The stock-flow-service nexus approach:
Conceptual advances and first empirical examples in tackling systemic interactions between the SDGs

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Introduction: Socio-metabolic research

Progress towards the SDGs requires far-reaching changes in the patterns of **societies' use of biophysical resources** such as materials, energy or land. Current **socio-metabolic research** (SMR) traces **flows of energy, materials or substances** to capture resource use: input of raw materials or energy, their fate in production and consumption, and the discharge of wastes and emissions. SMR is useful to analyse synergies or tradeoffs between specific SDGs (Haberl *et al.*, 2019).

SMR has been successful in **bridging social and natural sciences** in inter- and transdisciplinary analyses of **society-nature interactions**. It has yielded insights into eco-efficiency and long-term drivers of resource use. However SMR has not yet fully incorporated **material stocks**, nor the different **societal services these stocks provide** (Haberl *et al.*, 2017).

The stock-flow-service nexus

We introduce a new approach for integrating SMR with social science research on societal development patterns and trajectories towards the SDGs. We argue for a material stock–flow–service nexus approach (Fig 1) focused on the analysis of **interrelations between material and energy flows, socioeconomic material stocks and the services** provided by specific stock/flow combinations.

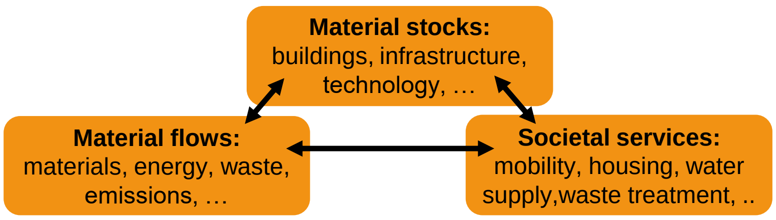

Figure 1. *The stock-flow-service nexus (Haberl et al., 2017)*

Material stocks represent the **physical infrastructure for production and consumption** (Weisz et al., 2015), and hence the material basis of societal wellbeing. They play a central role in deriving **services required for the functioning of society** such as **shelter, mobility and communication** from material and energy flows. Socioeconomic **material and energy flows** are required to **create stocks** such as buildings, infrastructures, machinery etc. in the first place, to maintain or improve them, to keep them in a usable state and to serve **dissipative uses** required to **provide services from stocks**. Configuration and quantity of stocks determine **future flows of waste and emissions** and **circular economy potentials** and are key to **closing material loops**. Understanding in-use stocks is therefore essential for sustainable development.

Trends in global material extraction and in-use stocks

From 1900 to 2010, global material extraction grew 10-fold. The share of stock-building materials in total extraction rose from 18 to 55% and stocks multiplied by a factor of 22 (Fig 2).

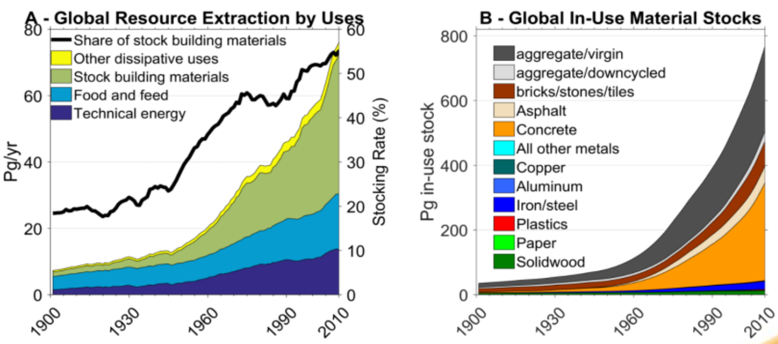

Figure 2. *Development of global material and energy use and material stocks, from 1900 to 2010. (A) Annual global extraction of resources by use and share of stock-building materials in total extraction (right axis). (B) Development of global material stocks by 12 main material groups. (Krausmann et al., 2017).*

The pivotal role of material stocks for resource use, emissions and waste – a systems perspective

Recent advances in socio-metabolic research yielded the **first ever thermodynamically consistent representation** of global resource use, its major uses and the role of material stocks, humans & livestock in transforming resource flows into waste and emissions (Fig 3). This provides a **comprehensive and systematic knowledge base for overcoming siloed approaches to sustainability and the SDGs**.

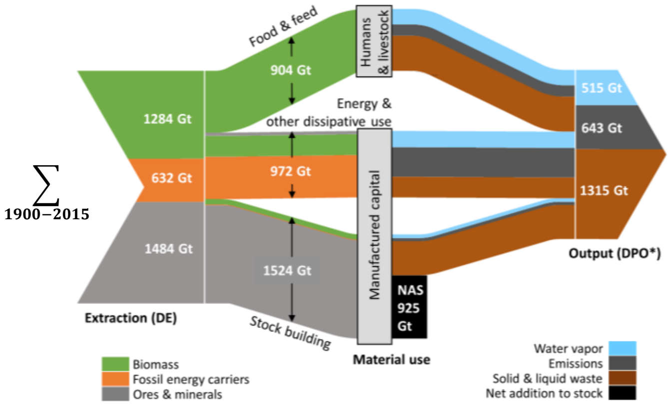

Figure 3. A sankey diagram of the cumulative flow of materials through the global economy from extraction to use and output of wastes and emission from 1900 to 2015. Net additions to stock (NAS) of humans and livestock (1 Gt) are not visible. All flows are proportional to their size (Krausmann *et al.*, 2018).

The physical basis of social well-being: energy & stocks

Analyses of the **interrelations between social well-being and material stocks and flows** (Fig 4) suggest that minimum levels of stocks and flows exist below which raising wellbeing requires increases in per-capita stocks and flows. However, above ~50 tons of concrete and ~100 GJ/yr of primary energy per capita, raising social metabolism does not seem to increase well-being.

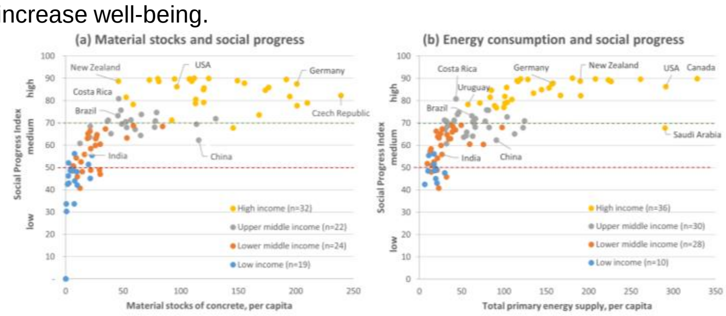

Figure 4. *Relation between social progress as measured by the SPI and the stocks of concrete (a) and flows primary energy supply (b) in >100 countries. The SPI is an index of social well-being considering nutrition, shelter, water, sanitation, safety, access to knowledge, human rights, environ-mental quality etc., but no monetary indicators such as GDP (Haberl et al., 2019)*

Conclusion

Research into the **stock-flow service nexus** has only recently begun, but preliminary results suggest that it represents a **useful framework to support policies aiming to achieve the SDGs** until 2030, and an even wider-reaching sustainability transformation thereafter.

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