Abstract

Human well-being and economic prosperity are intertwined with the material and energetic exchange between the lithosphere and the anthroposphere through socioeconomic metabolism (SEM). These increasingly intensive material transitions form society's biophysical basis ensuring essential services for citizens, but they also aggravate environmental deterioration threatening sustainability. Addressing these consequences requires global absolute reductions in resource consumption. Material efficiency has been underlined in SEM research and political agendas, as its goal is to moderate resource growth by generating more outputs with less materials while safeguarding prosperity. Understanding SEM patterns plays the prerequisite to deepen decoupling resource use from the economic activity, and calls for standardized and exhaustive investigations on historical pathways of material flows and stocks, and their interactions with economic outputs from a life cycle perspective.

This thesis targets to unearth SEM patterns by integrating different SEM approaches and decoupling analyses across global and national scales to foster sustainable transitions towards material efficient societies. Firstly, based on economy-wide material flow analysis (ew-MFA) principles and the EXIOBASE multi-regional input-output (MRIO) database, the international inequality and efficiency pathways of material footprints (MF) were deconstructed by tracking how different resources were consumed by final demands through end uses in 43 individual countries and the rest of world (RoW) during 1995-2013. The results identified global convergence and regional disparities of MF use patterns, the distributions and drivers of MF inequality, and highlighted the high sensitivity of fixed capital, dominated by construction and manufacturing activities with massive use of metals and minerals, to gross domestic production (GDP). These patterns support targeted implementations across scopes to facilitate resource efficiency and equality.

This thesis then conducted a global, standardized, and long-term decoupling analysis for three basic metals (iron, copper, and aluminum) from a life cycle perspective, by taking flow- and stock-based material indicators. The trajectories of metal stocks, global convergence and national diversity of efficiency transitions in terms of metals, life cycles, and economic growth, were investigated. The results open runways of harmonized metal-economy relations and inspire metal demand solutions by step changes on metal productivity regarding metal mining, transformations, and uses across different scales.

Finally, an integrated framework combining ew-MFA and dynamic material flow analysis was applied to four eastern European transition countries (Bulgaria, Croatia, Poland, and Romania) to quantify their national stocks, covering 16 types of stock building materials during 1990-2019. These stock dynamics were incorporated into circularity assessment and decoupling analysis throughout all life cycle stages of the entire socioeconomic system. These insights benchmark and inform on resource efficiency and circularity trajectories in transitioning economies.

The SEM networks are complex and necessitate reliable data basis when zooming in to specific geographical and material scopes. Recommendations for further research include data acquisition, model optimization, and perspectives to inspire more sophisticated research design supporting sustainability ambitions.