The stock-flow-service nexus:
Implications for socio-ecological transformations towards sustainability and circularity

Helmut Haberl

Thanks to D. Wiedenhofer, F. Krausmann, C. Görg *et al.*

European Forum Alpbach, Technology Symposium
24 August 2018

Universität für Bodenkultur Wien
Department für Wirtschafts- und Sozialwissenschaften
Institute of Social Ecology

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 741950).

Challenges for a socioecological transformation toward sustainability

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

- **Socioeconomic**
  - eradicating poverty and hunger, reducing inequality
  - establishing good education, sanitation, housing, health-care, etc.
- **Ecological**
  - zero (or negative) carbon emissions in the next decades,
  - coping with limitations of exhaustible mineral resources such as metals or phosphorous,
  - viable balance between the use of renewable resources and the maintenance of healthy, carbon-rich and biodiverse ecosystems

→ **Fundamental transformation of resource use (material and energy flows, land use) are needed, which requires far-reaching changes in society, culture, and the economy**

FWF Der Wissenschaftsfonds.

European Research Council
Established by the European Commission

Socioecological transformation: multiple crises require systemic solutions

The TWI 2050 approach

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

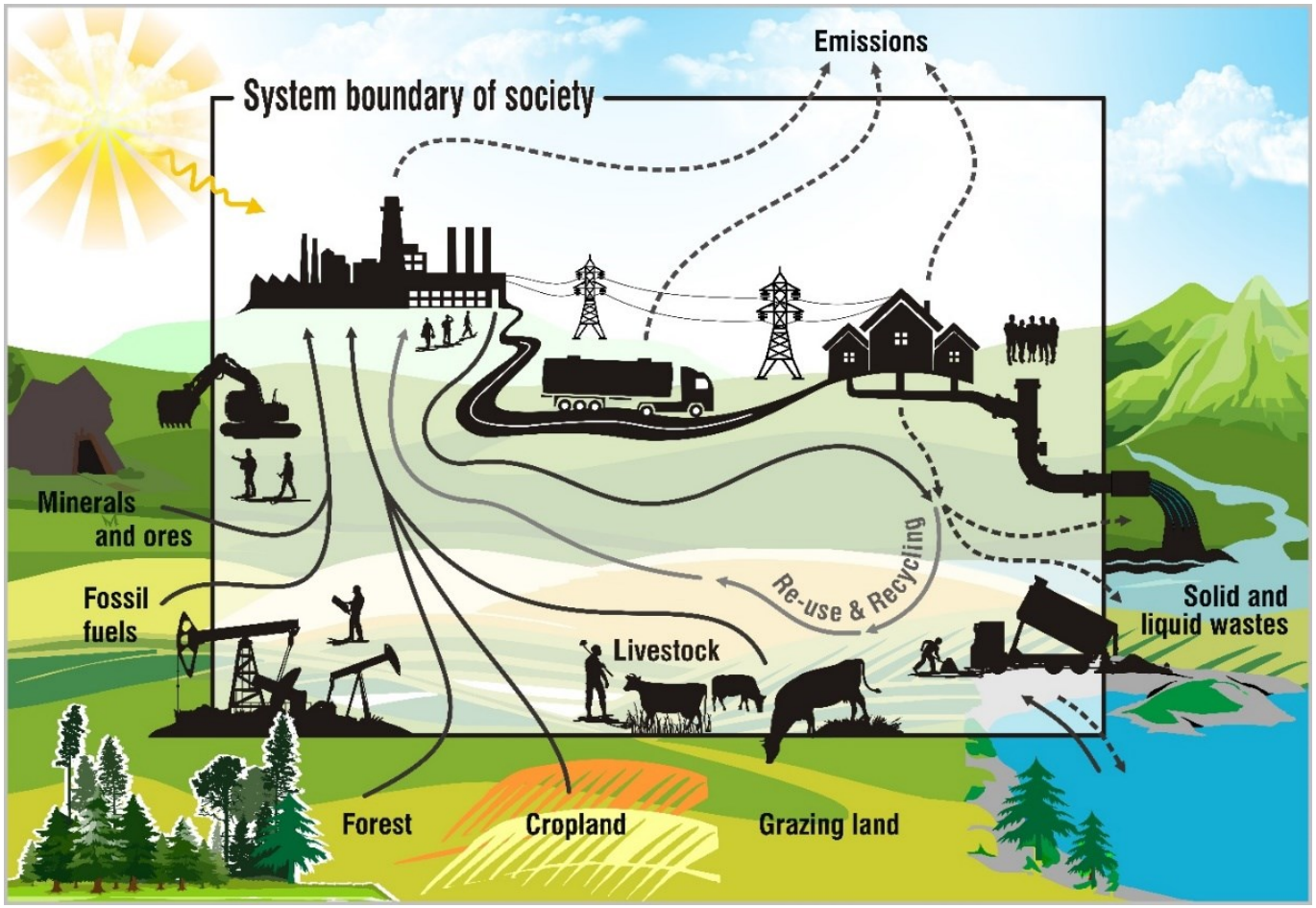
FWF Der Wissenschaftsfonds.

TWI2050: Transformations to Achieve the Sustainable Development Goals. IIASA, 2018

European Research Council
Established by the European Commission

Social metabolism: A systemic perspective on resource use

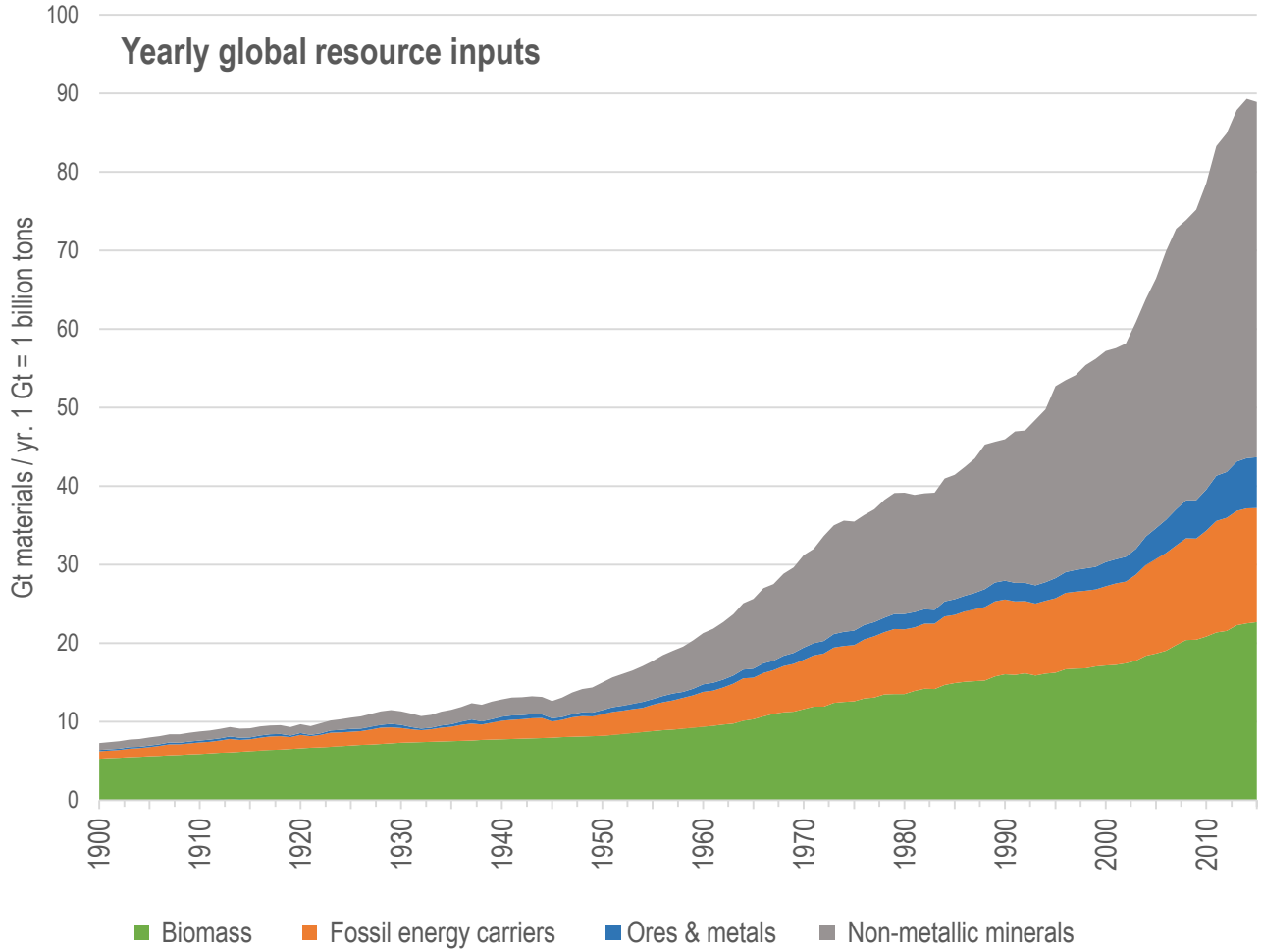
University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



FWF Der Wissenschaftsfonds.
European Research Council
Established by the European Commission

A century of global resource extraction: from agrarian to industrial society

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



Biomass grows ~ with population

Industrialization fuelled by **fossil energy** and enabled by **growing building & infrastructure stocks**

Growth 2015/1900:
Resources x 12
GDP x 32

FWF Der Wissenschaftsfonds.

Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

European Research Council
Established by the European Commission

Most sociometabolic research so far …

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

- focused on yearly flows of resources (materials, energy) and **neglected material stocks** (e.g. buildings, infrastructures, machinery)
- analyzed resource efficiency as ratios such as:

  resources : GDP *or* emissions : GDP

Shortcomings

→ Neglects that materials stocks (co-)determine flows

→ Neglects that most services result from specific stock-flow combinations, not from flows alone *(how to use gasoline without a road & a car?)*

→ Focuses on economic indicators such as GDP that may be a part of the problem

Haberl et al 2017. Sustainability, 9, 1049

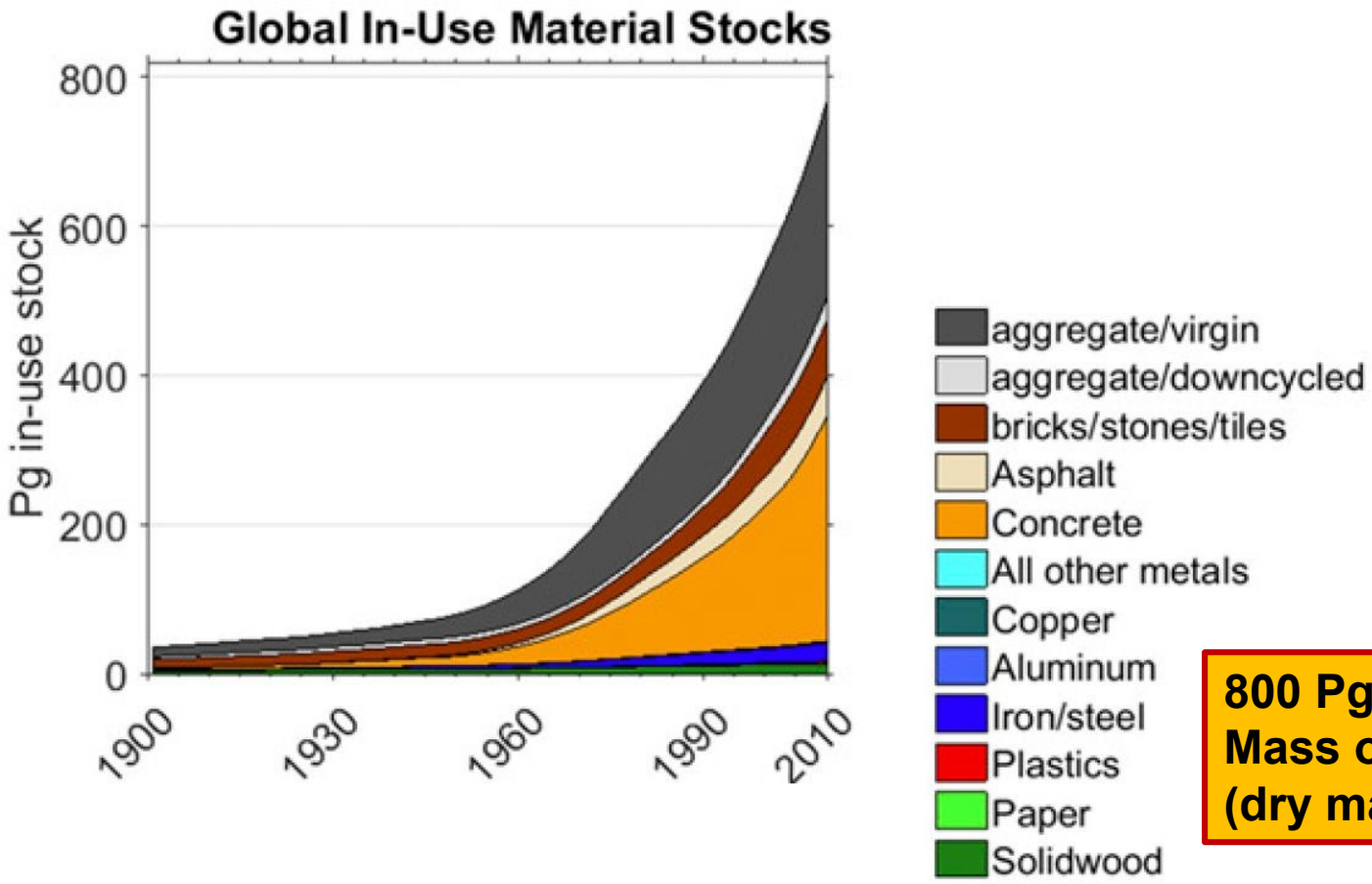
Why stocks are important

- They transform resources into services such as shelter, nutrition or mobility.
- Building up and maintaining stocks requires large amounts of resources.
- They shape social practices (including production and consumption), thereby creating path dependencies for future resource use

GHG emissions from fossil fuels required for using existing infrastructures until the end of their lifetime amount to ~one-half of the remaining emission budget for the 2°C target
(Raupach et al. 2014, *Nature Clim. Change* 4, 873–879

Global material stocks 1900-2010

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



800 Pg = 800 billion tons
Mass of plants on land (dry matter): ~900 Pg

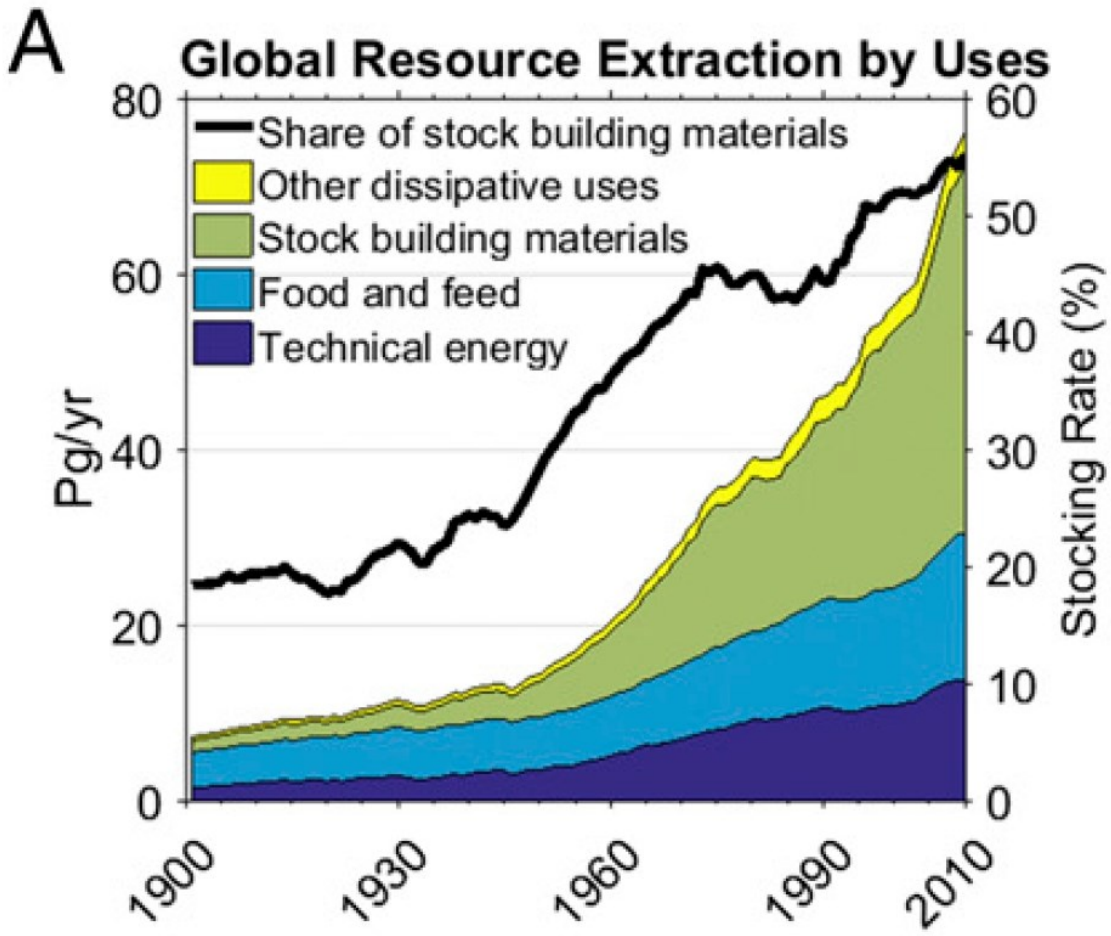
FWF Der Wissenschaftsfonds.

Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

European Research Council
Established by the European Commission

Toward stockpiling society (*not* throwaway society)

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

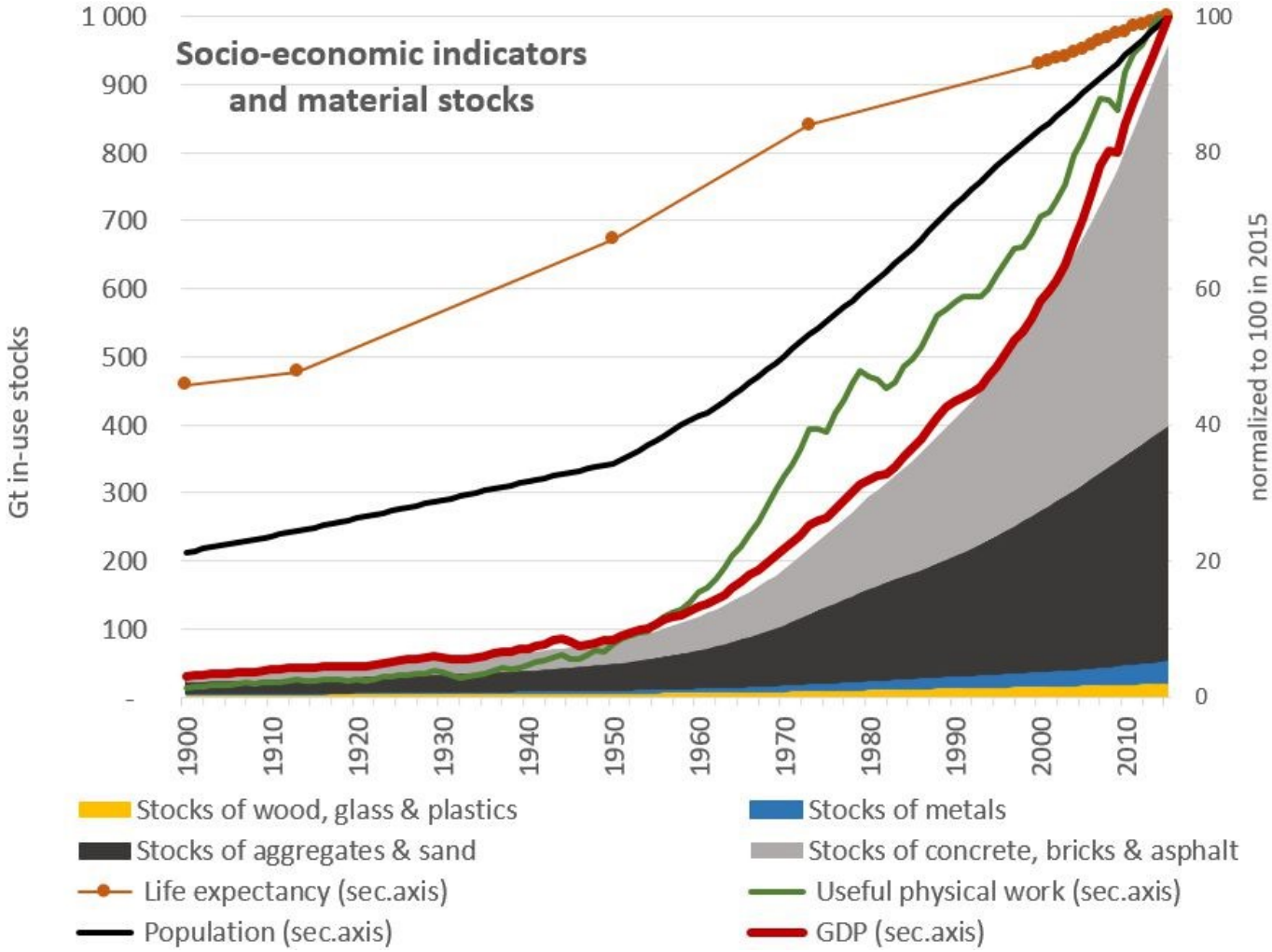


Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

FWF Der Wissenschaftsfonds.

European Research Council
Established by the European Commission

Long-term trajectories of material stocks & other socioeconomic indicators



University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

Growth of physical work (exergy) and material stocks highly correlated with GDP

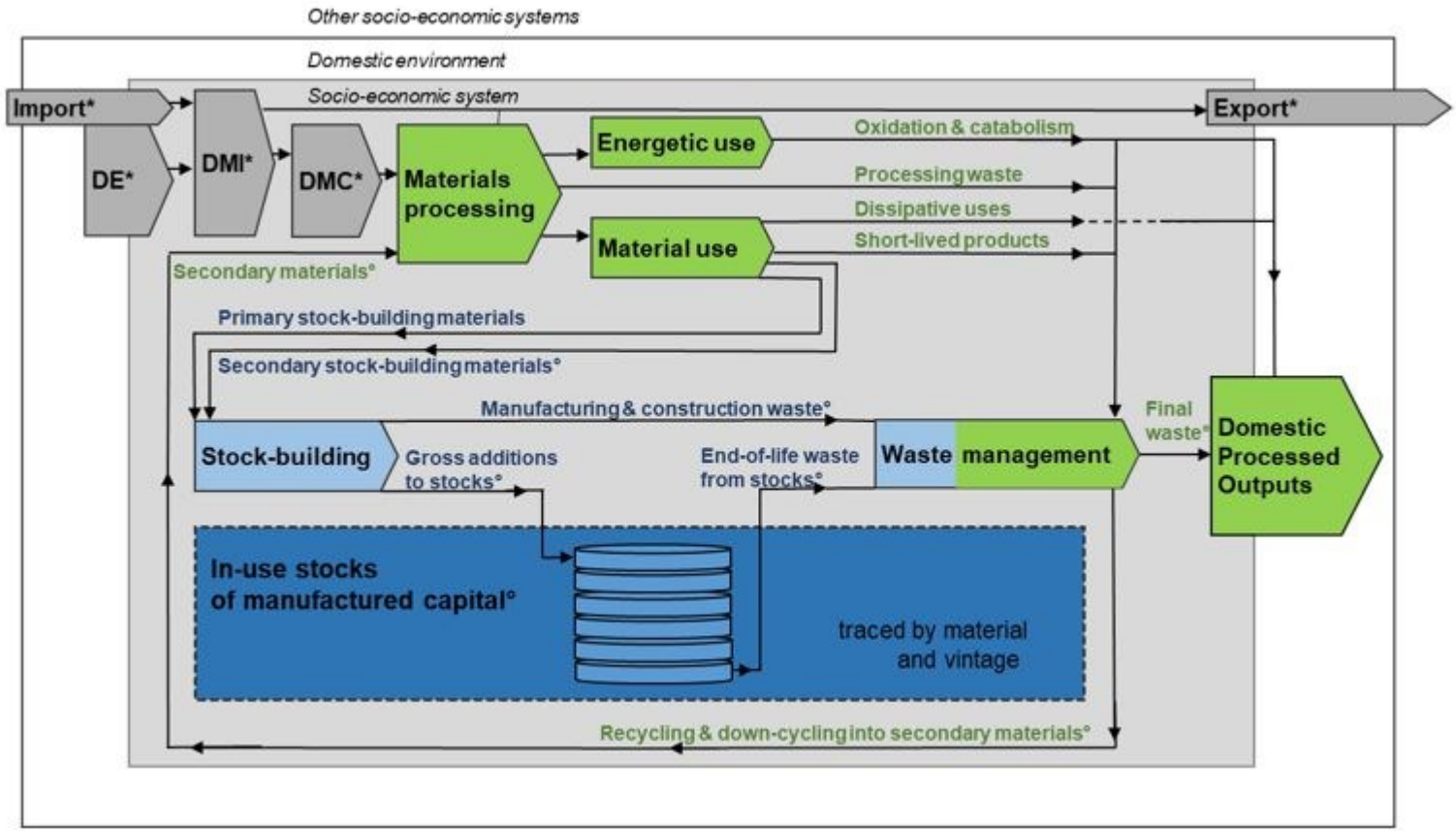
Population & life expectancy grow more slowly than GDP or material stocks

Krausmann et al. 2018. *Global Environmental Change* 52, 131–40.

FWF Der Wissenschaftsfonds.
European Research Council
Established by the European Commission

Stock data allow consistently linking resource inputs and wastes / emissions

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

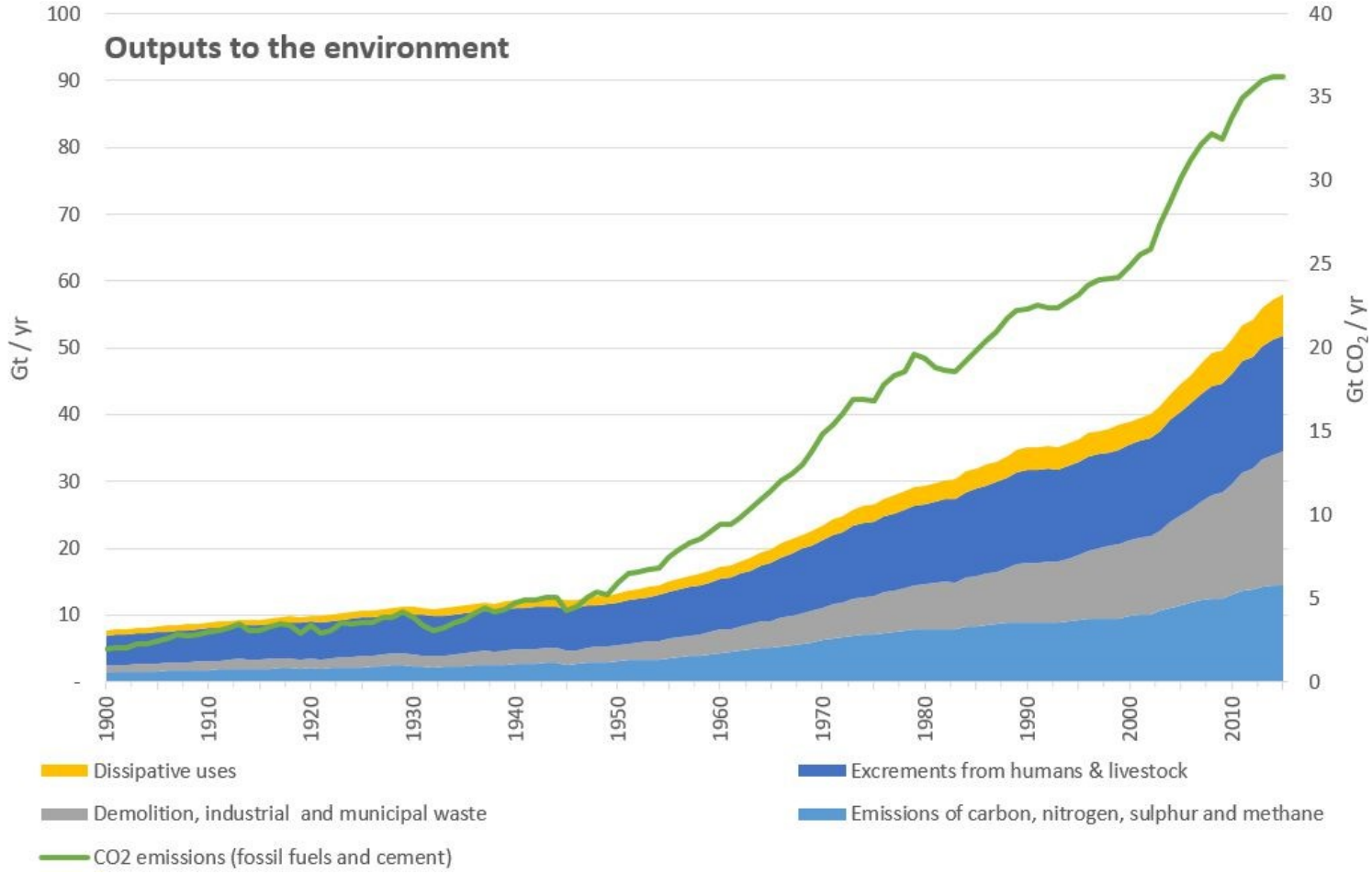


Unpublished graph, do not share, cite or quote!

FWF Der Wissenschaftsfonds.
European Research Council
Established by the European Commission

Outflows from global socioeconomic metabolism: wastes & emissions

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



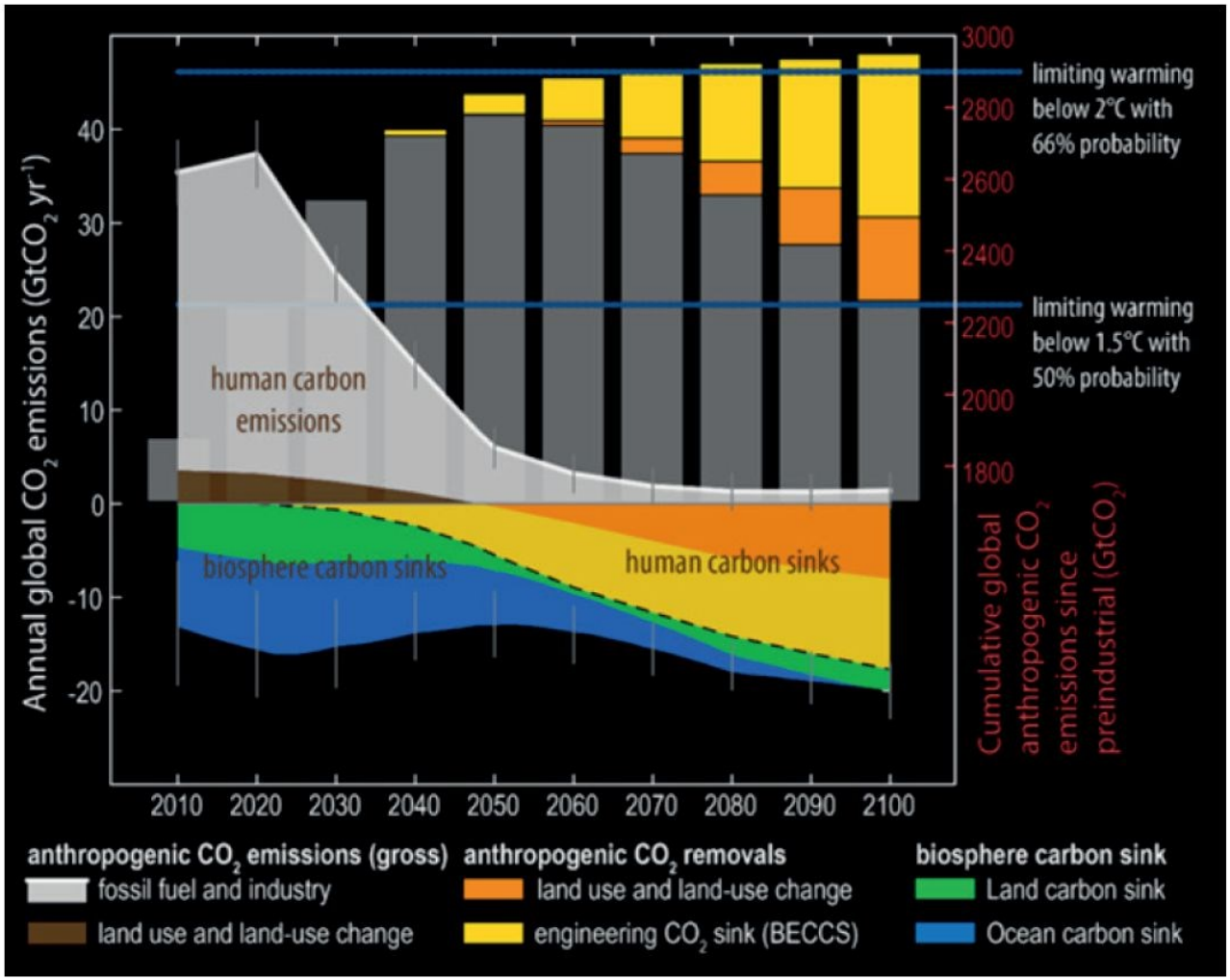
Krausmann et al. 2018. *Global Environmental Change* 52, 131–40.

FWF Der Wissenschaftsfonds.

European Research Council
Established by the European Commission

Limiting climate change: the challenge

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



Core messages

CO_2 from fossil fuels phased out until 2050

If decarbonization does not proceed fast enough, **substantial human C-sinks (e.g. BECCS)** must be established

BECCS: bioenergy with carbon capture & storage

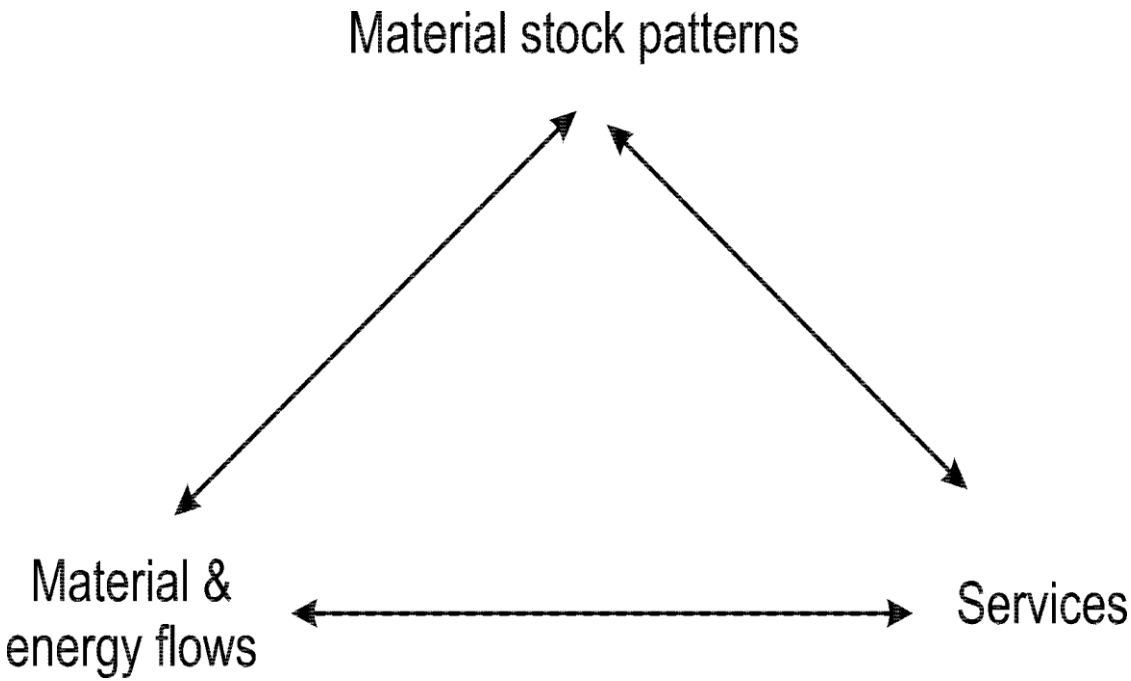
FWF Der Wissenschaftsfonds.

TWI2050: Transformations to Achieve the Sustainable Development Goals. IIASA, 2018

European Research Council
Established by the European Commission

The stock/flow/service nexus

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



Key characteristics of stocks
- **Functional types** e.g. buildings, infrastructures, machinery
- **Spatial patterns** e.g. urban form
- **Qualities** e.g. thermal quality of buildings

Material and energy flows are key for understanding resource constraints & ecological impacts, e.g. climate change

Service indicators beyond GDP establish links between resource use, well-being and satisfaction of human needs

FWF Der Wissenschaftsfonds.

Haberl et al 2017. Sustainability, 9, 1049

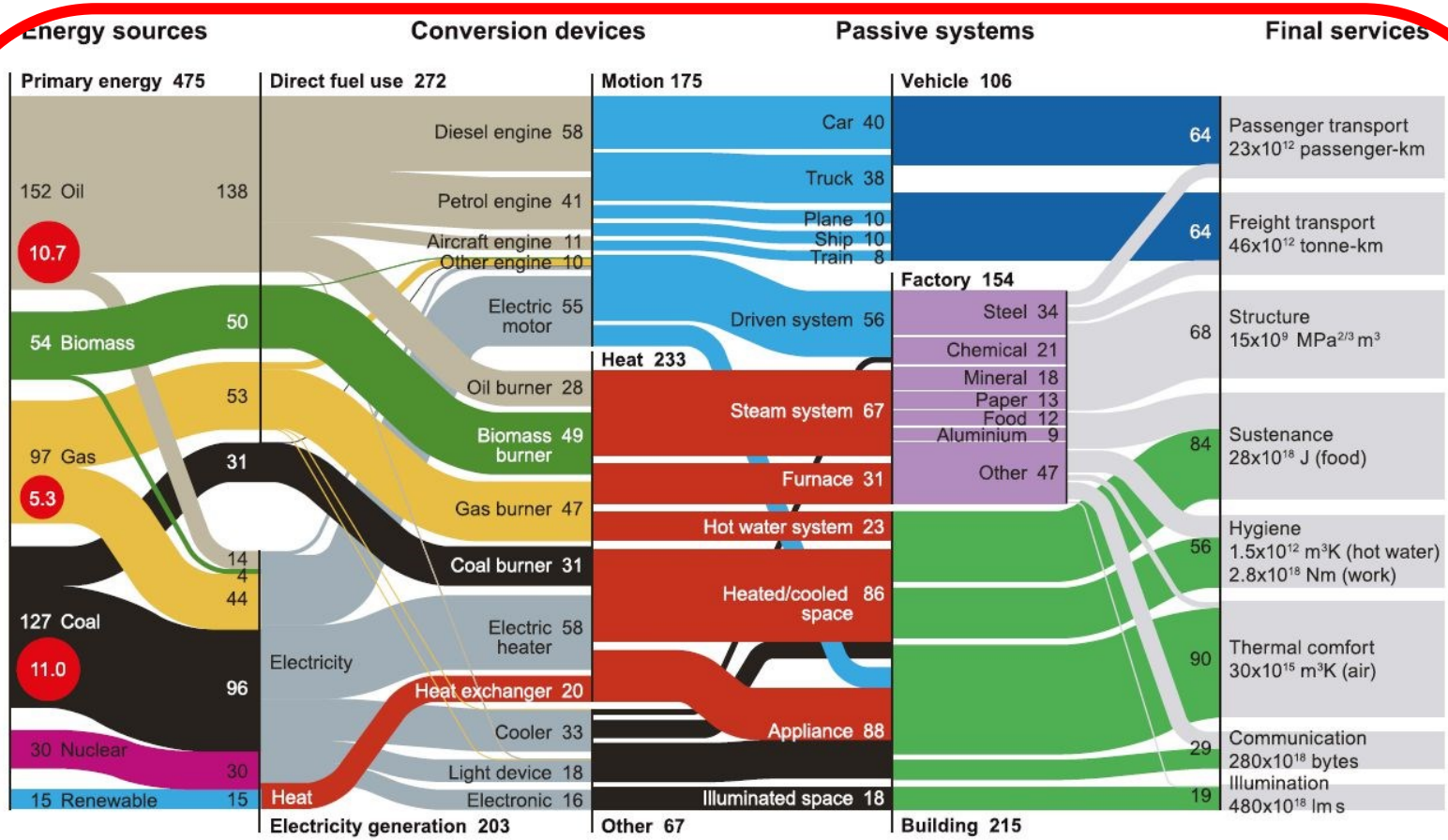
European Research Council
Established by the European Commission

Example: energy services

Global energy flows and services, 2005

Extraction & conversions depend on stocks

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



FWF Der Wissenschaftsfonds.

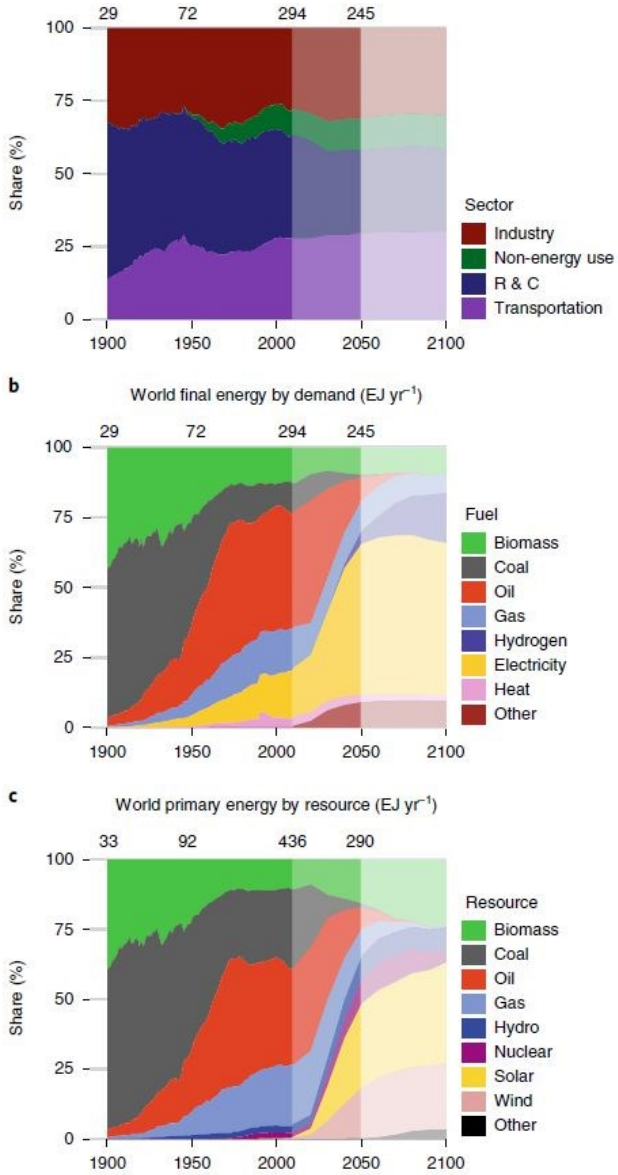
Cullen & Allwood. 2010. *Energy Policy* 38 (1): 75–81.

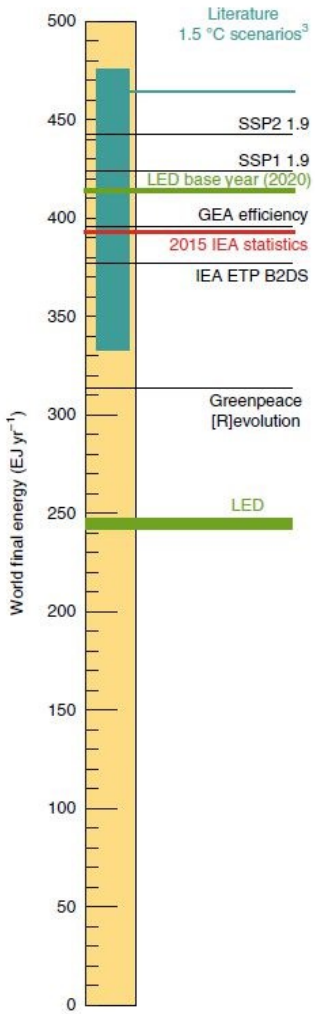
European Research Council
Established by the European Commission

Is avoiding BECCS possible?

… perhaps, with a service-centred approach

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology





A new study by Arnulf Grübler and others suggests that **focusing on the demand-side** can
- supply sufficient energy services
- almost halve energy use
- ~ achieve the 1.5 degree target.

This will require **massive improvements of buildings** (thermal quality) and **completely different investment patterns** in new urban developments, transport infrastructures and strongly altered patterns of production and consumption

Grubler et al. 2018. *Nature Energy* 3 (6): 515.

European Research Council
Established by the European Commission

Material stocks, flows, GDP, and GHG emissions

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

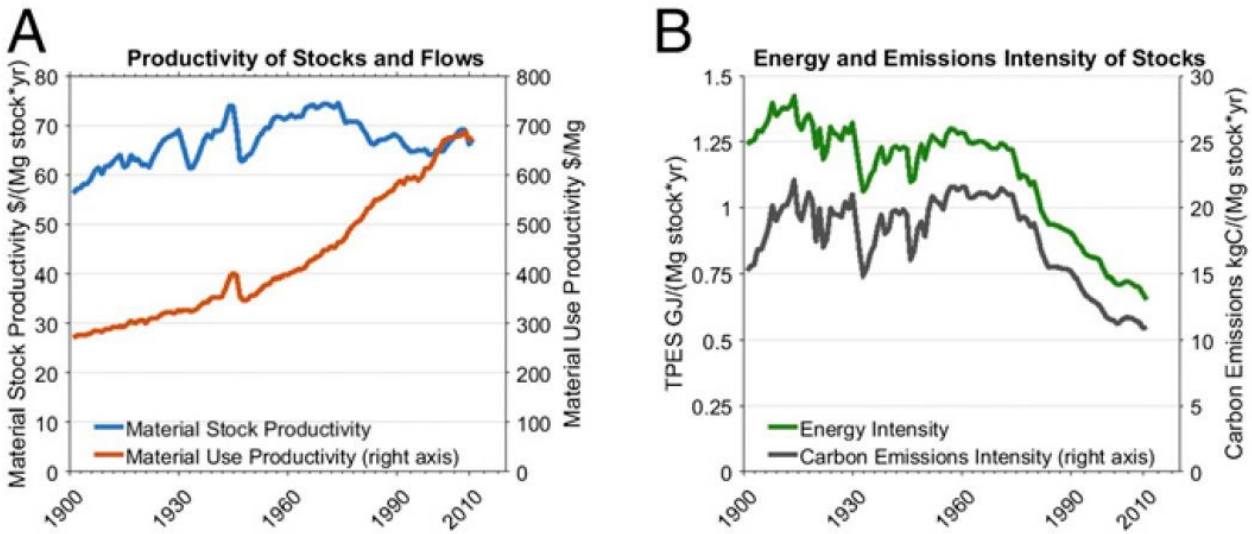


Fig. 2. Development of global stocks in relation to GDP, energy use, and CO_2 emissions 1900–2010. (*A*) Global stock productivity (GDP/material stock) and material use productivity (GDP/annual material consumption, right axis). (*B*) Energy and carbon emission intensity of material stocks. Total primary energy supply (TPES) and CO_2 emissions from fossil fuel use per megagram of material stock. Material use (domestic material consumption) is in megagrams (9), GDP in constant international dollars of 1990 (45), CO_2 emissions in kilograms of C (46), and TPES in gigajoules (9).

Rising resource efficiency is business as usual. Slow improvements of energy / GHG efficiency

Can GDP growth be decoupled from rising material stocks?

Should we rather focus on **sufficient delivery of services with less resources**, regardless of GDP?

FWF Der Wissenschaftsfonds.

Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

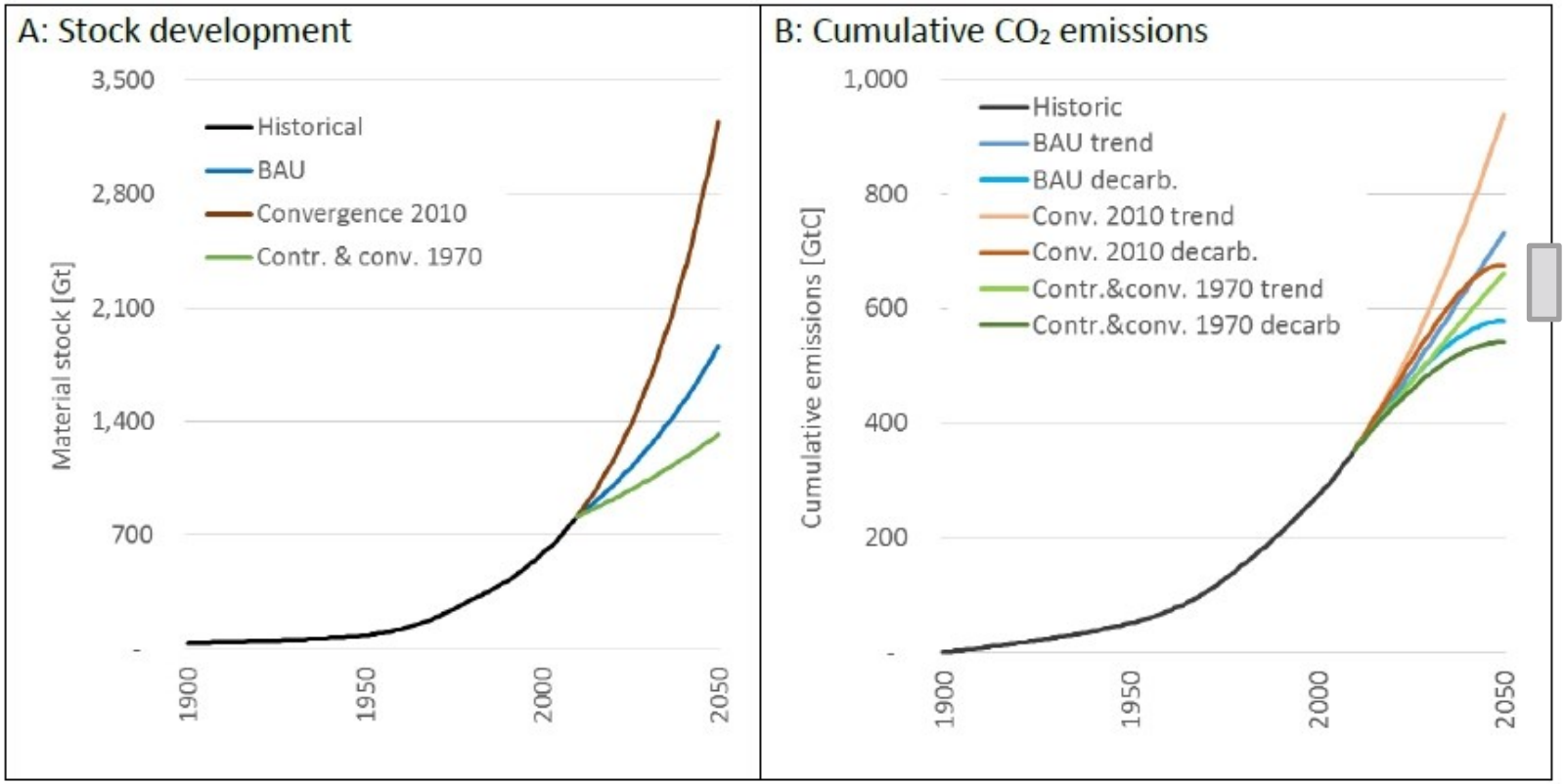
European Research Council
Established by the European Commission

Stock growth as driver of GHG emissions

Limiting stock growth needed for climate change mitigation

University of Natural Resources and Life Sciences, Vienna
:cology

Figure S4: S4A: Stock development 1900-2010 and three scenarios 2010 to 2050; S4B: Cumulative CO_2 emissions in Gt C from 1900 to 2010 (historical) and 6 scenario variations for the development to 2050.



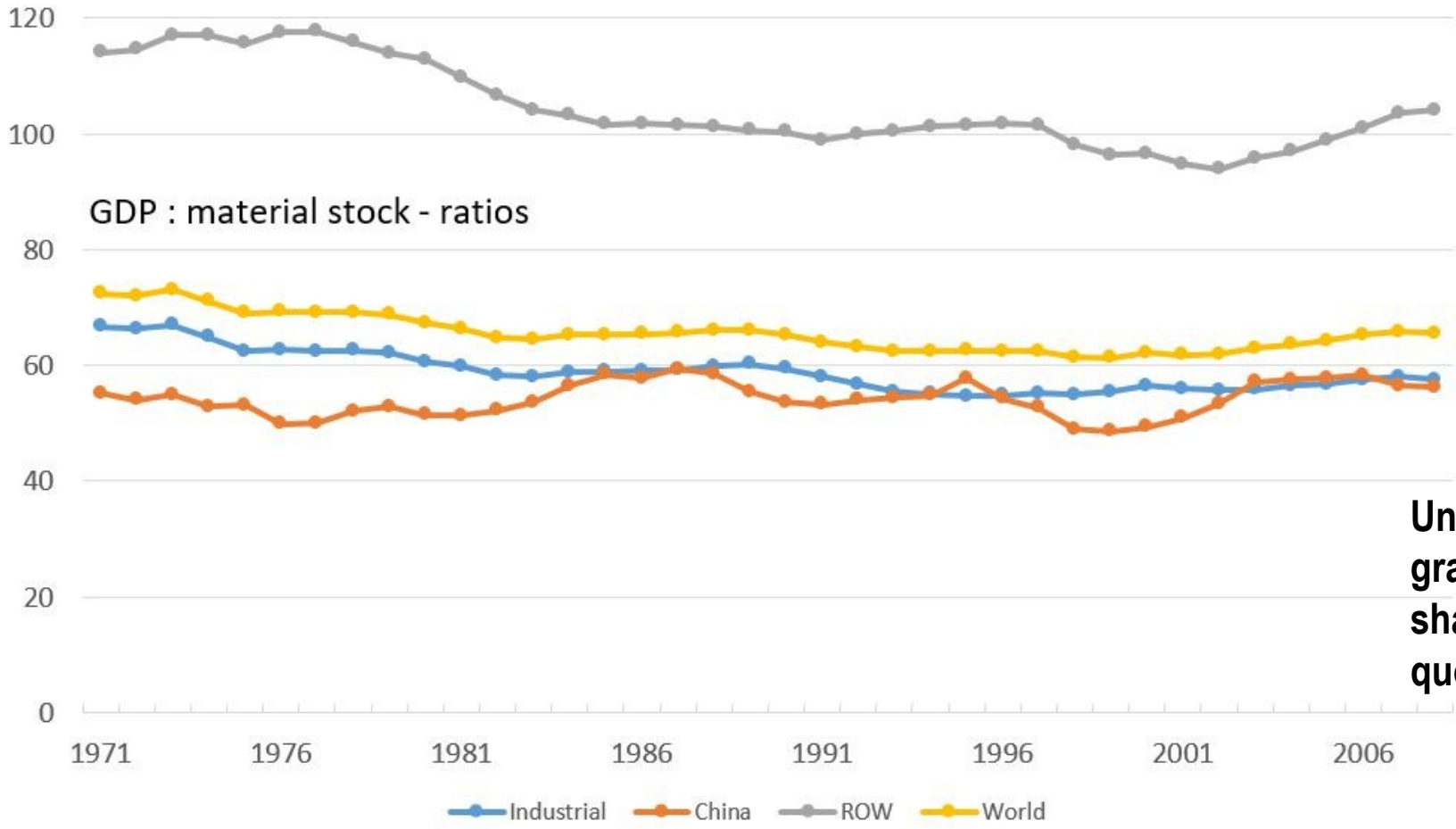
Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

FWF Der Wissenschaftsfonds.
European Research Council
Established by the European Commission

GDP/material stock ratios: how constant?

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

Intl. Geary-Khamis $ (PPP) per ton of material stock (inflation-corrected)



Unpublished graph, do not share, cite or quote!

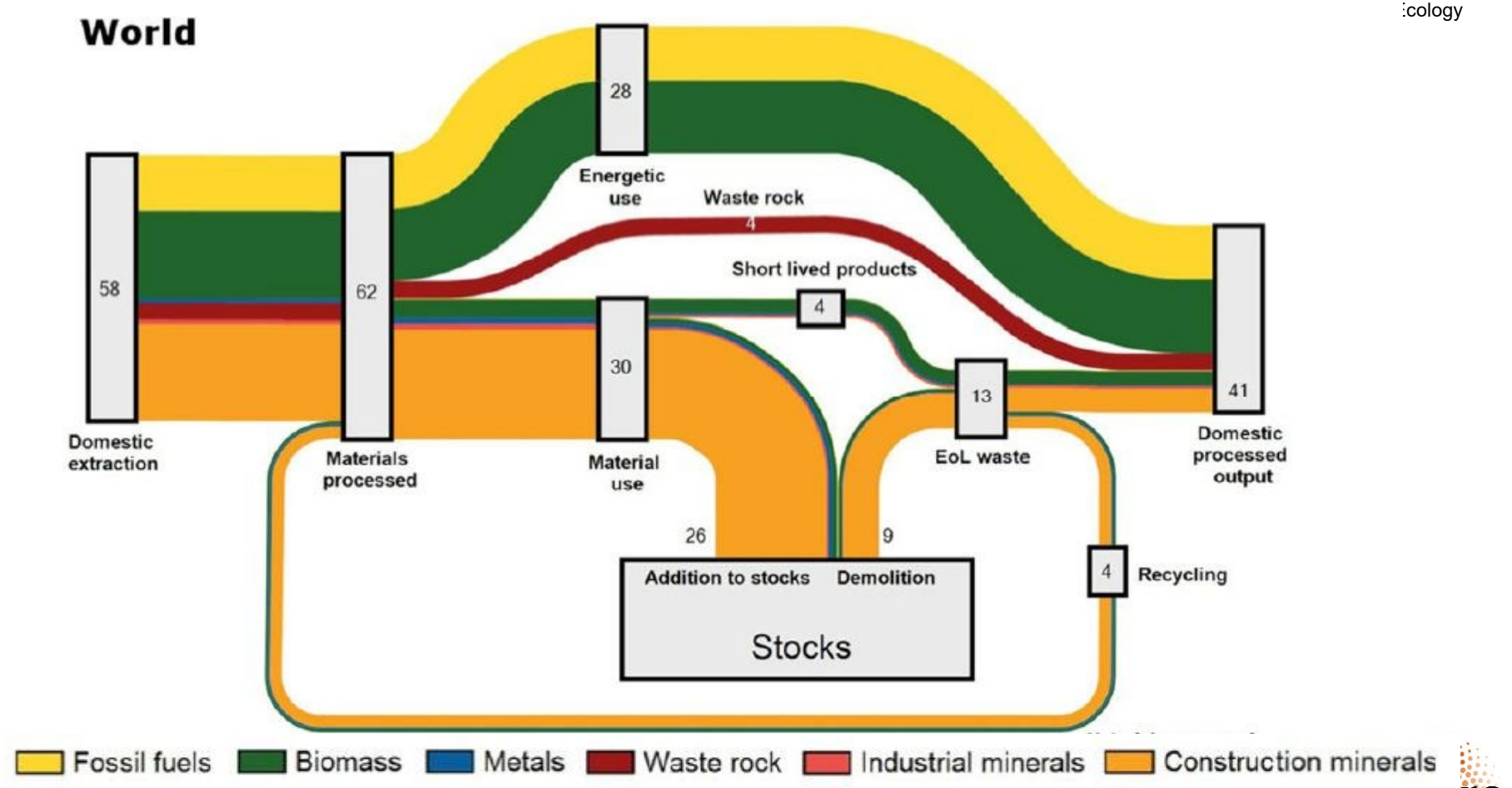
FWF Der Wissenschaftsfonds.

Data source: Krausmann, Wiedenhofer et al. 2017. PNAS 114(8), 1880-1885

European Research Council
Established by the European Commission

Prospects for attempts to move toward a circular economy in a stockpiling age

University of Natural Resources
, Vienna
:cology



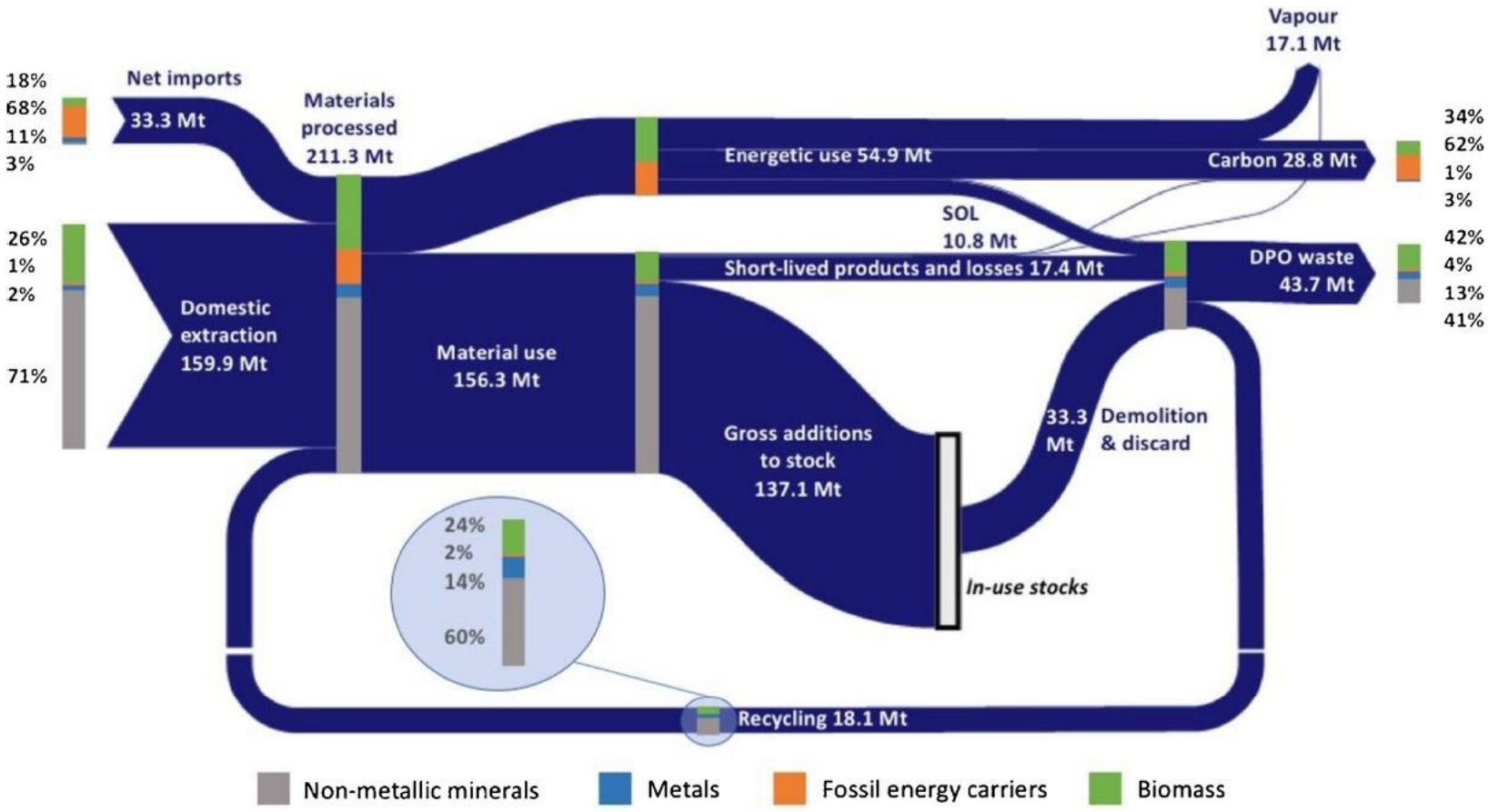
FWF Der Wissenschaftsfonds.

Haas et al. 2015. *J. Industr. Ecol.* 19, 765–777.

erc
European Research Council
Established by the European Commission

Circularity in Austria 2014

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology



Jacobi et al. 2018. *Resour., Conserv. Recyc.* **137**: 156–66.

FWF Der Wissenschaftsfonds.
European Research Council
Established by the European Commission

Implications for sociometabolic transitions towards sustainability

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

- Current sustainability strategies inadequate or insufficient to „bend the curve“ - the **gospel of eco-efficiency is not good enough**
- **Focus on demand-side** (energy, food, etc.) → Δ qualities of stocks!
- Reaching **circularity** requires stabilization of stocks
- Different investment patterns can shift incentives towards **low-resource living** compared to wasteful lifestyles prevailing today
  - Thermal quality of **existing building stock** rises much faster
  - All **new housing** meet low-energy & zero-GHG-emission standards
  - **Transport-saving** patterns of settlements & infrastructures
  - **Low-GHG transport** infrastructures (roads? airports?)
  - Changing patterns of **production & consumption in all sectors**

FWF Der Wissenschaftsfonds.

European Research Council
Established by the European Commission

Future research @SEC

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

- Analyze the **stock/flow/service nexus**
  - Multi-dimensional **time-series analyses** of stock/flow/service relations and eco-efficiency
  - **Cross-country and panel data** analyses of stock/flow/service relations & eco-efficiency
  - **Scaling laws**: are there scaling laws of stock-flow relations?
  - Importance of **spatial patterns** („urban form“)
- Building a **global model of stock-flow-service relations & related GHG emissions** allowing analysis of option spaces
  - Decarbonization pathways
  - Moving towards the SDGs

FWF Der Wissenschaftsfonds.

European Research Council
Established by the European Commission

University of Natural Resources and Life Sciences, Vienna
Institute of Social Ecology

University of Natural Resources & Life Sciences, Vienna

Department for Economic and Social Sciences
Institute of Social Ecology

Helmut Haberl
Dominik Wiedenhofer
Fridolin Krausmann
Christoph Görg
et al.

Schottenfeldgasse 29, A-1070 Wien
helmut.haberl@boku.ac.at

Free data download:
https://www.wiso.boku.ac.at/en/institut-fuer-soziale-oekologie-sec/data-download/