Mapping the absolute environmental sustainability of global economic sectors within the planetary boundaries framework

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The planetary boundaries (PBs) framework defines the safe operating space (SOS) for humanity, with recent assessments indicating that seven of nine boundaries have been transgressed. Absolute environmental sustainability assessment (AESA) evaluates the economic activities against the Earthâ€™s system limits. To date, most AESA applications have quantified national-level responsibilities, offering insights for technological pathway and policy design. However, technological change, supply-chain management, and regulatory interventions are ultimately implemented at the level of economic sectors. A systematic assessment of which global sectors drive PB transgressions, and how their production-based and consumption-based responsibilities differ across multiple control variables, remains lacking.
This study addresses this gap by quantifying the absolute sustainability performance of global economic sectors from both production and consumption perspectives. We employ an Environmentally Extended Multi-Regional Input-Output (EE-MRIO) model based on Exiobase v3.9.6, which captures 163 industrial sectors and their interregional supply-chain linkages. Environmental footprints are calculated under production-based (PBA) and consumption-based accounting (CBA). Using the PB-based impact assessment (PB-IA) method, we apply characterization factors (CFs) to translate the environmental footprints into metrics related to nine PB control variables (CVs): climate change, biogeochemical flows (nitrogen and phosphorus surplus), land-system change, freshwater use, biosphere integrity (functional and genetic diversity), stratospheric ozone depletion, and atmospheric aerosol loading. Absolute sustainability is evaluated by comparing sectoral pressures against allocated shares of the global SOS, applying gross value added (GVA) as the sharing principle for PBA and final consumption expenditure (FCE) for CBA. For interpretability, sectors are aggregated into ten NACE-based categories.
Our results reveal strong asymmetries between production- and consumption-based responsibilities across sectors. Agriculture, forestry and fisheries exhibit dual transgressions (PBA and CBA perspectives) across all assessed CVs, indicating systemic pressure both at the production base and along global food supply chains. Mining, manufacturing, electricity generation, and transport display dual transgressions primarily in climate change and aerosol loading. In contrast, construction remains within its allocated SOS under PBA but shows consumption-based transgressions for climate change and aerosol loading, driven by embodied emissions in upstream material supply chains. A systematic disparity emerges between economic value creation and PB transgressions. Approximately 30~40% of global GVA and FCE is observed to be transgressing, whereas the remaining 60~70%â€”largely associated with service-oriented sectorsâ€”operates within the SOS across all indicators. Notably, agriculture contributes less than 5% to global GVA yet dominates multiple PB transgressions. Manufacturing and construction, responsible for more than one quarter of global FCE, act as the primary force for climate change and aerosol loading transgressions.
Overall, this study advances the AESA beyond national assessments and provides a comprehensive mapping of absolute sustainability at the sector level. By quantifying both PBA and CBA transgressions, the findings demonstrate that mitigation strategies targeting only one side of the economic system are insufficient and highlight the need for sector-specific interventions that address both direct emissions and demand-driven supply-chain effects. Identifying structural leverage points across productionâ€“consumption networks is essential for maintaining global economic activity within planetary limits.