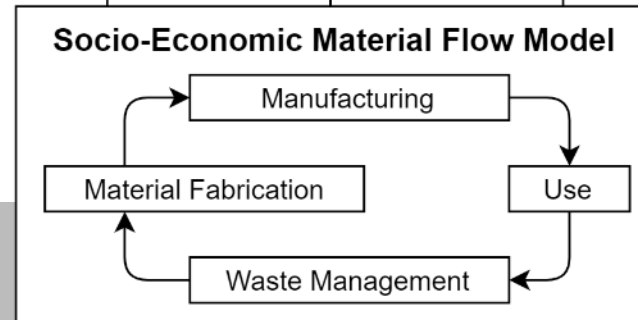


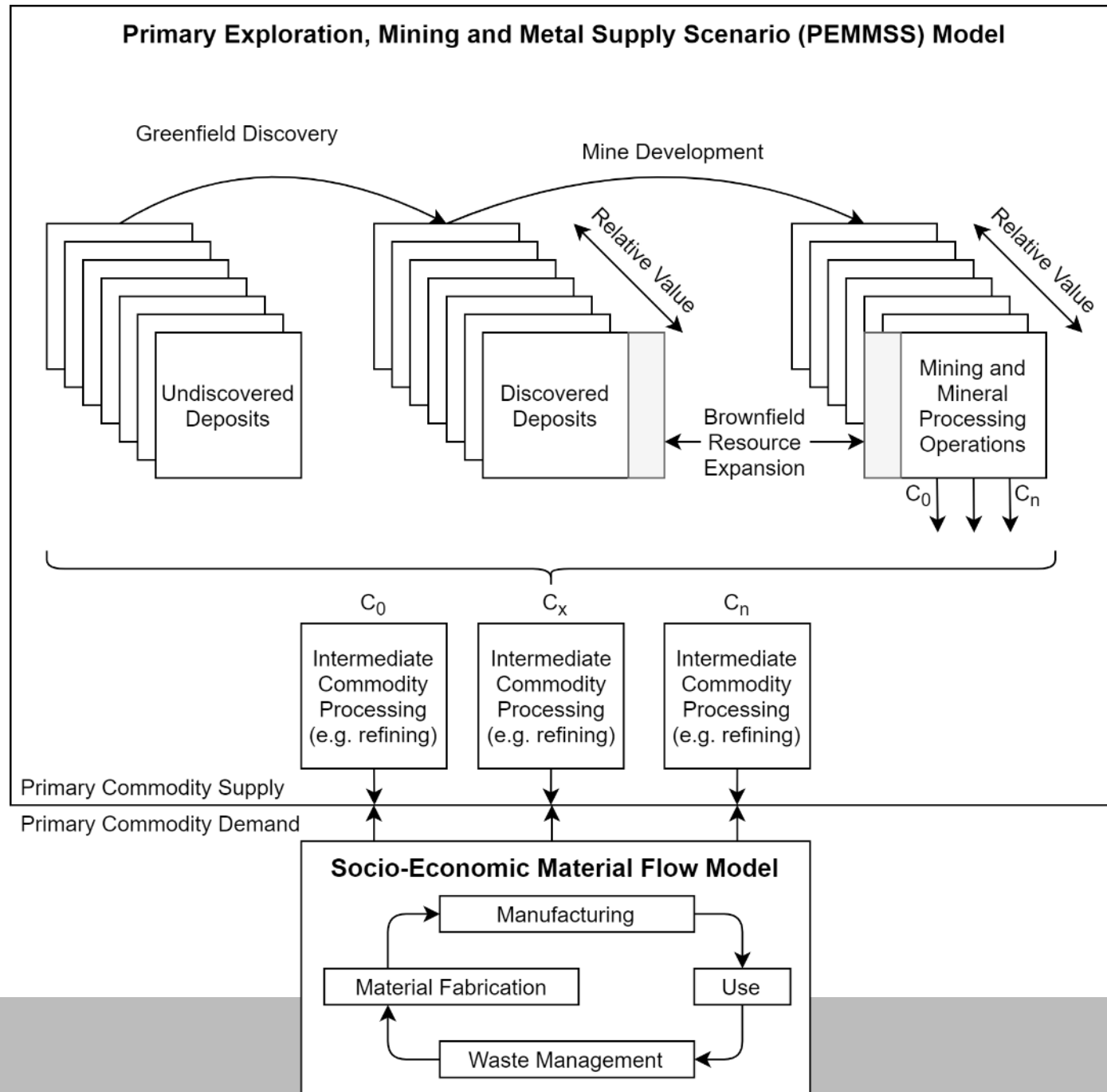
Black boxes for primary supply
obscure the diversity in
possible industry impacts and
outcomes

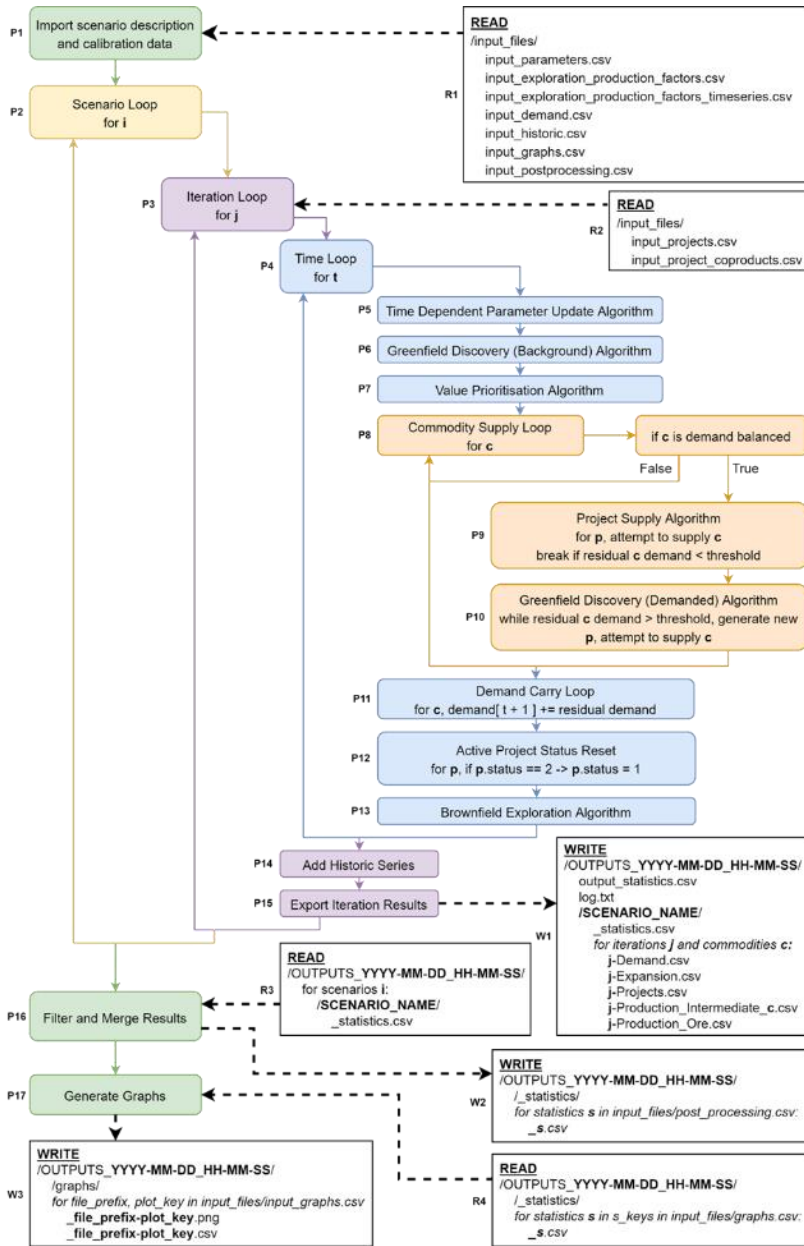


Primary Exploration, Mining and Metal Supply Scenario (PEMMSS) model

Primary Commodity Demand

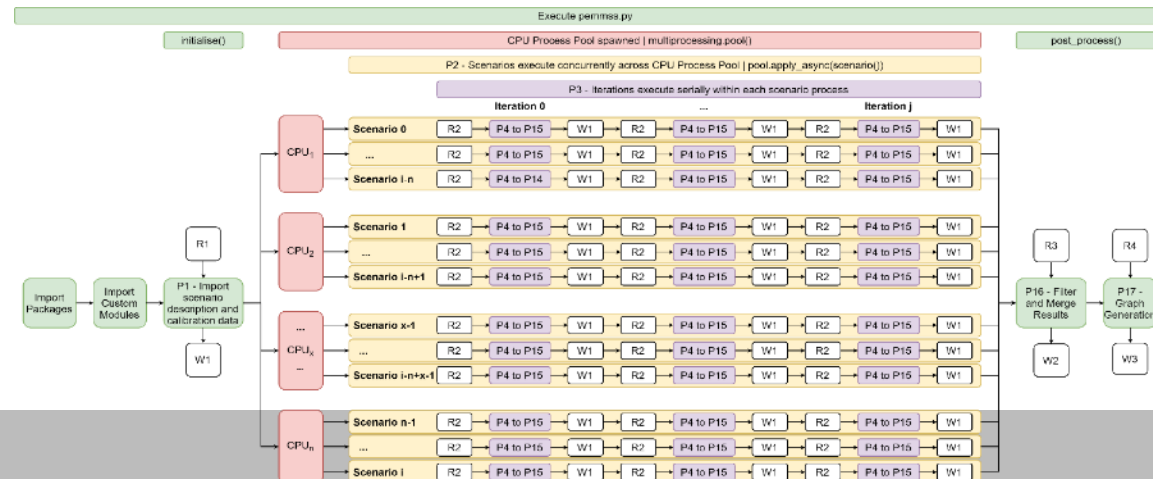




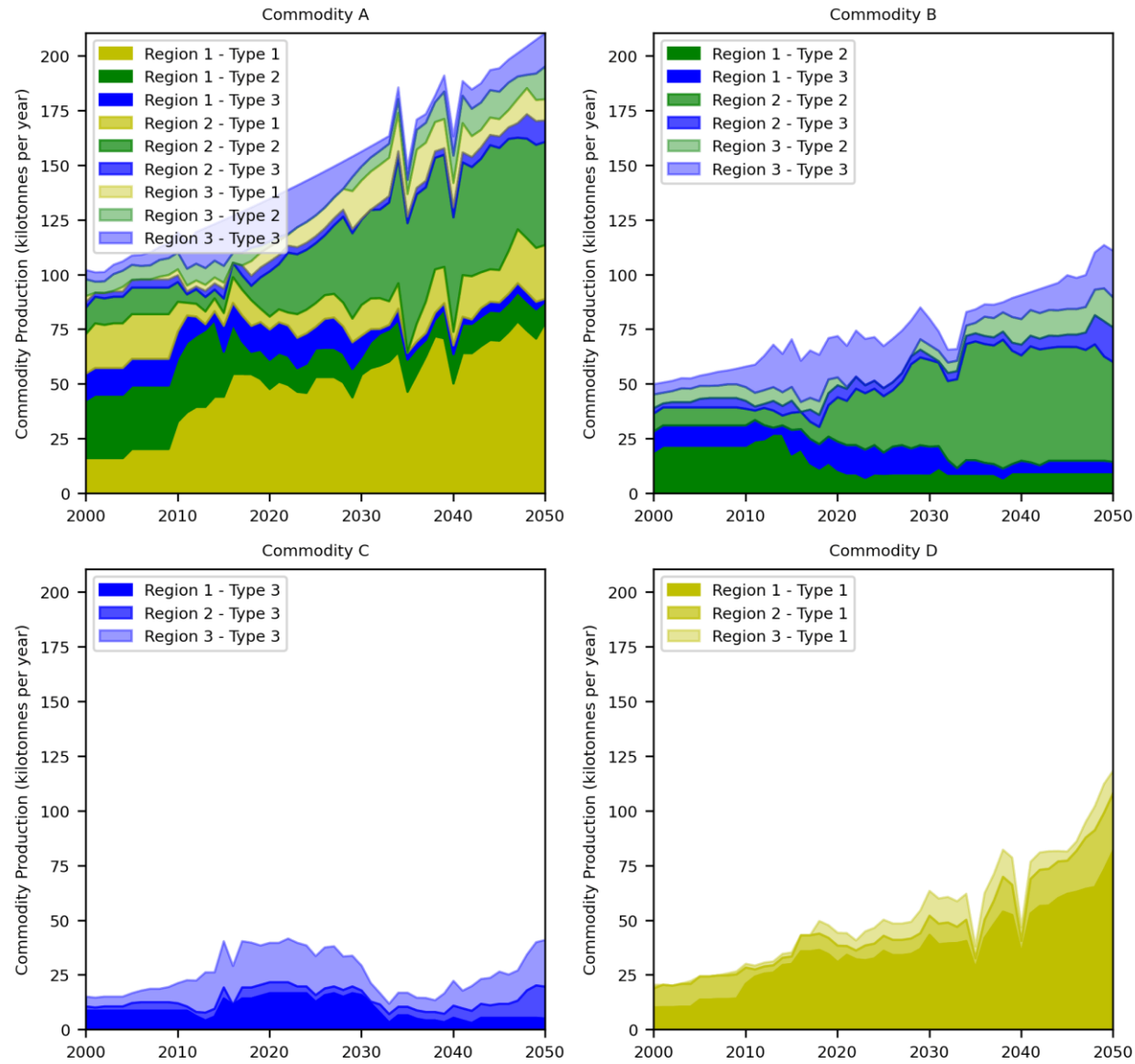


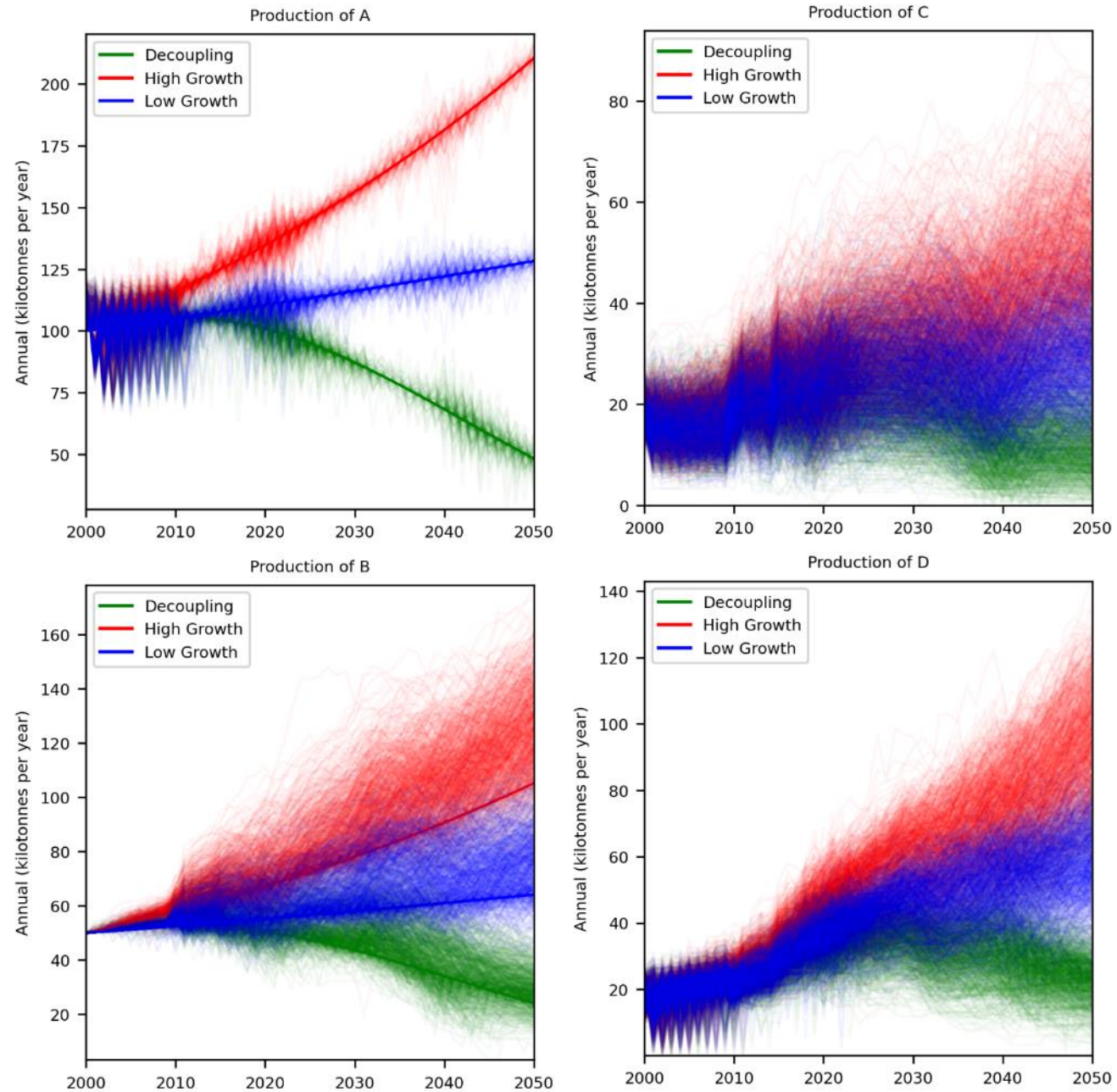
```

pemmss.py
206 # Background greenfield discovery
207 # P6
208 if parameters['greenfield_background'][i] > 0:
209     for gb in range(parameters['greenfield_background']
210                     projects.append(deposit.resource_discovery(fac
211
212 # Priority Ranking Algorithm
213 # P7
214 if parameters['priority_active'][i] == 1:
215     # Sort then prioritise existing mines
216     projects.sort(key=lambda x: x.value['ALL'])
217     projects.sort(key=lambda x: x.status, reverse=True)
218 else:
219     projects.sort(key=lambda x: x.value['ALL'])
220
221 # Commodity Supply-Demand Balance Algorithm
222 # P8
223 for c in demand:
224     if demand[c]['balance_supply'] == 1:
225
226     # Project Loop
227     # P9
228     for project in projects:
229         # break loop if residual demand less than
230         if demand[c][year_current] <= demand[c]['d
231         break
232
  
```



Iteration 0

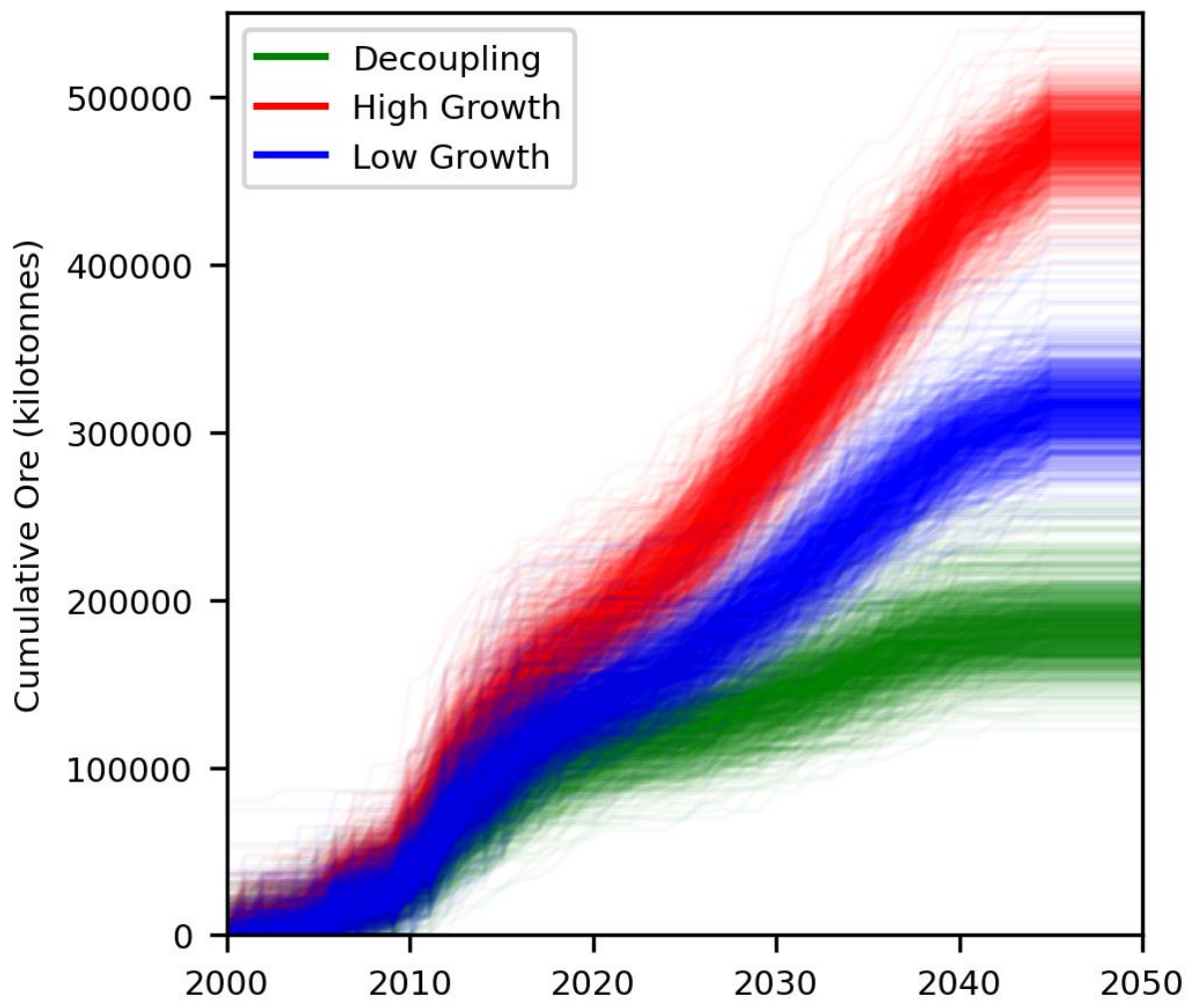




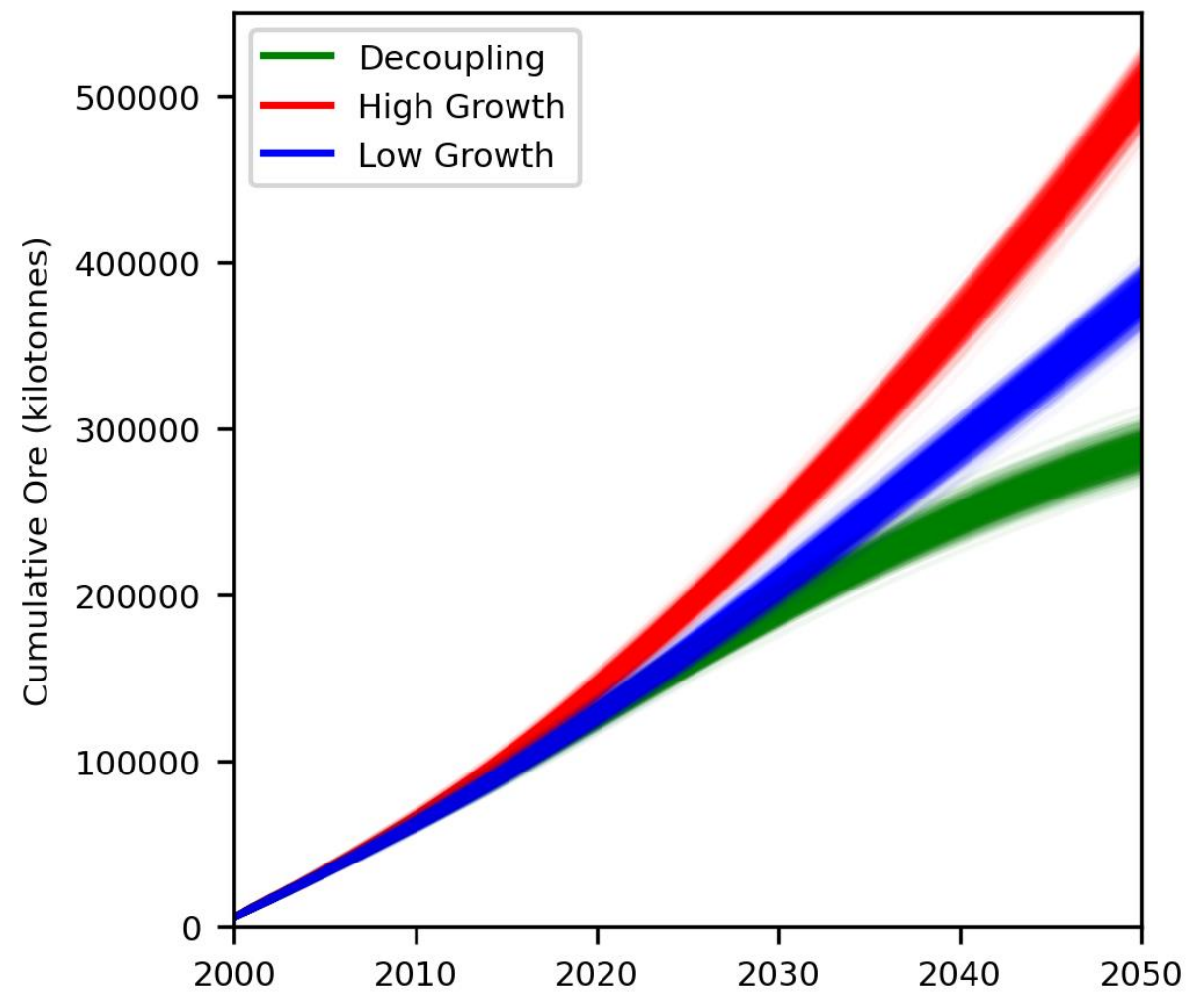
UTS4 Co-products – 1000 iterations



Ore Discovered

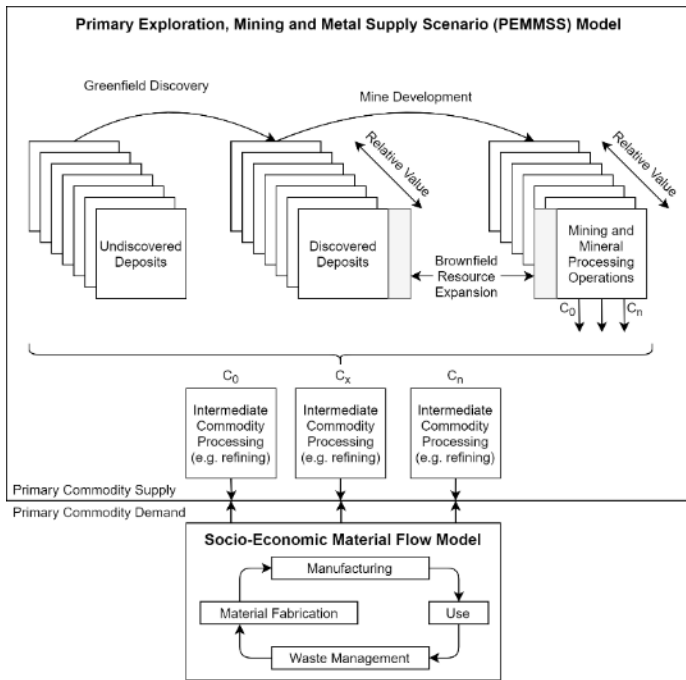


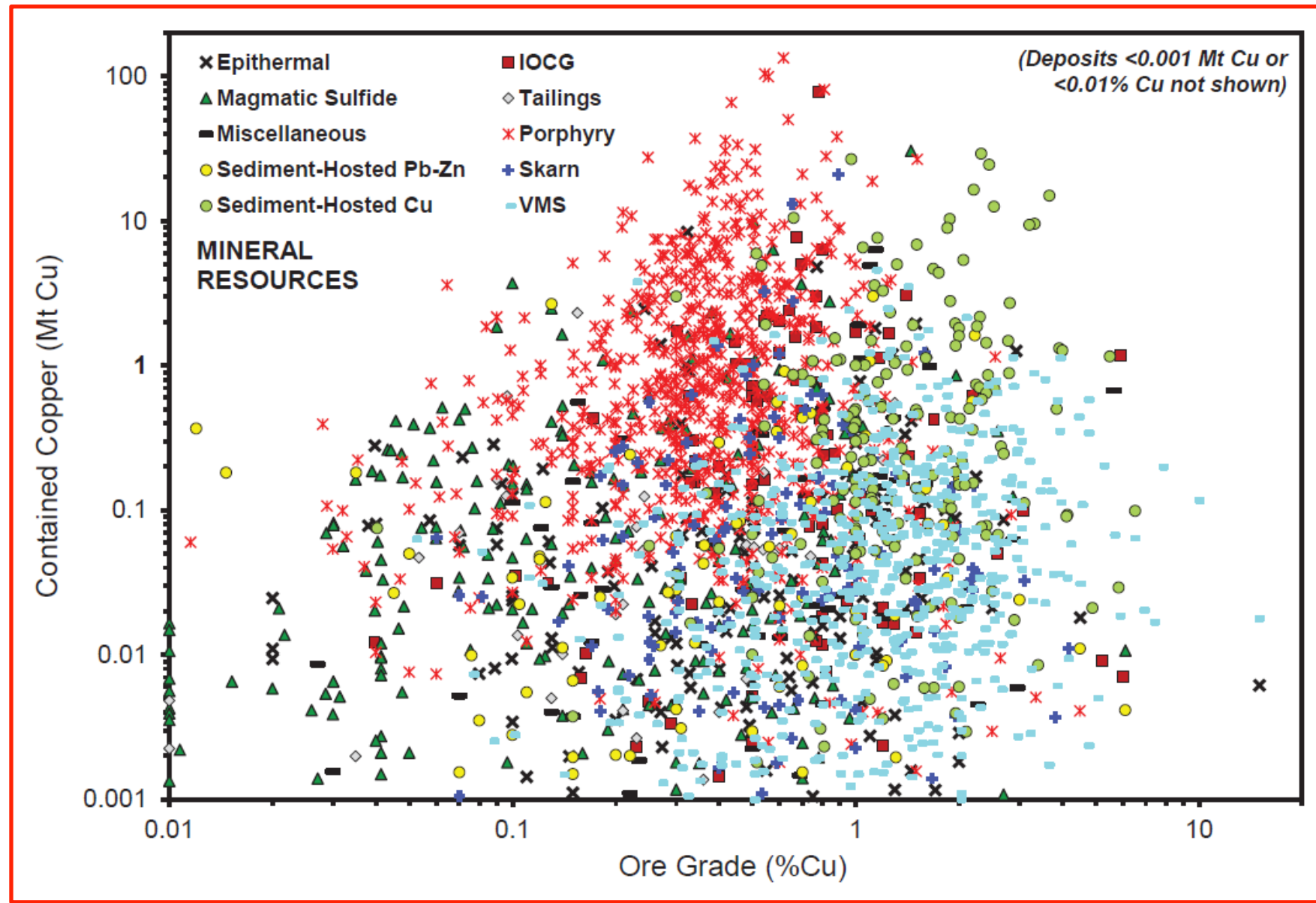
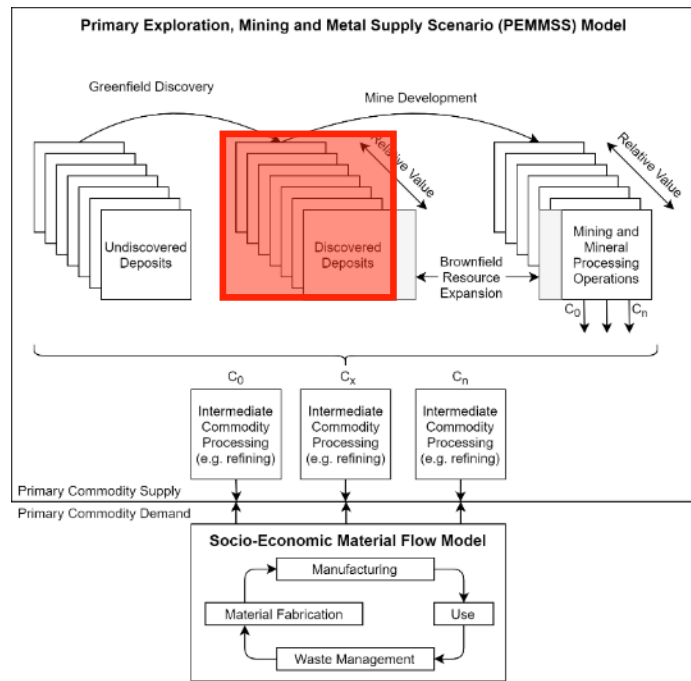
Ore Mined



UTS4 Co-products – 1000 iterations – Ore Requirement

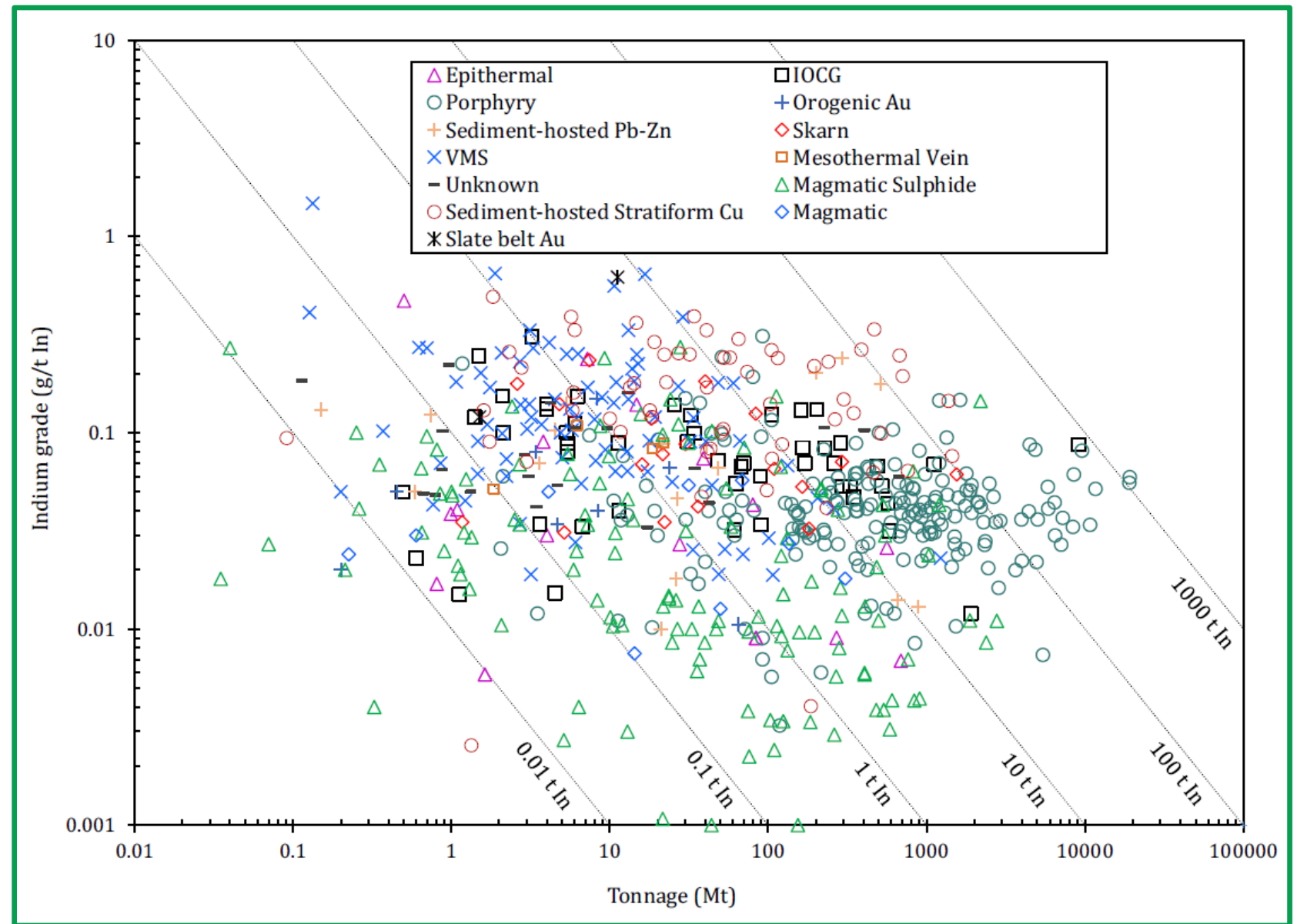
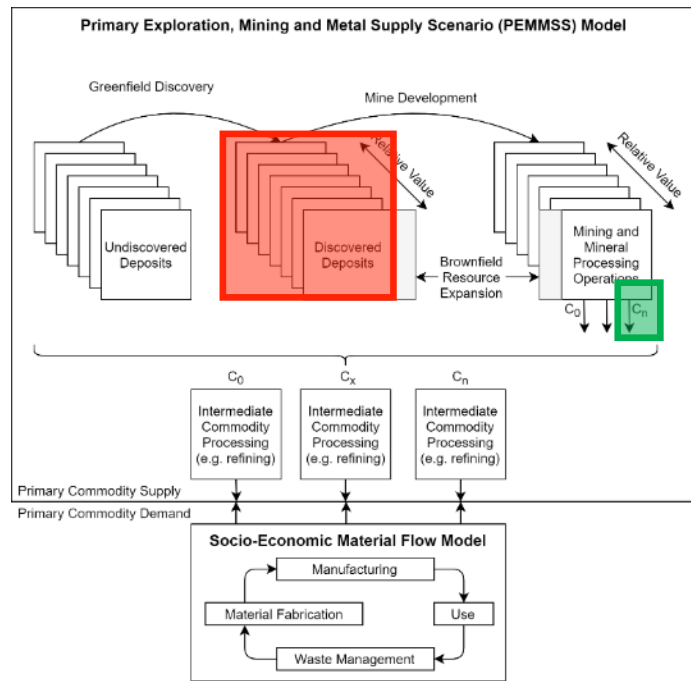
The PEMMSS model is data intensive,
but can handle data gaps
and is reasonably flexible





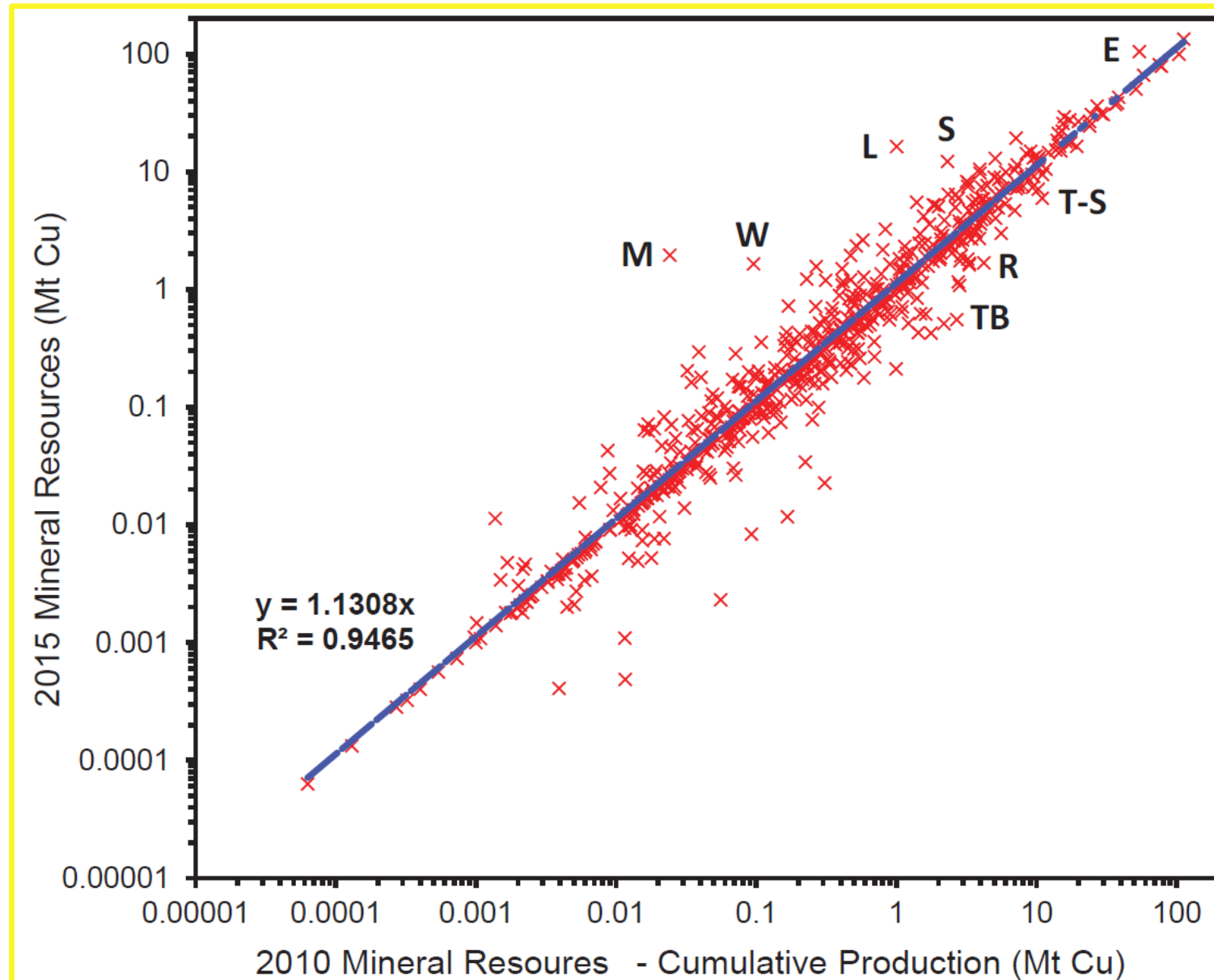
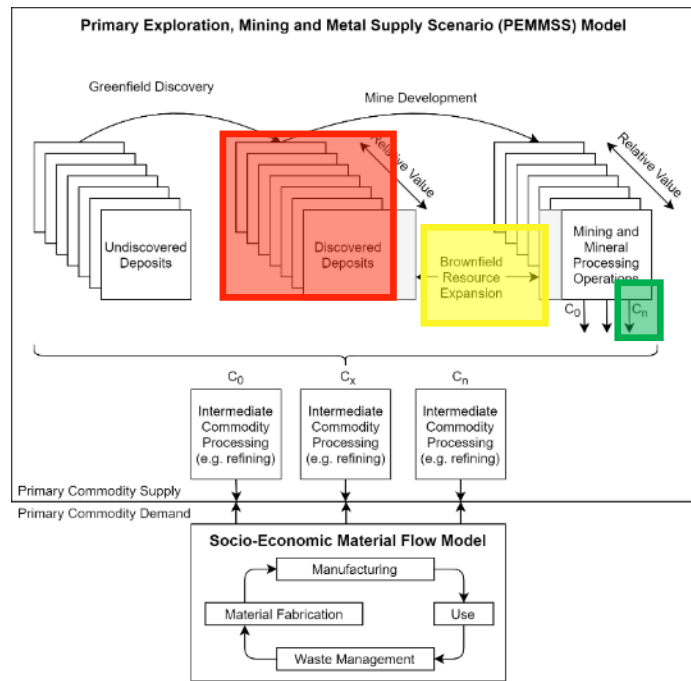
(Mudd & Jowitt, 2018)

UTS Calibrating for Copper – Known Resources



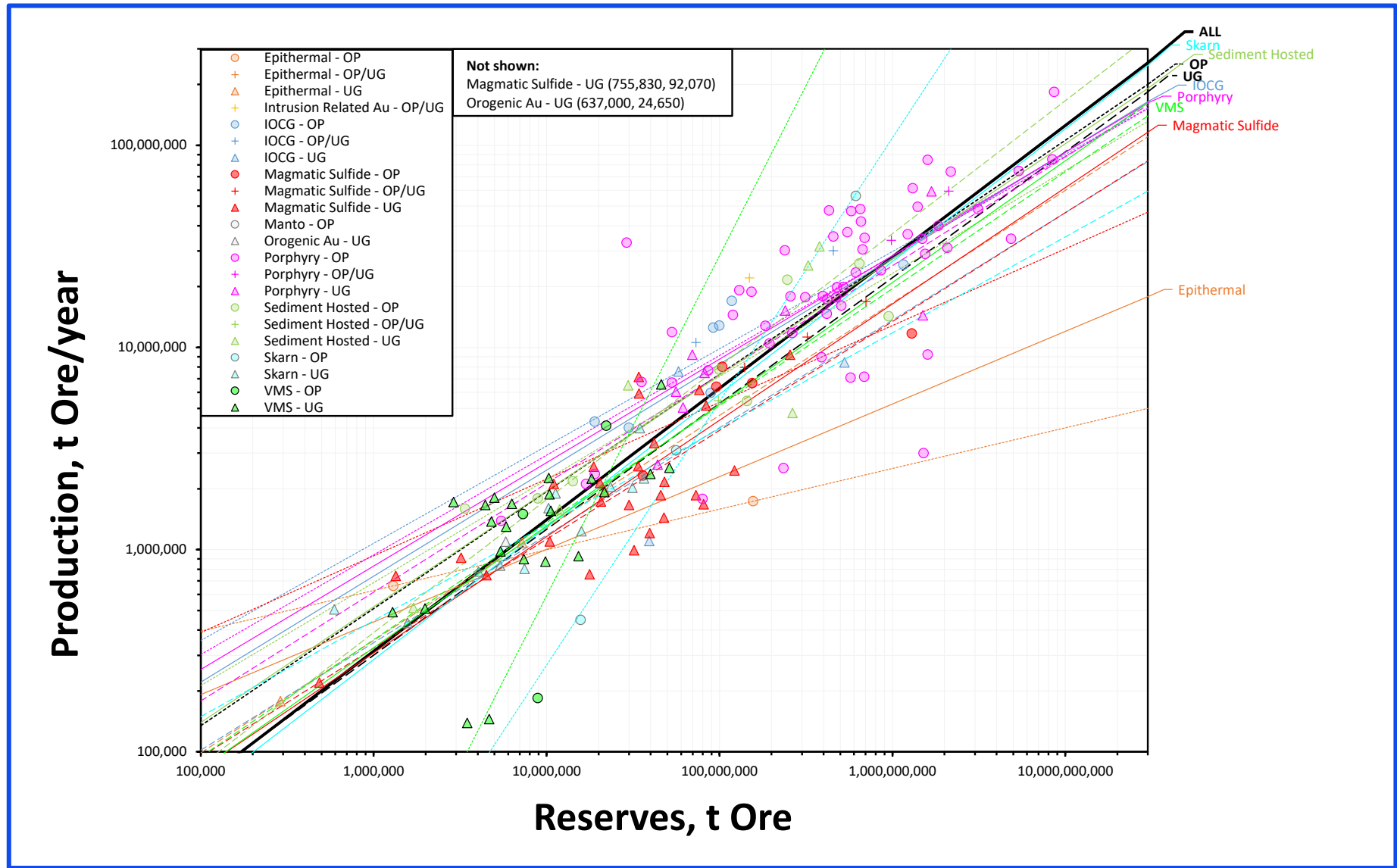
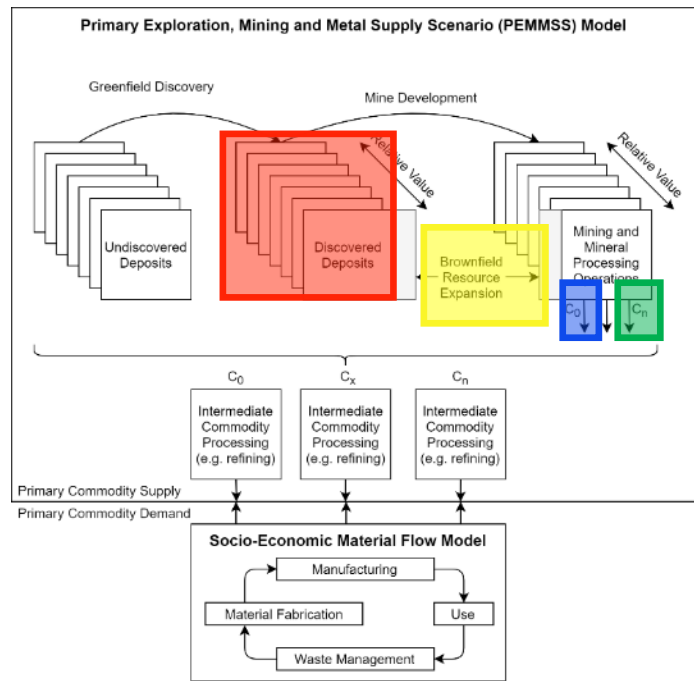
(Werner et al., 2017)

UTS Calibrating for Copper – Co-Product Grades



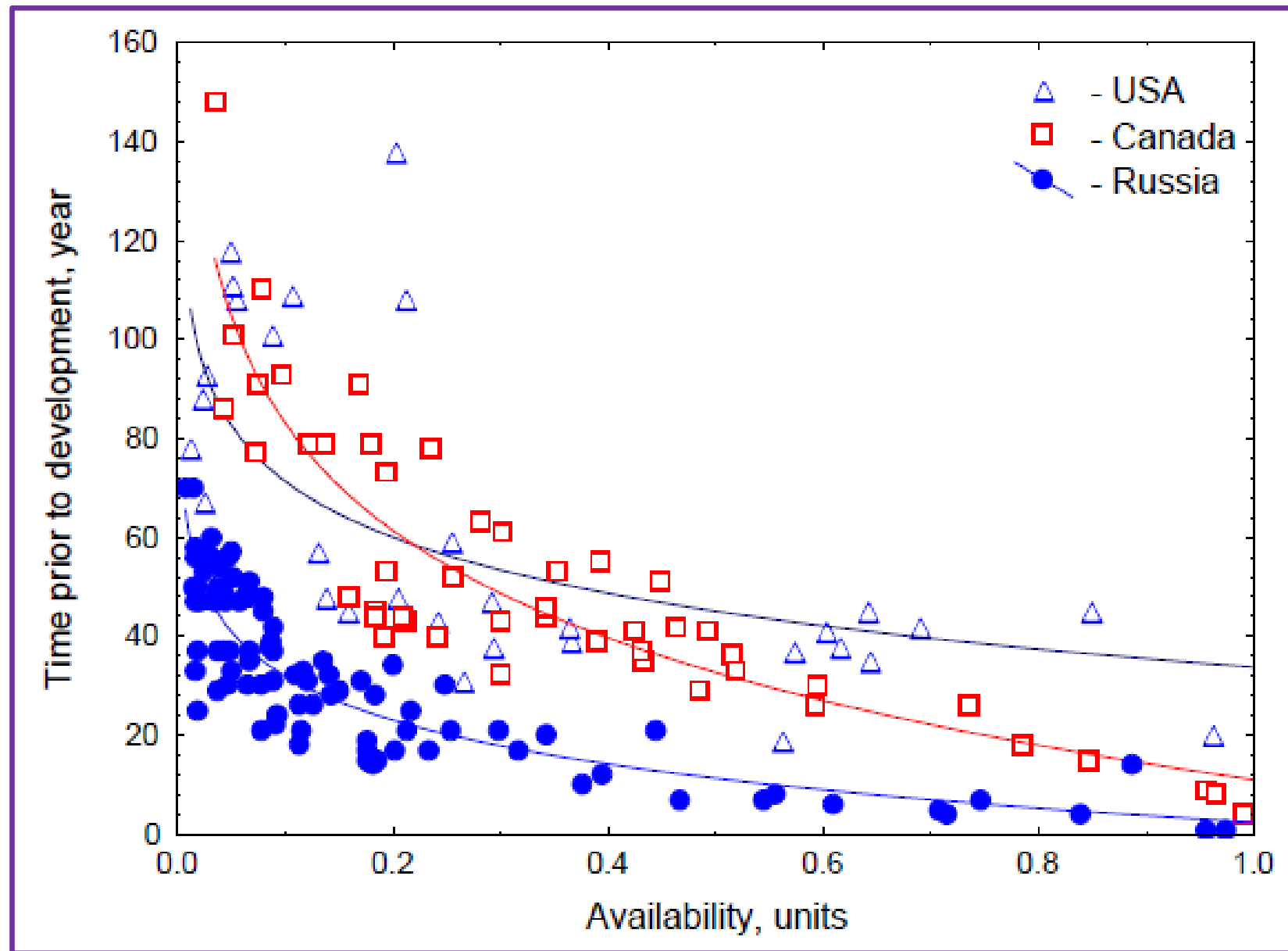
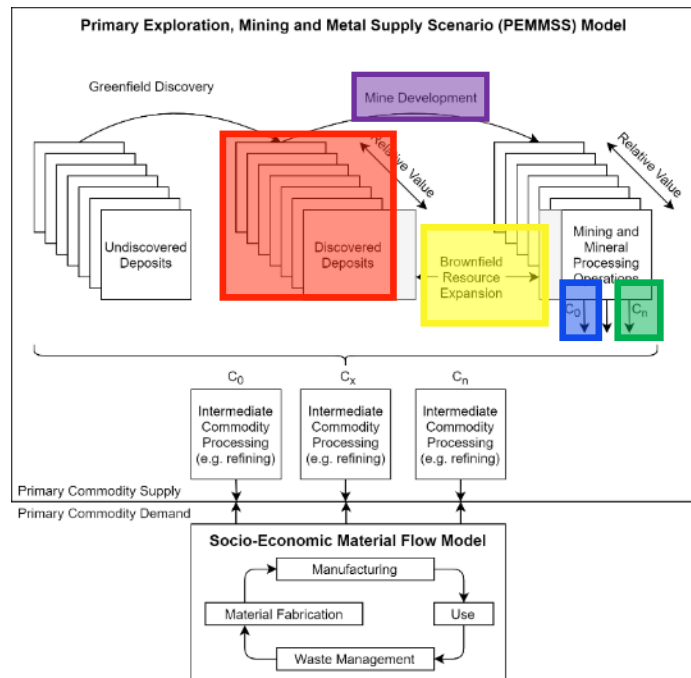
(Mudd & Jowitt, 2018)

UTS Calibrating for Copper – Brownfield Expansion



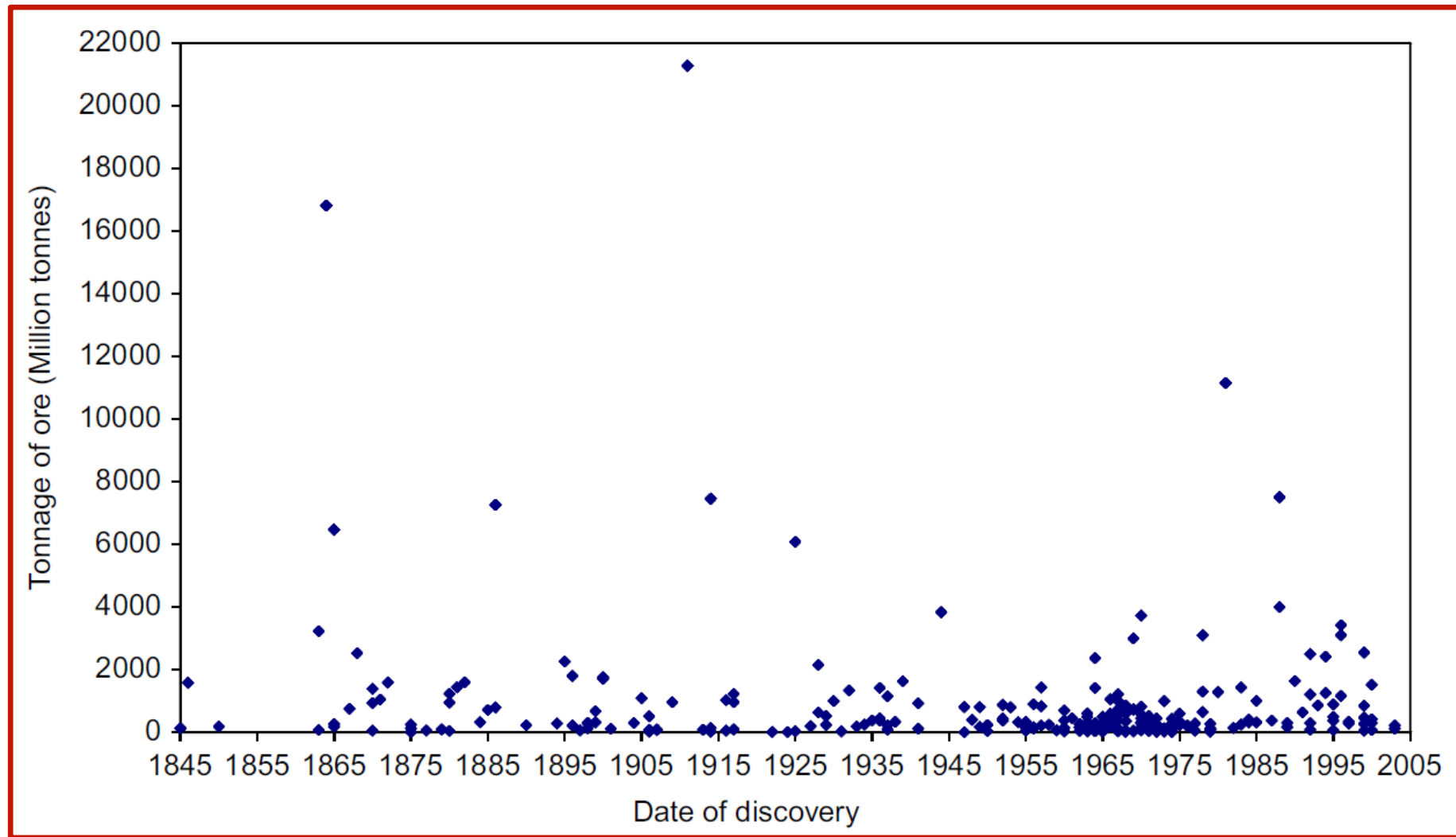
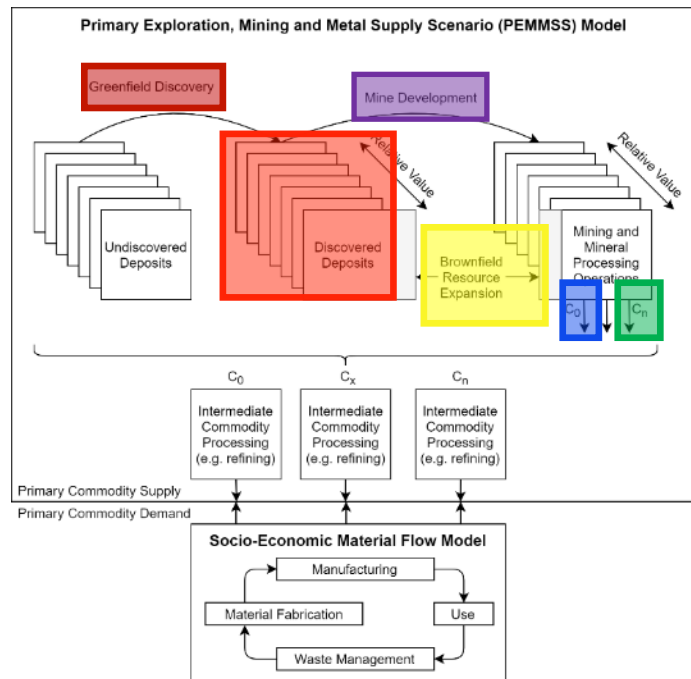
(unpublished)

UTS Calibrating for Copper – Production Capacity



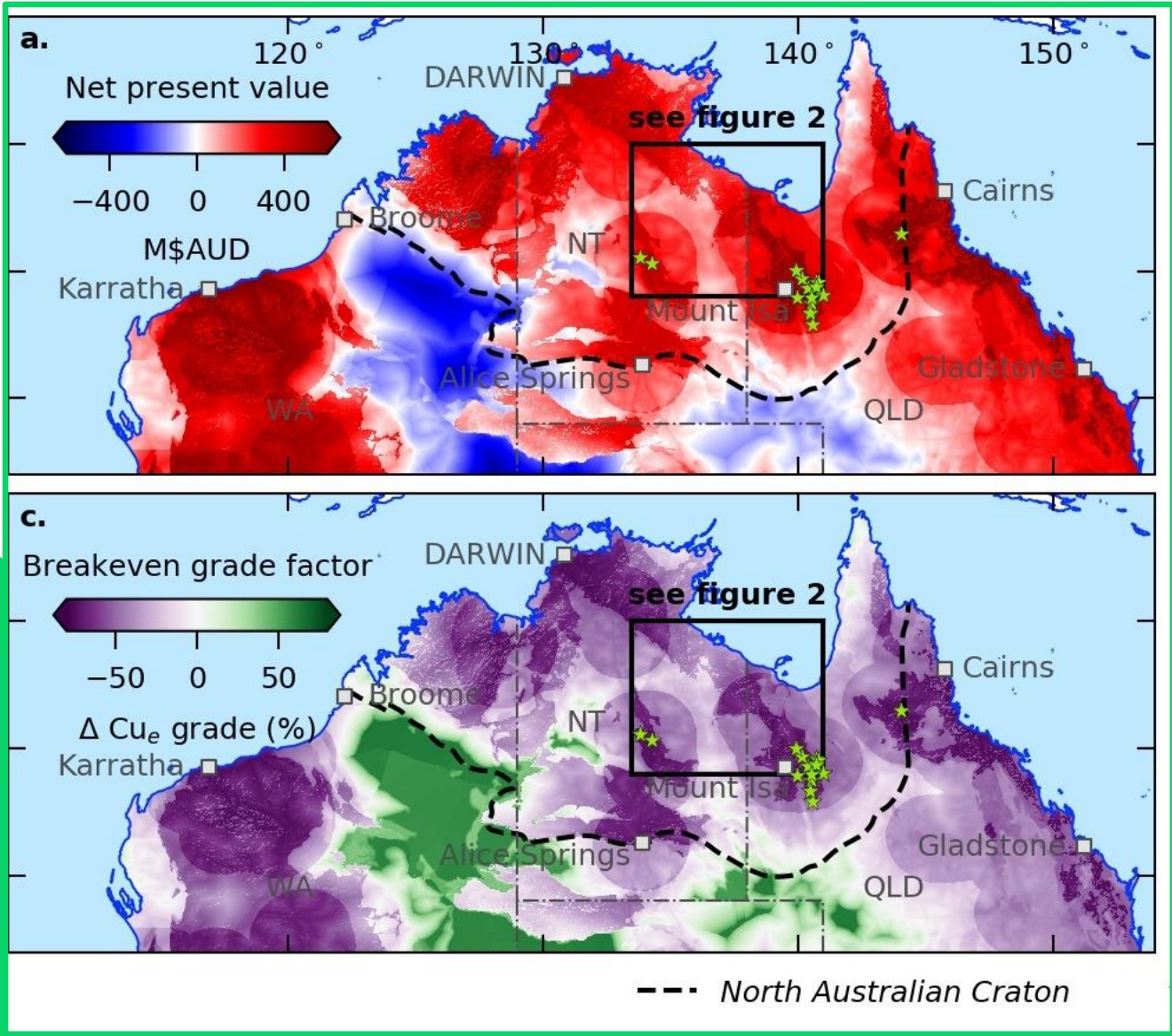
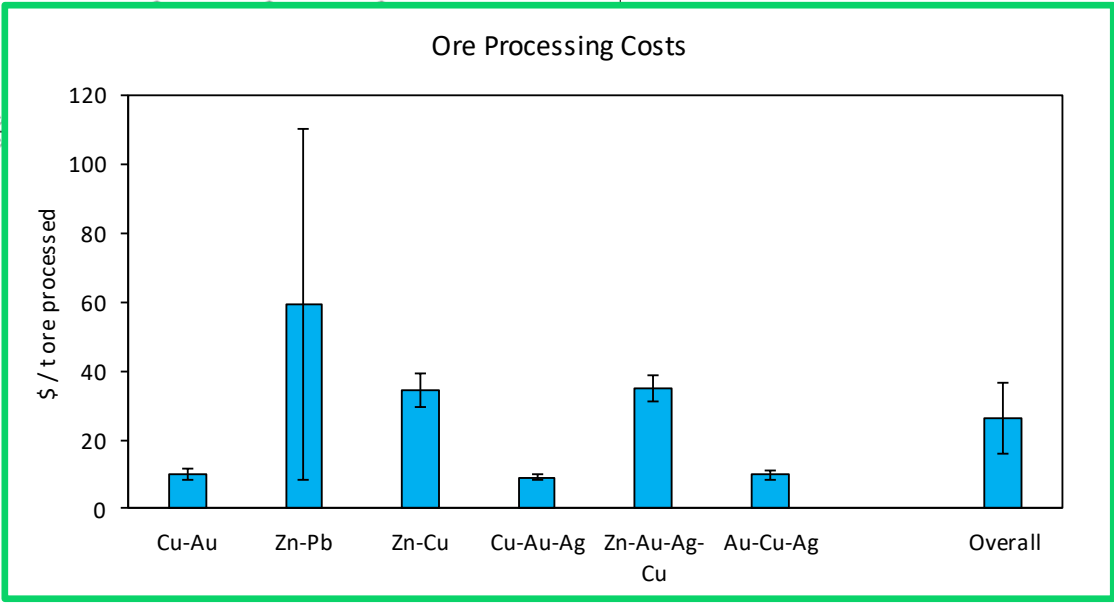
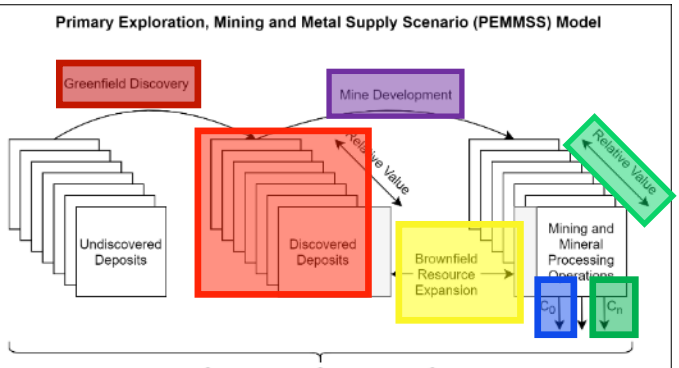
(Kharitonova et al., 2013)

UTS Calibrating for Copper – Development Periods



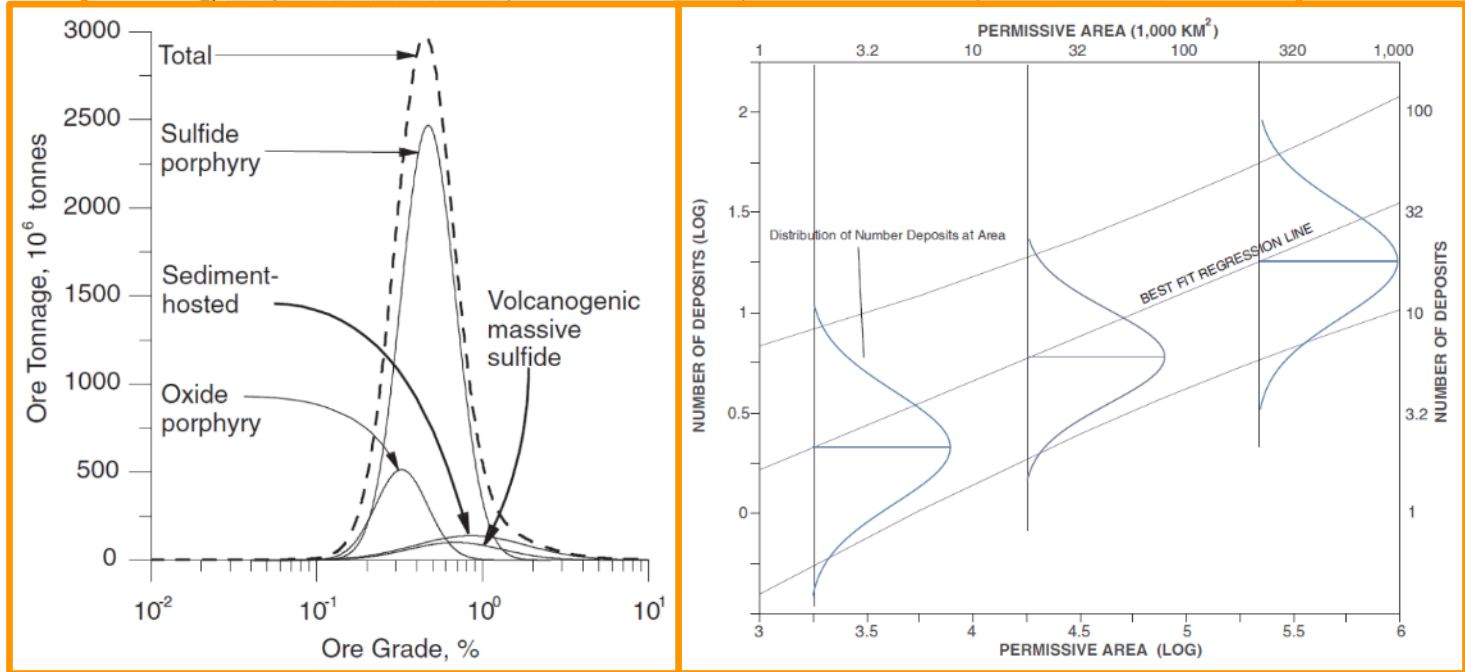
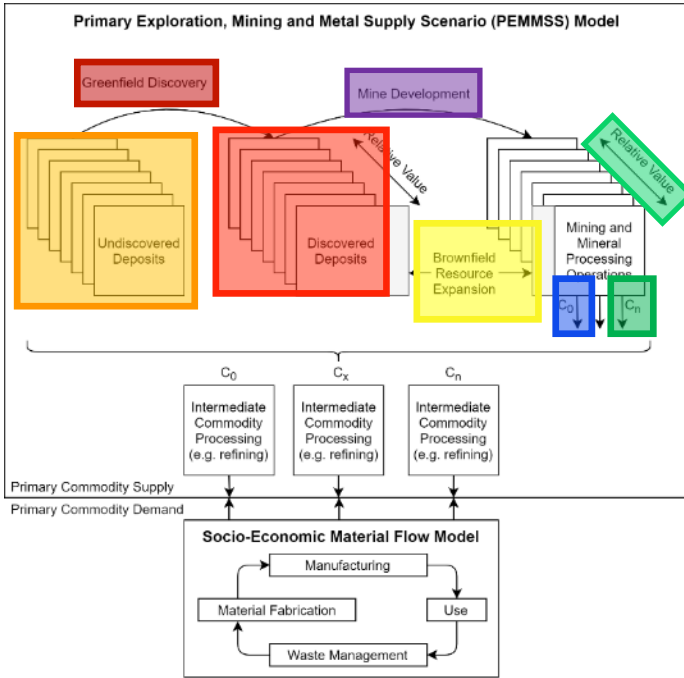
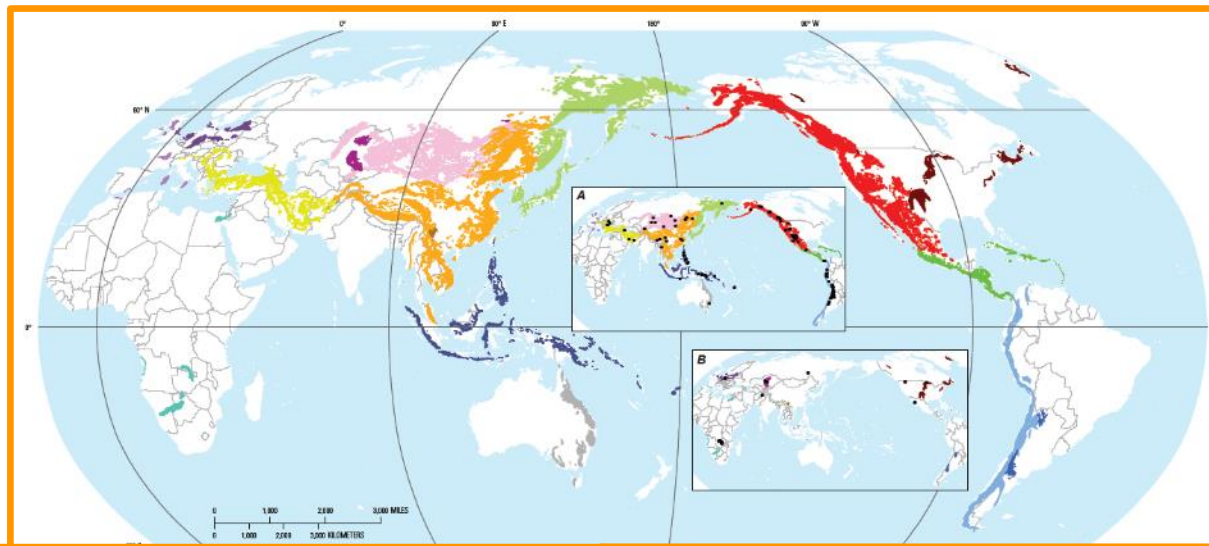
(Crowson, 2012)

UTS Calibrating for Copper – Deposit Discovery Rates



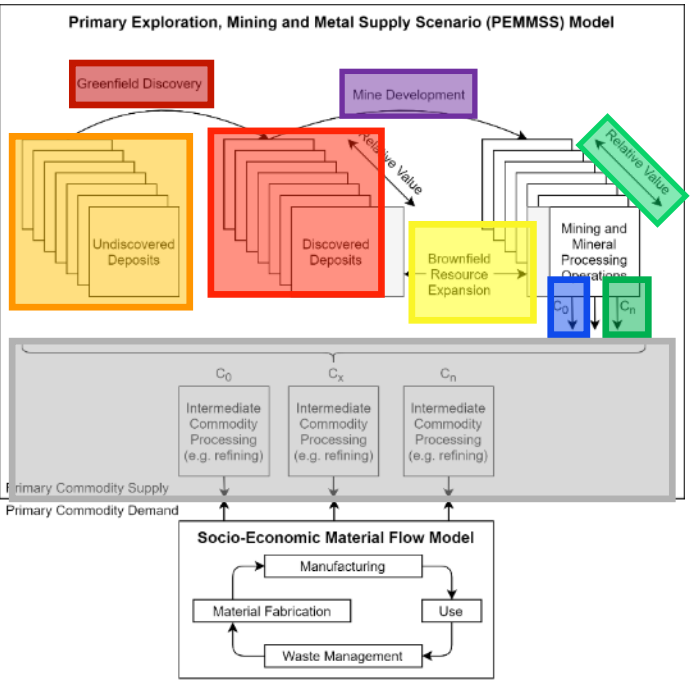
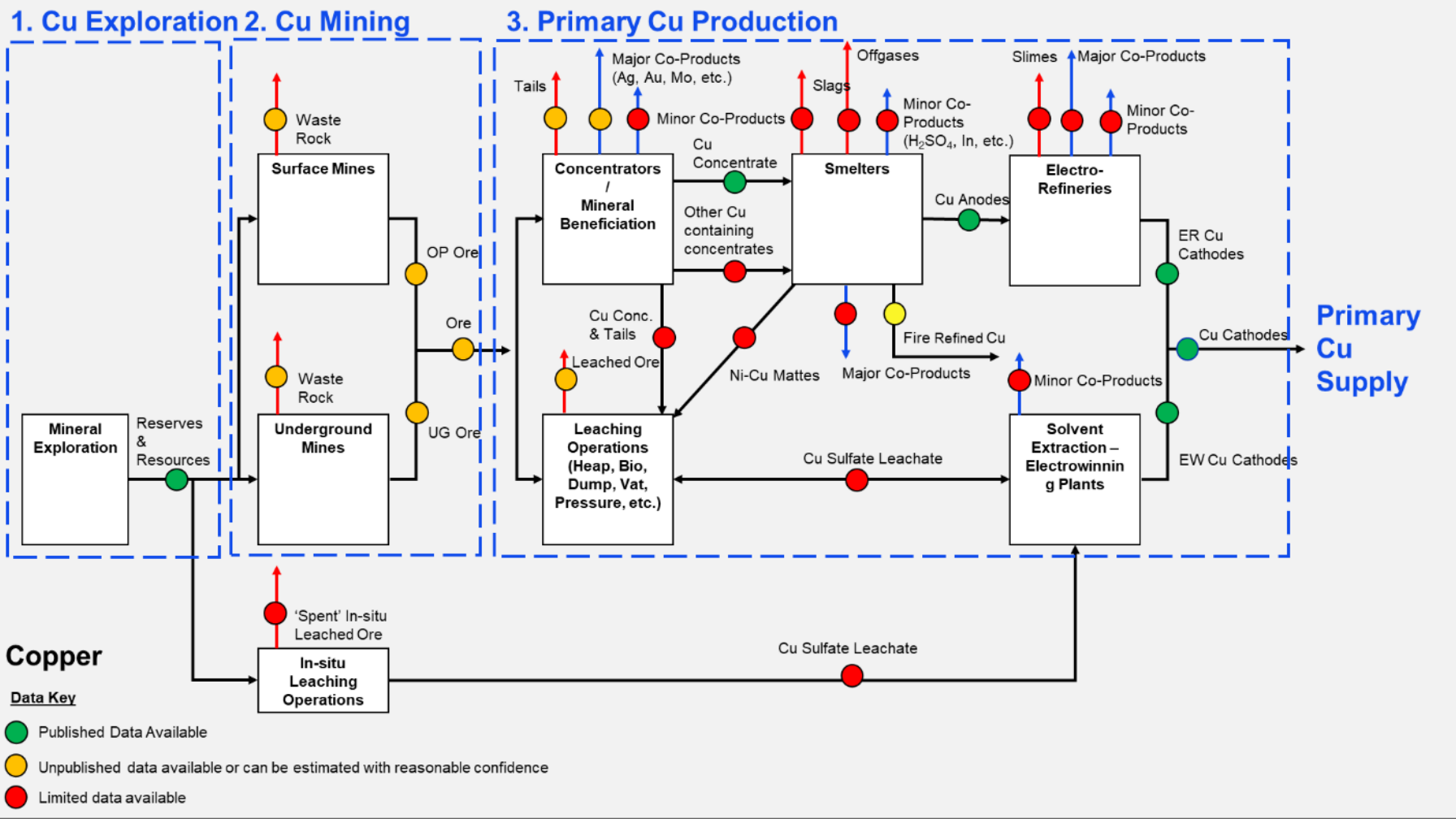
(Walsh et al., 2020; Haynes et al., 2020)

UTS Calibrating for Copper – Deposit Value



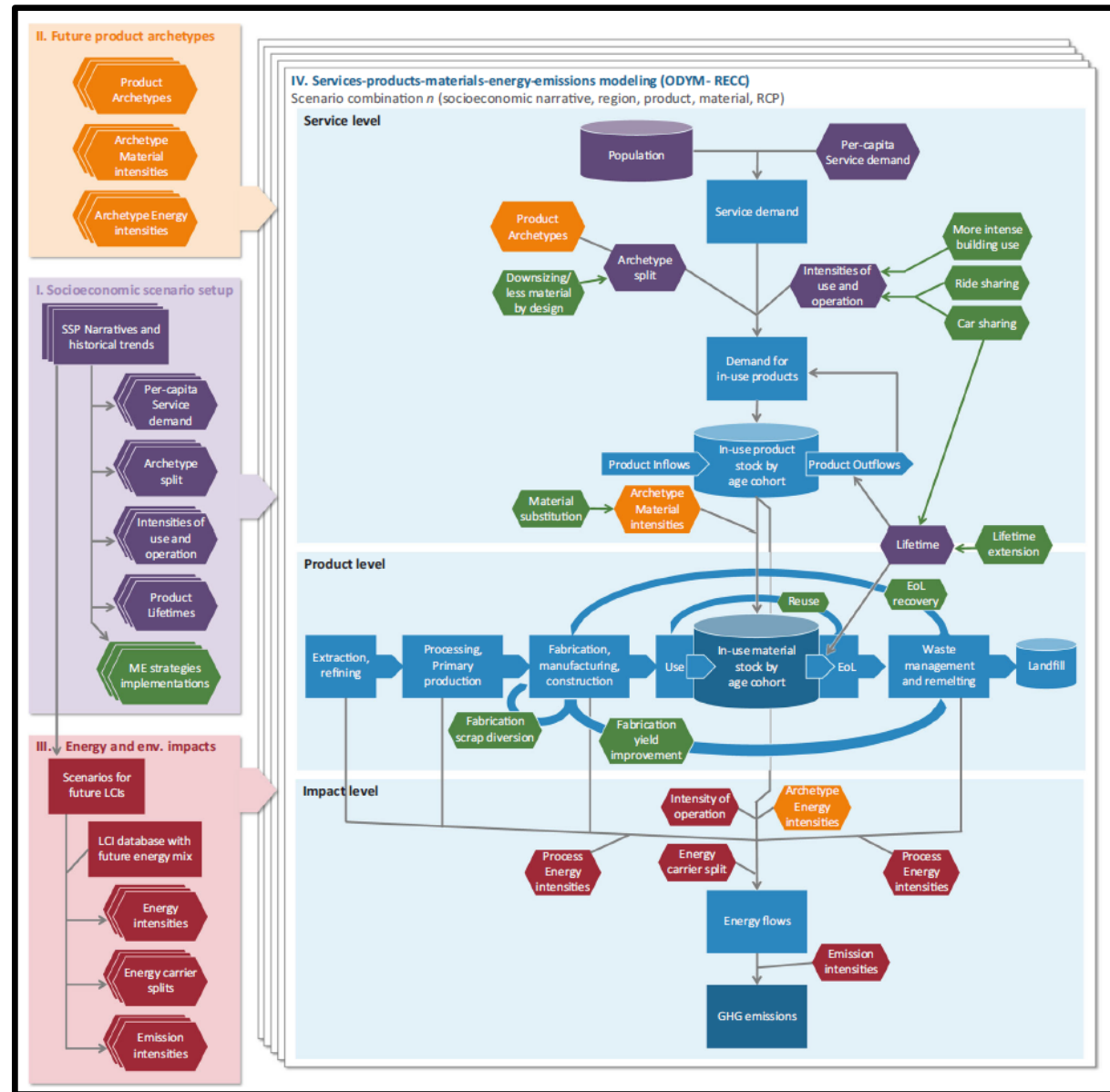
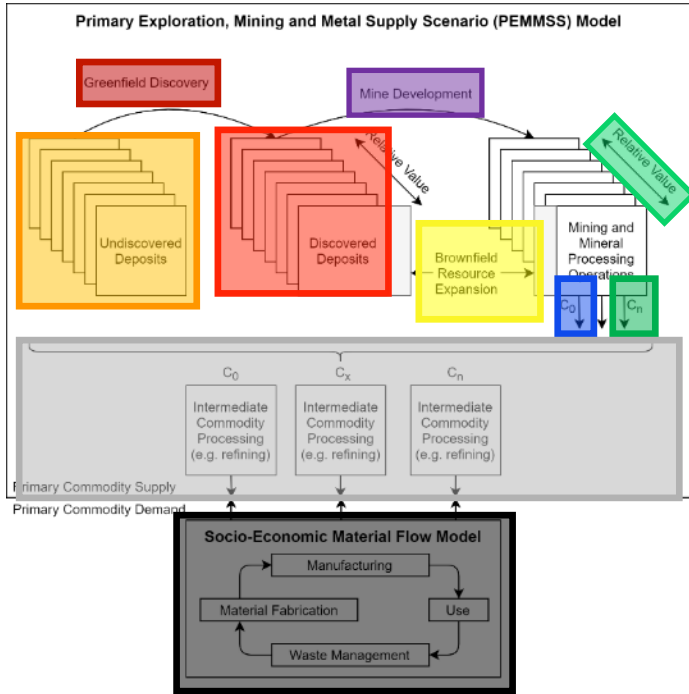
(Gerst, 2008; USGS / Singer et al., 2008; 2018)

UTS Calibrating for Copper – Undiscovered Deposits



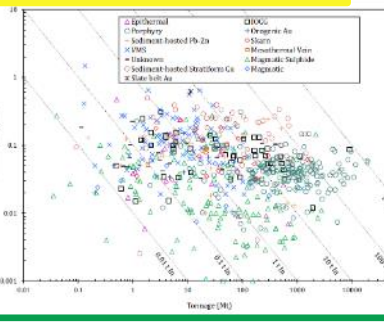
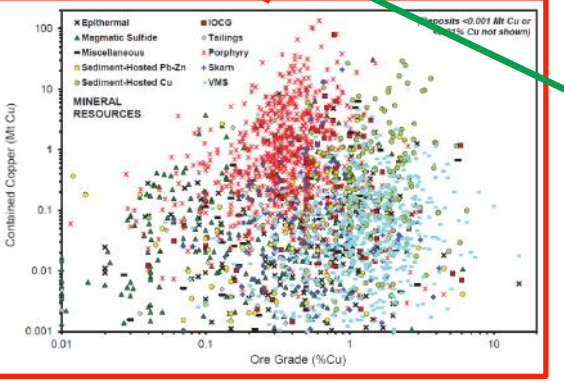
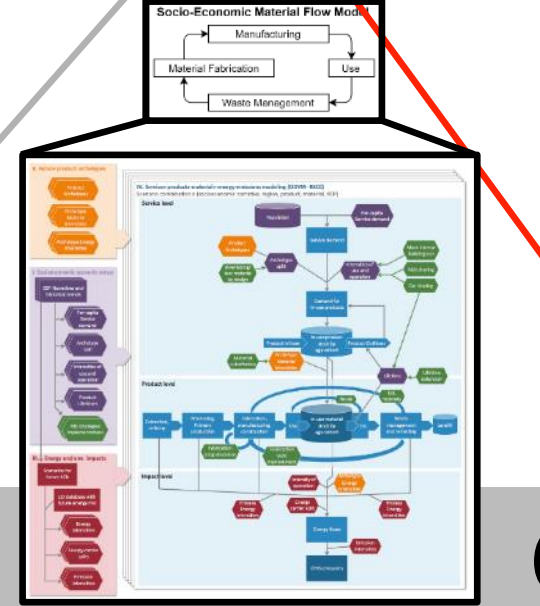
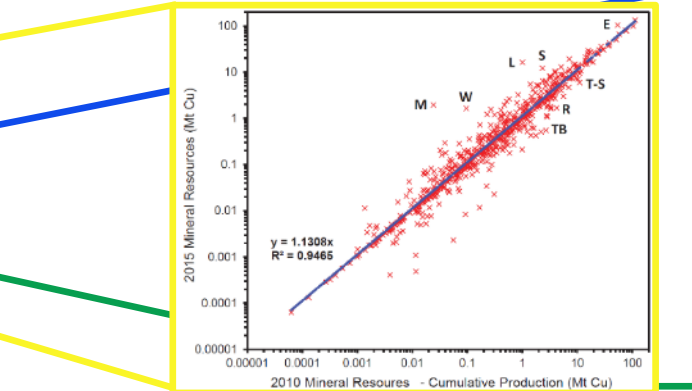
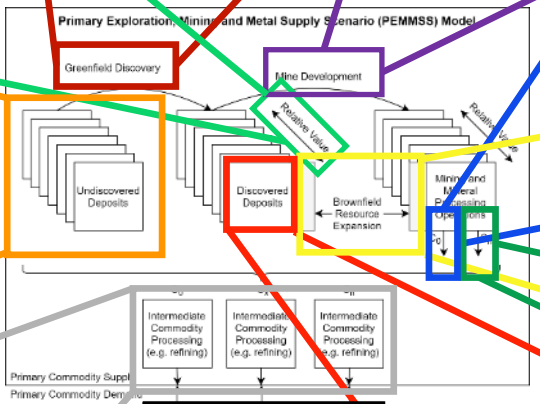
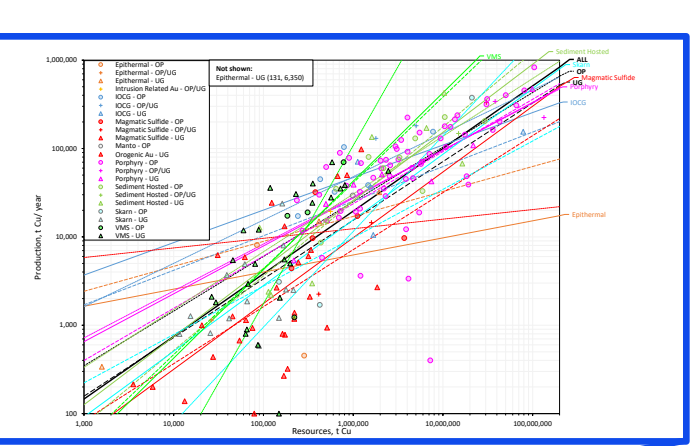
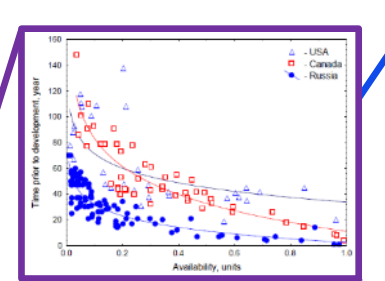
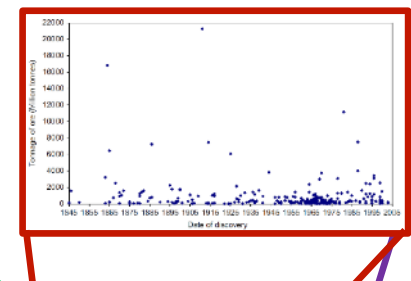
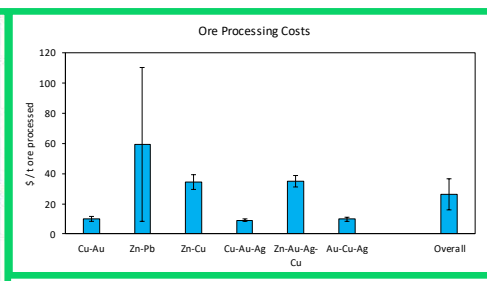
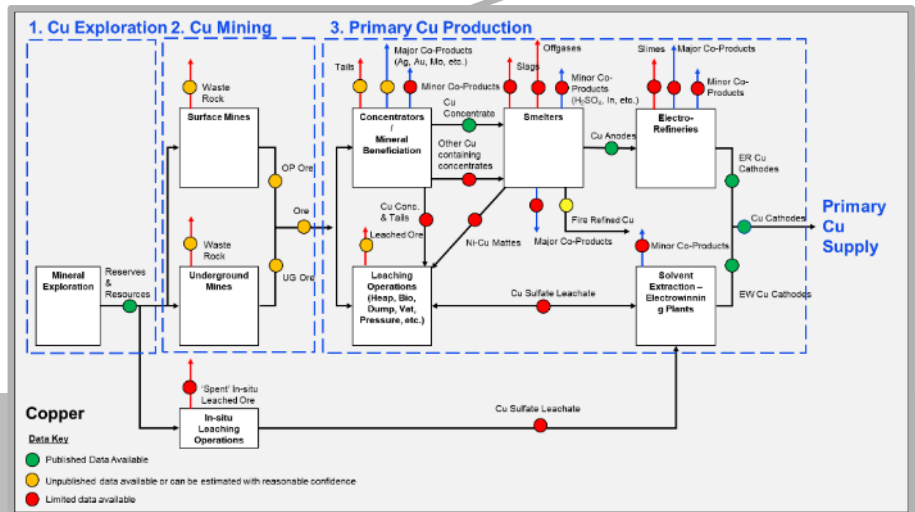
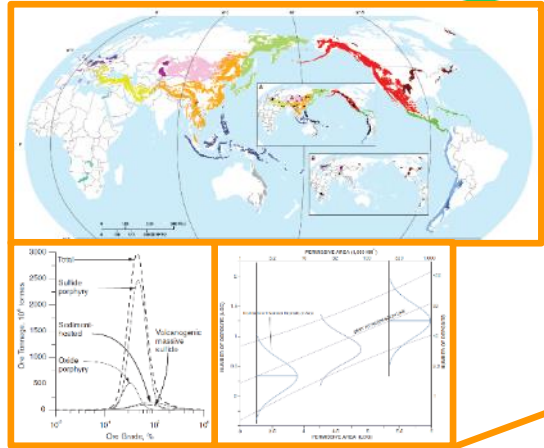
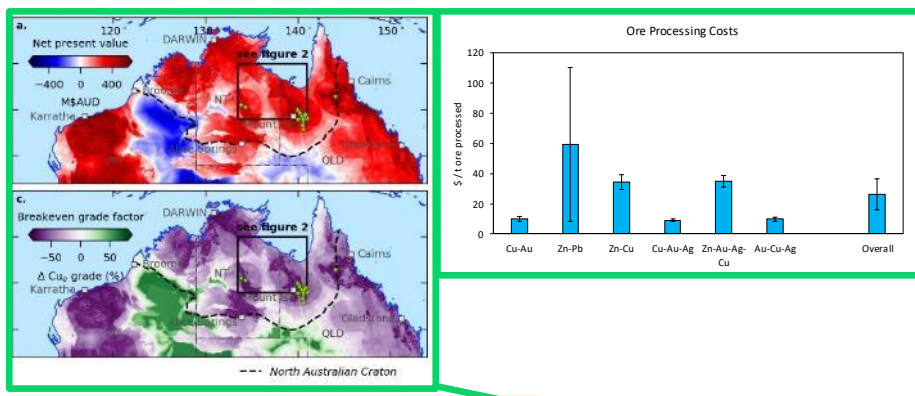
(unpublished)

UTS Calibrating for Copper – Processing Pathways



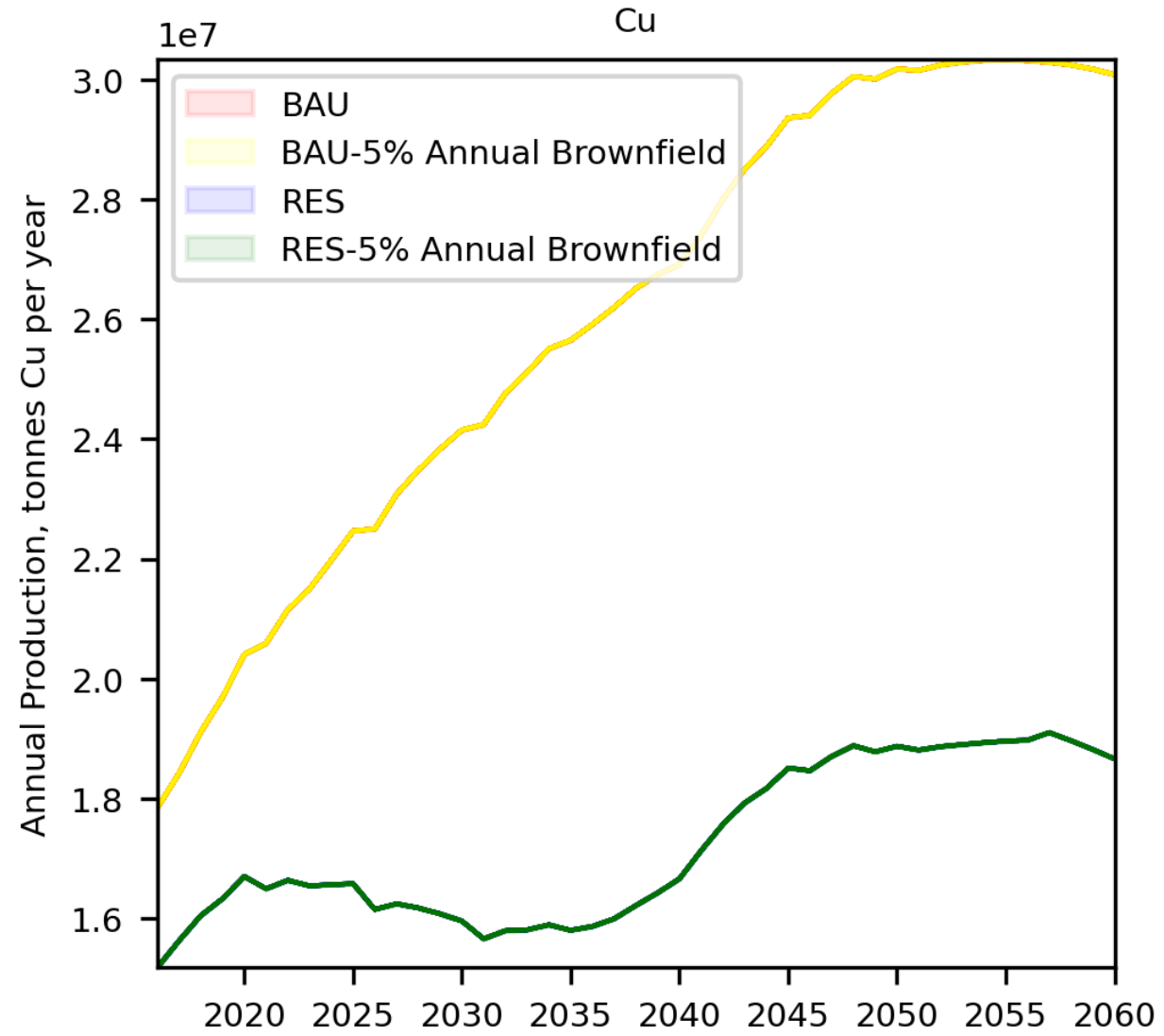
(Pauliuk et al., 2020)

UTS Calibrating for Copper – Linking to Demand



Calibrating for Copper

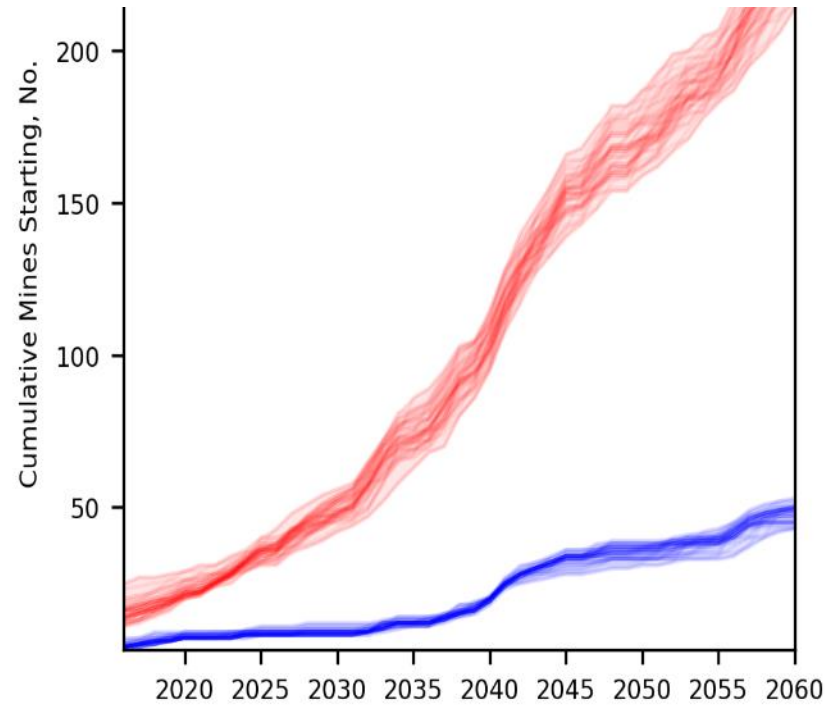
SSP 2 RCP 2.6



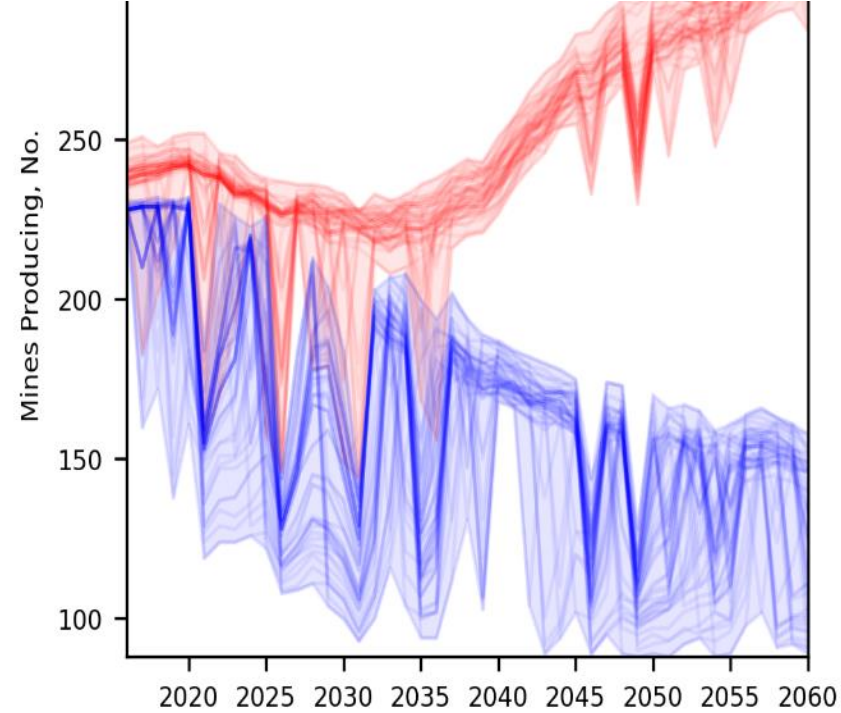
SSP 2 RCP 2.6



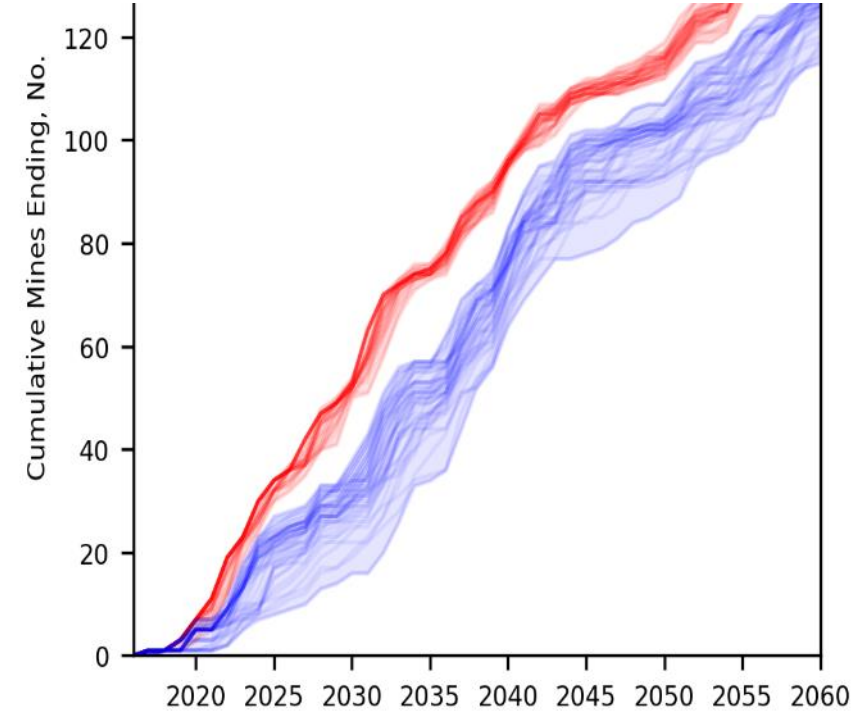
New Mines Required



Mines Producing



Mine Closures

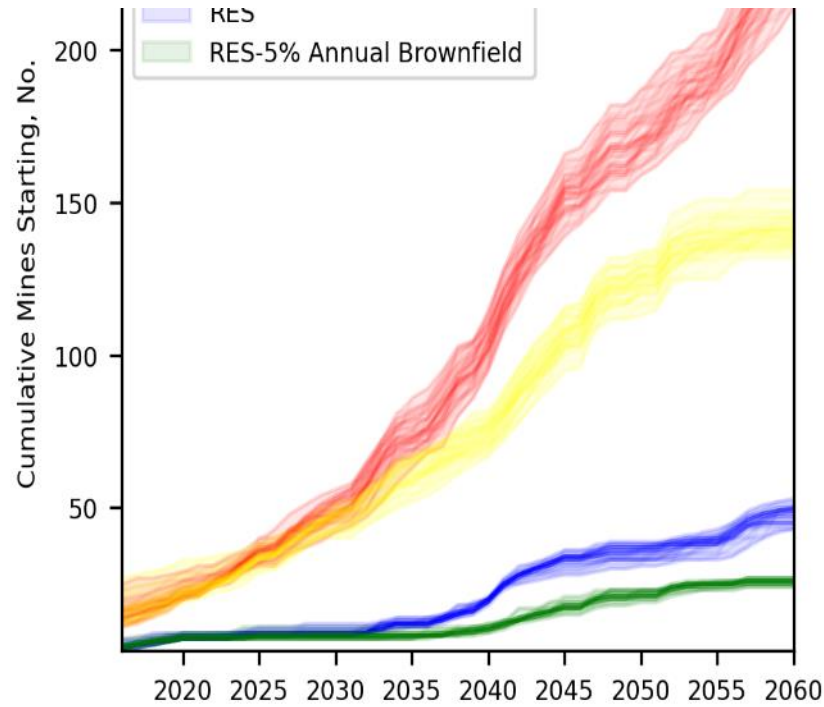


Unpublished and Preliminary. These Results Will Change.

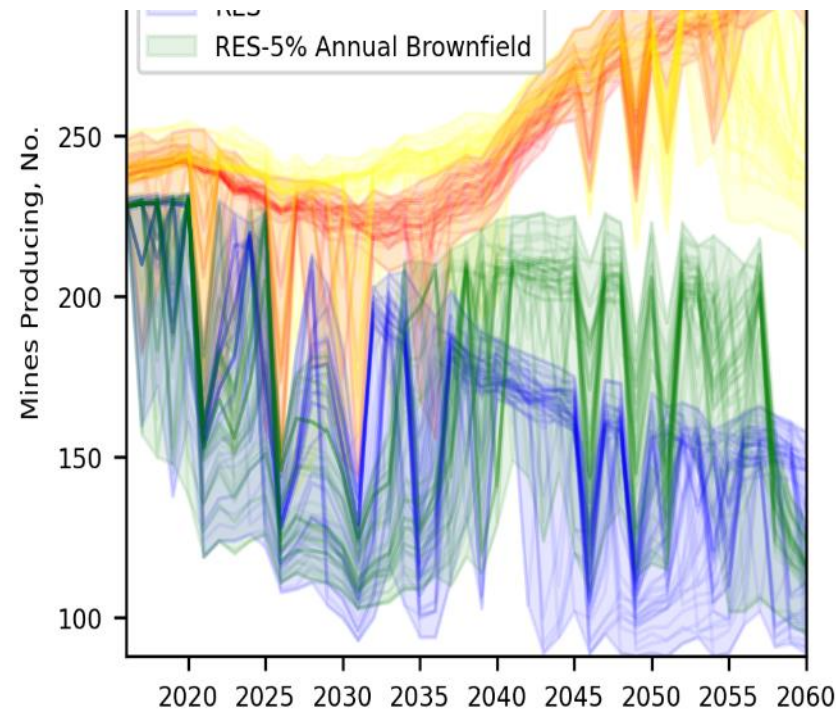
SSP 2 RCP 2.6



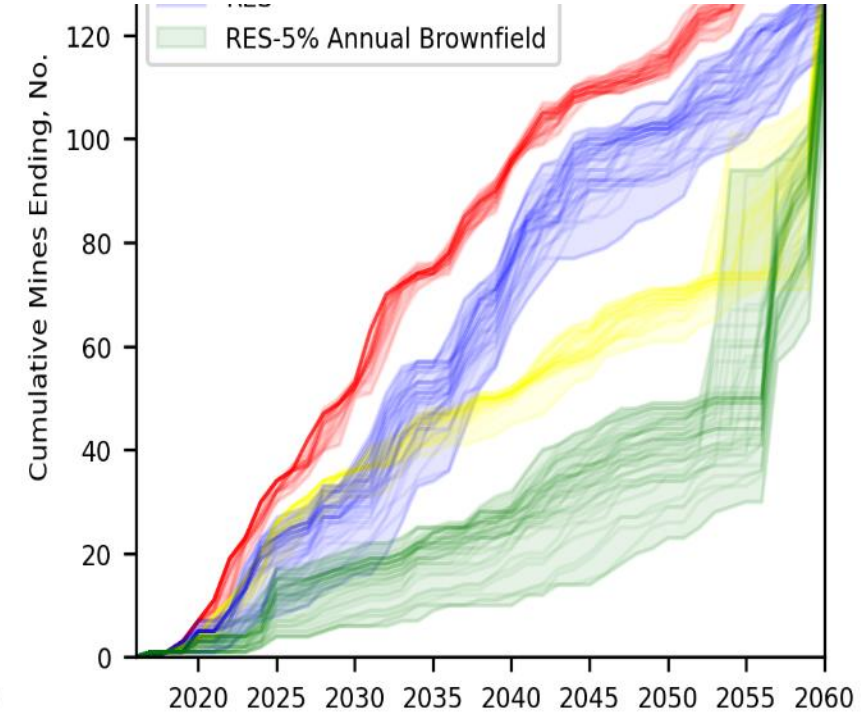
New Mines Required



Mines Producing



Mine Closures



Unpublished and Preliminary. These Results Will Change.



But what does this all mean
for prospective LCA?

No two mines have the same impact on the landscape



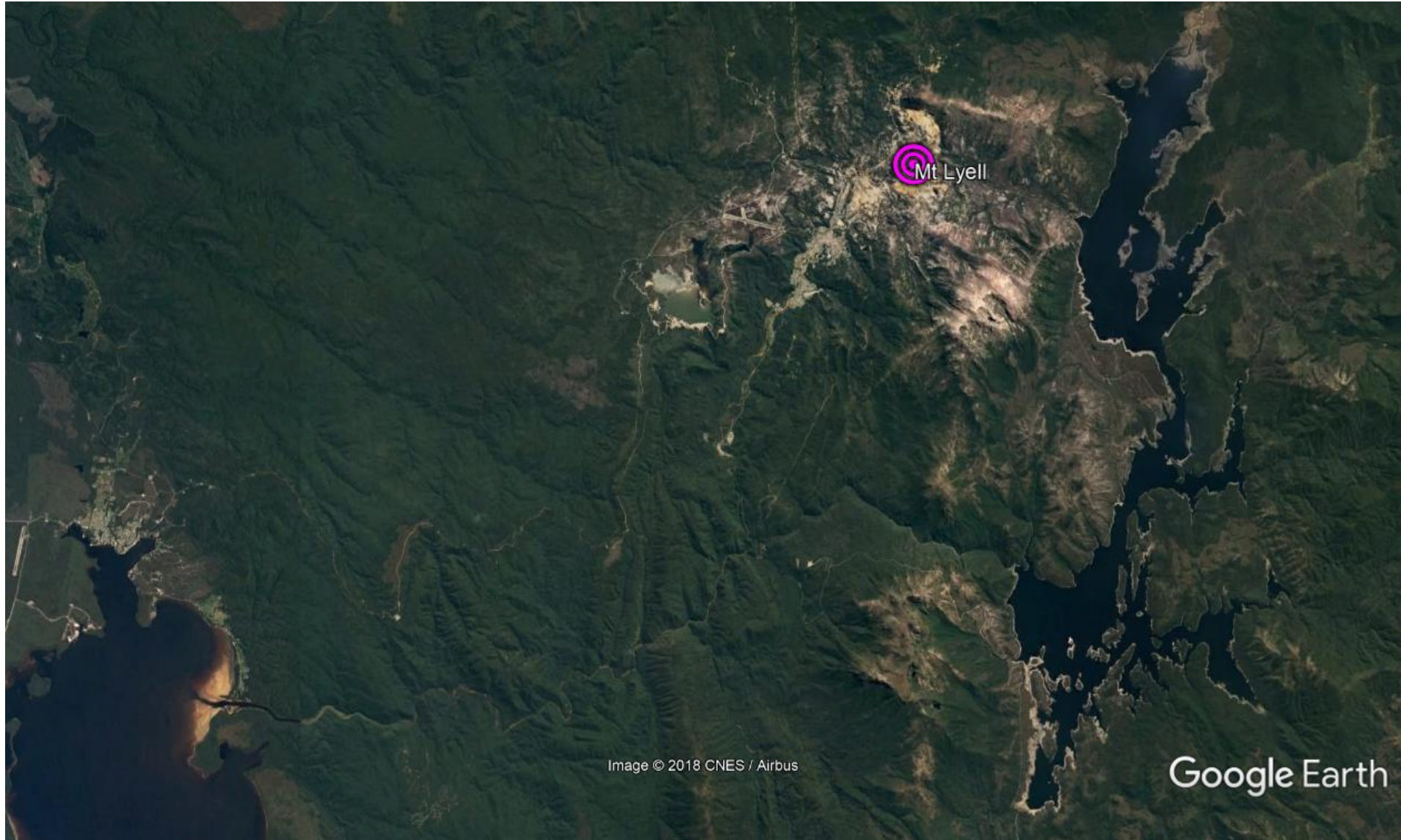
No two mines have the same impact on the landscape



No two mines have the same impact on the landscape



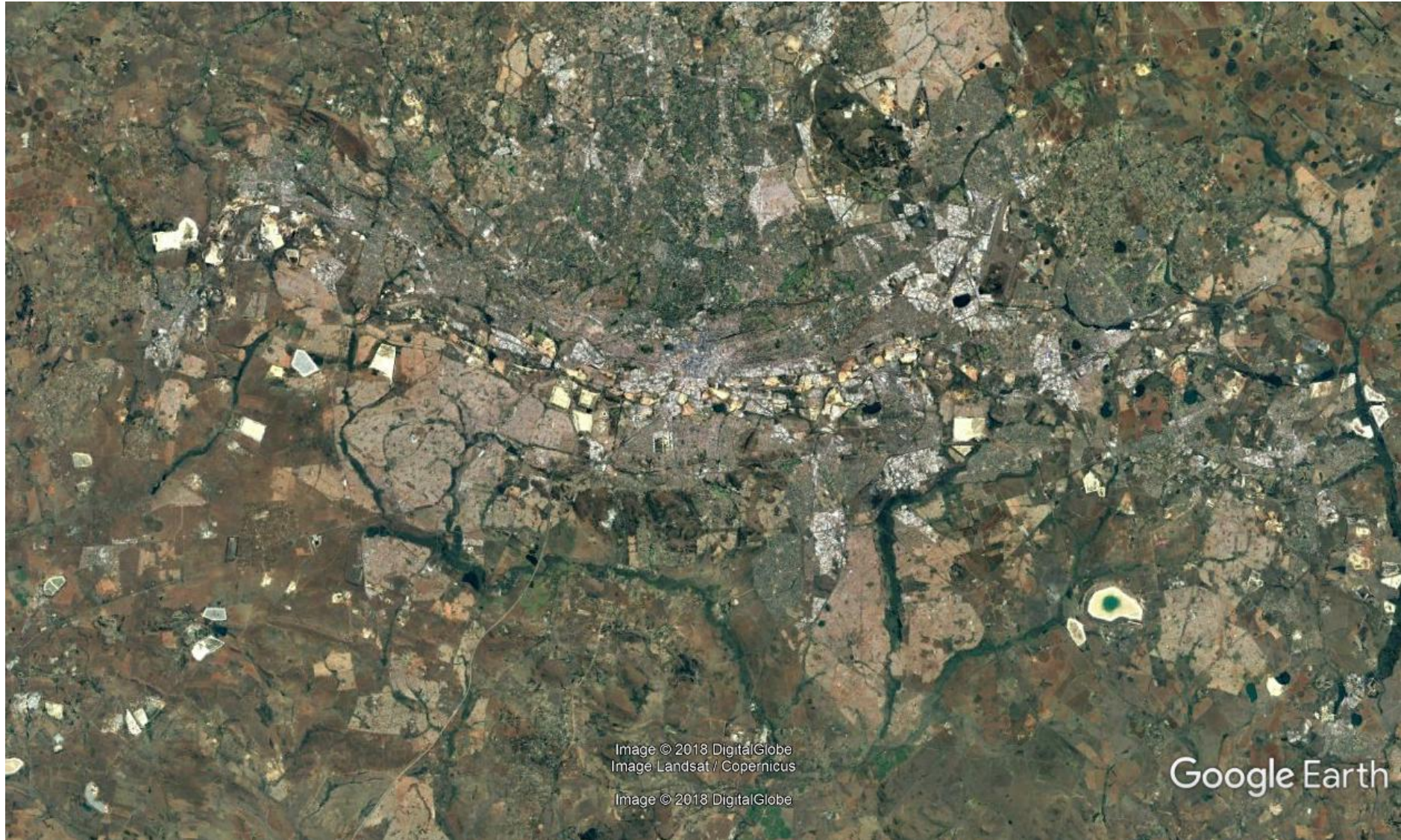
No two mines have the same impact on the landscape



No two mines have the same impact on the landscape



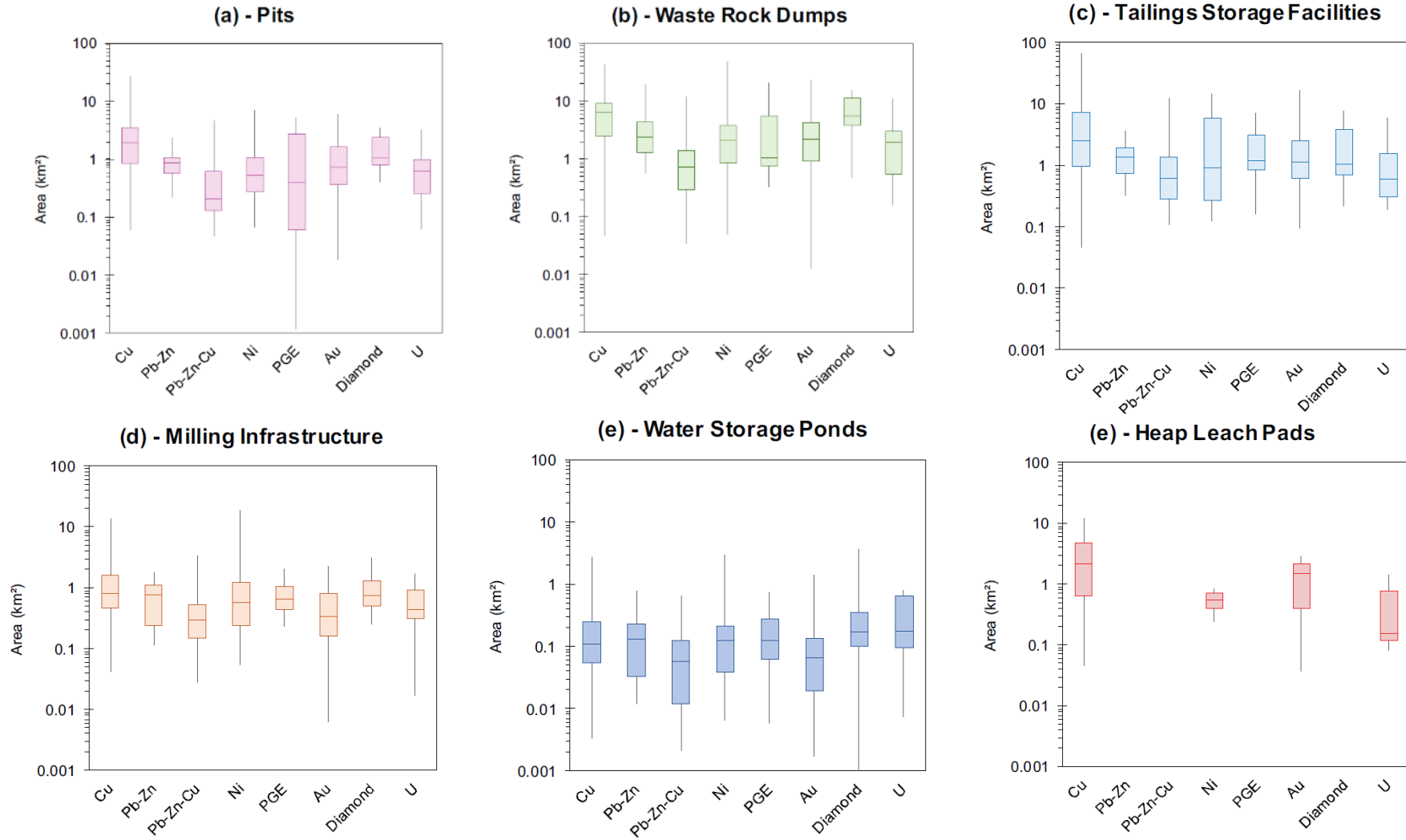
No two mines have the same impact on the landscape



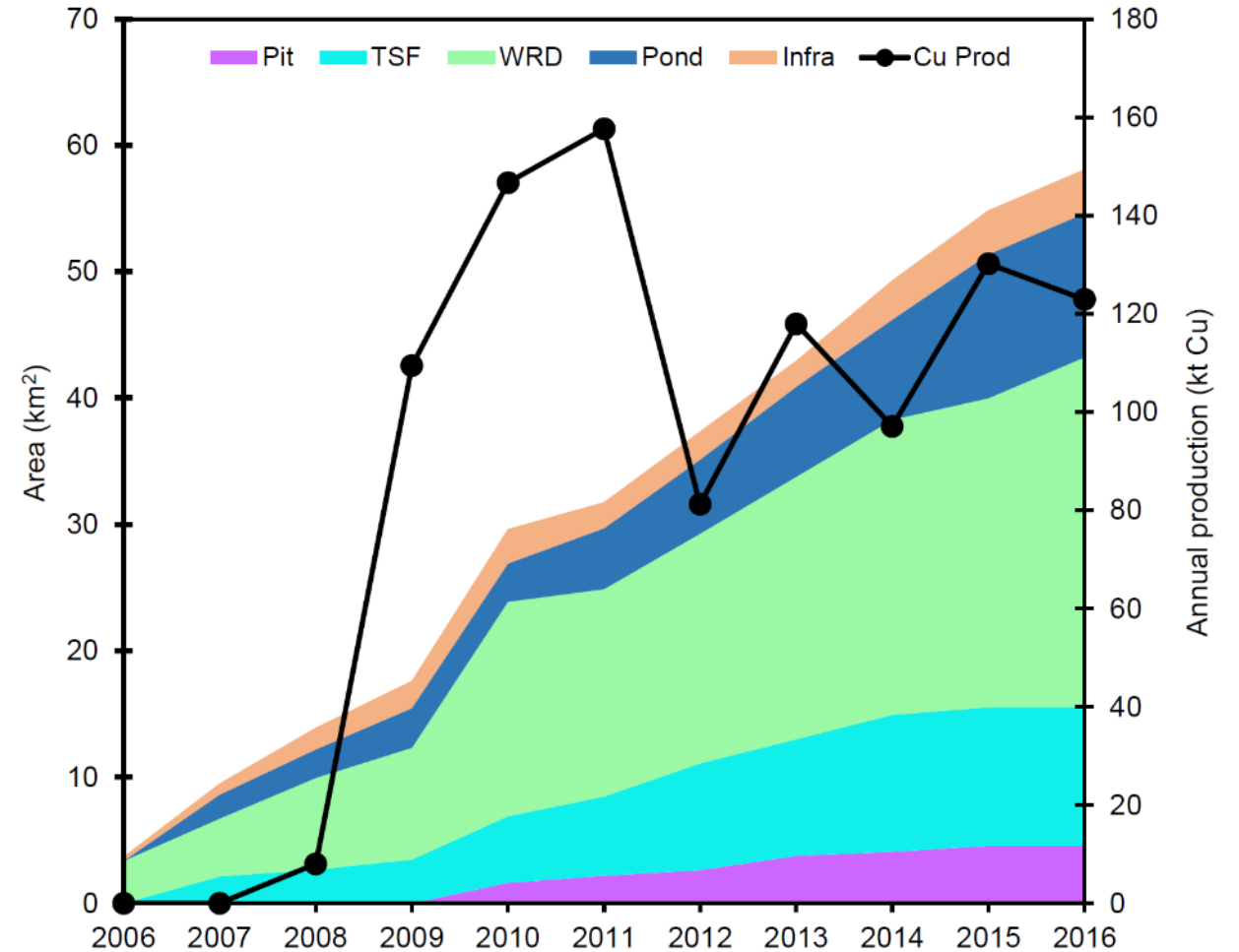
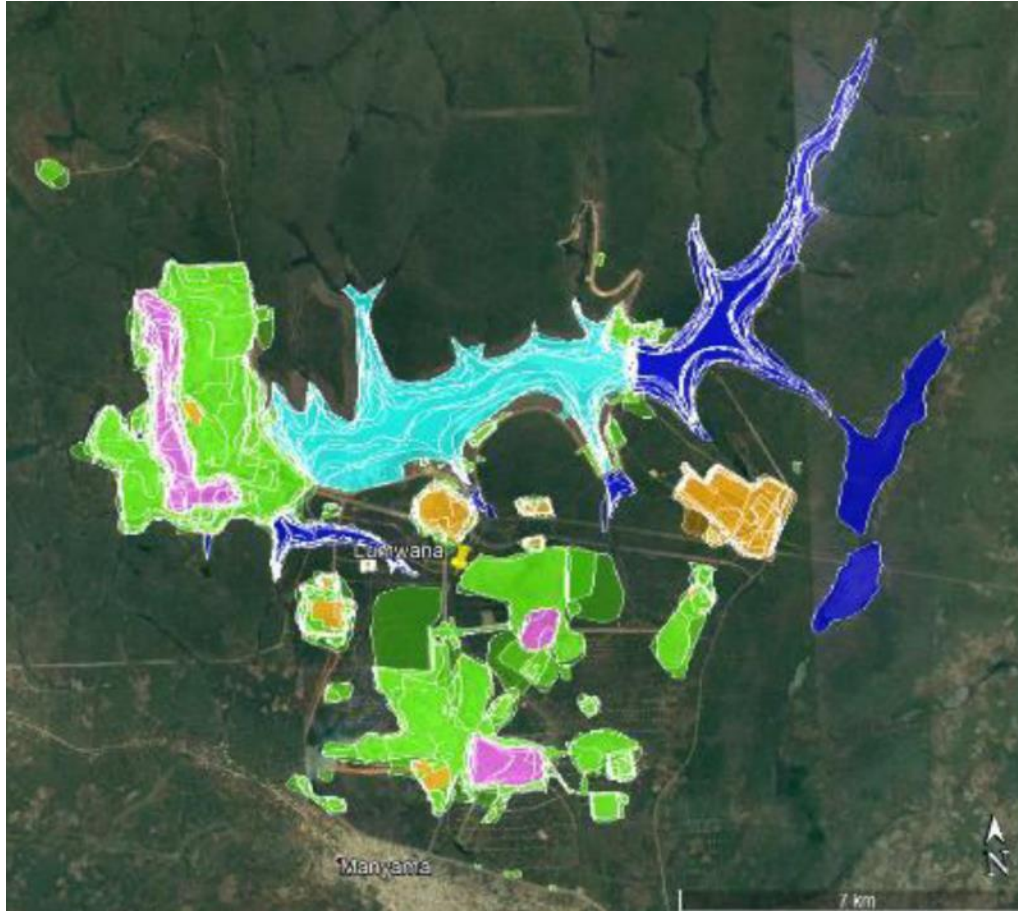
No two mines have the same impact on the landscape



There is considerable variability in land-use, but some *relative* differences between commodity groups



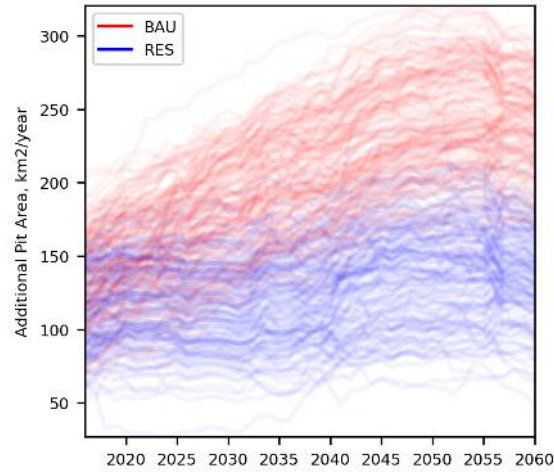
A complication for LCA is that land transformations don't always coincide with production



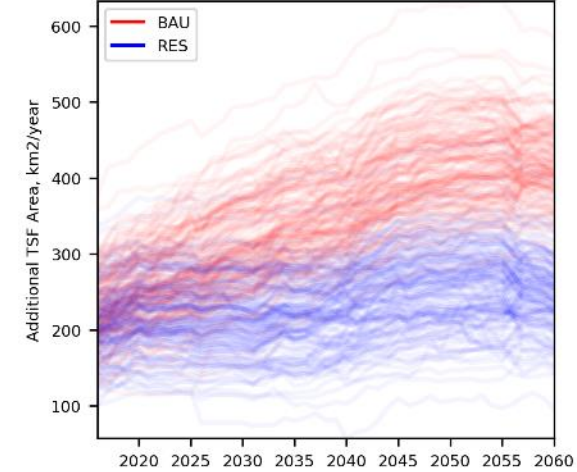
Future land-transformations of mining are highly uncertain



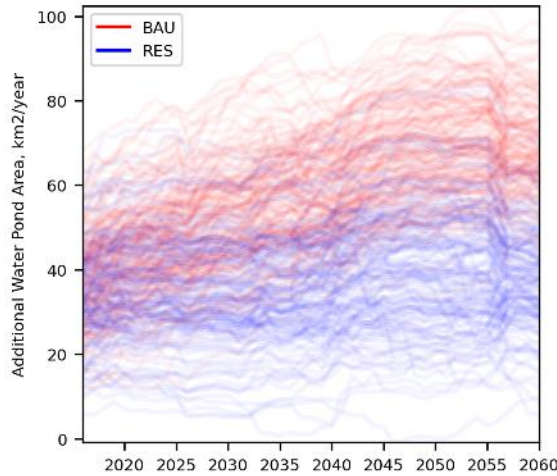
Pits



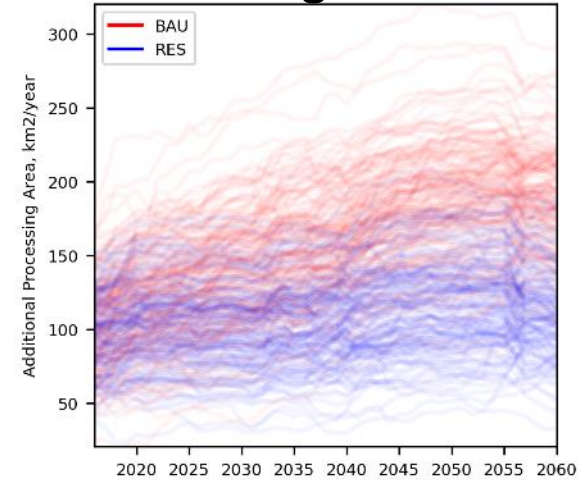
Tailings Storage Facilities



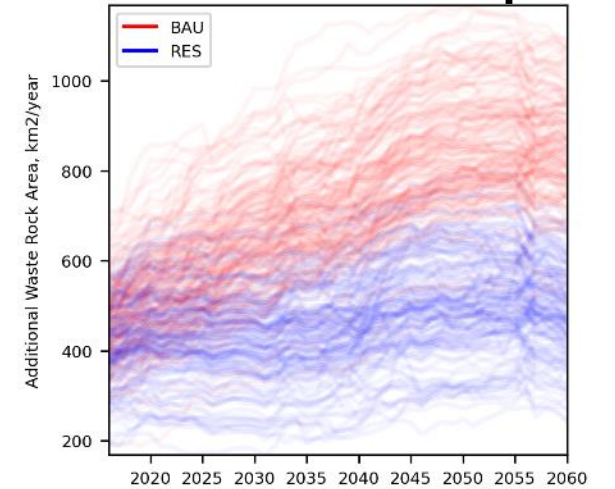
Water Ponds



Processing Facilities

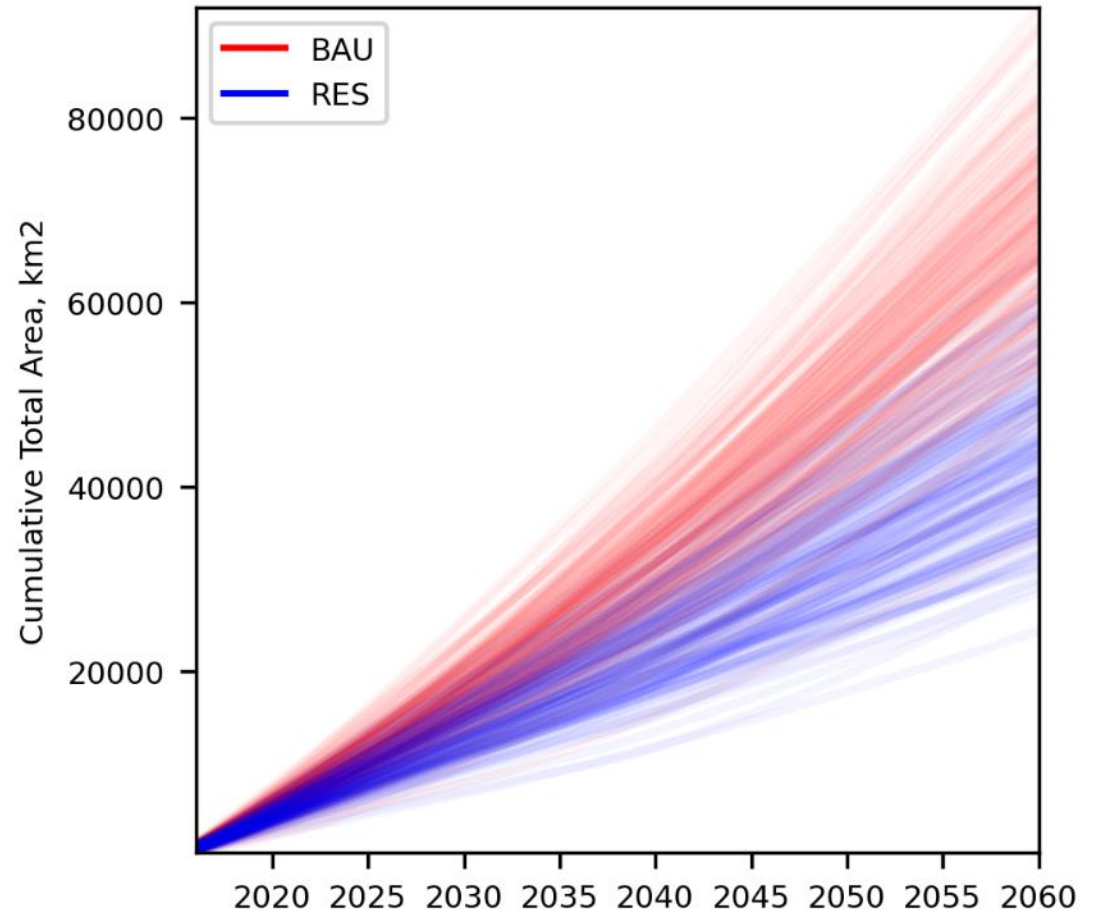
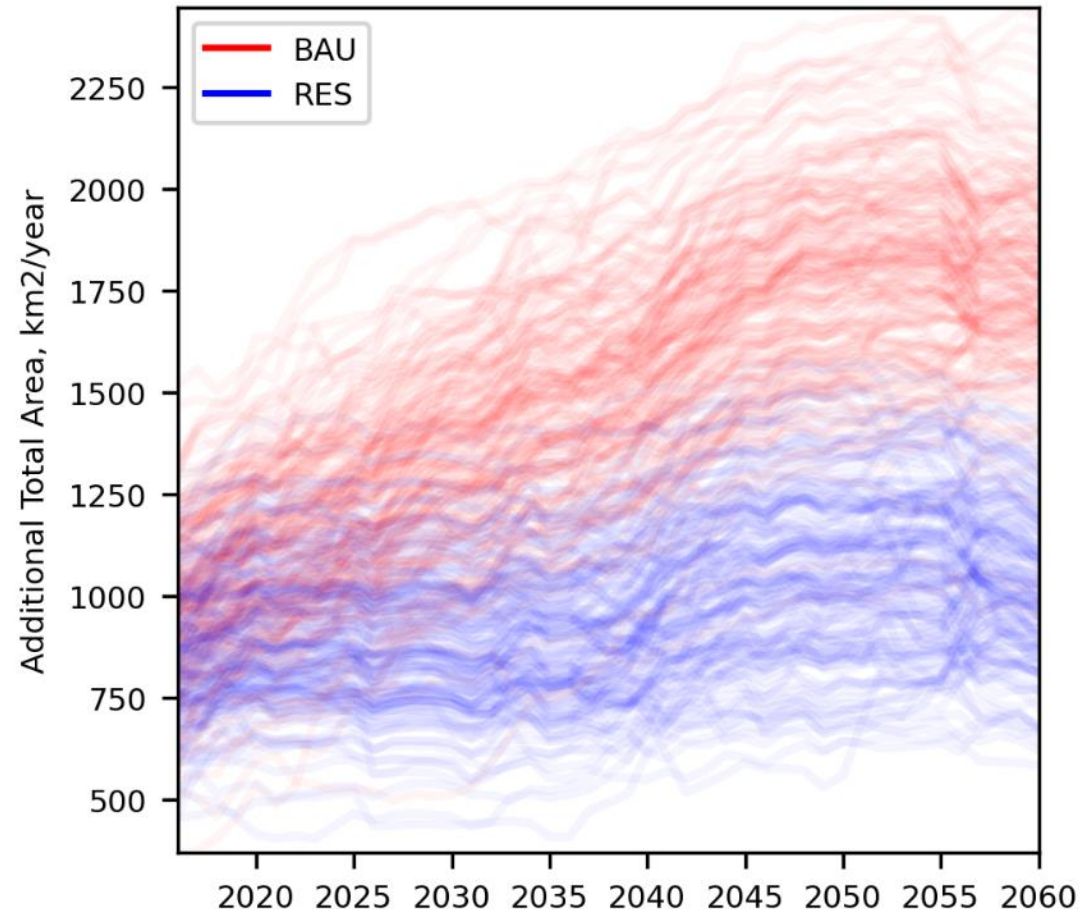


Waste Rock Dumps



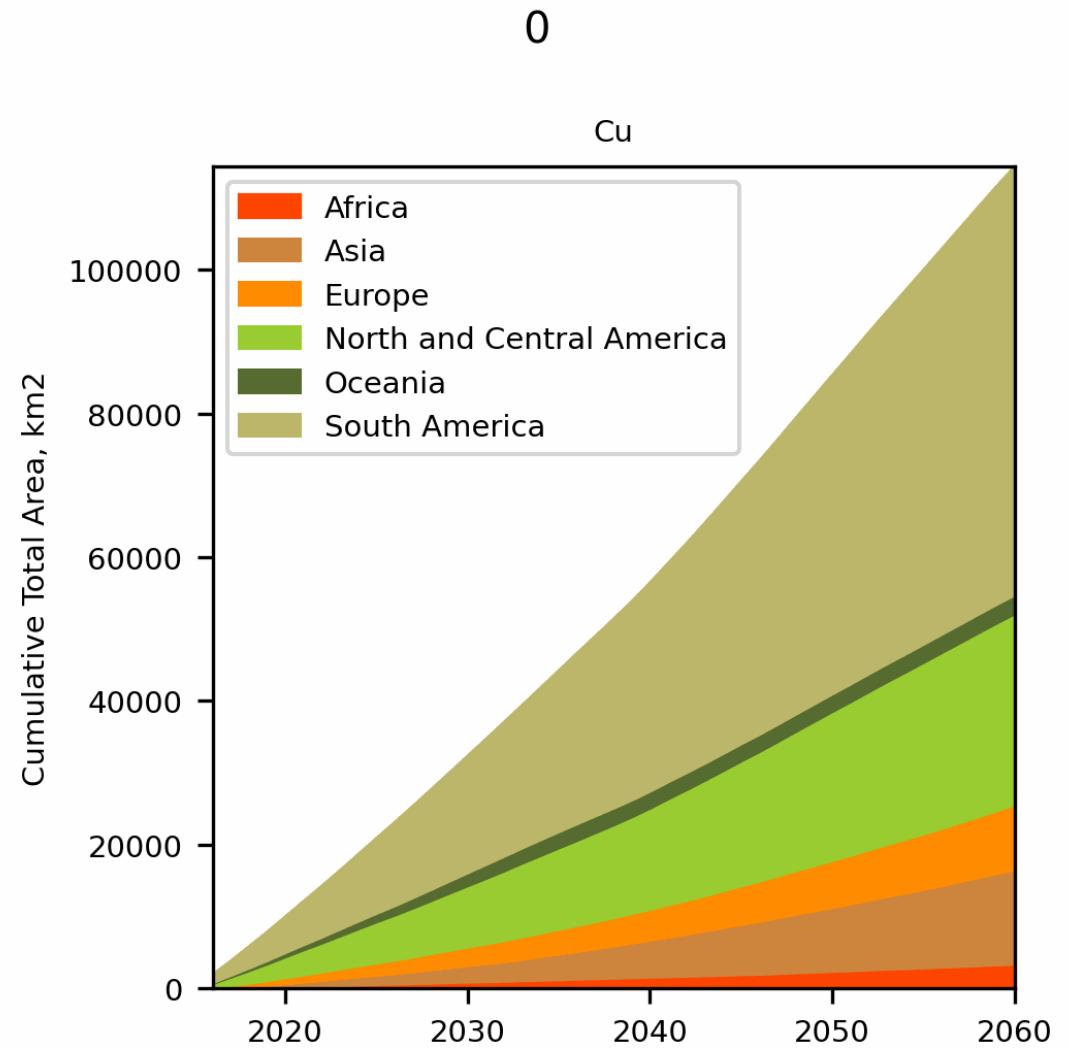
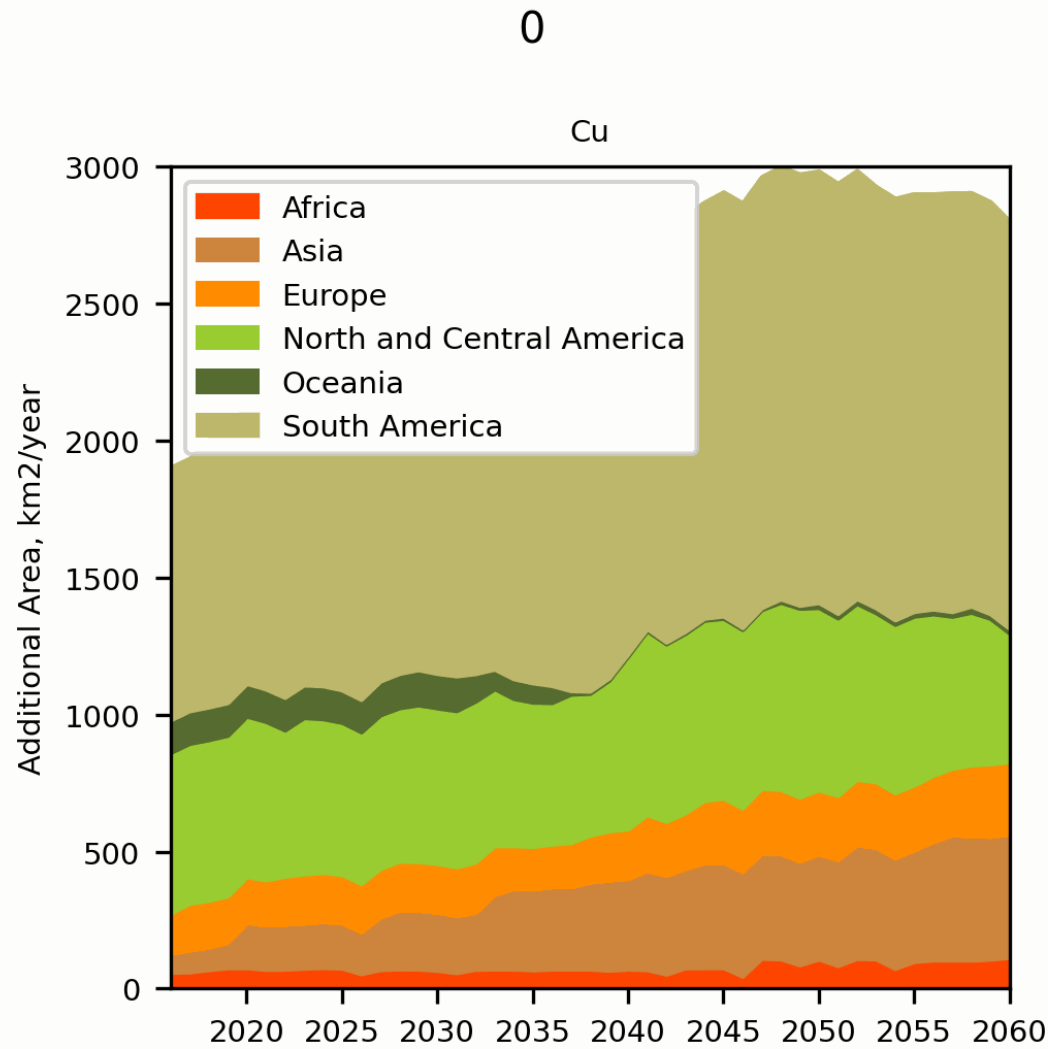
Unpublished and Preliminary. These Results Will Change.

Future land-transformations of mining are highly uncertain



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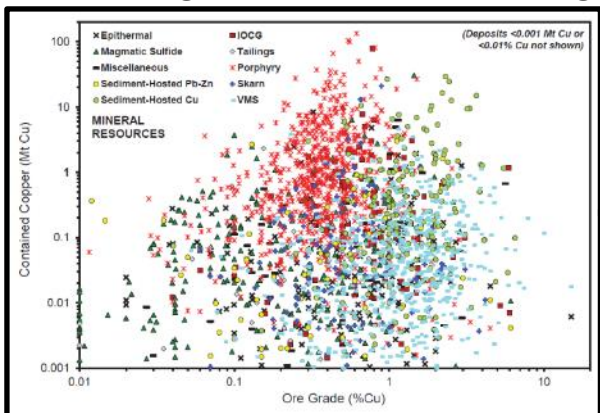
Including the regional mix of these changes and impacts



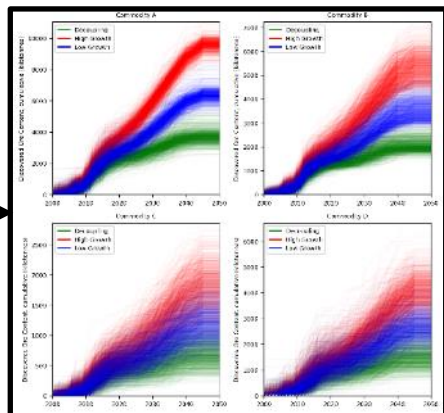
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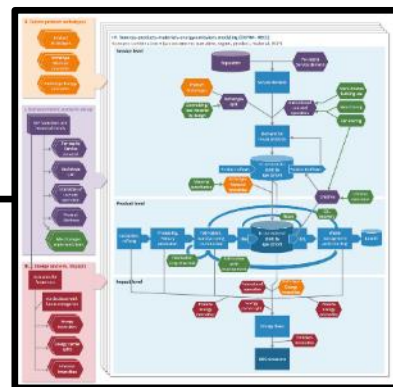
Geological Understanding



Primary Supply Scenarios



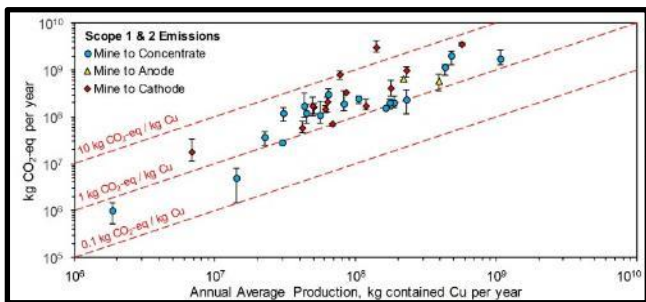
Socio-Economic Metabolism



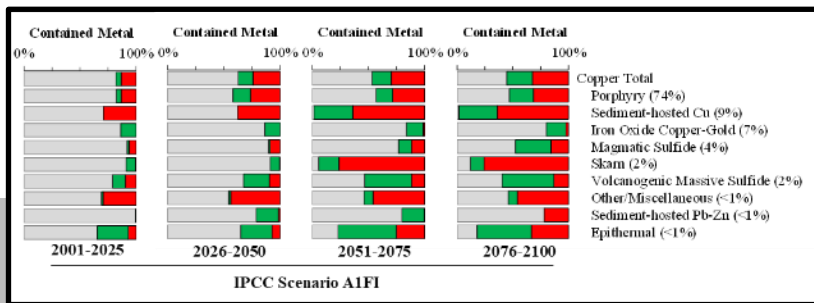
Technosphere

Environment

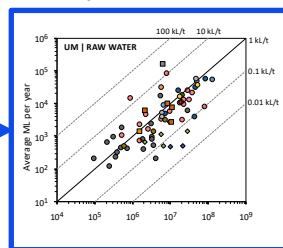
GHG



Climate Risk

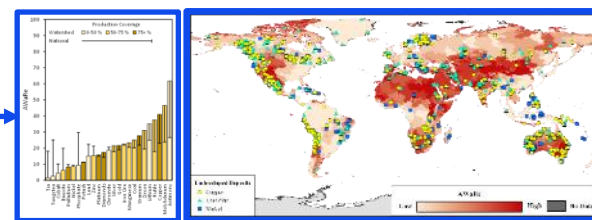


Life Cycle Inventory



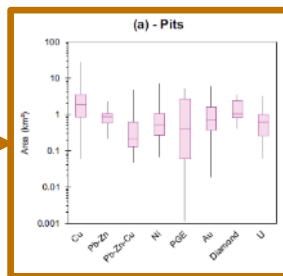
Water

Spatial Impact Assessment

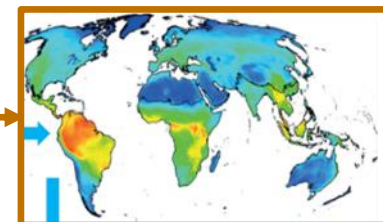


Scarcity

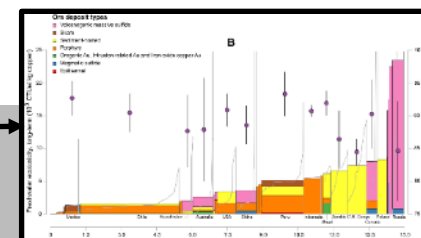
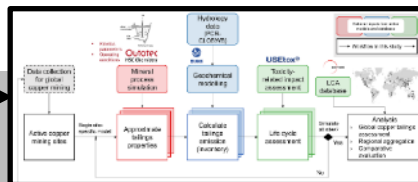
Land



Biodiversity



Emissions





COMPLETED	IN PROGRESS		
STAGE 1 PEMMSS Model Development	STAGE 2 Scenarios for Individual Base Metal Commodities <ul style="list-style-type: none">- Cu- Ni- Pb- Zn	STAGE 3 Integrated Scenarios for Co-Product Metal Commodities <ul style="list-style-type: none">- Cu-Ni-Co- Zn-Pb-In-Ge- Cu-Mo	STAGE 4 Adding Environmental Extensions <ul style="list-style-type: none">- Life Cycle Inventories- Greenhouse gas emissions- Water consumption- Land-use impacts

Scenario modelling of land-use and biodiversity impacts is being supported by an ARC Discovery Project

Ecologically responsible mining to fuel a green energy transition

University of Queensland – Laura Sonter, Martine Maron, Rick Valenta, Eve McDonald-Madden

University of Technology Sydney – Stephen Northey, Bernardo Mendonca

University of Kent – Joseph Bull

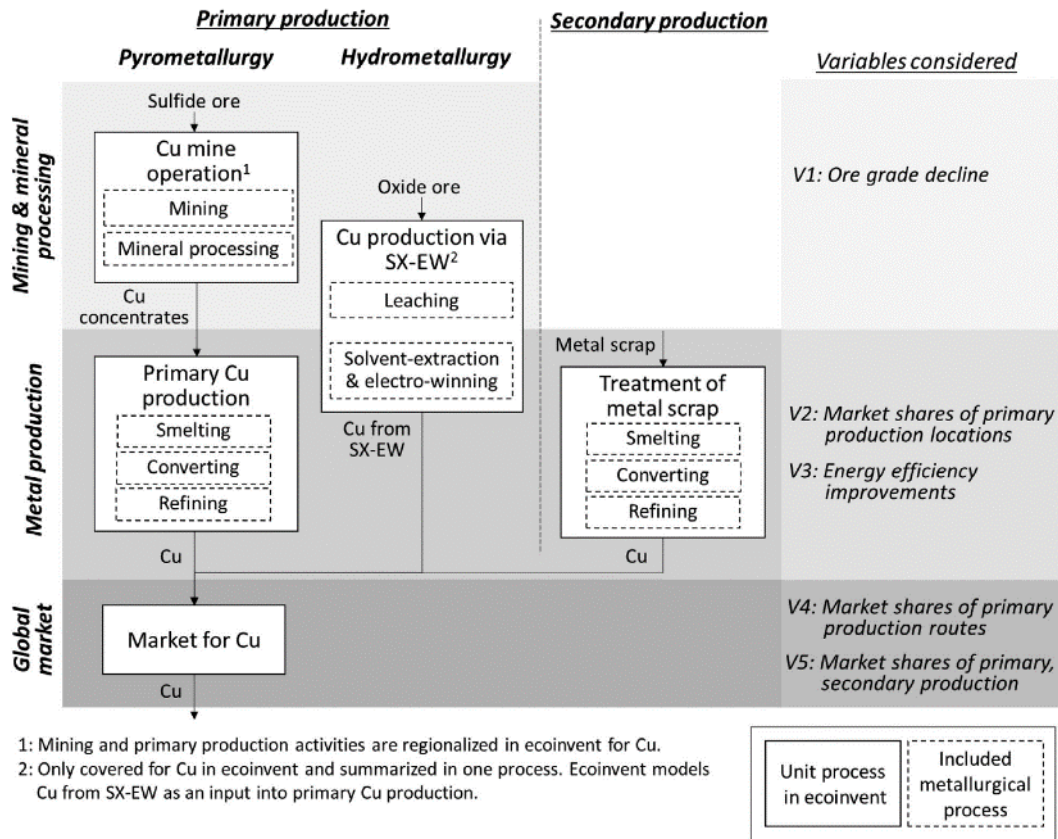
Vienna University of Economics and Business – Stefan Giljum

International Institute for Applied Systems Analysis – Piero Visconti



Moving beyond the foreground

Complementary approaches are linking background databases to integrated assessment models to incorporate energy sector and recursive changes overtime



Functional unit	Scenario	Climate change	Human toxicity	Metal depletion	Particulate matter formation	Photochemical oxidant formation
		Copper	PMS	-23	-23	-13
	SMS	-21	-26	-25	-25	-25
	MS	-41	-43	-36	-28	-43
	ES-BAU	-11	0	0	-2	-3
	ES-Mitigation	-50	0	0	-5	-5
	MS + ES-BAU	-47	-43	-36	-29	-44
	MS + ES-Mitigation	-69	-43	-36	-31	-45



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Mohan Yellishetty (Monash University)

Primary Exploration, Mining and Metal Supply Scenario (PEMMSS) model

GitHub - <https://github.com/sanorthey/pemmss>

Northey et al. (2023). Resources, Conservation and Recycling Advances 17: 200137.

<https://doi.org/10.1016/j.rcradv.2023.200137>