Yale

Life Cycle Assessment of **Copper Recycling** based on openLCA software

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Self-Introduction

Yuang Chen

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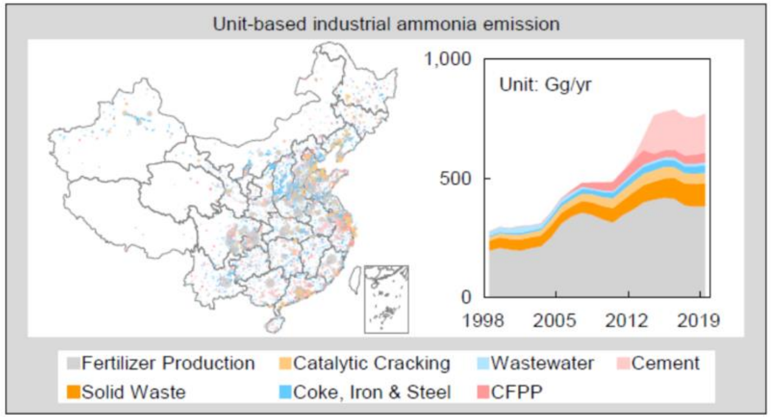
My current research interests lie in **regional pollutant transmission** (emission inventory and air modeling) and **LCA/IO**, which focuses on industrial processes like cement production.



Research Focus

Publications

1. Rapid increase in China's industrial ammonia emissions: evidence from unit-based mapping, ***Environmental Science & Technology***, in peer review

2. Impacts of provincial trade on atmospheric nitrogen deposition in China, ***Atmospheric Chemistry and Physics***, in peer review

Personal Life

Student Union

Sampling

Cats!!!

Introduction — 1. Why Copper?

- **Large Demand, Wide Application**
  - Copper is everywhere in our daily lives.
  - Copper demand has more than doubled in the past 40 years, reaching 23 Tg in 2019 (data from IWCC)
- **The Role in a “Greener” Future**
  - Application in renewable energy systems, e.g., low carbon technologies, .
  - Cleaner infrastructure, e.g., building materials and transportation.

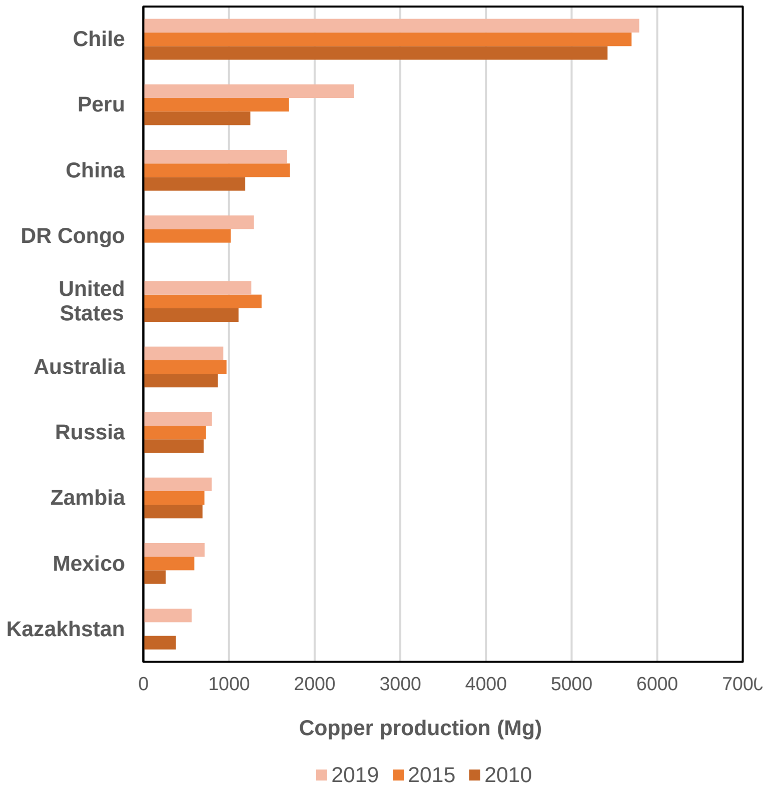


Figure 1. Ten leading countries in copper production in 2019 (data from USGS)

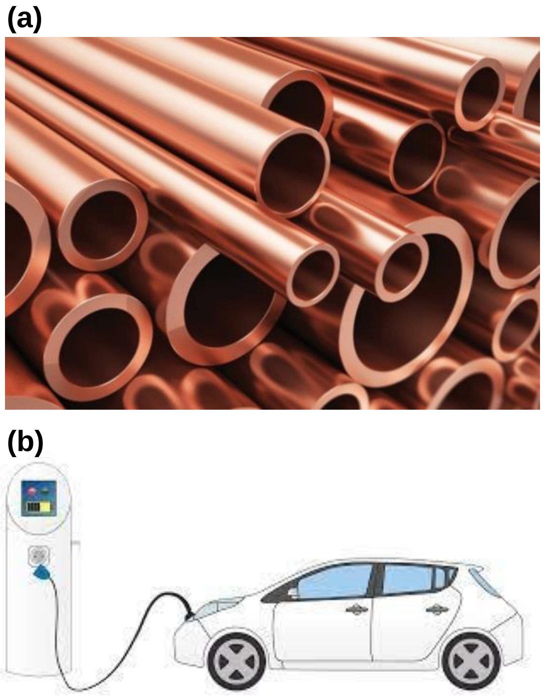


Figure 2. Applications of copper, including **a)** copper tube and **b)** electric vehicle (ELV).

Introduction — 2. Why Recycling?

- **Abundant Waste, Low Efficiency**
  - About 95% of used copper is “potentially recyclable”.
  - Global recycling rate 30% – 40%
- **Environmental-friendly**
  - Copper ore grades are declining.
  - Less CO_2, less energy

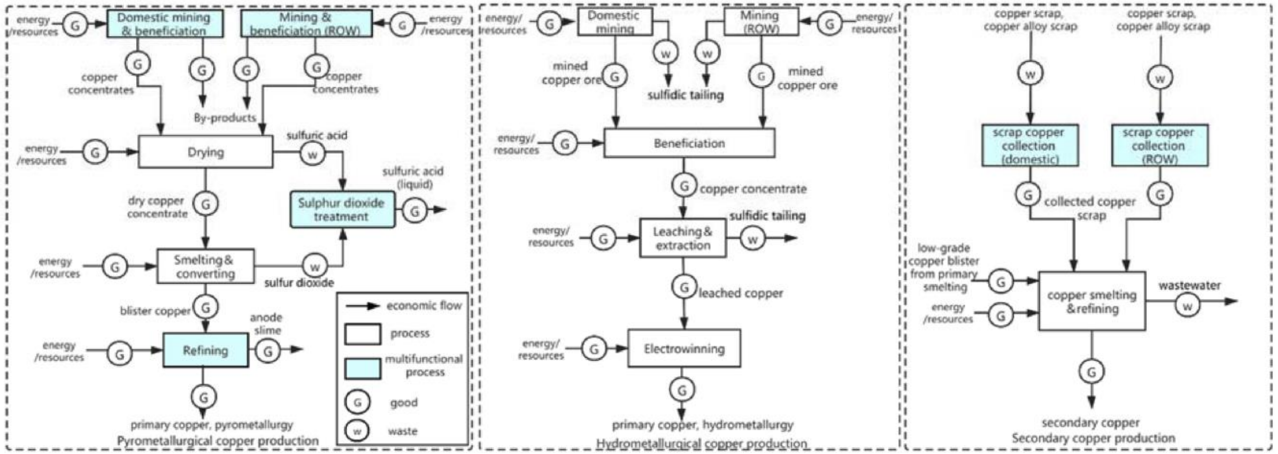


Figure 3. Chinese copper production system: pyrometallurgical, hydrometallurgical and secondary copper production. (modified based on Dong et al.)

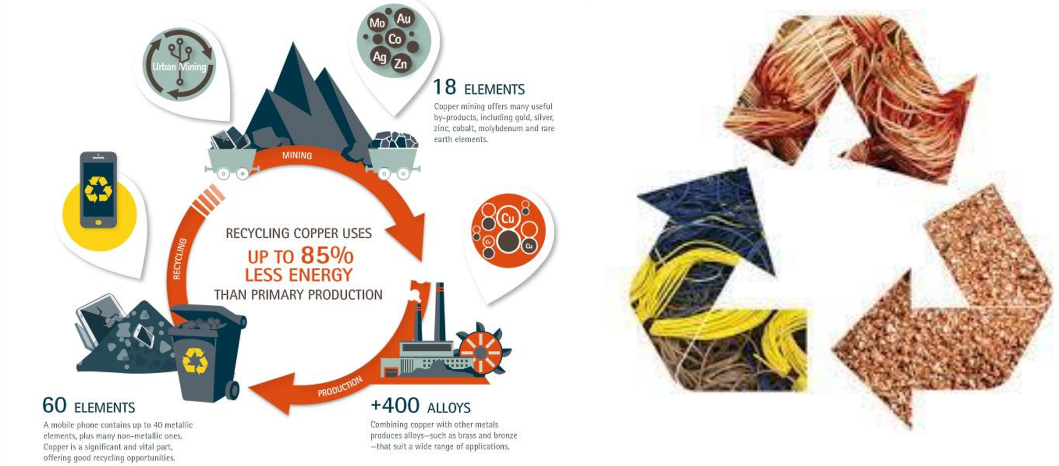


Figure 4. Europe’s demand for copper is increasingly met by recycling. (Graph from European Copper Institute)

Introduction — 3.openLCA

- **Open Source** http://www.openlca.org/
  - Various standard databases available
  - Active Online forums
  - FREE :)
- **Functional**
  - Clear and transparent systems
  - Multi-regional, multi-sectoral

Model and assess any product of its life cycle, from the mineral extraction to its production, use and disposal.
——Introduction to openLCA by itself.

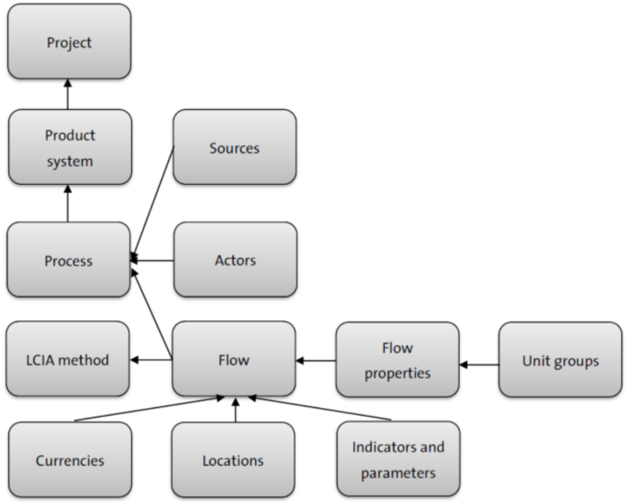


Figure 5. Elements in openLCA

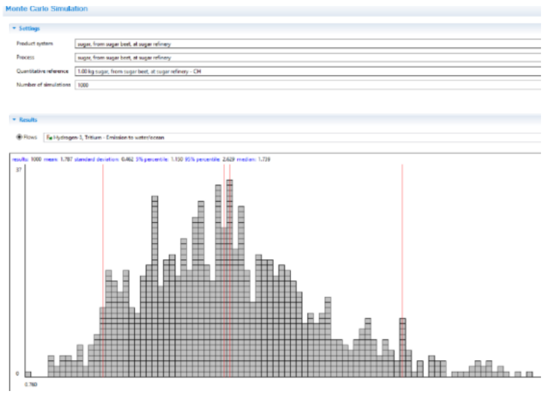
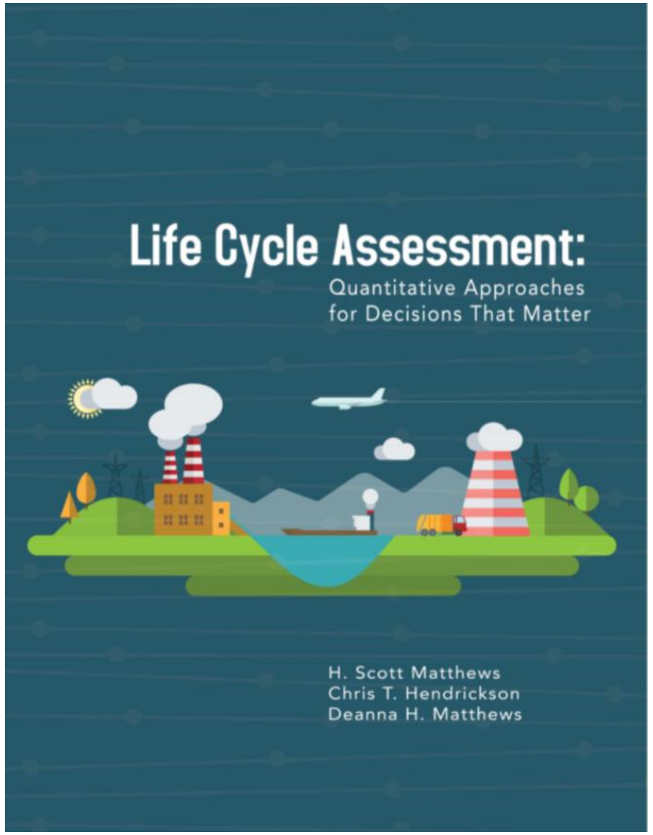


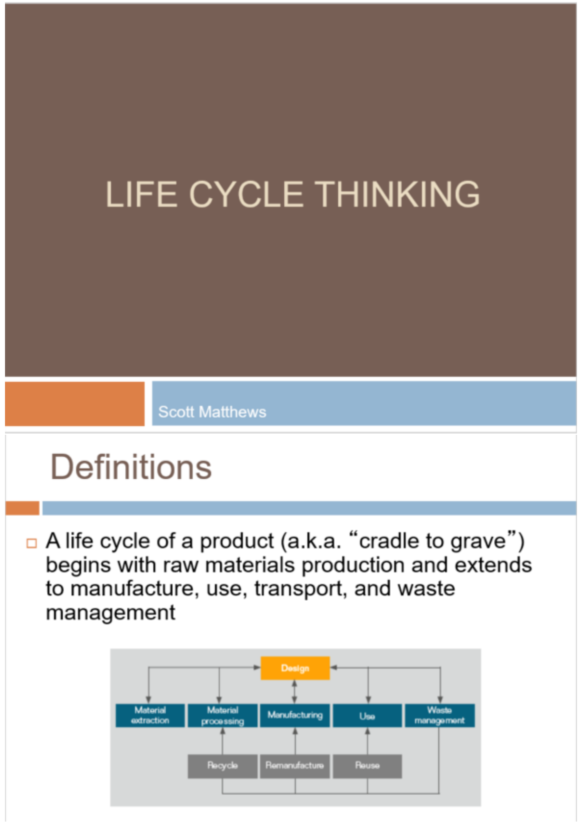
Figure 6. Monte Carlo simulations in openLCA

Methods and Data — Learning LCA

Anyone interested, I can send you the Google Drive link.



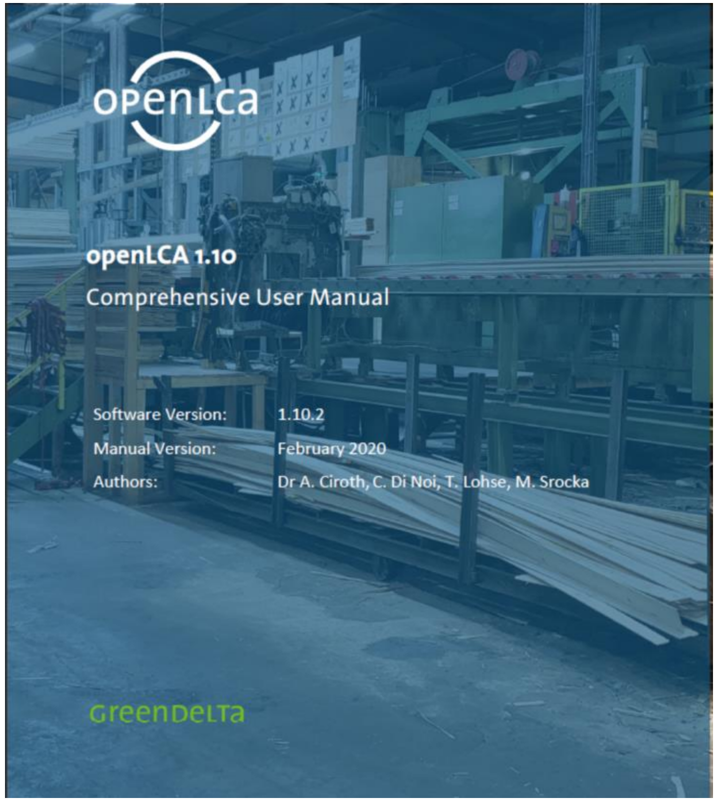
LCA textbook



LCA lecture notes

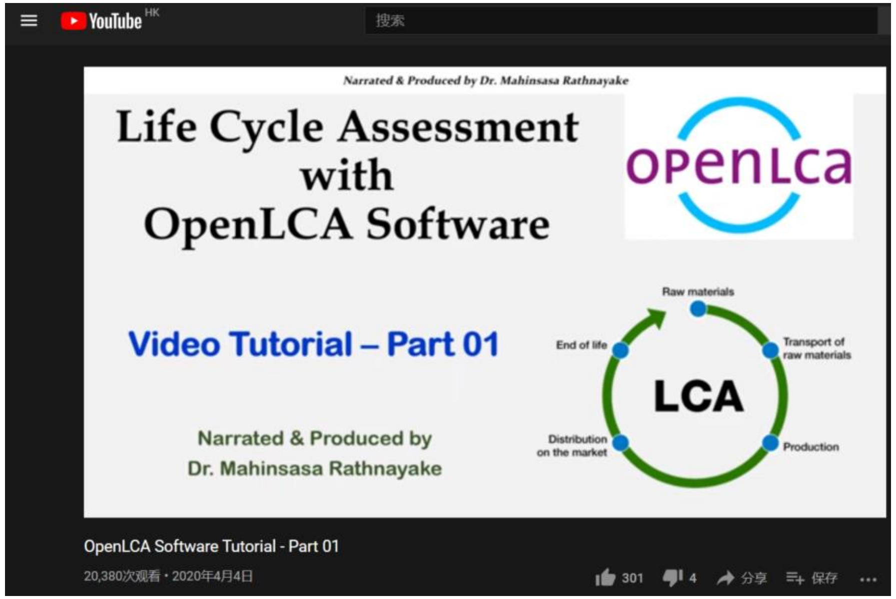
Notes for literature and books

Methods and Data — Learning openLCA

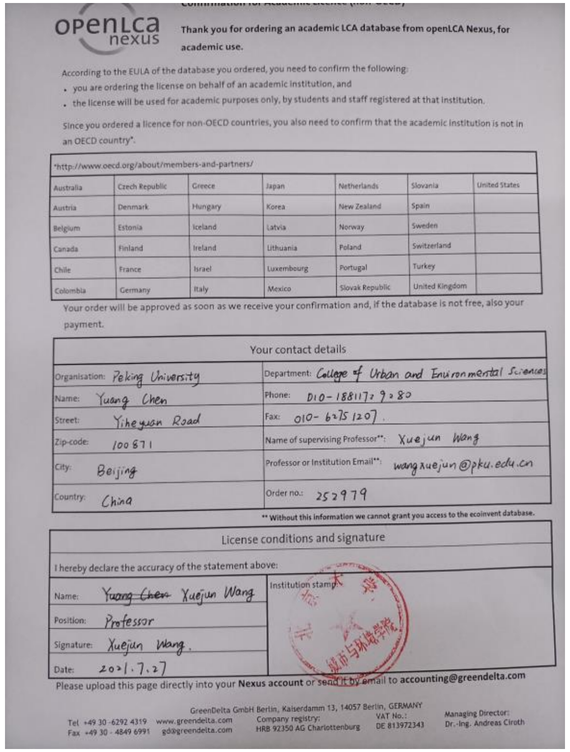


User Manual for openLCA
(129 pages)

Take-away here: Practice
(and better computer :)



YouTube tutorials
(with German accent)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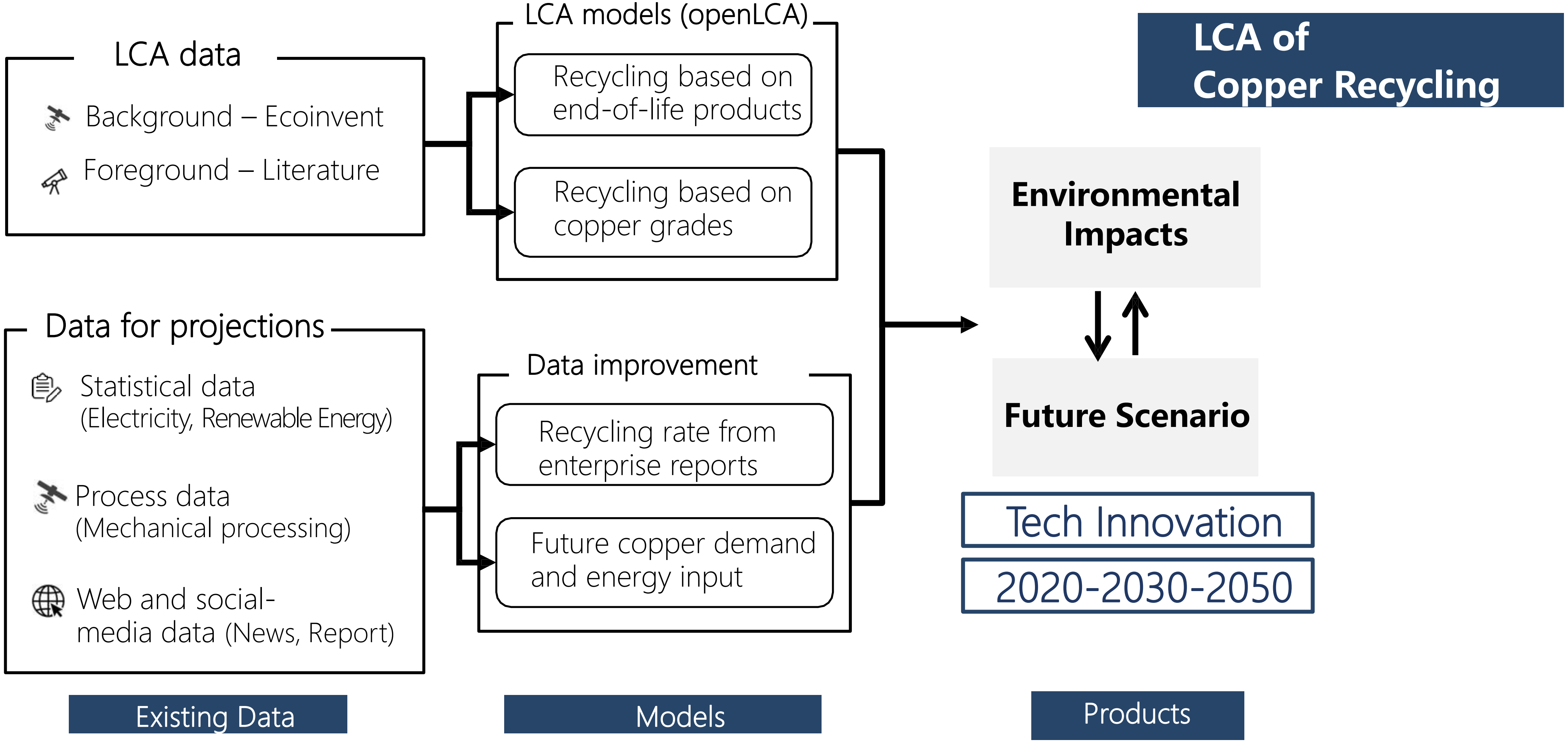
Application for free databases
(which costs 5 days)

Methods and Data



Methods and Data

Table 1. Processes for copper recycling from cables, electric and electronic equipment waste (WEEE), end-of-life vehicles (ELV), construction & demolition waste (C&D) and municipal solid waste (MSW).

Processes	Cable	WEEE	MSW	C&D	ELV
Collection		√			√
Rebuilding				√	
Transport 1	√	√	√	√	√
Mechanical Processing	√	√	√	√	√
Transport 2	√	√	√	√	√
Smelting/ Reducing		√	√		√
Converting	√	√	√	√	√
Electrorefining	√	√	√	√	√

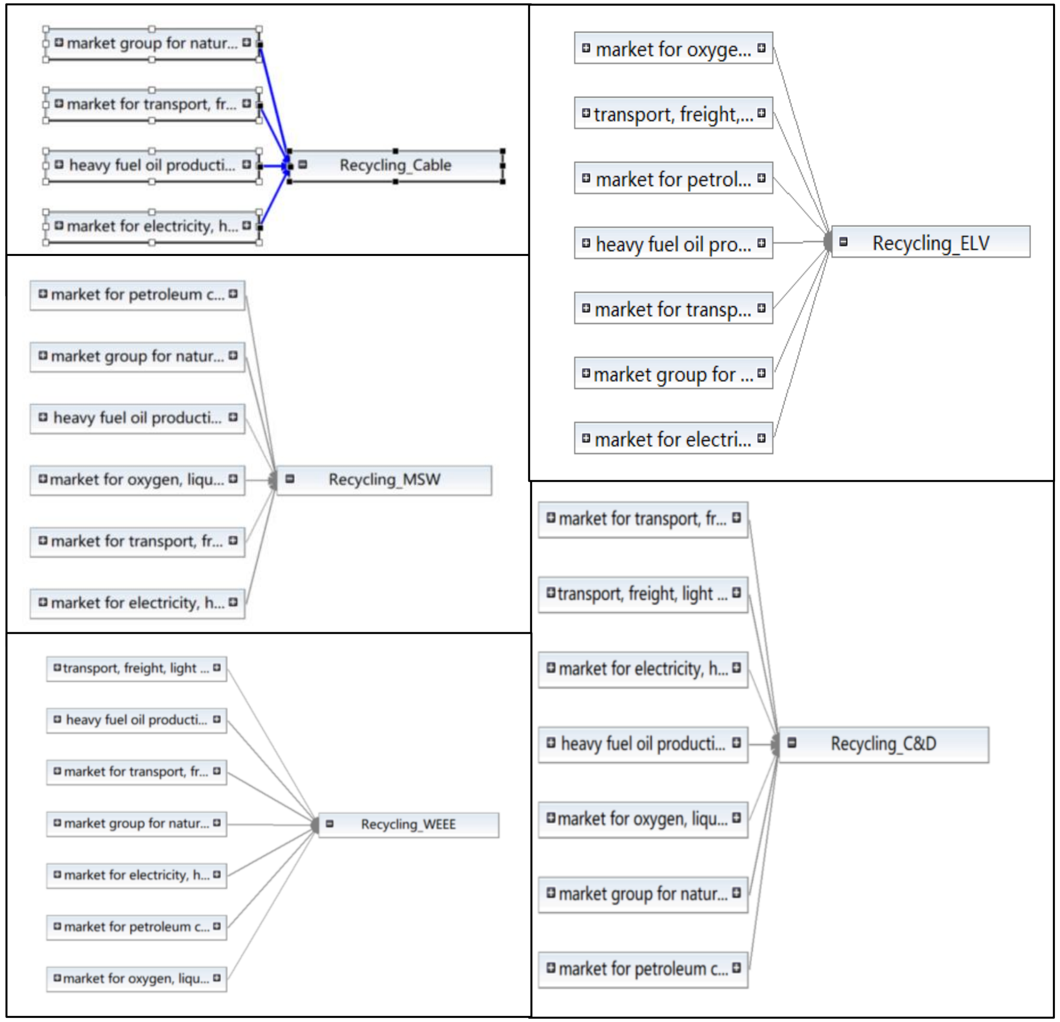


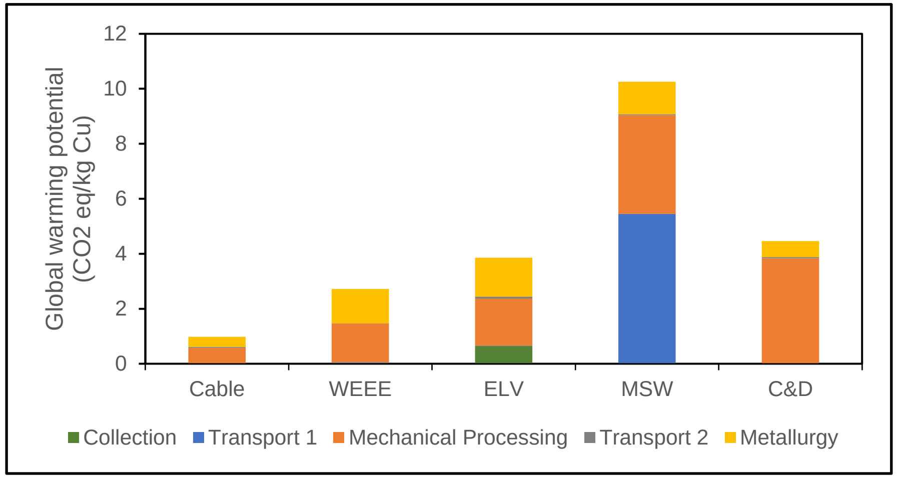
Figure 7. Recycling models for ELV, Cable, C&D, WEEE and MSW. (screenshots from openLCA)

Results

In regard of global warming potential (GWP) and cumulative energy demand (CED):

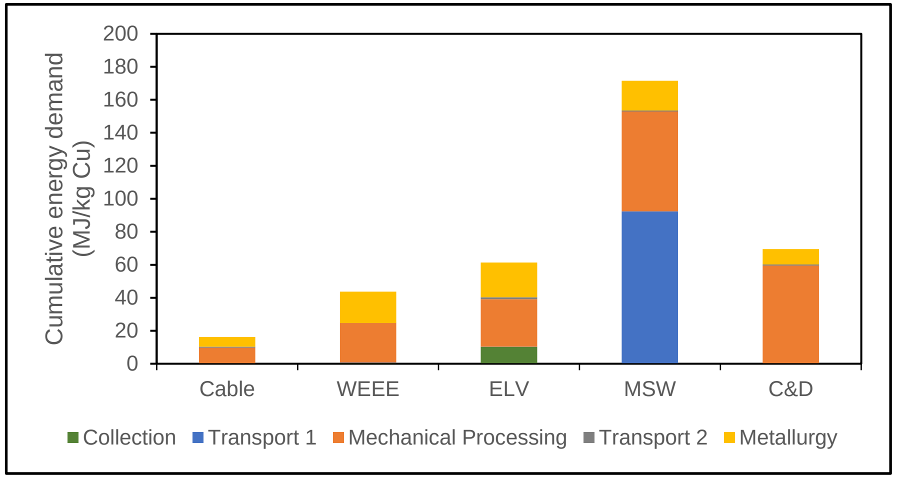
- ➢ Recycling from municipal solid waste (MSW) is the most CO2-extensive and energy-extensive.
- ➢ Mechanical processing and metallurgy are usually the largest contributors to CO2 emissions.

(All input data from Schäfer et al.)



Processes	Cable	WEEE	ELV	MSW	C&D
Collection	0.00298	0.0344	0.66	0	0
Transport 1	0.00981	0.0156	0.005	5.45	0.000871
Mechanical Processing	0.569	1.42	1.71	3.59	3.84
Transport 2	0.032	0.00245	0.0695	0.0357	0.041
Metallurgy	0.367	1.25	1.41	1.18	0.577
Sum	0.98	2.72	3.85	10.3	4.45

Figure 8. Global warming potential (GWP) results from the copper recycling system model (CO2 eq/kg Cu). Highlight represents the type with the most GWP, all processes with >1 CO2 eq/kg Cu GWP are marked red.



Processes	Cable	WEEE	ELV	MSW	C&D
Collection	0.0465	0.536	10.3	0	0
Transport 1	0.166	0.264	0.0847	92.4	0.0148
Mechanical Processing	9.58	23.9	28.8	60.5	59.5
Transport 2	0.543	0.0416	1.18	0.605	0.695
Metallurgy	5.98	19	21	18	9.33
Sum	16.3	43.8	61.3	171	69.5

Figure 9. Cumulative energy demand (CED) results from the copper recycling system model (MJ/kg Cu). Highlight represents the type with the most CED, all processes with >20 MJ/kg Cu CED are marked red.

Next Steps

- Collect and clean data from statistical yearbooks, which include energy consumption, electricity production, copper consumption & production, and trade data.
- Reach out to companies with cutting-edge copper recycling technologies, to acquire/ purchase detailed parameters like recycling efficiency.
- Simulate future scenarios regarding copper recycling rate, copper production from recycling and the related energy and environmental influence.

References

1. International Copper Study Group. *The World Copper Factbook 2018*; Lisbon, Portugal, **2018**.

2. Copper Development Association. *2013 Technical Report—the U.S. Copper-Base Scrap Industry and Its By-Products*, **2013**, https://www.copper.org/publications/pub_list/pdf/scrap_report.pdf

3. Elshkaki, A.; Graedel, T. E.; Ciacci, L.; Reck, B. K. Copper Demand, Supply, and Associated Energy Use to 2050. *Global Environ. Change* **2016**, *39*, 305– 315, DOI: 10.1016/j.gloenvcha.2016.06.006

4. Samuelsson, C., & Björkman, B. Copper recycling. In *Handbook of recycling* (pp. 85-94). Elsevier. **2014**

5. Ciacci, L.; Reck, B. K.; Nassar, N. T.; Graedel, T. E. Lost by Design. *Environ. Sci. Technol.* **2015**, *49*, 9443– 9451, DOI: 10.1021/es505515z.

6. Hertwich, E. Increased carbon footprint of materials production driven by rise in investments. *Nat. Geosci.* **2021**, *14*, 151– 155, DOI: 10.1038/s41561-021-00690-8

7. Dong, D.; van Oers, L.; Tukker, A.; van der Voet, E. Assessing the Future Environmental Impacts of Copper Production in China: Implications of the Energy Transition. *J. Clean. Prod.* **2020**, *274*, 122825, DOI: 10.1016/j.jclepro.2020.122825

8. Schäfer, P., & Schmidt, M. Discrete-point analysis of the energy demand of primary versus secondary metal production. *Environ. Sci. Technol.* **2019**, *54*(1), 507-516.

Appreciation

- Thanks for all your attention!
- Thanks to Prof. Zimmerman for this great chance!
- Thanks to Zimmer people for your suggestions and support!
- Especially many THANKS to Tong for the neat and clear learning materials, weekly online meetings (hope we can meet in person one day), valuable time for discussions and the most important, showing me what research is like.

- Feel free to ask questions!