Circular Economy and Material Efficiency Potentials for Bulk Materials in Buildings and Vehicles – Insights from the EU CIRCOMOD Project

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ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM

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Motivation

- **Global material consumption is rapidly increasing, associated with about 23% of GHG emissions.**
- The potential for GHG reduction through CE and material efficiency strategies has been established (IRP, EC)
- Rising interest in scope 3 GHG due to climate policy failing to reach required decarbonization rates to reach Paris goals
- IAM-based climate change mitigation scenarios do not represent CE strategies
- **New generation of models and model-based scenarios needed for comprehensive, consistent and robust assessment of CE-GHG link**

CIRCOMOD overview

1. develop **an overall schema** for analysing CE strategies.
2. **collect and develop data** shared on a **public data platform** for CE-climate strategy assessment.
3. Compile overview of **CE options per sector** for demand- and supply-side interventions.
4. **expand and combine** leading material flow and climate mitigation models.
5. extend current **economic theories** and models with circular economy features.
6. develop **new scenarios** relevant for climate policymaking, including CE measures.

Consortium members

- Utrecht University (UU)

Project timeline:
Scenario working package just started
First scenario results due in Q2(2025)
Final scenario runs in Q1(2026)

- Phorzheim University
- Systemic
- Power Algae
- PBL Netherlands Environmental Assessment Agency

Principles for model coupling and scenarios

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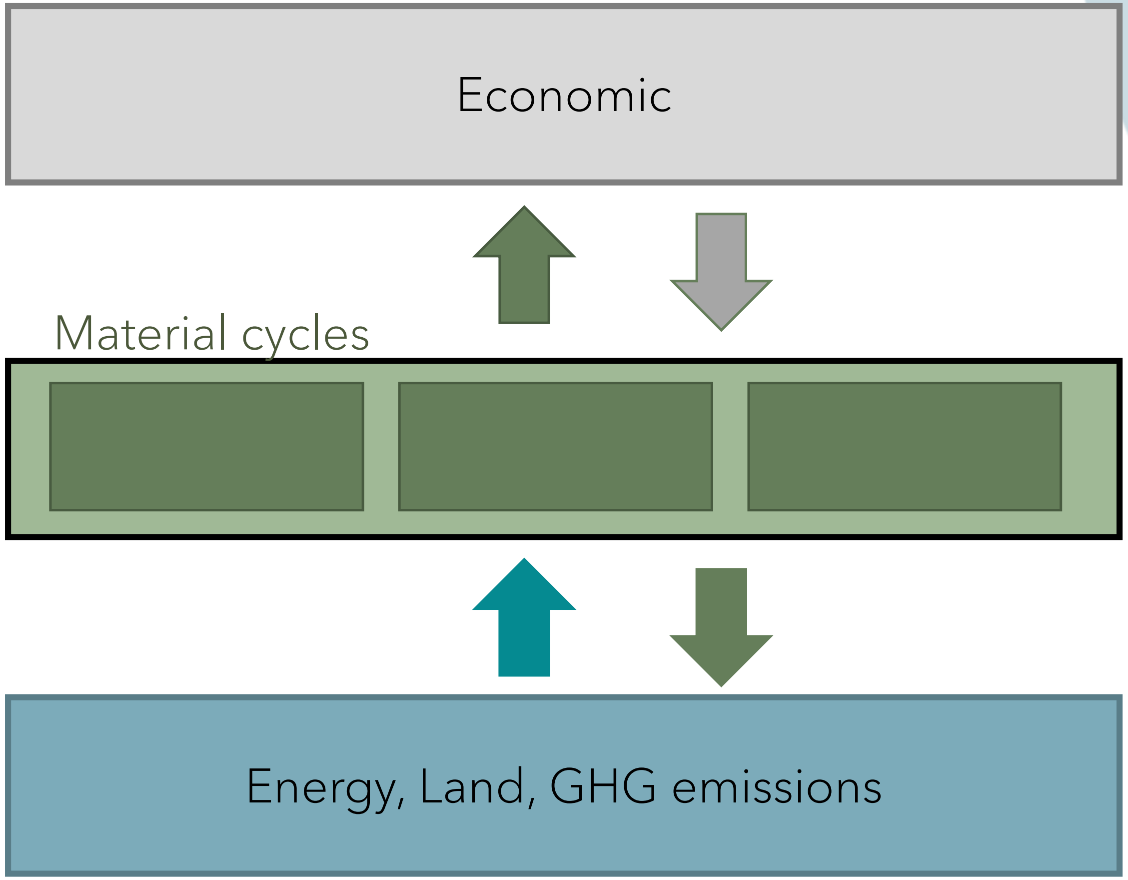
Comprehensiveness

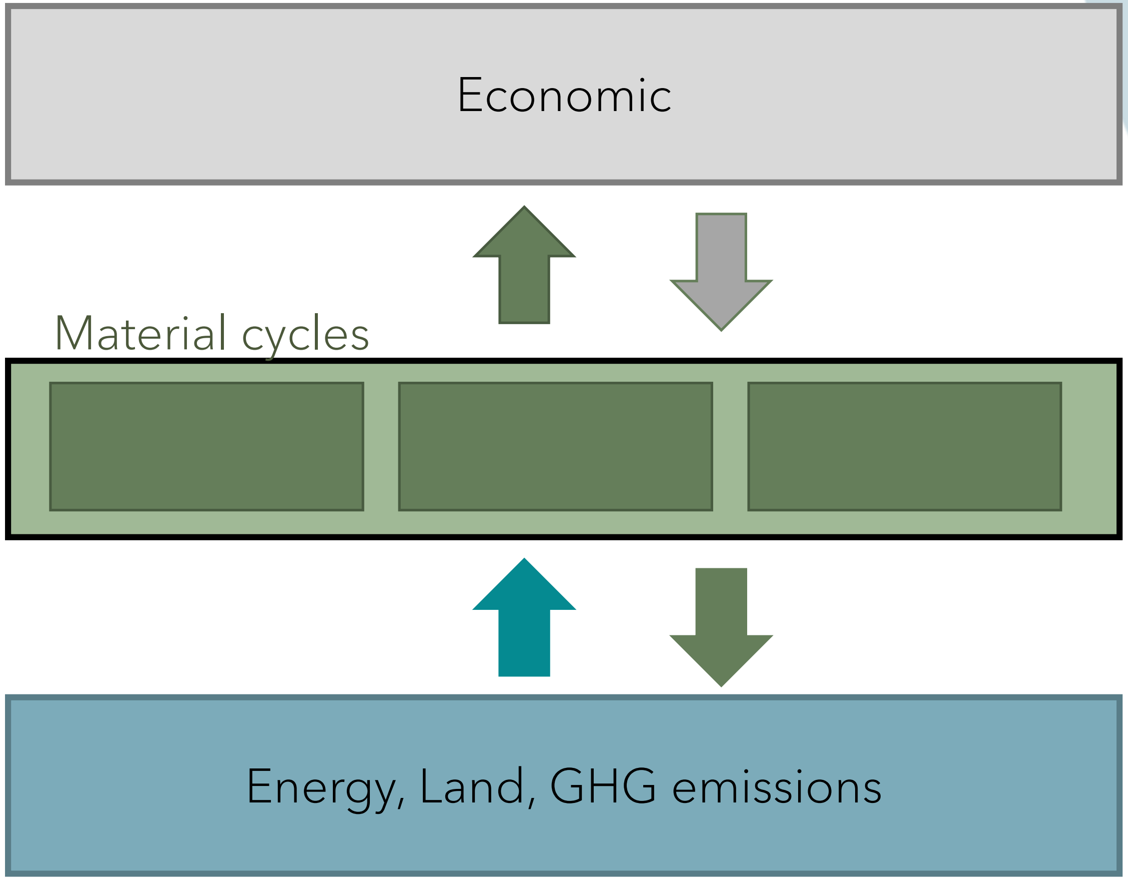
- Cover relevant end-use sectors and materials
- Cover supply and demand-side solutions for CE
- Cover also energy transformation and different socio-economic conditions



Principles for model coupling and scenarios

Consistency

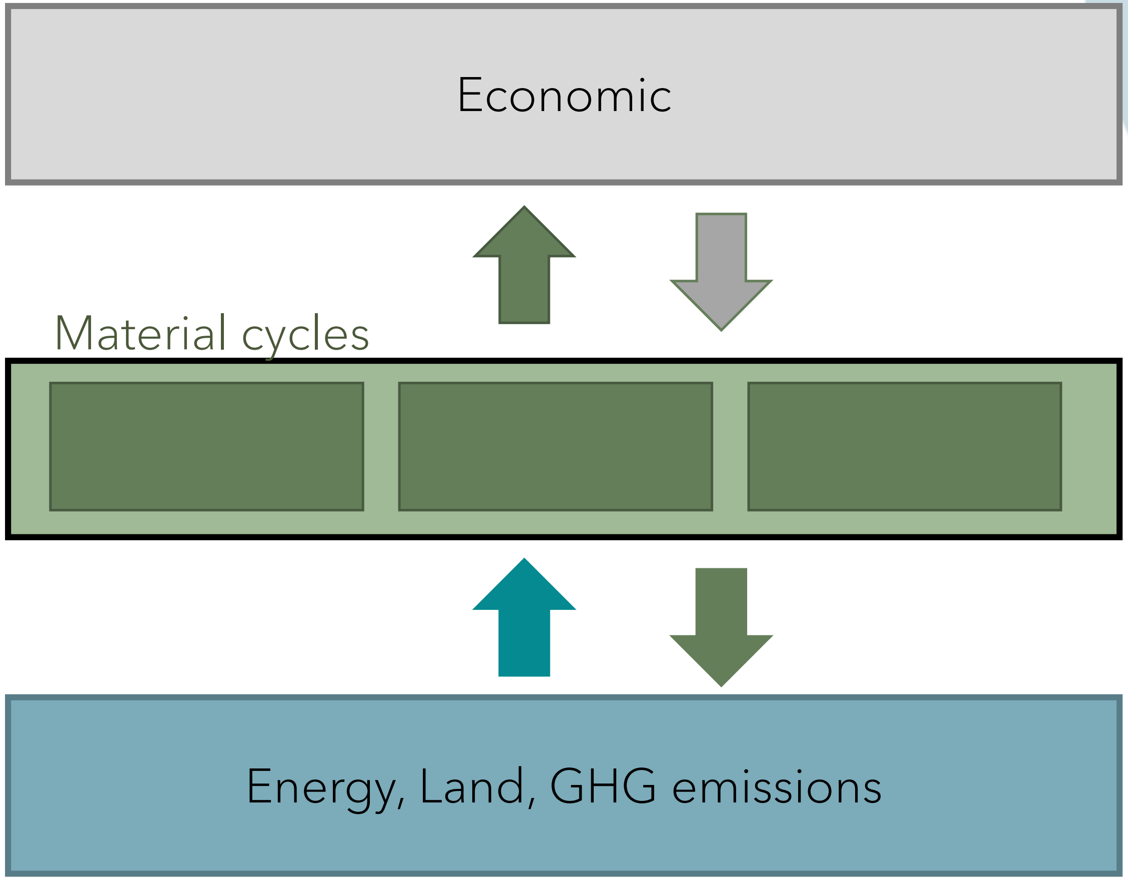
- Process details adding up to sectoral aggregates
- Material and energy systems consistency
- Monetary and Physical consistency



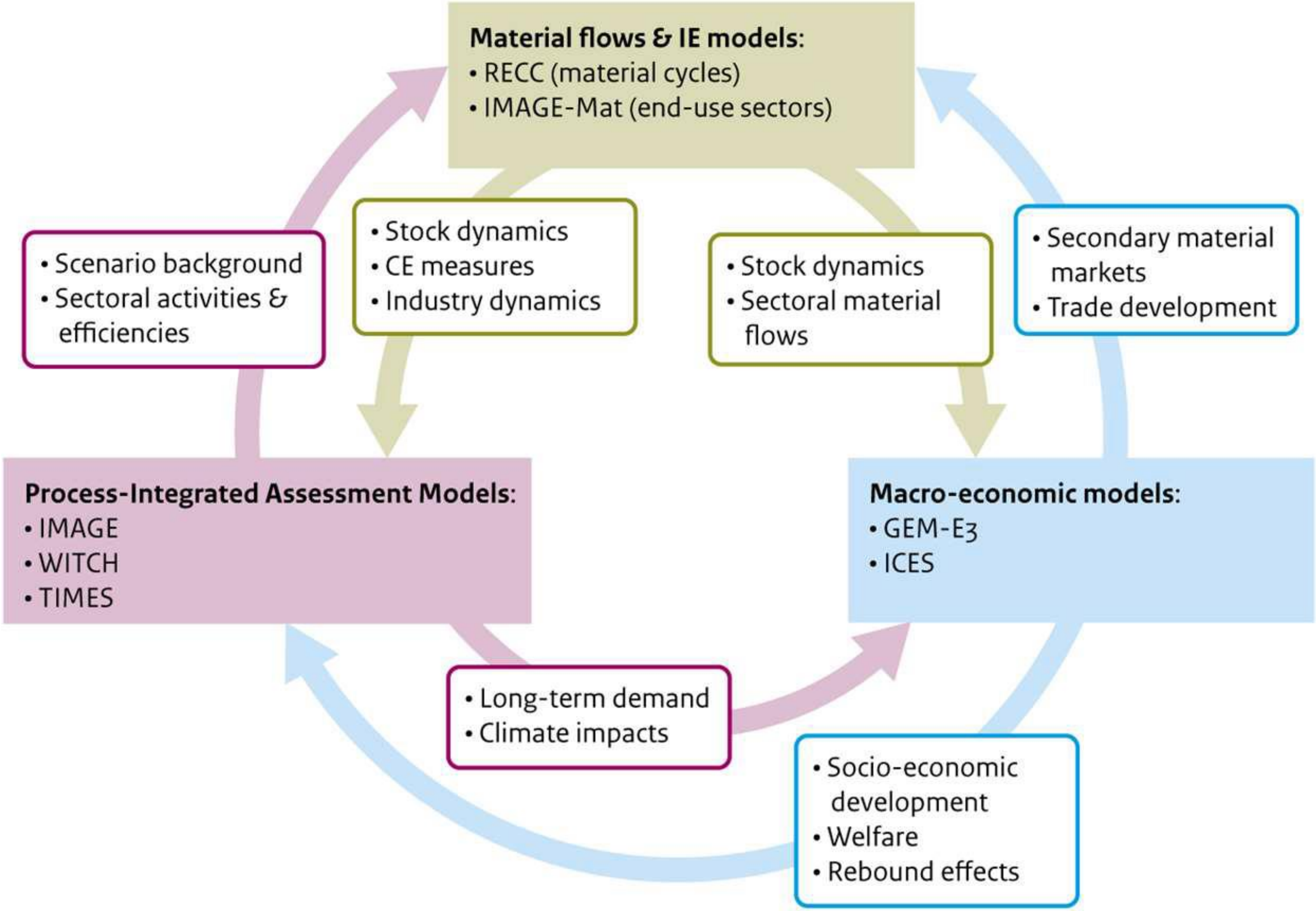
Principles for model coupling and scenarios

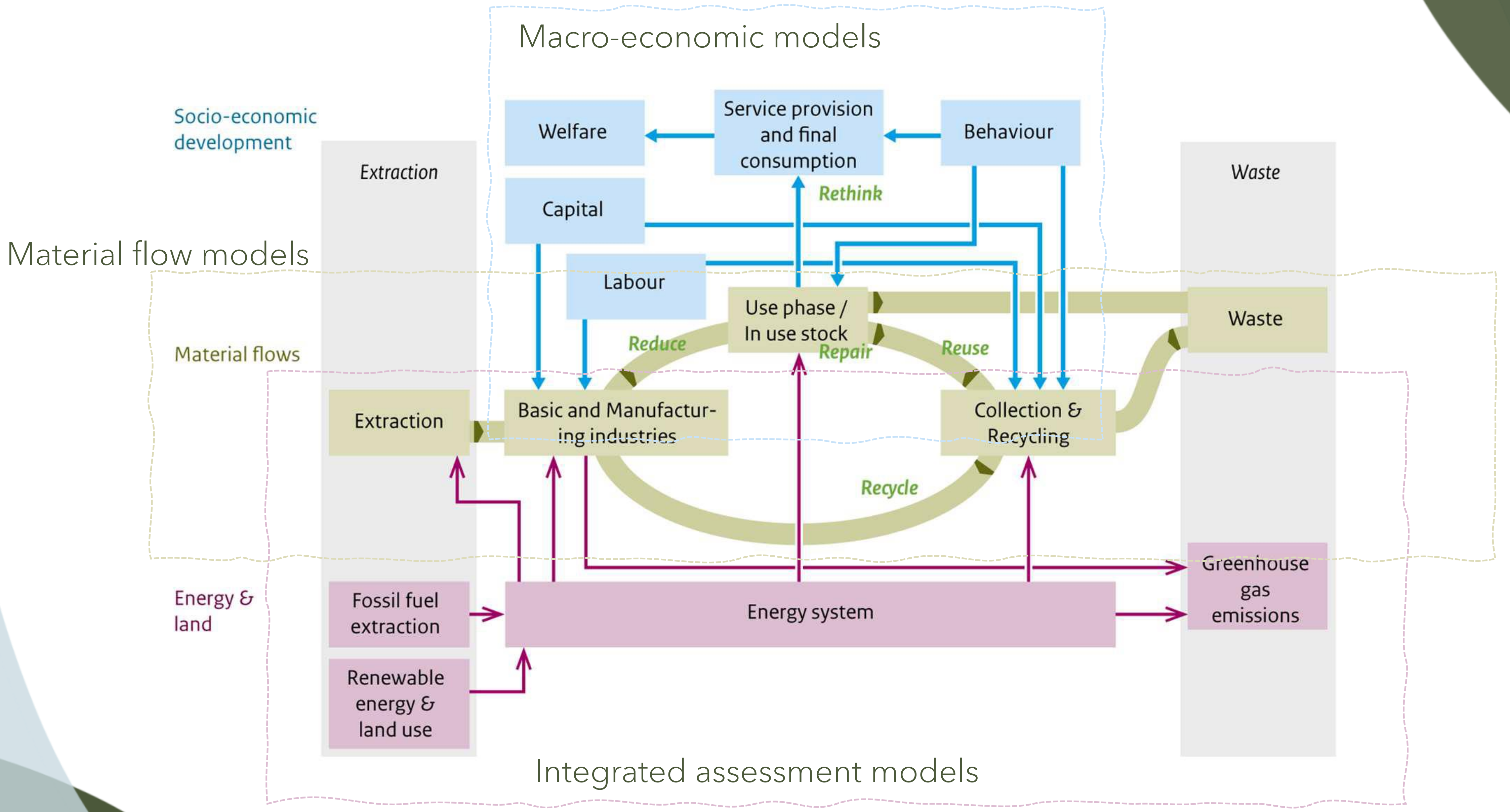
Robustness

- Consider many possible developments, including disruptive events (technology, demand, trade)
- Highlight options that are very likely to be effective under many circumstances, not just under ideal conditions
- Stylize major findings: Aggregate indicators and qualitative conclusions so that they are broadly applicable.



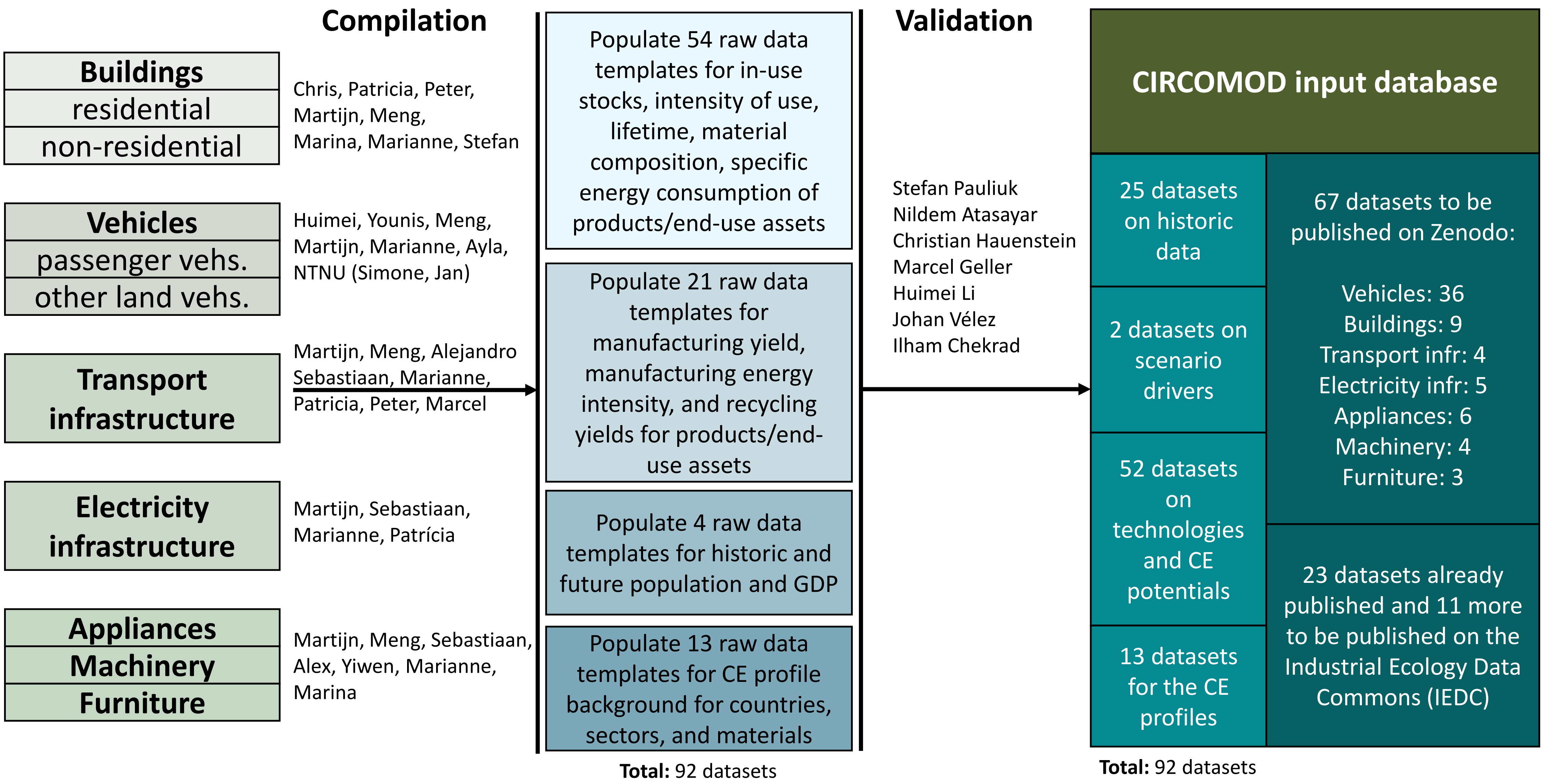
Modelling the CE-GHG link in CIRCOMOD




Macro-economic models
Material flow models
Socio-economic development
Material flows
Energy & land
Extraction
Waste
Welfare
Service provision and final consumption
Behaviour
Capital
Labour
Rethink
Use phase / In use stock
Repair
Reduce
Reuse
Recycle
Extraction
Basic and Manufactur-ing industries
Collection & Recycling
Waste
Greenhouse gas emissions
Fossil fuel extraction
Energy system
Renewable energy & land use
Integrated assessment models

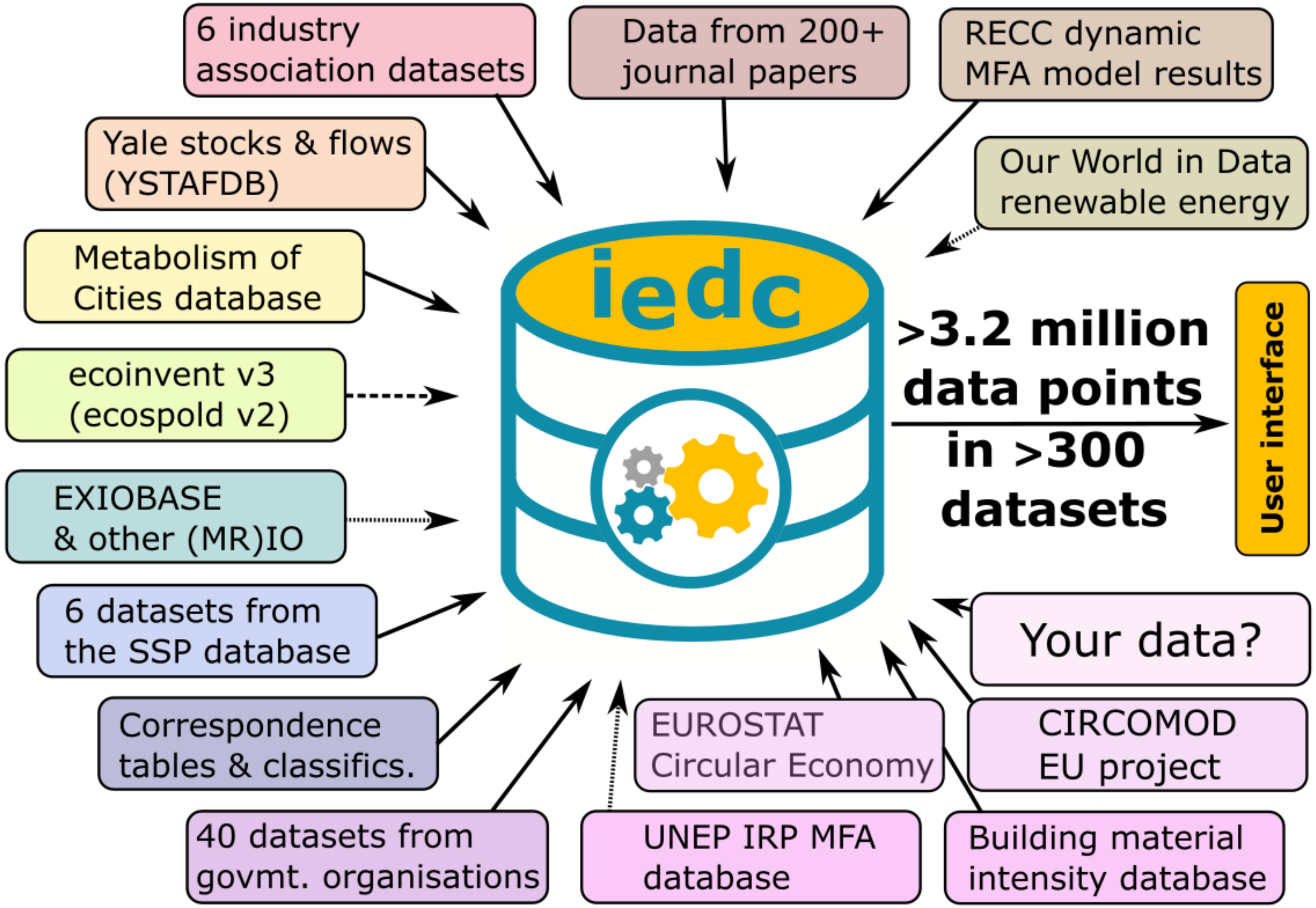
CIRCOMOD Data Collection

CIRCOMOD input database data collection and validation scheme



Industrial Ecology Data Commons (IEDC)

The IEDC is an open database for stocks, flows, process coefficients, material composition, lifetime, and energy intensity of products, criticality indicators, & many more.
Datasets of 10-50000 numbers hidden in pdfs and websites can now find a new home!
Launched in 2018, the IEDC is continuously improved and expanded.



23 CIRCOMOD input datasets already published and 11 more to be published on the Industrial Ecology Data Commons (IEDC)

https://tinyurl.com/iedc-freiburg

Circular economy in the global building stock – implications for materials, energy, and GHG

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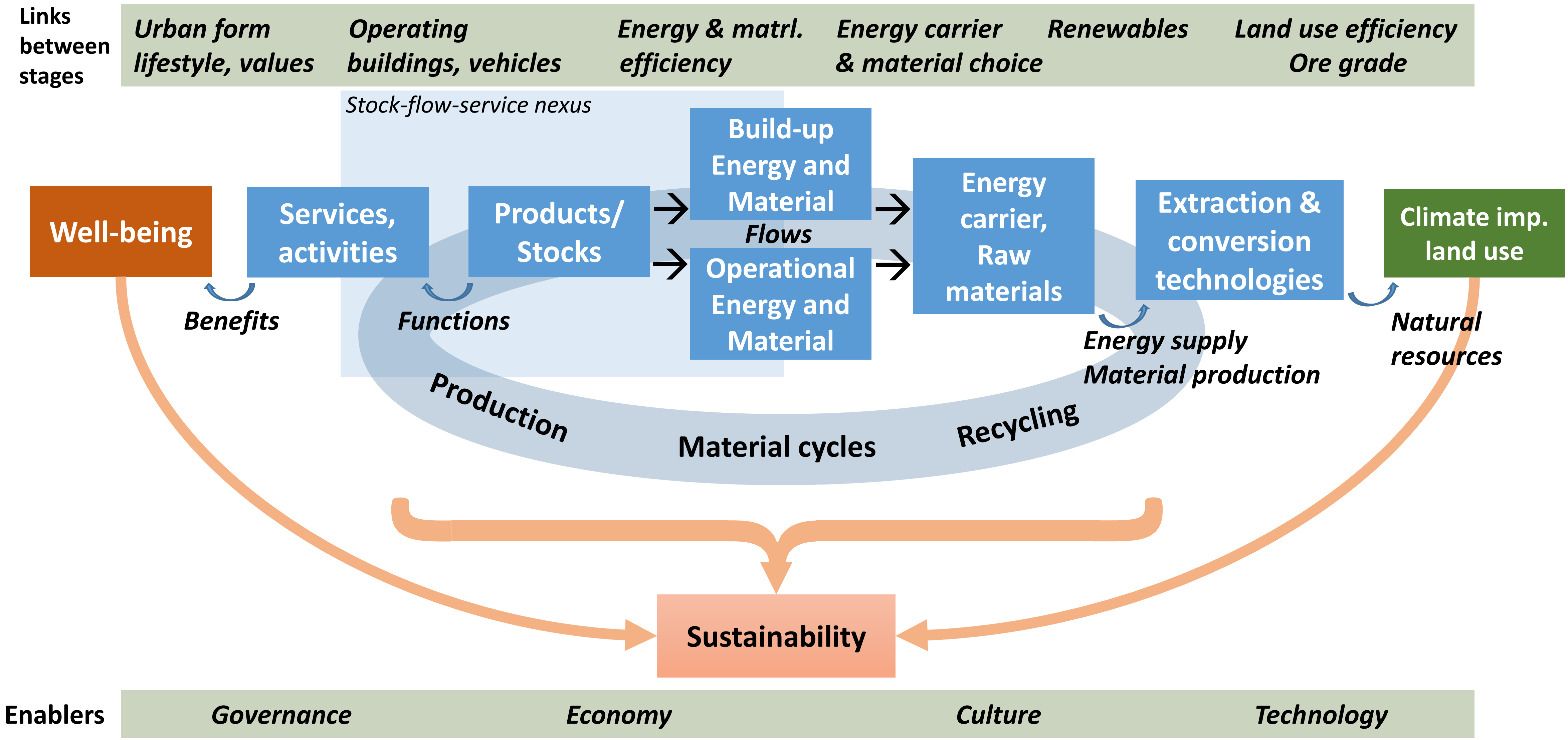
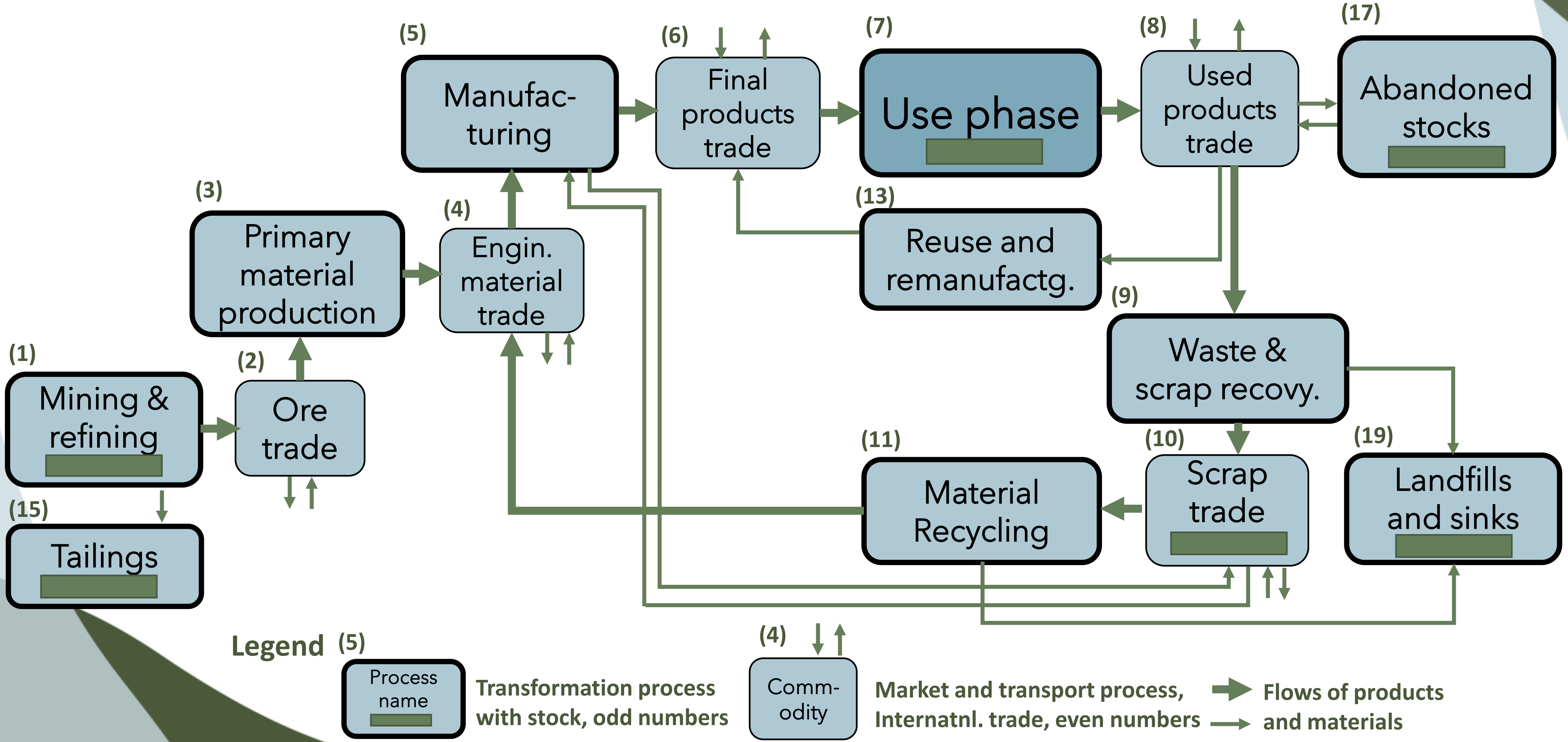
Synthesis Framework: The material and energy service cascade (ESC) and the service-stock-flow nexus (SFSN)



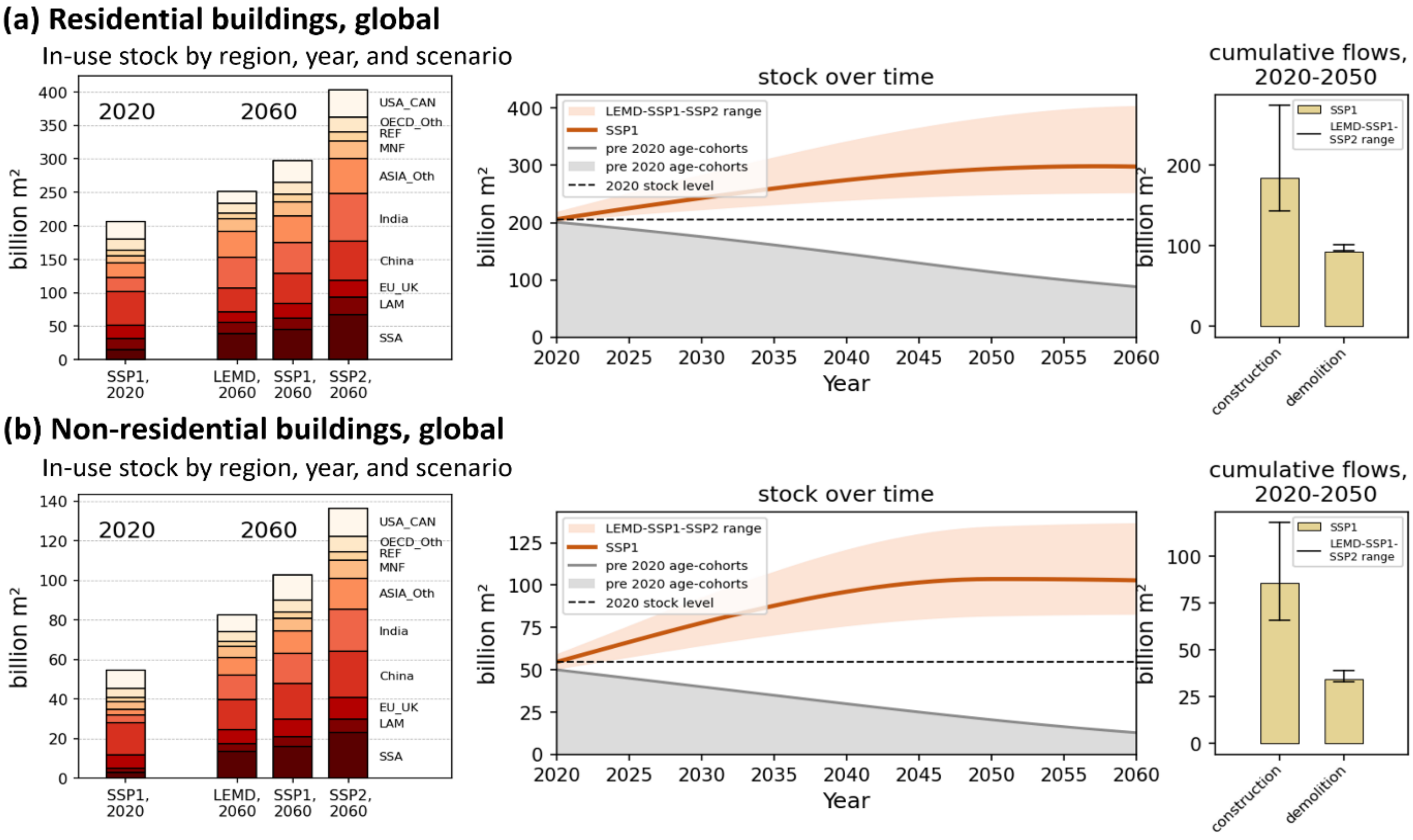
Source: Bergsdal et al. (2007), DOI 10.1080/09613210701287588; Kalt et al. (2019), DOI 10.1016/j.erss.2019.02.026; Haberl et al. (2017), DOI 10.3390/su9071049

CIRCOMOD material cycle system definition

For a given region (no trade at global scale), end-use sector, and time frame
Multi-layer quantification for products, materials, energy input and GHG per process

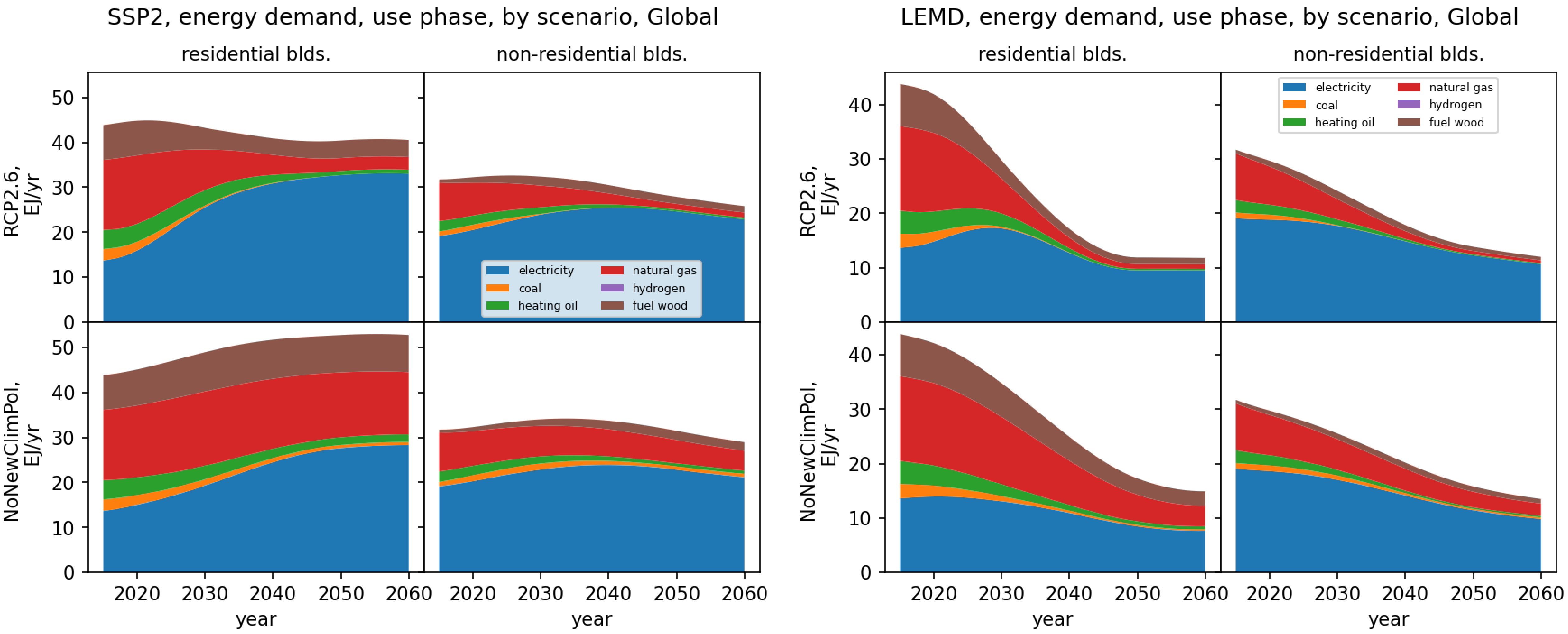


Stock and cumulative flows, global, 2020-2060



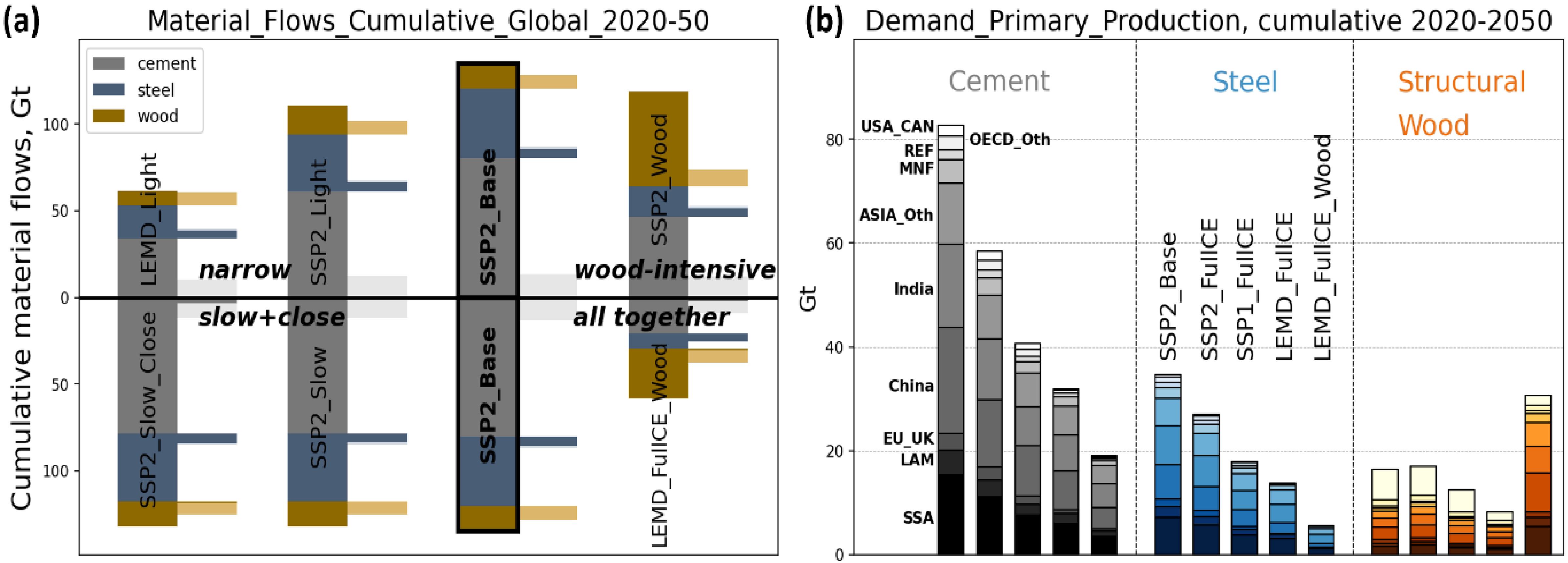
Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

Use phase energy demand, global, 2020-2060



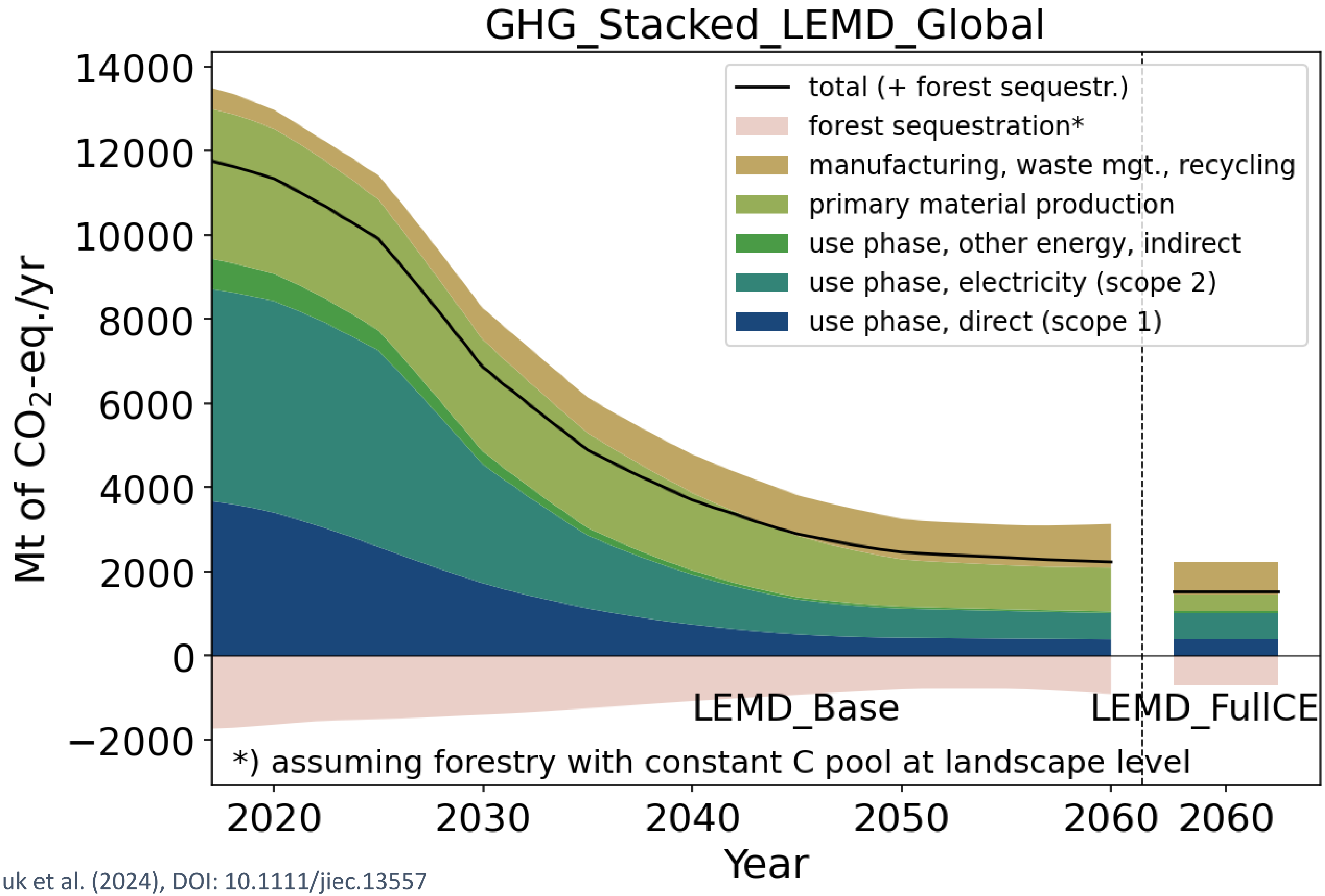
Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

Cumulative material flows, global, 2020-2060



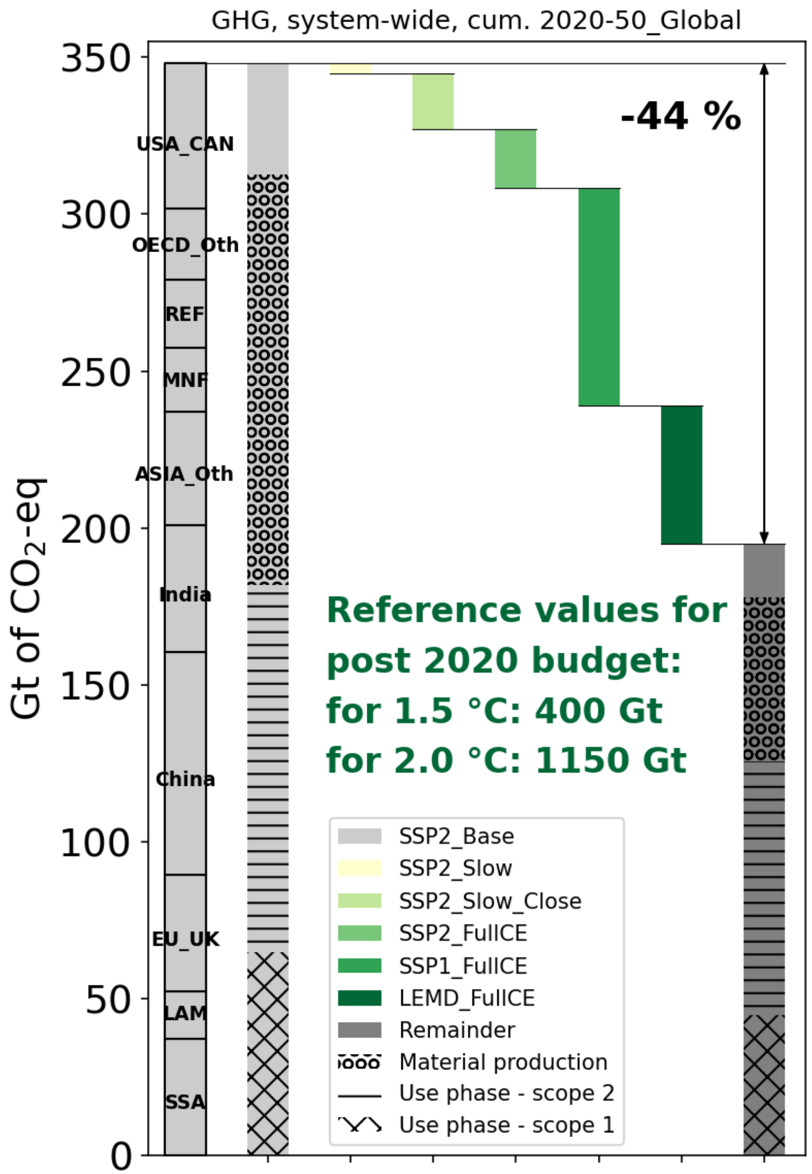
Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

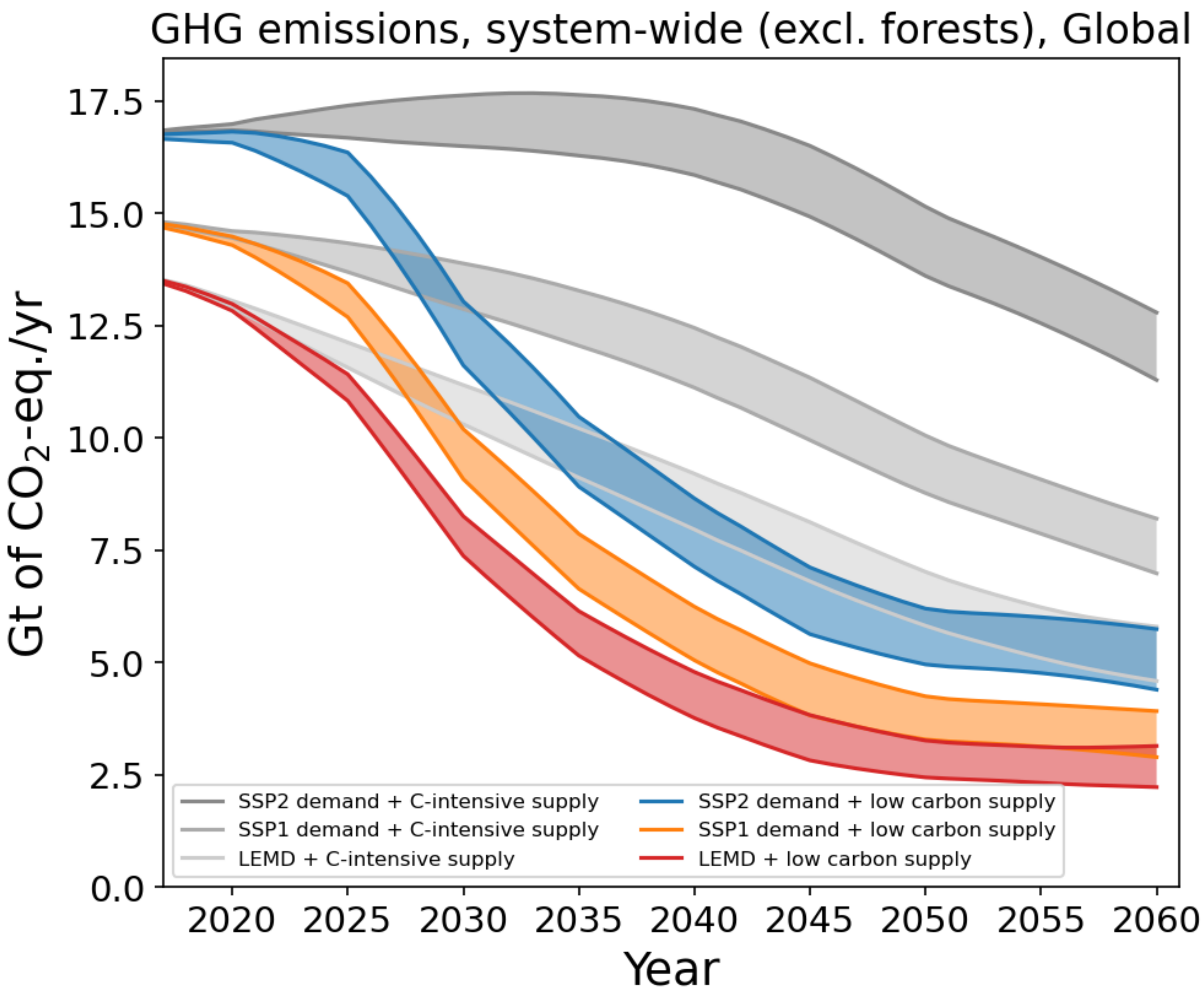
GHG time series by sector and region



Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

GHG reduction and scenario dependency

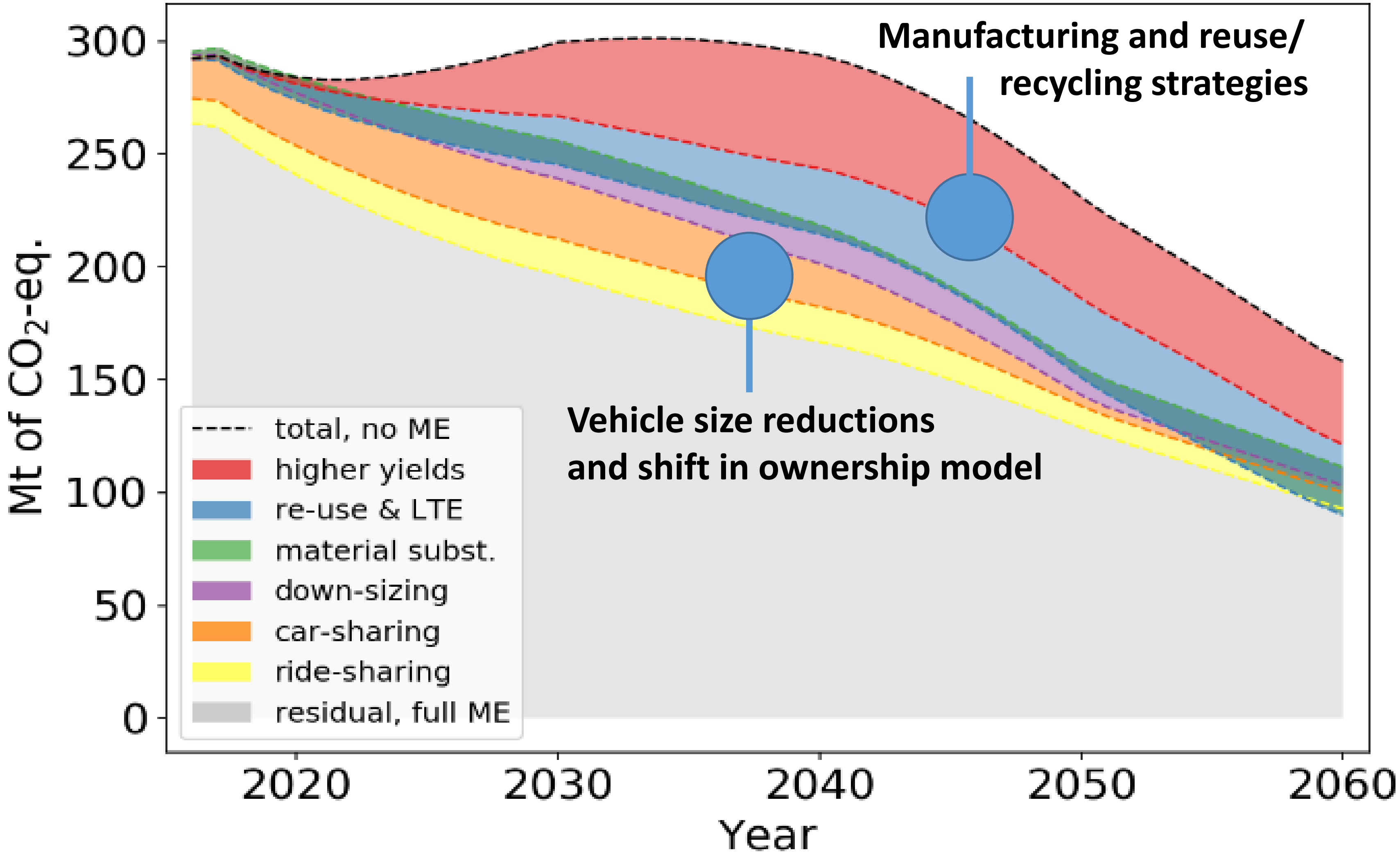




Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

Expanding into vehicles

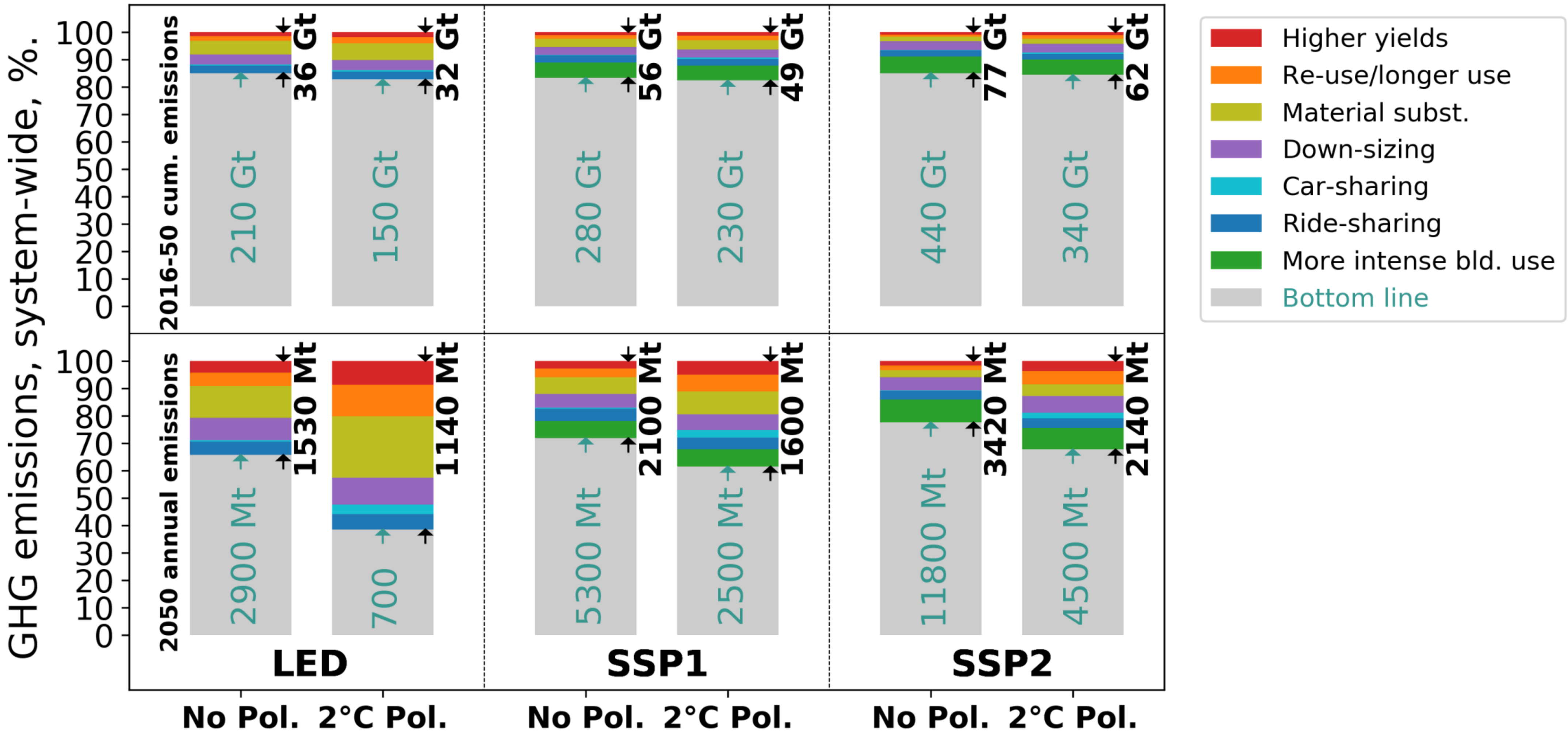
Reduction in material-related GHG, passenger cars



World, scenario with low mitigation and adaptation challenges (SSP1),
Low-carbon energy mix

Source: Pauliuk et al. 2021, https://doi.org/10.1038/s41467-021-25300-4

Material efficiency and climate impact, global scale



Source: Pauliuk et al. 2021, https://doi.org/10.1038/s41467-021-25300-4

Key takeaways

- Industry is not an end-use sector, it's output is largely driven by the product and material stock dynamics in transport, buildings, and services
- Studying demand-side solutions is key – they offer the largest reduction potential for raw material consumption and GHG
- Different modelling approaches deliver specific insights (economic, material, energy, land). Need consistent data!
- Tbd: Combined modelling framework allows for a robust, comprehensive and consistent analysis, including economic implications and rebound effects.

Thank you for your attention!

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Supplementary material

Scope of R strategies

	IAM/Energy system/	IE	CGE
Refuse	Exo service reduction		Income and labour repercussion
Rethink	Exo demand shifts		Capital stock depreciation, without material stock depr.
Reduce	Material substitution, yield improvement		Material productivity
Reuse/Repair/Refurbish/Remanufacture/Repurpose	Longer lifetime – possibly relate to manufacturing		If value chain is different include separately
Recycle	Need to introduce recycling for specific materials	Covered in detail including material quality	Need to introduce new sectors for recycling
Recover	Incineration of residues and some material		Incineration of residues and some material

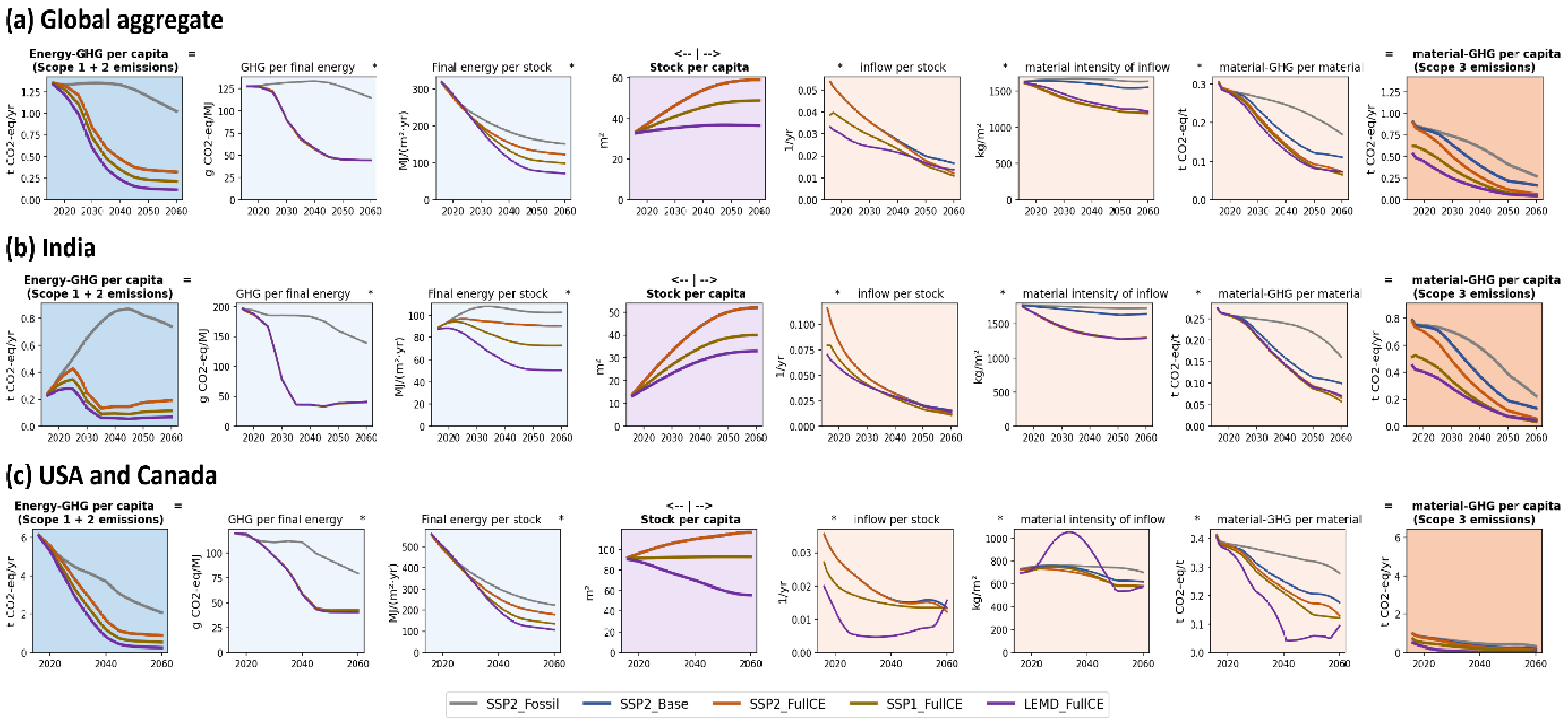
Main driver: per capita floorspace for residential and non-res. buildings

Table 1: Central parameters for the stock-flow-service nexus of the use phase: Initial and future service level (per capita floorspace) for the different socio-economic scenarios, and the typical building lifetime. Building lifetime can vary across age-cohorts and here, typical values are indicated. Region and scenario acronyms are defined in the text.

	2015 per capita stock (m²)		**2050 per capita stock, m², LEMD / SSP1 / SSP2**		**Typical Building lifetime (yr)**	
Regions	**residential**	**non-res.**	**residential**	**non-res.**	**residential**	**non-residential**
SSA	11.4	0.8	19.4/26.9/33.4	7/10/12	50	45
LAM	34.4	3.0	30.3/34.4/44.3	7/10/12	50	45
EU_UK	37.7	12.5	31.2/40.1/46.2	12.8/16.1/20	100-180	60-80
China	36.1	10.8	31/40/50	13/16/20	27-40	30
India	11.7	0.8	25/28.7/38.1	7/10/12	50	45
Other_Asia	20.8	2.6	29.4/34.3/39	7.5/10.5/12.6	50	45
MNF	24.6	8.3	29.6/38.9/43.6	9/12/15	100	45
REF	23.5	5.9	29.5/38.9/43.5	9/12/15	120	60
Other_OEDC	38.0	6.5	30.5/39.9/44.5	9/12/15	100	50
USA_CAN	66.8	24.1	42.5/66.8/83.7	18/26/30	110	45

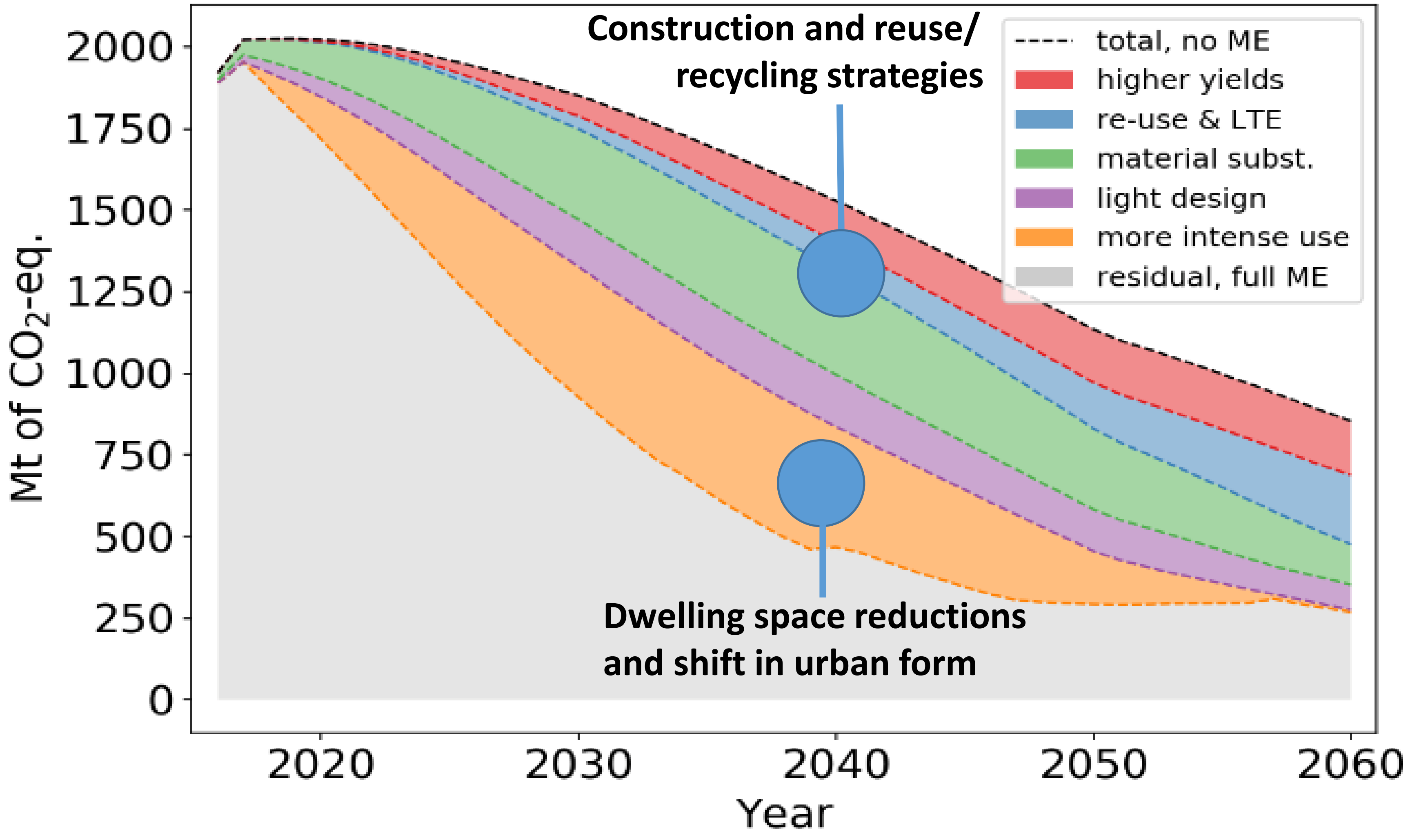
Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

Decomposition analysis of Scope 1+2 and Scope 3 GHG



Source: Pauliuk et al. (2024), DOI: 10.1111/jiec.13557

Reduction in material-related GHG, residential blds.



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