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Which countries and income groups are responsible for the environmental footprints of global food trade?

Chris Youngman, Kayanat Iltaf, Fan Zhang, Sebastian Vollmer
University of Göttingen · RTG 2654 Sustainable Food Systems · christopher.youngman@uni-goettingen.de

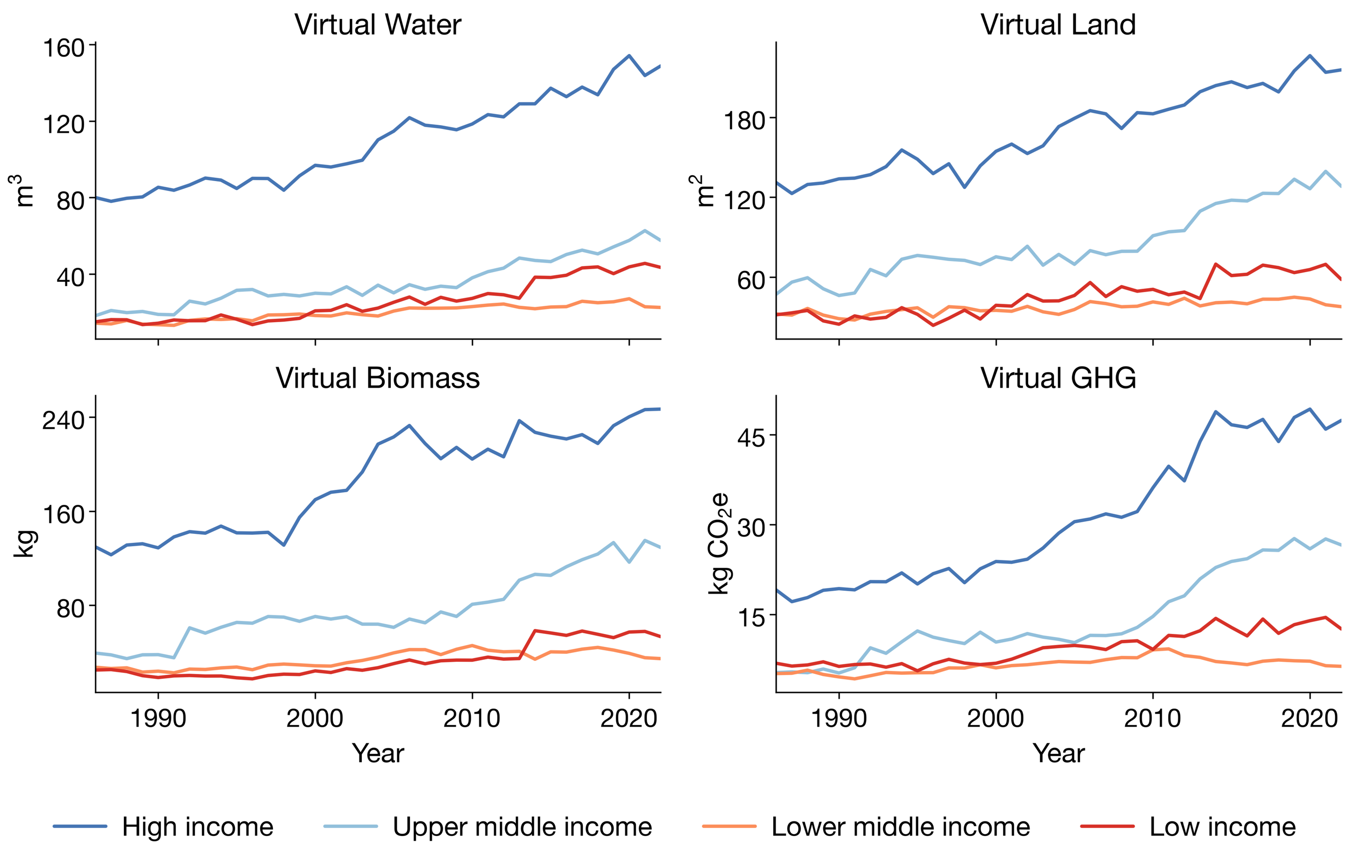
What is a virtual resource?

The water, land, biomass and GHG used to grow food are counted where it is finally consumed.

1 Results

Figure 1 · Per-person inflows keep diverging

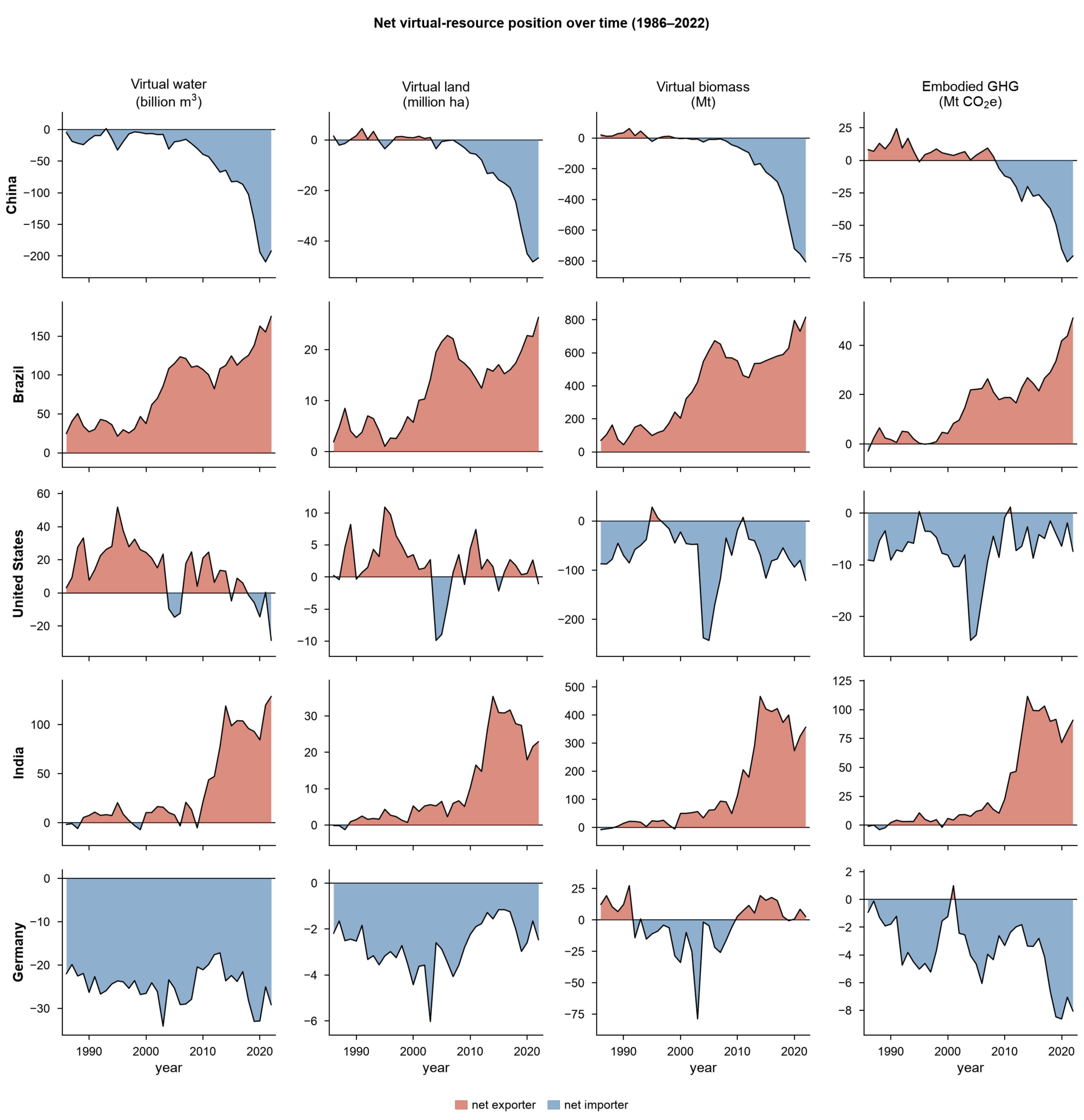
Virtual resource inflows per person by income group, 1986–2022. Dark blue = high income, light blue = upper middle, orange = lower middle, red = low income. Axis units are per person per year.



Per-person inflows rose in every income group, so trade expansion reached the poorest. But high-income consumers stay several times above every other group, and the embodied-GHG gap widens fastest after 2010. Global totals grew unevenly: virtual land and biomass by roughly 33% and 47%, virtual water and production-stage GHG by roughly 80% and 82%. Growth was shared; the gains were not.

Figure 2 · Big economies split into exporters and importers

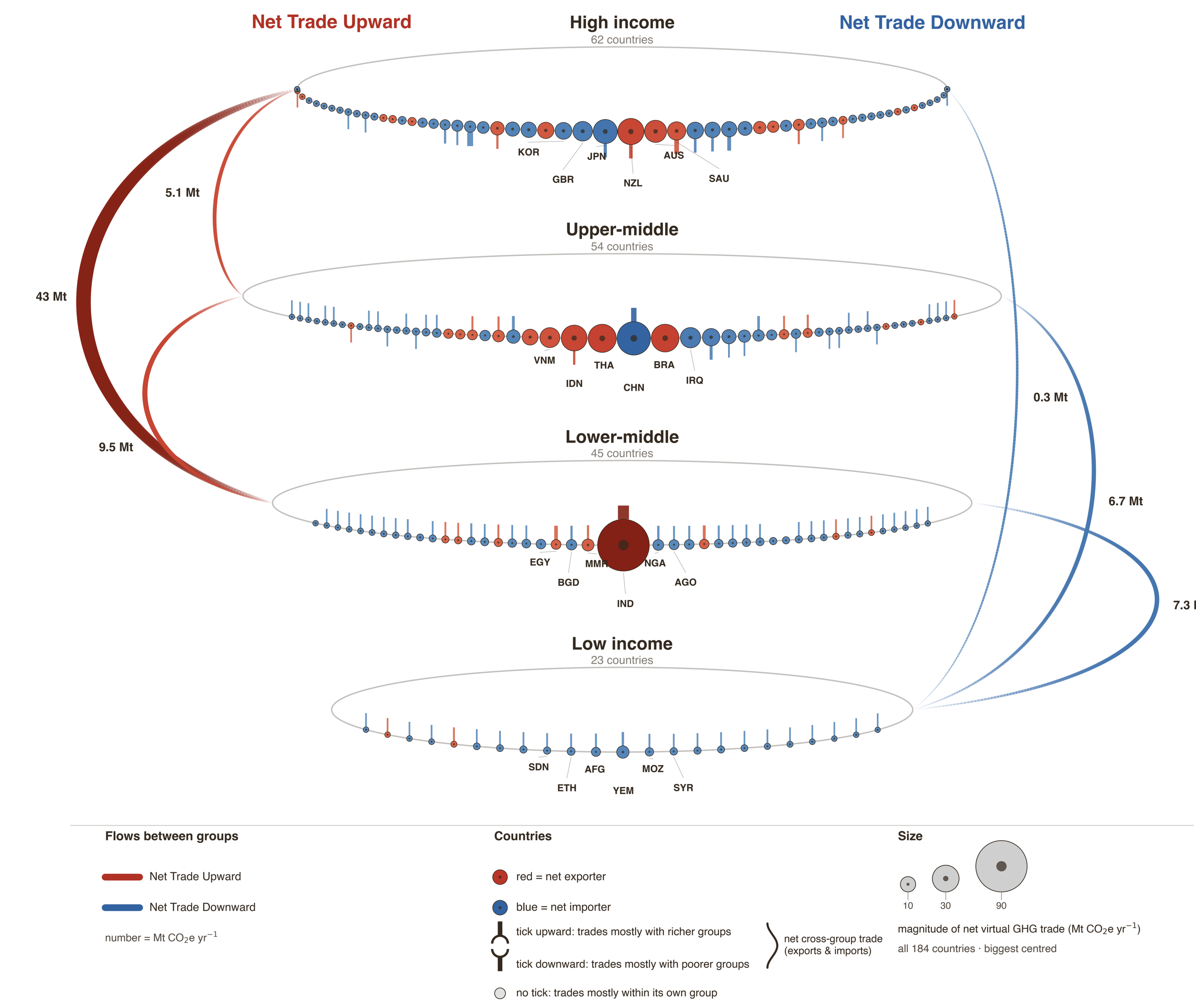
Net virtual-resource position (exports minus imports) by year, 1986–2022, for five pivotal economies across the four resources. Red = net-exporter years, blue = net-importer years – the same colour key as Figure 3.



Brazil and India swung from rough balance to large net exporters of all four resources as their farm exports scaled, while China deepened into a heavy net importer and Germany stayed a persistent one. The United States moved from surplus toward deficit. The embodied cost of feeding richer consumers is increasingly carried by a few middle-income suppliers, and the split widens after 2005.

Figure 3 · Virtual GHG trade runs uphill

Net cross-group flows of GHG embodied in traded food, annual mean 2013–2022. Red arcs carry emissions to richer income groups, blue arcs to poorer. Each dot is a country: red = net exporter, blue = net importer.



Netting the two directions leaves high-income countries taking in 62 Mt CO_2e per year more than they send out, while lower-middle-income countries ship out a net 59 Mt and upper-middle income sits near balance despite being the second-largest gross exporter. High-income countries have been the largest net importers of every virtual resource throughout the record, absorbing 39–46% of all cross-group flows, and their annual net imports deepened by 66–209% – for embodied GHG, from about 0.01 to 0.06 Gt CO_2e.

2 Discussion

Attribute the burden where the demand sits

National inventories stop at the border, so emissions embodied in imported food appear on no importer's account. Consumption-based attribution assigns the 291 Mt CO_2e per year in high-income food imports to the consumers who trigger it – the precondition for any instrument that prices or regulates trade-linked emissions.

A narrow set of value chains carries most of it

Traded virtual GHG concentrates in bovine meat (24%), dairy (16%), rice (16%) and palm oil (6%), so intervention need not be broad-based: measures aimed at beef and dairy chains, paddy-rice systems and palm-oil production reach around three-fifths of the total. Beef is the strongest single lever – per unit of protein it requires 12 to 28 times more land and emits 6 to 34 times more GHG than other livestock products.

Demand- and production-side policy must move together

Because a few corridors carry most of the flow, dietary change and procurement standards in high-income importers, paired with efficiency gains among the major exporters (Brazil, Argentina, Thailand, Indonesia) would yield disproportionate reductions. Upper-middle-income virtual GHG exports grew 179%, driven by livestock and soy, so exporter-side efficiency is where the trend is set.

Prices still do not carry the environmental cost

Traded food enters the market at prices that do not reflect the resource cost of producing it, and the flows do not follow scarcity. Setting aside trade among high-income countries, the largest suppliers of virtual water to high-income importers are Brazil, India and Indonesia – and India withdraws roughly two-thirds of its available blue water. Pricing frameworks that internalise these costs are the missing instrument.

Take-home

Three decades of trade growth have concentrated the environmental cost of high-income food consumption onto the middle-income economies that supply it, while the apparent withdrawal of the poorest countries is an artefact of their most dynamic members graduating upward. The food system must attribute these flows to final consumers if climate change is to be mitigated equitably.

3 Data & methods

- FABIO physical multi-regional input–output framework, augmented with product-specific greenhouse gas emission factors.
- 185 countries · 87 commodity sectors · 1986–2022, bilateral and annual.
- Four extensions embodied in trade: water (m³), land (ha), biomass (t) and greenhouse gases (t CO_2e), attributed to the country of final demand and aggregated by World Bank income group.
- Crop emission factors are interpolated between benchmark datasets and rescaled by country–year production intensity; animal products come from FAO GLEAM v3.
- Countries are held at their 2022 income class. Under a time-varying classification the poorest group appears to disengage from trade – an artefact of its most dynamic members graduating upward.

Data sources

- FABIO EE-MRIO tables – v1.1 (1986–2013) and v2 beta (2014–2022); transactions Z, final demand Y and physical water / land / biomass accounts (Bruckner et al.).
- FAOSTAT – GHG emissions, cropland area and production (country–year emission-intensity scaling).
- Carlson et al. (2017) and Cao et al. (2026) – crop emission-factor benchmarks, temporally interpolated.
- FAO GLEAM 3 – livestock and animal-product emission intensities.
- IPCC AR6 – GWP_{100} with climate-carbon feedbacks (CH_4, N_2O).
- World Bank – country income classification (OGHIST), held fixed at 2022.
- National population series – for per-capita flows.