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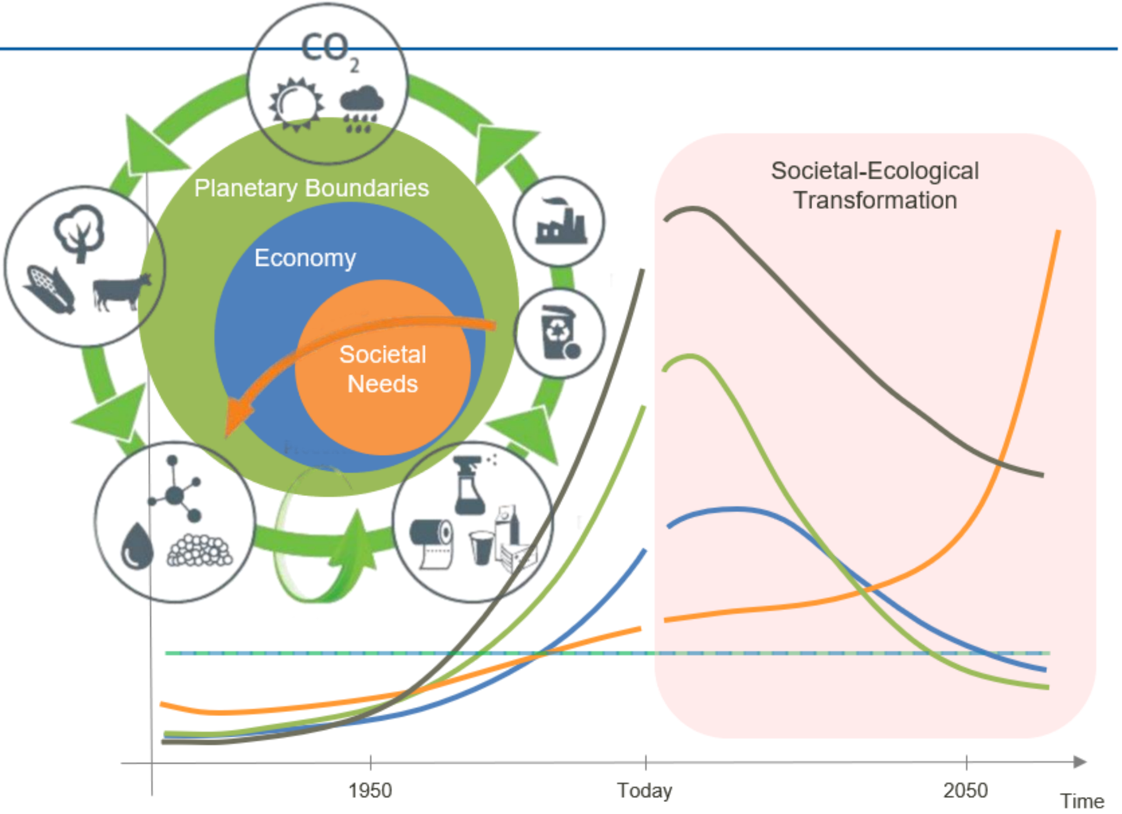
Holistic and Integrated Life Cycle Sustainability Assessment: Background, Methods and Results from Two Case Studies



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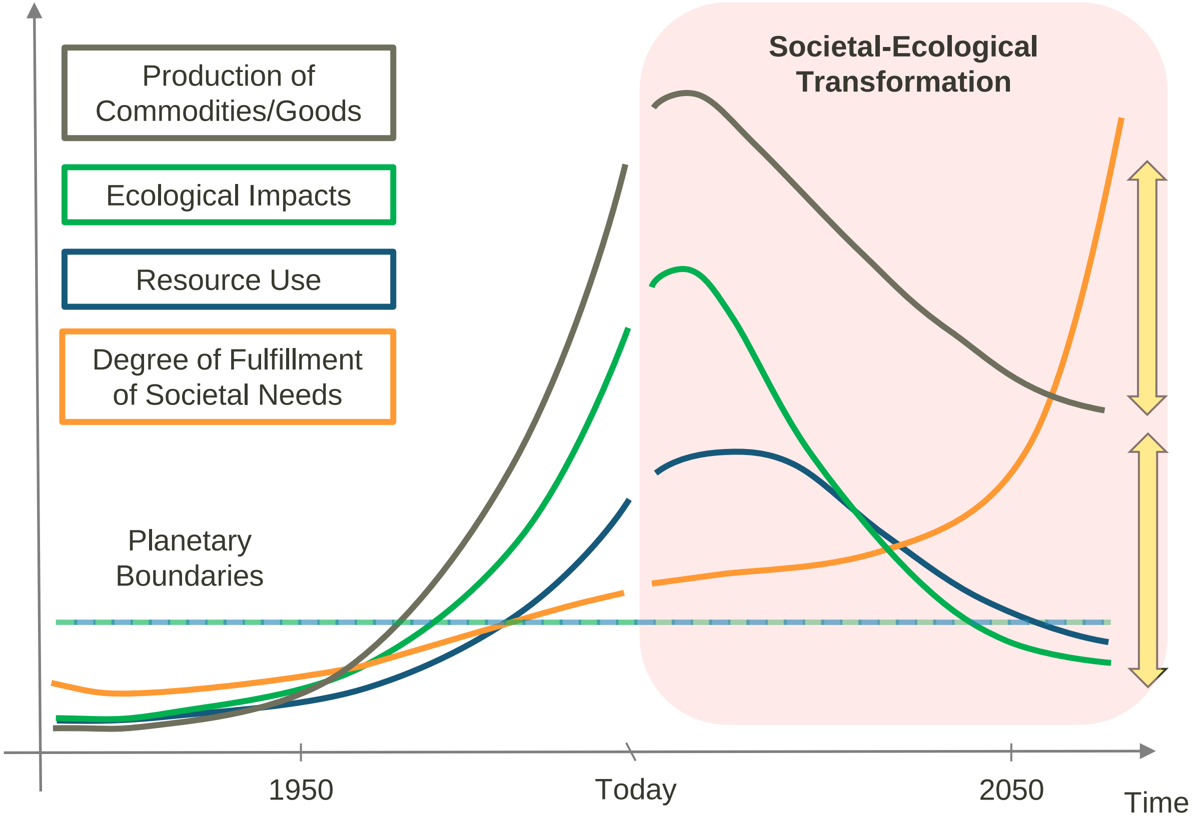
1. Societal-Ecological Transformation and Sustainable (Bio)Economy

2. Holistic and Integrated Life Cycle Sustainability Assessment (HILCSA)

3. HILCSA Case Studies and Results

4. Conclusion and Outlook

1. Societal-Ecological Transformation and Sustainable (Bio)Economy



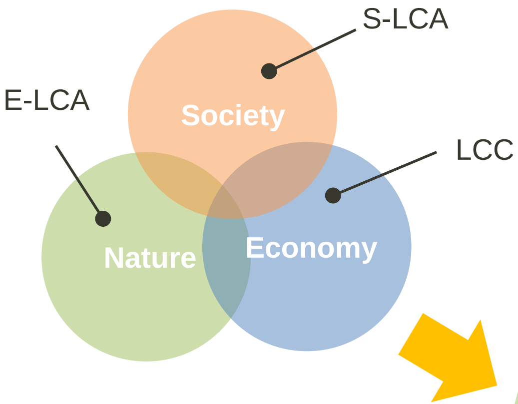
- Need for double decoupling

1. Decoupling of fulfillment of societal needs from increasing production of material commodities/goods (sufficiency)

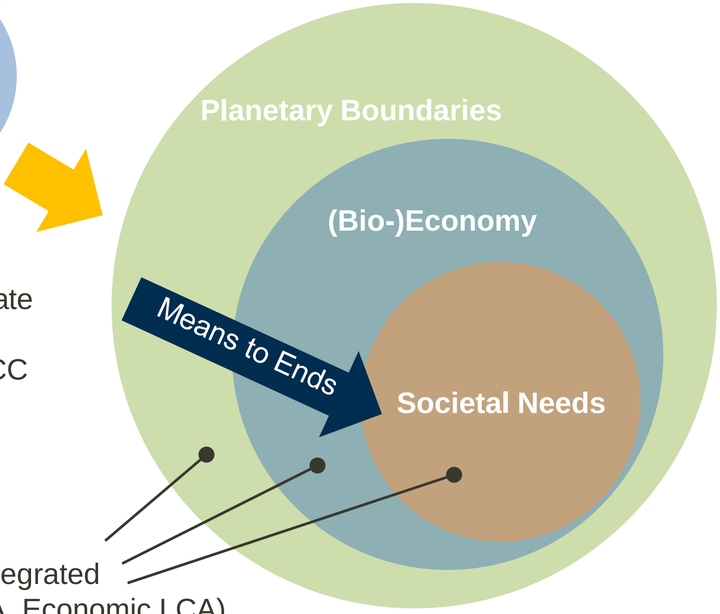
2. Decoupling of sufficient material production from increasing resource use and negative ecological, social and economic impacts (efficiency)

(Zeug et al., 2023a)

2. HILCSA: Towards Holistic and Integrated Life Cycle Sustainability Assessment



Status quo: Three pillar approach, additive and separate methods and results
LCSA = S-LCA + E-LCA + LCC



Holistic and Integrated
LCSA = f (S-LCA, E-LCA, Economic LCA)

Holistic and Integrated Sustainability Framework

Holistic: *Transdisciplinary contextualization in social sciences and political economy*

Integrated: *Social, ecological and economic aspects in one method*

- ➢ Long-term and global fulfillment of societal needs and well-being as an end (social sustainability)
- ➢ Long-term stability of our environment as a basis of reproduction within planetary boundaries (ecological sustainability)
- ➢ Technologies and economic structures as efficient, effective and just provisioning systems enabling the fulfillment of societal needs within planetary boundaries (economic sustainability)

(Zeug et al., 2020) (Zeug et al., 2021a) (Zeug et al., 2023a) (Guinée, 2016)

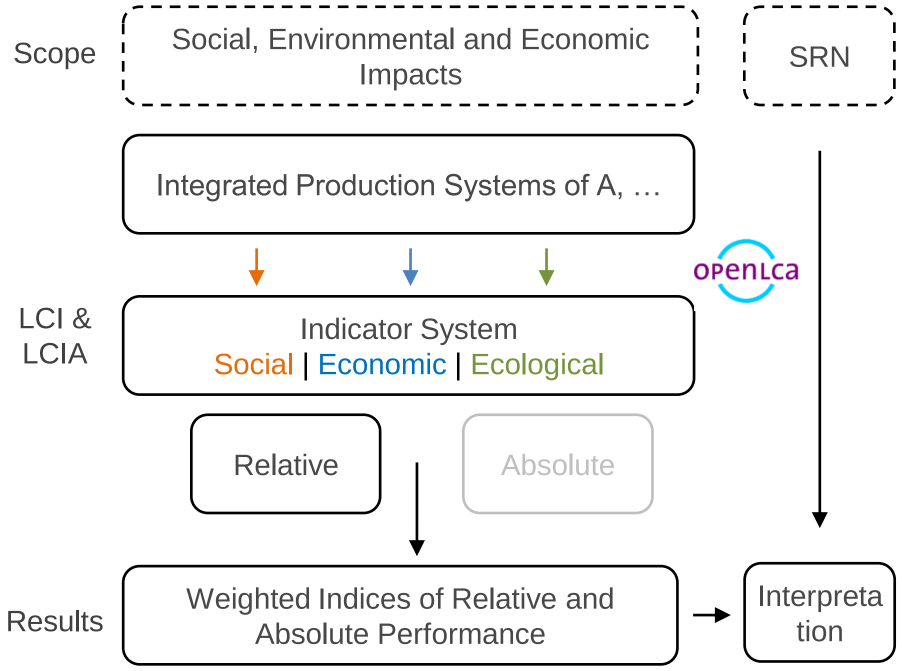
2. HILCSA: Method and Model

- Systematic LCA of ecological, social and economic impacts & the political economy of products and production systems, no in depth technical simulation
- In principle, applicable to many economic sectors, database support, full-software implementation, licensed for commercial and non-commercial use, recently HILCSA v2.1.1 released

Possible research questions:

- How socially, ecologically, and economically sustainable is the production of A compared to B, C, D?
- What are substitution effects, hotspots, trade-offs, and synergies?
- Under which technical, economic and social conditions would A, B, C and D environmentally socially and economically desirable?
- What does A, B, C, D mean in context of political economy & ecology, societal-ecological transformation and discourses and narratives?

Method and Model Framework of HILCSA according to ISO 14040/14044



(Zeug et al. 2021)) (Zeug et al., 2023a)

2. HILCSA: LCI & LCIA

Sustainability Framework		Indicators	Sources	Properties	Examples	Units for LCIA
Societal Needs	9 SDGs & subgoals	21 Indicators	Ecoinvent v3.7 ReCiPe (Endpoint) SoCa v2 (openLCA S/E-LCA) Responsa (S-LCA)	Qualitative / quantitative Functional Unit / Activity variable	Social security expenditures Payment according to basic wage	RESPONSA – PRP – Risk Levels SoCa – Risk Levels ReCiPe – physical EF 3.0 - physical
Economy	10 SDGs & subgoals	59 Indicators			Cumulative Energy Demand Average remuneration level	
Planetary Boundaries	5 SDGs & subgoals	29 Indicators	Ecoinvent v3.7 ReCiPe (Endpoint) Environmental Footprint 3.0		Fossil resource scarcity Climate Change Land Use	

14/17 SDGs addressed

Around 100 indicators

Elaborated Indicator sets & LCIA models

Normalization by relative substitution factors of impact f of product system A compared to B (dimensionless risk level)

Indicator Values of Total Product System

f for each SDG subgoal & indicator

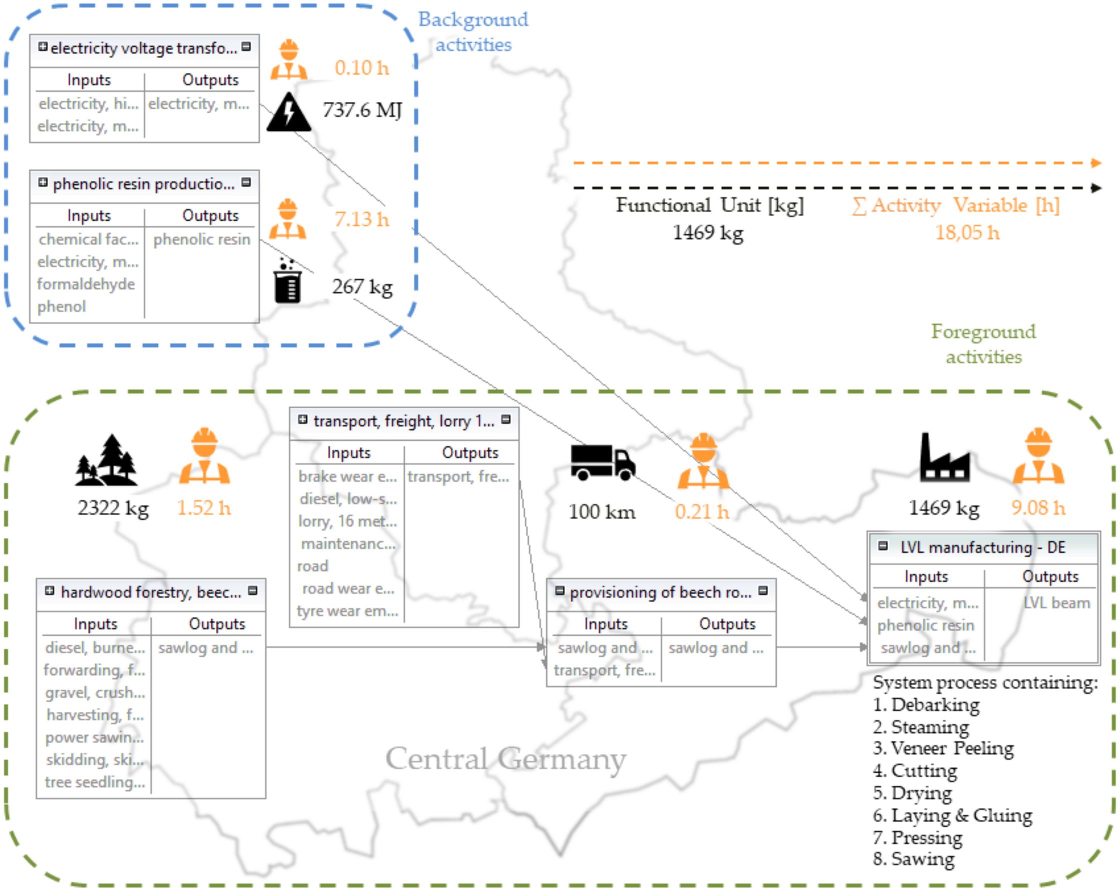
$$\frac{x^{A}_{sSDG}}{x^{B}_{sSDG}} = f^{sSDG}$$

Risk Level	f
Very Low	$f = 0.01$
Low	$f = 0.1$
Medium	$f = 1.0$
High	$f = 10$
Very High	$f = 100$

Aggregation to SDGs and weighting according to stakeholder participation (Zeug et al., 2019)

(Zeug et al. 2021)

3. HILCSA Case Studies and Results: Laminated Veneer Lumber for Building



- Substitution of Steel Beams by Laminated Veneer Lumber (LVL) in the building sector
- Existing and established regional production system in Saxony-Anhalt
- Local beech wood as primary resource
- Cradle to gate
- 18 % phenolic (fossil) resin in LVL
- Primary data from companies, secondary data soca v2 (Ecoinvent 3.7.1 APOS)

(Zeug et al. 2022)

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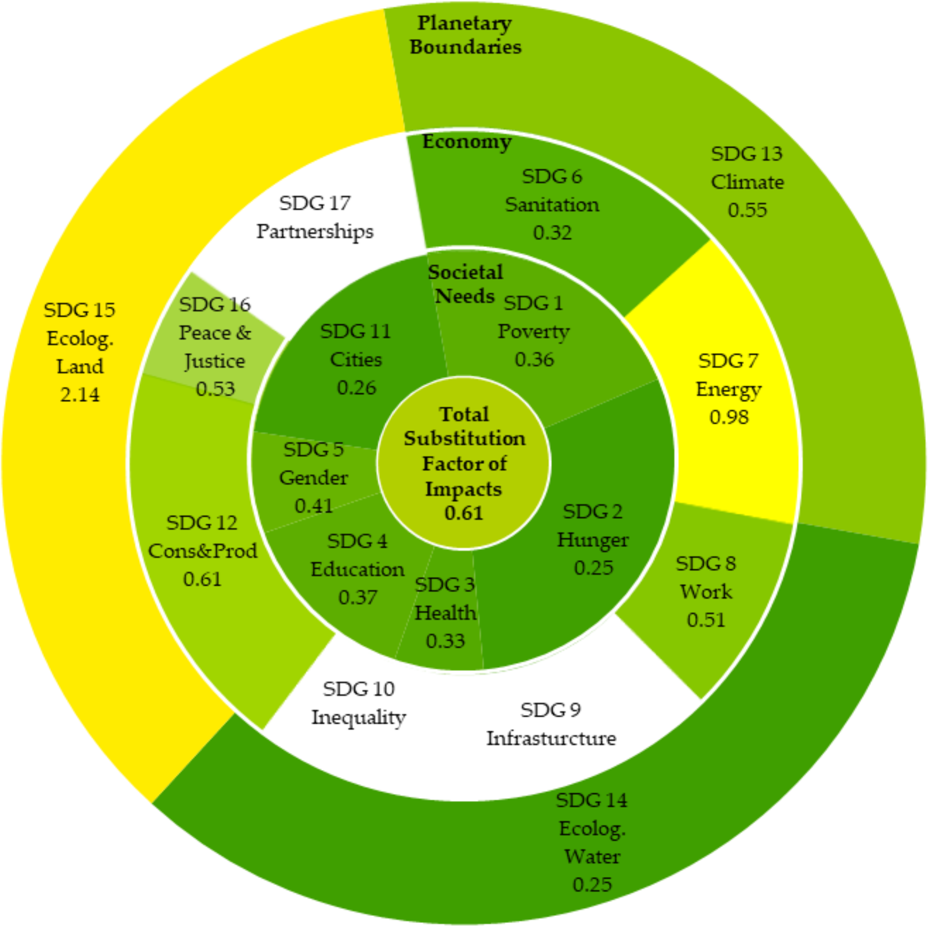
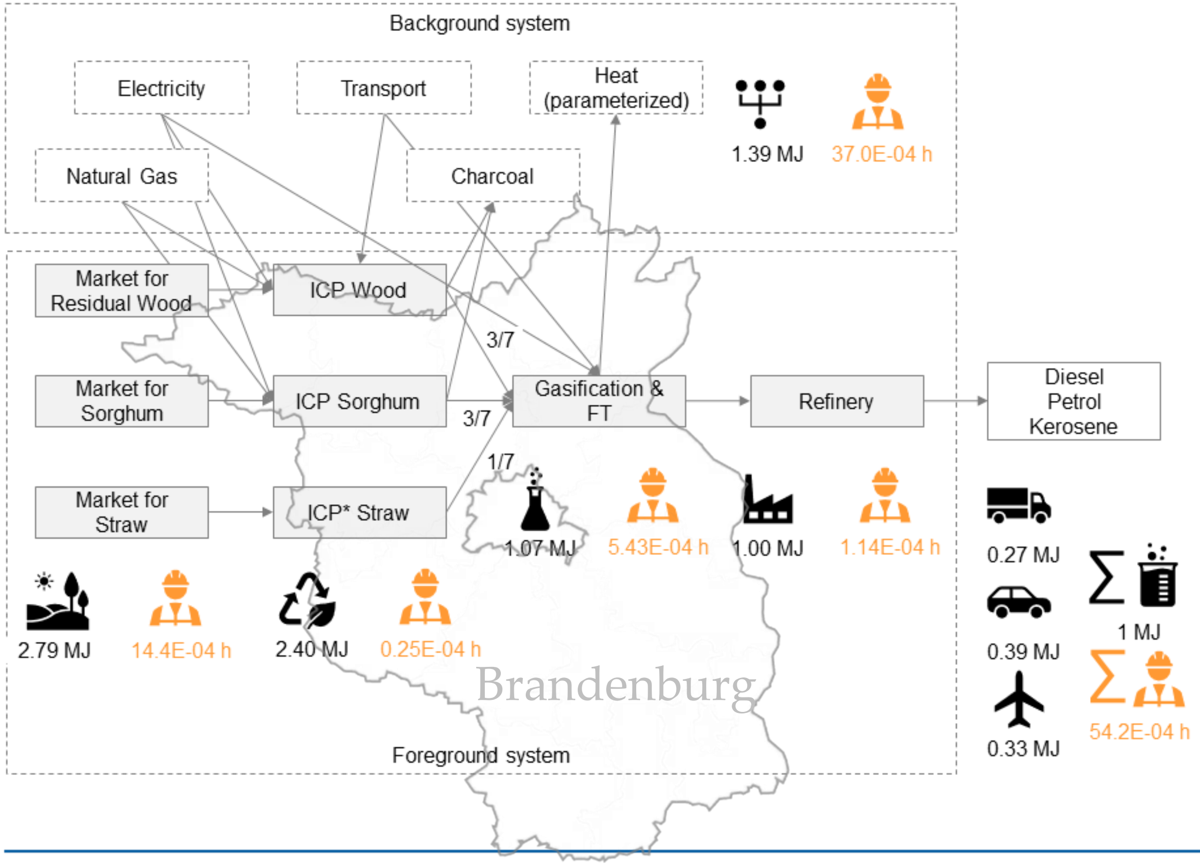


- $f = 0.62 \rightarrow$ LVL beams are less unsustainable than steel beams in most terms, 60% of neg. impacts
- $f^{social}=0.31$, better working conditions, less externalization
- $f^{ecological}=1.01$, less ecotoxicity, less GHG-emissions are compensated by much more land use ($f^{ID83}=18.15$)
- $f^{economic}=0.60$, less fossil resource extraction & energy consumption
- Phenolic resin production for 70 out of 74 indicators the main contributor of negative impacts (mass fraction only 18%)
- Aggregated results do not change much when $R = 1$, $f = 0.57$, $f^{social} = 0.33$, $f^{ecological} = 1.02$ and $f^{economic} = 0.59$

Risk Level	Very Low	Low	Medium	High	Very High
f	0.01	0.1	1.0	10	100

(Zeug et al. 2022)

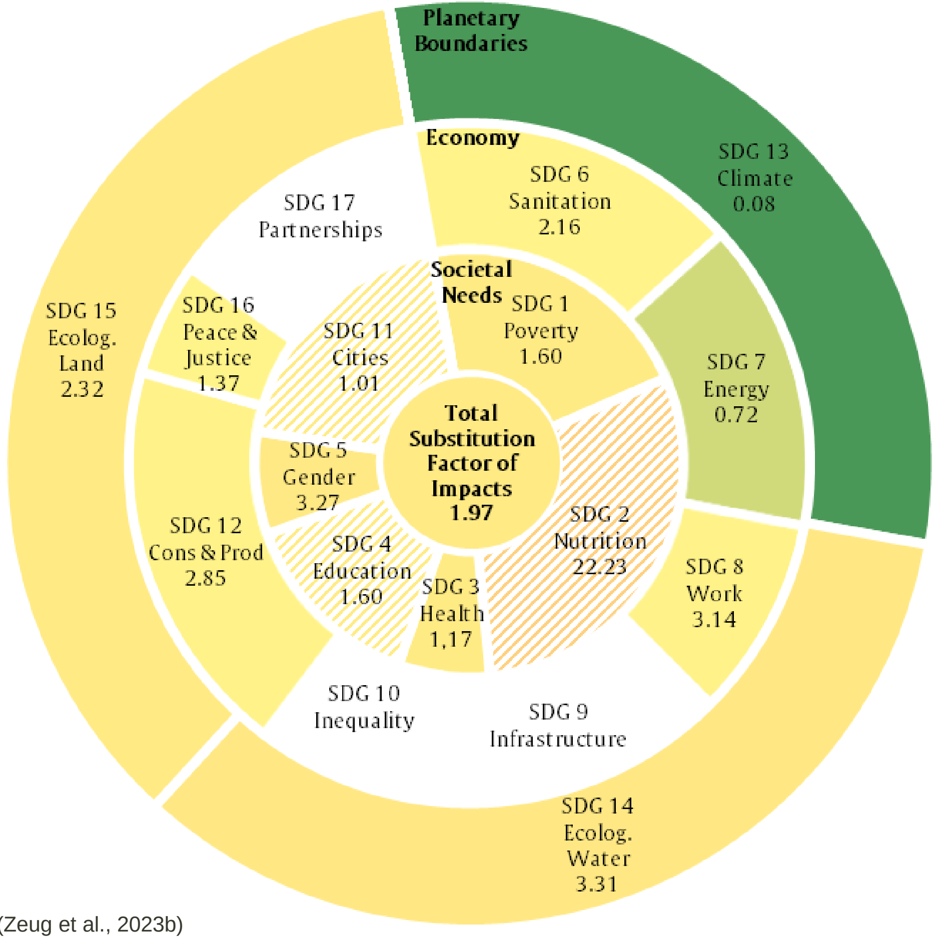
3. HILCSA Case Studies and Results: Biomass to Liquid



- Substitution of fossil fuels by biomass to liquid (BtL) fuels (as well as compared to electric vehicles and trains)
- Prospective regional production system in Brandenburg
- Local Sorghum, straw and residual wood as primary resources
- Cradle to gate BtL production, common use phase of BtL & fossil fuels, cradle to grave for all transport options
- Modelled in a prospective electricity grid mix in Germany in 2030 (2030: 163 gCO2eq./kWh; 2017: 589 gCO2eq./kWh)
- Energetic conversion efficiency 56 % (inputs, output fuel)
- Primary data from companies and research, secondary data soca v2 (Ecoinvent 3.7.1 APOS)

(Zeug et al., 2023b)

3. HILCSA Case Studies and Results: Biomass to Liquid



- $f = 1.97 \rightarrow$ significant higher impacts of BtL production compared to fossil fuels
- Especially high risks for health and indigenous rights indirectly by indirect land use changes (f^{ID5}=125.5), land use (f^{ID91}=139.2) & water use (f^{ID87}=142.3) of sorghum, straw and electricity
- Pollution from ash treatment (f^{ID17}=19.7); migrant workers under bad conditions (f^{ID43}=16.2); working accidents (f^{ID57}=20.2), use of minerals and metals (f^{ID71}=19.2)
- Working conditions are not much worse than fossil fuel production systems, but 2.7 times more work
- 28 % working time in Germany; 35 % in India as biggest contributor, nearly entire workflow related to hard coal mining
- Most positive effects come from credits from heat use in FT process, substituting fossil heat production

Risk Level	Very Low	Low	Medium	High	Very High
f	0.01	0.1	1.0	10	100

(Zeug et al., 2023b)

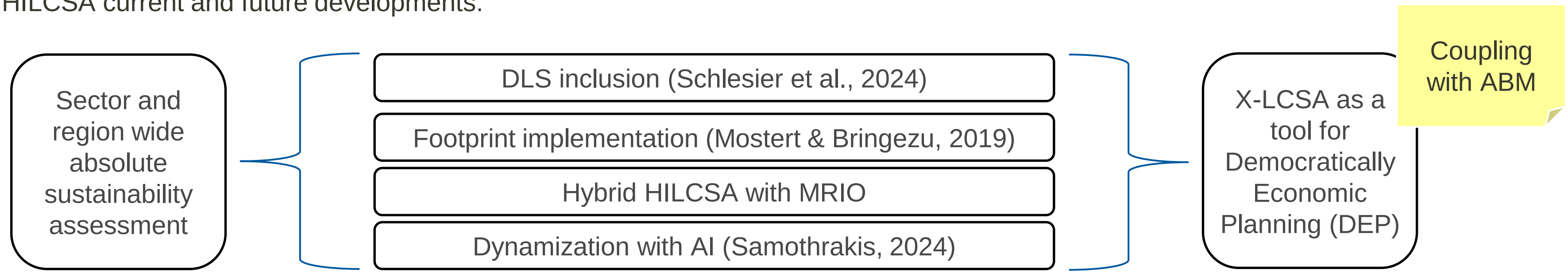
4. Conclusion and Outlook: Bioeconomy & HILCSA

Bioeconomy can be more sustainable, but inherent contradictions if it is only a substitution (e.g. land use) (cf. Bringezu et al. 2020)

- 1. Food, 2. Materials, 3. Energy, I. Reduce, II. Reuse, III. Recycle, use in general as far as planetary boundaries are not transgressed
- Social, ecological and economic effects are intertwined in synergies and trade-offs; GHG savings can be overcompensated by ecological, social and economic risks; focus only on GHG has high risk for mis-regulation and mis-management
- When the German BE relies on increasing biomass imports, global inequalities and externalizations are maintained (extractivism cf. Backhouse et al. 2021)
- Innovations and technology are necessary but by no means sufficient for socio-ecological transformation, biggest challenges are not technological ones, but societally overcoming structural mindsets of political economy and growth oriented capitalism

Currently several case studies with HILCSA are in preparation and publication (chemical industry, agriculture, transport, wasterwater management, …) and HILCSA is licensed for SMEs

HILCSA current and future developments:



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