Future Material Demand for Global Silicon-based Photovoltaic Systems

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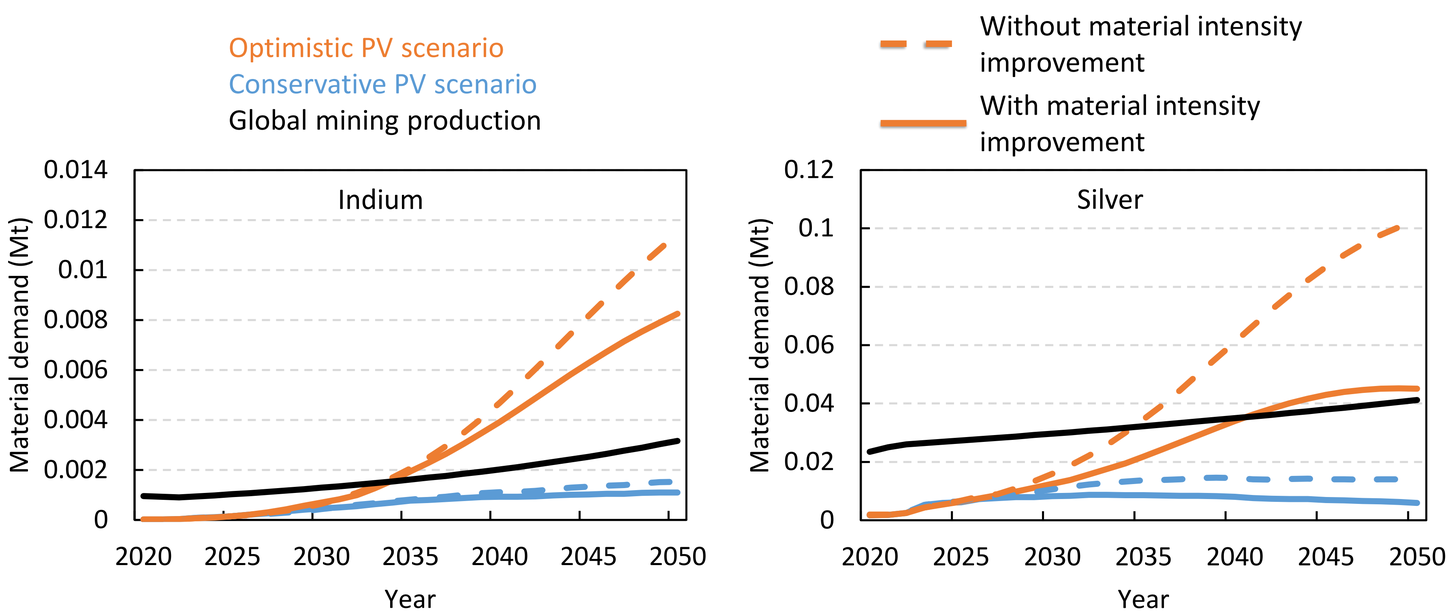
Research objectives

- Project future global **PV deployment scenarios,** based on the growth trend from 1 GWp in 2000 to 100 GWp in 2012 and 1000 GWp in 2022 [1].
- Develop **dynamic material flow analysis model** [2] for global PV systems, considering **PV technology, efficiency**, **lifespan,** etc.
- **Estimate and compare material demand** under different PV deployment scenarios and assess whether existing production capacities and reserves can meet future demand.
- Explore options to **reduce material demand in PV systems.**

Dynamic material flow analysis model

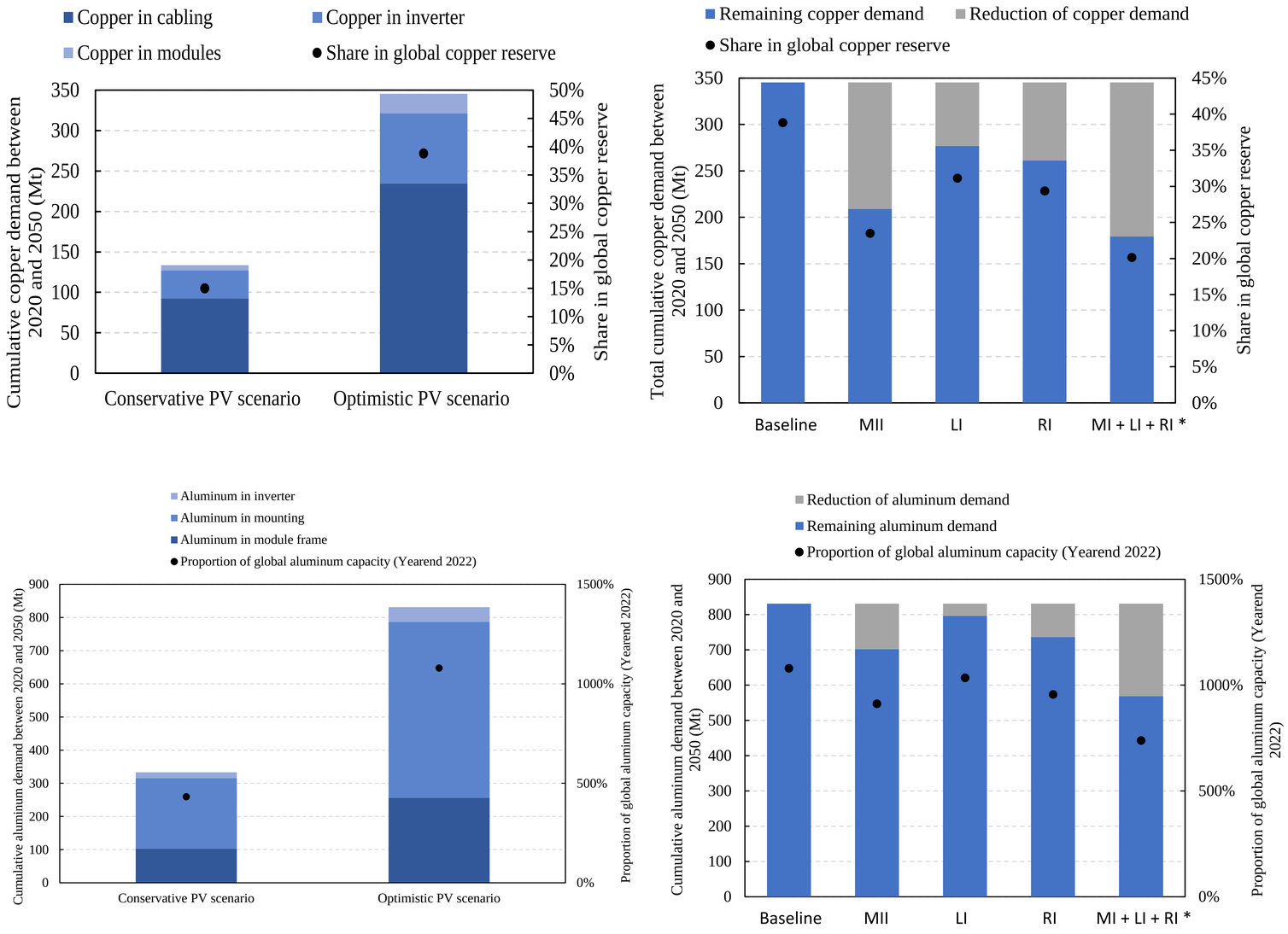
- **PV deployment scenarios**: Conservative PV scenario (15.5 TWp by 2050) and Optimistic PV scenario (63.4 TWp by 2050).
- **PV technologies and module efficiency**: assume an annual increase of 0.5 % and reach efficiency limitations of 20 % for Al-BSF, 24 % for PERC, 26 % for both TOPCon and SHJ, 26.5 % for IBC, and 39 % for perovskite-silicon tandem modules [2].
- **Market share, lifetime, and material compositions for different PV system components: module, inverter, cabling, and mounting structure.**

Critical materials in PV modules: indium and silver



- With increasing **PV module efficiency** and decreasing **material mass per module area**, **material intensity** will improve.
- **Material intensity improvement could reduce indium and silver demand by 28 % and 56 %,** respectively, by 2050 in optimistic PV scenario.
- **Indium** used in PV sector will **exceed global production after 2030.**
- **Silver will surpass global production after 2030, but this will be delayed until after 2040 if material intensity improves.**

Critical materials in PV balance of system: copper and aluminum



- **Cabling accounts for most copper demand** [3], and **mounting is the largest driver of aluminum demand** [4].
- **Further material intensity improvement** in balance of system components could be the **most effective way** to reduce copper and aluminum demand.
- **Combined options could cut cumulative material demand by 48 % for copper and 32 % for aluminum between 2020 and 2050.**
- Even with combined reduction options, copper demand could reach 20 % of global reserves, and aluminum demand could be 7.4 times global yearend 2022 capacity.

* *MII = material intensity improvement*
LI = lifespan improvement
RI = recycling improvement
MI + LI + RI = material intensity improvement + lifespan improvement + recycling improvement

Conclusions

- **Dynamic material flow analysis model is developed for PV systems.**
- **Indium and silver could exceed global production.**
- **Combining various options may be necessary to reduce the demand for copper and aluminum.**

[1] Adapted from IRENA RENEWABLE CAPACITY STATISTICS (2023)
[2] C. Xu et al., *Resour. Conserv. Recycl.*, **210**, 107824 (2024)
[3] M. Aliang, Master thesis (2024)
[4] P. Xie, Master thesis (2024)

Acknowledgement: *This work is supported by Flagship project "Materials for circular renewable energy technologies" at TU Delft.*