The Role of Input-Output Analysis in Modeling Sustainability Transitions

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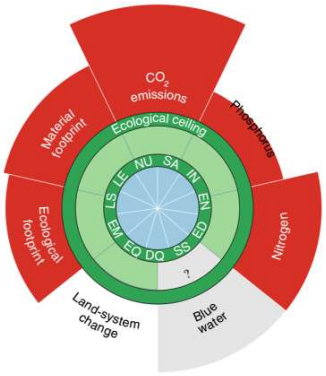
Introduction: sustainability transition scenarios

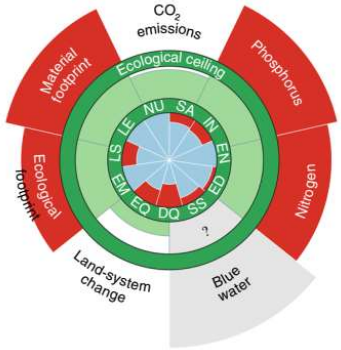
The social shortfall and ecological overshoot of nations

Andrew L. Fanning [1,2] ✉, Daniel W. O'Neill [1], Jason Hickel [3,4] and Nicolas Roux [5]

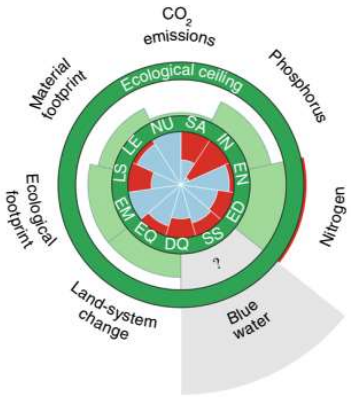
2015



Germany



China



Nepal

"deep transformations are needed to safeguard human and planetary health"

Introduction: sustainability transition scenarios

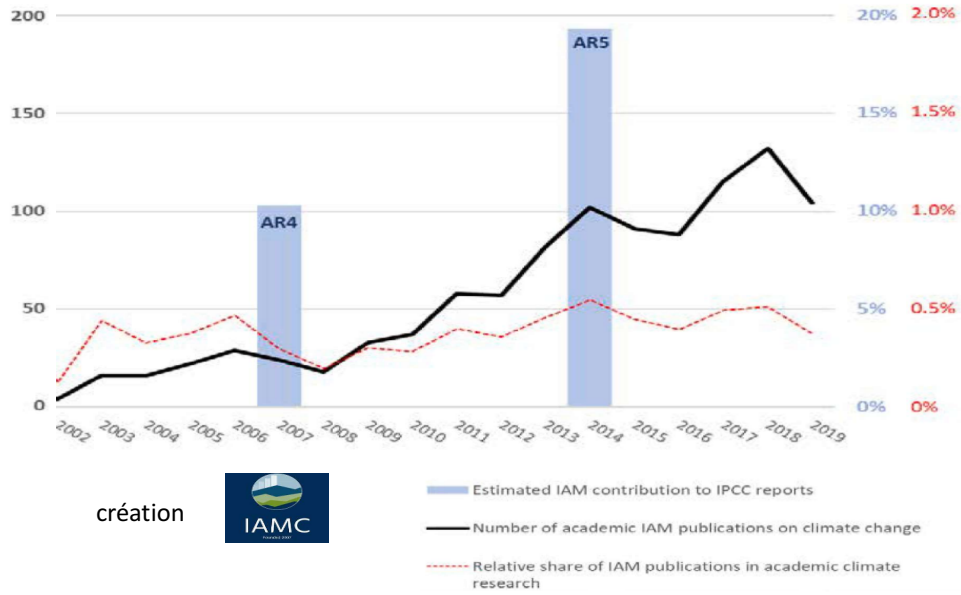
- Need to explore **feasible forward-looking scenarios and transformation pathways** conducing to a ‘safe and just space’

- Pathways should provide information on **detailed socioeconomic and ecological transformations and associated policies**

- Key insights for economic and ecological planning

Integrated assessment models: capabilities and gaps

- Central tools for exploring strategies for climate change mitigation and other policy goals (van Beek et al., 2020)



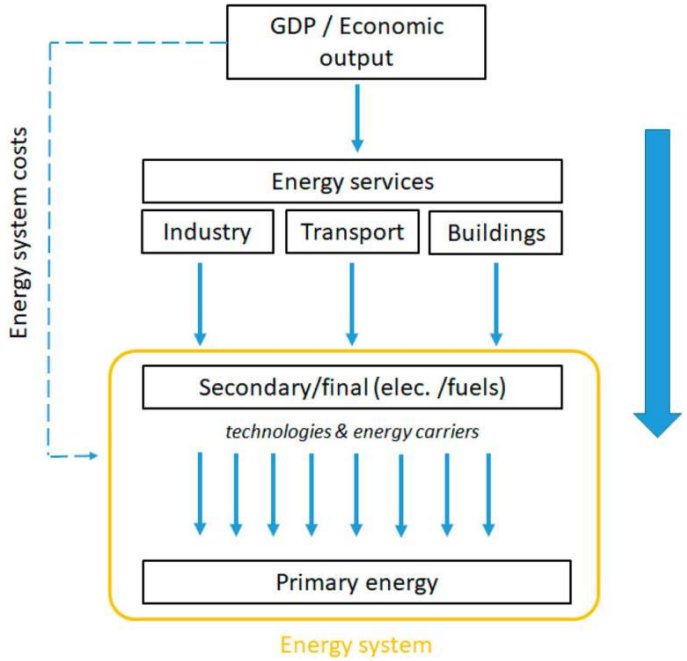
création IAMC

Integrated assessment models: capabilities and gaps

- Central tools for exploring strategies for climate change mitigation and other policy goals (van Beek et al., 2020)
- Simulate interactions within and between critical systems including energy, economic, and land-use
- Quantify forward-looking scenarios and transformation pathways, and cost-effective technological developments to achieve climate targets

Integrated assessment models: standard modeling approach(es)

Figure 1. Linear representation of energy – economic systems in typical IAMs (based on ESMs).



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Integrated assessment models: gaps

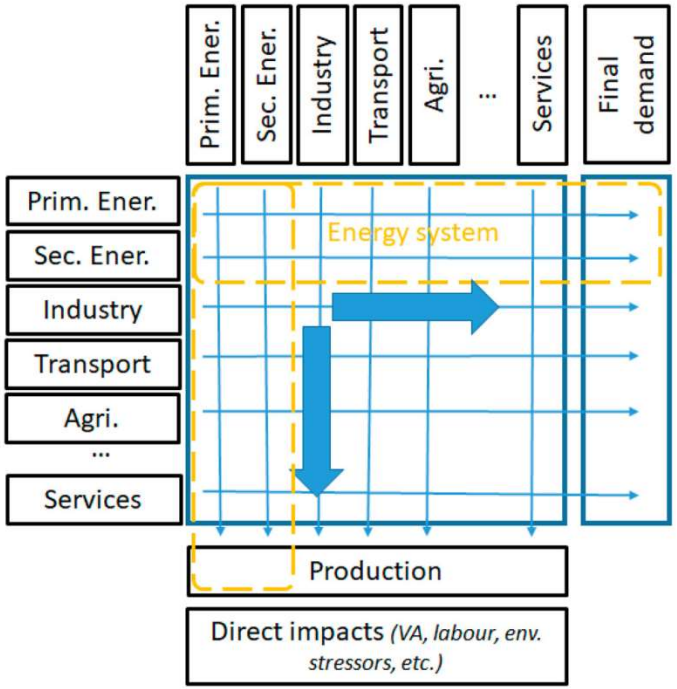
- Weak coverage of **linkages between biophysical and economic systems**
  - Lifecycle impacts of technologies and net energy availability (Pauliuk et al., 2017; Delannoy et al., 2024)
  - Material balances
  - Role of energy in economic growth
- Insufficient representation of **energy demand patterns**, **structural change** in the economy, inter-sectoral linkages and broad **environmental impacts across supply chains**
- **'Green growth machines' anchored in neoclassical economics**

Environmentally-Extended Input-Ouput-Analysis (EEIOA)

- IOA: basis of applied macroeconomics (Leontief, Stone) emphasizing a multi-sectoral approach and inter-industrial linkages in the economy
- Focus on assessing **impacts across entire supply chains from the perspective of consumption**
- EE-IOA: environmental and material aspects of supply chains, key tool in Industrial Ecology
- MRIO approach and recent database development (GTAP, EXIOBASE, EORA, WIOD, etc.): comprehensive **environmental and socioeconomic impacts through supply chains and trade**

Environmentally-extended Input-Ouput-Analysis (EE-IOA)

Figure 2. Interdependence of economic sectors in IOA.



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Environmentally-extended Input-Ouput-Analysis (EE-IOA):

- Capabilities
  - **Environmental** (carbon, other pollutants, material, resource, etc.) and **socio-economic** (labour) **footprints of nations** (Hertwich & Peters, 2009; Giljum et al., 2016)
  - **Industrial ecology** of linked material and carbon footprints (Hertwich, 2021)
  - Ecological overshoot of nations, carbon inequalities and progress towards the SDGs (Fanning et al., 2022; Chancel, 2022; Gómez-Paredes & Malik, 2018).
- Gaps
  - Focus on **past relationships** and not on forward-looking scenarios
  - **Static approach**: fixed technical, socio-economic (labour, trade) and environmental coefficients

IAM-IO linking

- Recent efforts to combine IAM and IO to address novel challenges in forward-looking scenarios
- Soft-linking (independant models and data)
  - Scenario-based LCA-IOA: **life cycle env. impacts of future technology development** and deployment (e.g. Hertwich et al., 2015)
  - **Environmental and socio-economic impact assessment of future transition scenarios** (supply and demand-side transformations) (e.g. De Koning et al., 2016)
- Towards more advanced IAM-IO integration:
  - fostering a structured community interaction based on multi-model ecology, including IAMs, ESMs, MRIOs, and LCA-IOs
  - Built-in IAM-IO integration (e.g. Budzinski et al., 2023)

Ecological Macroeconomic IAMs

- Need for a new economic approach of energy transition models encompassing complexity, nonequilibrium and uncertainty (Hafner et al., 2020)
- Emerging **Ecological Macroeconomic Models (EEM)** (Hardt & O'Neill, 2017): combination of Post-Keynesian macroeconomics and ecological economics
- **Towards Ecological Macroeconomic IAMs**: integrating *IOA*, *system dynamics* and/or *stock-flow consistent* (SFC) macroeconomics
  - Better capture economic and biophysical linkages to assess integrated concerns about ecological impacts, financial stability, and social progress

Multi-dimensional sustainability impact assessment of global/regional scenarios

- Implications of mitigation pathways for SDGs (Soergel et al., 2021) and planetary boundaries (van Vuuren et al., 2025) with IAMs
- EEMRIO framework: integration of various scenario information
- More consistent and comprehensive assessments at country scale based on projected environmental footprints (consumption-driven) further related to SDGs and/or ecological boundaries
- Assessment of employment impacts through supply chains, income distribution and ecological inequality within and between countries

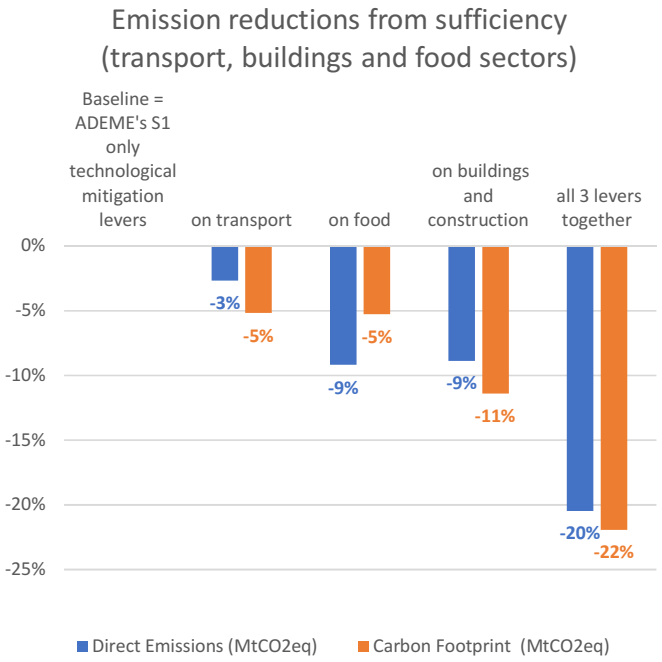
Calculating lifestyle shifts and sufficiency

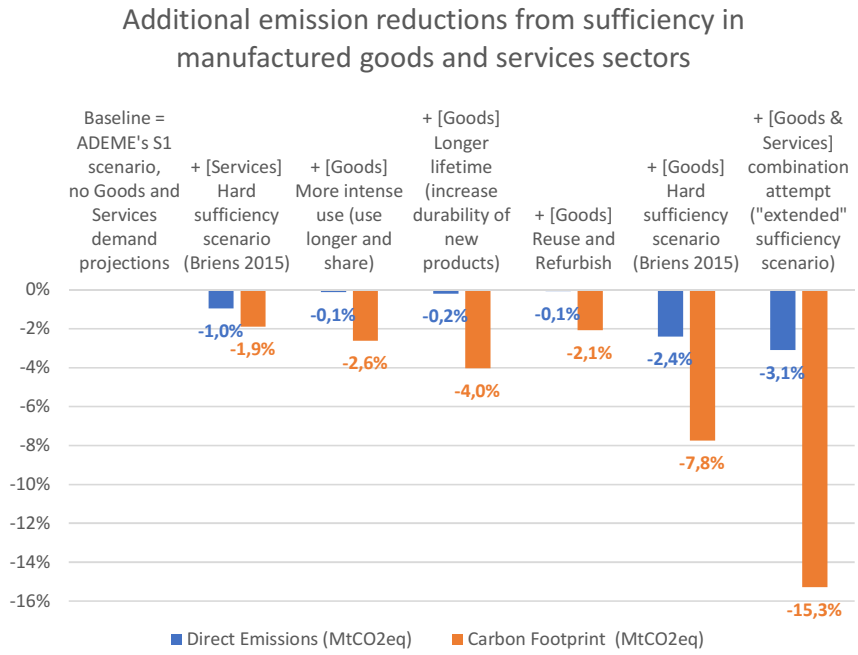
- MRIO: comprehensive exploration of **demand-oriented measures from an economy-wide perspective** (Wood et al., 2018):
  - Three main options: i) detailed changes of consumption-pattern, ii) modification of inputs for production in industries and iii) reducing direct environmental impacts
- **Lifestyle shifts and sufficiency** = avoiding material and energy demand through changes in practices and behaviours (while delivering well-being for all)
  - Reductions of consumptions, modal shifts, product longevity, sharing practices, etc. (Sandberg, 2021)
- **IOA: comprehensive representation of sufficiency** ranging from direct end-use energy sufficiency for transportation and housing to granular differentiation between high vs low resource-intensive or luxury vs essential goods and services (Vita et al., 2019)

Calculating lifestyle shifts and sufficiency: case-study on France

BUILDINGS / CONSTRUCTION		
- m2	Energy sufficiency practices in housing consumption - More people per household, so housing surface -5% - Tertiary surfaces: -10% - New constructions: tertiary -60%, housing -97% - Real estate activity (proportional to total surface) - Energy use in housing and tertiary (due to smaller surfaces) + Reuse of elements and materials	
TRANSPORT		
- p.km/t.km	- Passenger flows: -45% - Freight transport: -45% - Goods flows + Higher occupancy rate for passenger transport Modal shift (-road, +train, +active modes, -airplane) - Vehicles : -45% - Vehicle weight reduction + Vehicle repair + Reuse of materials ("other transport equipment") - Car sales services (linked to number of registrations and vehicle fleet)	
FOOD		
- meat - calories - waste	Less meat-based diet (households and restaurants) - Chemical inputs (organic agriculture) - Plastic packaging - Drinks, sugar, tobacco	
MANUFACTURED GOODS		
- needs + reuse (less new)	- Communication and audiovisual equipment (+lifespan, +sharing, -needs) - Electronic appliances (+reuse) - Computers and office equipment (+reuse) - Clothing (+reuse) - Household chemicals - Machinery and equipment - Domestic furniture (+reuse) - Everyday objects (toys, instruments, sports items, etc.) (sharing) - Media and paper supports	
SERVICES		
- Finance (including insurance for fewer material goods) - Advertising - Telecom. - 'Comfort' services - Economic administration and defense + education Note: Needs for recreational and health services evolve little	Financial services	Insurance activities become non-profit, fewer financial services for households: - Auto insurance (proportional to vehicle fleet) - Health insurance decreases due to better health from good practices (diet, sports, lifestyles) **-40%**
	Business services	- Advertising - Other business services consumed by households **-55%**
	Telecommunication services	- telecommunications **-60%**
	Personal services	- Body care - Pet services - Other personal services **-20%**
	Recreational, cultural, and sports services	Encourage cultural activities not requiring material support => - consumption of cultural services (?) - commercialization of sports activities - gambling (stopped) **+2%**
	Hotel - catering	- Restaurant consumption, especially fast food + Collaborative neighborhood kitchens - Hotel and camping nights - Tourist accommodation infrastructure + Free accommodation with residents **-45%**
	Health	- Fewer health needs due to healthier lifestyle + Social action without housing - Veterinary activities due to fewer animals **-2%**
	Education	+30% per student (Increase in continuing education not included) **+30%**
	Public administration	- Shared defense at European level - R&D in economic affairs **-13%**
	Trade unions and associations	(-)

Calculating lifestyle shifts and sufficiency: case-study on France





Fontaine et al.

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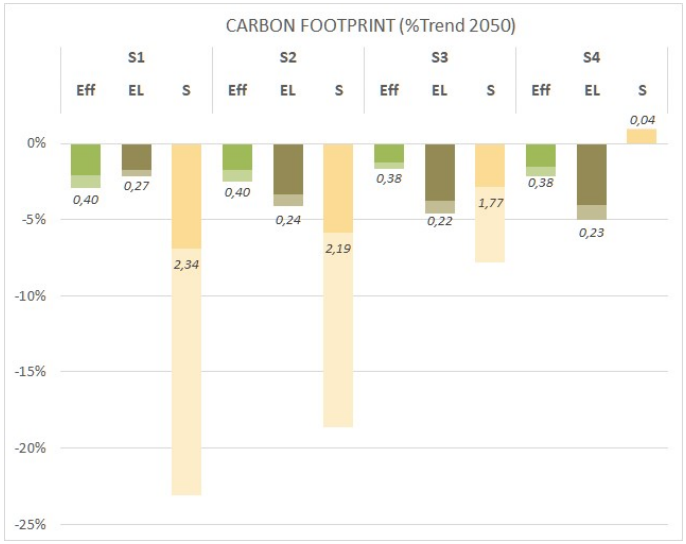
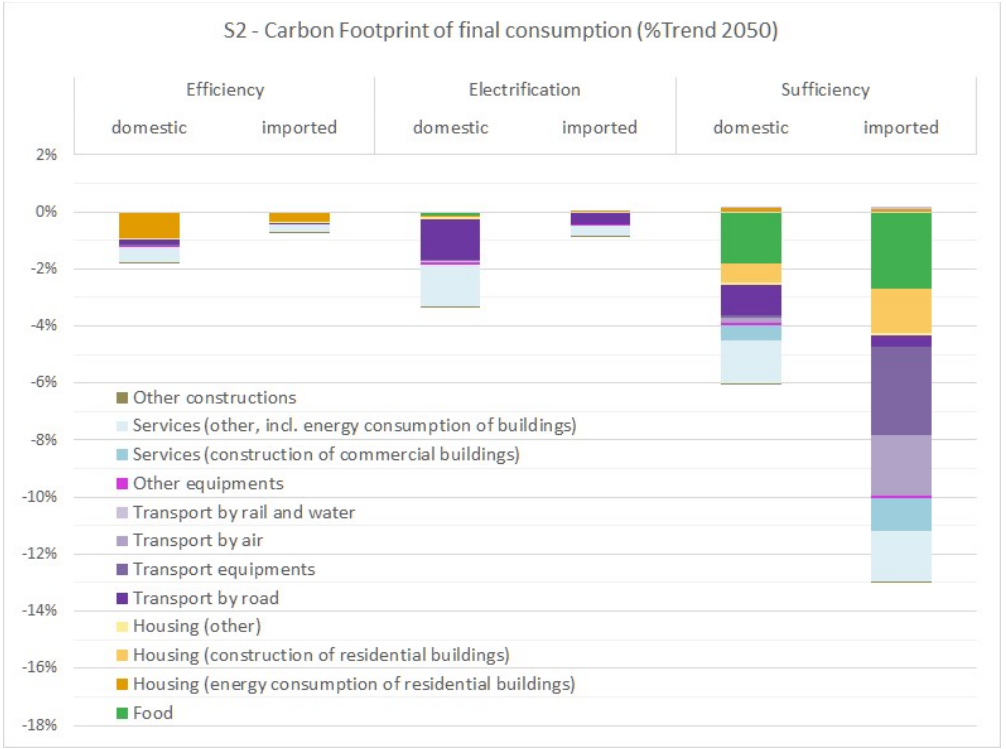




Fontaine et al.

Informing structural change aligned with a post-growth transition

- **Post-growth (PG)**

  Prosperous economy that does not rely on continued growth; principles of *equity*, *sufficiency*, and *service provision* to achieve strong social outcomes while minimizing environmental impacts (Kallis et al., 2012; Hickel et al., 2021)

- **Limitations of current PG (climate) modeling practices** (IAMs and EMMs) (Edwards et al., 2025):

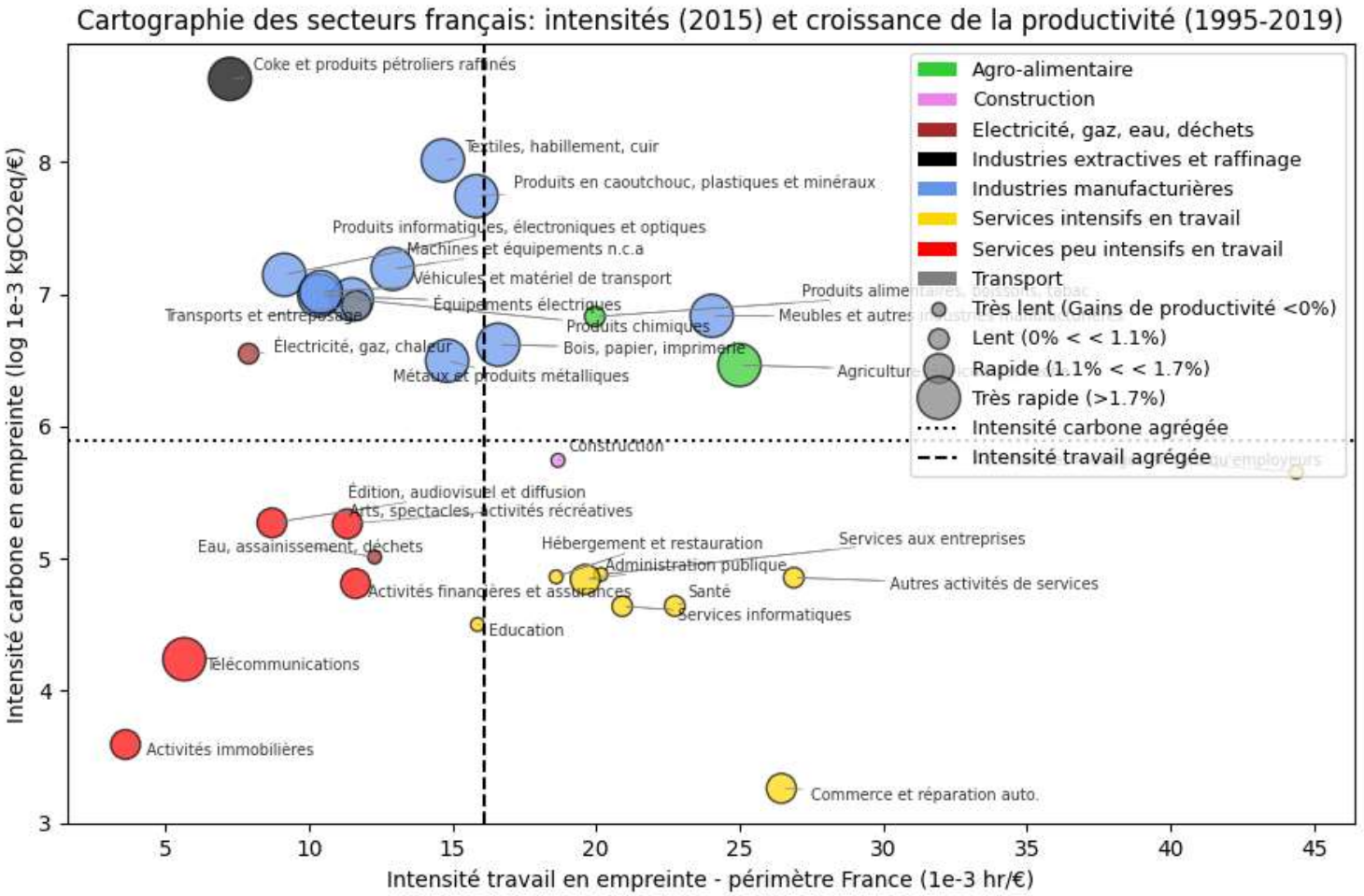
  Exogenous reductions of GDP/aggregate consumption and/or proportional downsizing of economies: 'reverse causality error'? (Savin & van den Bergh, 2024)

- Need to capture **sector-specific resizing**, sectoral interdependencies and **structural change from both supply and demand sides** = complexities of a planned and differentiated PG transition

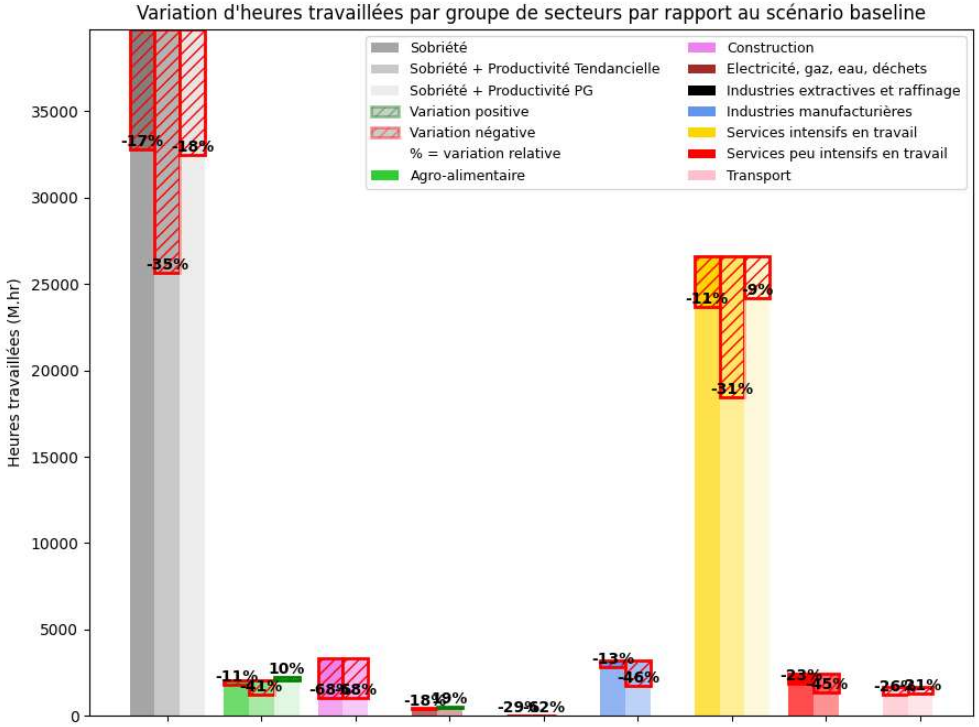
Informing structural change aligned with a post-growth transition

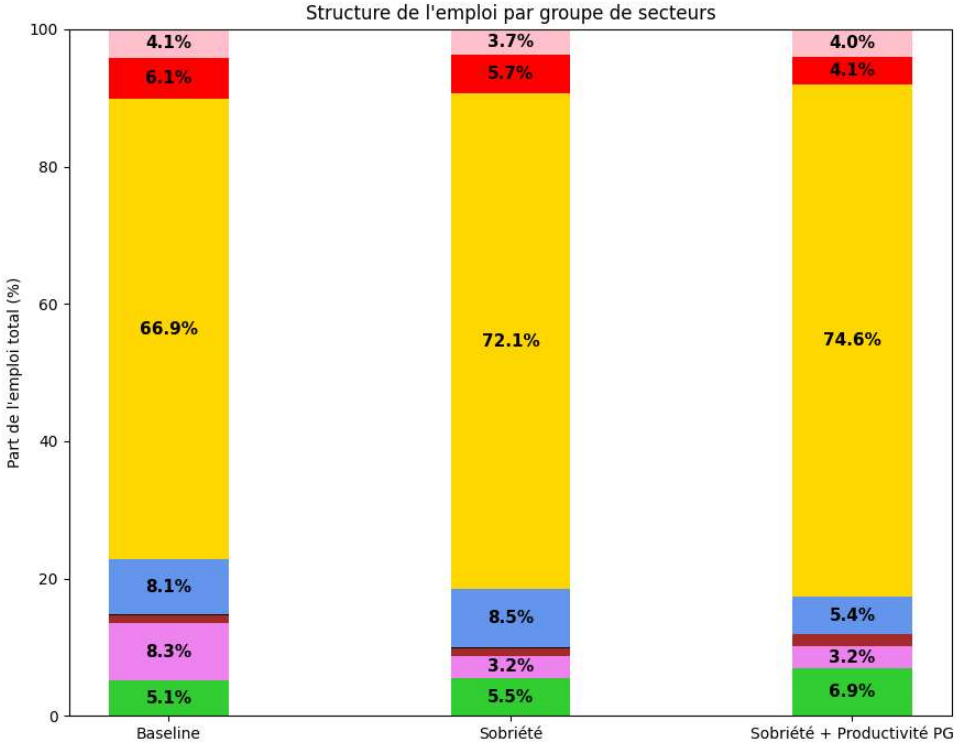
- **Sector-specific resizing** based on *ecological impacts* and *contribution to societal well-being* (Hardt et al., 2021)
- **Demand-side**: *sufficiency* principle and *equitable needs satisfaction*
- **Supply-side**: emphasizing sectors with low environmental impacts, *high labour-intensity* (and meaningful work) and *low potential for growth of labour productivity*
- IOA: assess structural change for PG by **integrating both consumption and production sides** = describe changes of both consumption and production structures, and assess environmental and employment impacts

Informing structural change aligned with a post-growth transition: case study on France



Destarac et al.

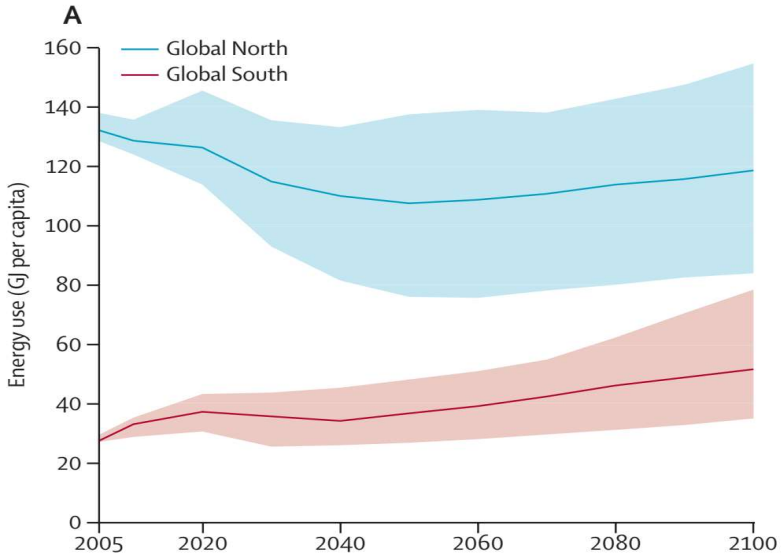




Destarac et al.

Informing structural change aligned with a global post-growth transition

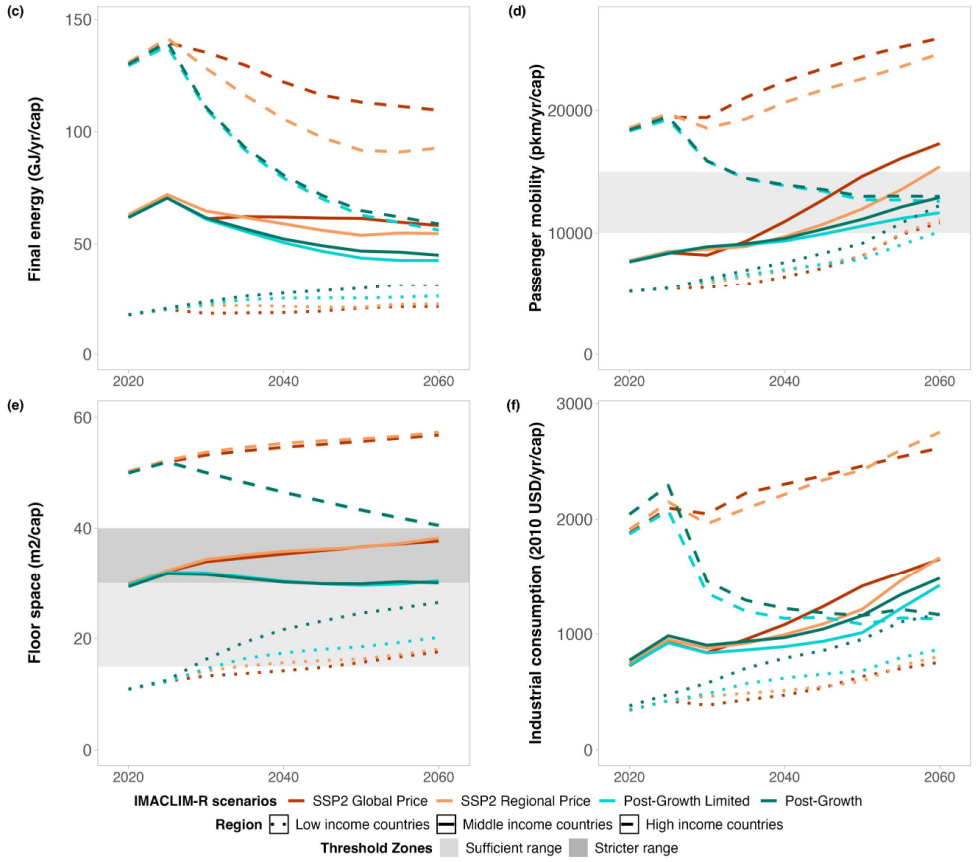
- Introducing **international justice** considerations (Zimm et al., 2024), **spatial differentiation** and explore structural change within and between countries

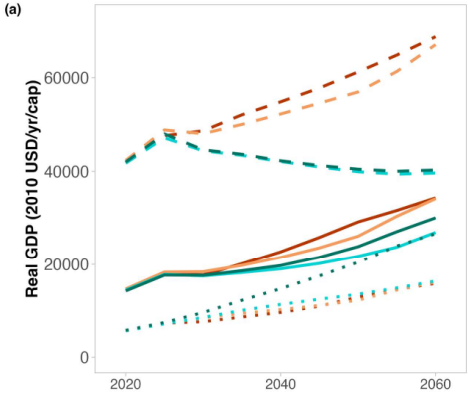


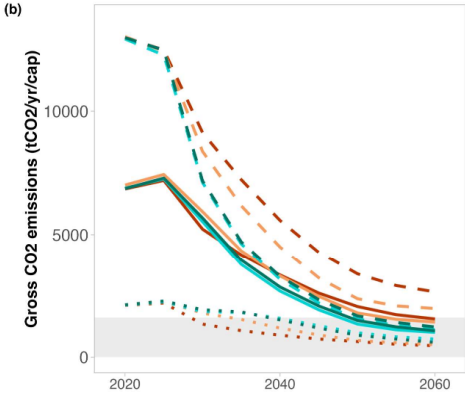
Hickel & Slamersak, 2022

Informing structural change aligned with a global post-growth transition

- Introducing **international justice** considerations (Zimm et al., 2024), **spatial differentiation** and explore structural change within and between countries
- How *sufficiency and a PG transition in high income countries* can go hand in hand with *economic sovereignty and living standard / resource convergence in the Global South* (Kallis et al., 2025)
- **Global PG and convergence scenarios with a multi-regional IO-based macroeconomic IAM**:
  - sufficiency-oriented demand-side transformations and structural economic shifts in high- and medium-income countries
  - catch-up of living standards and faster sovereign economic development in low-income countries







Dabbaghian et al.

Informing structural change aligned with a global post-growth transition

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- How *sufficiency and a PG transition in high income countries* can go hand in hand with *economic sovereignty and living standard / resource convergence in the Global South* (Kallis et al., 2025)
- **Global PG and convergence scenarios with a multi-regional IO-based macroeconomic IAM**:
- EEMRIO could be used to explore further how *unequal ecological exchange* (e.g. Dorninger et al., 2021) evolves according to structural change and PG policies

Conclusion

- **IAM–IO linking and IO-based Ecological Macroeconomic IAMs** offer strong potential to quantify transformation pathways toward sustainability and the satisfaction of human needs within ecological limits.
- These approaches are particularly valuable for **assessing structural changes linked to deep lifestyle shifts, sufficiency strategies, and post-growth transitions**—across national and global scales
- Further development of these models and scenario analyses is essential to inform **actionable strategies and guide economic and ecological planning**

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