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1 ton of CO_2 offset
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Carbon-Footprint Accounting for the Next Phase of Globalization: Status and Opportunities

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A significant portion of global carbon emissions is embodied in international trade. Accurate carbon-footprint accounting is essential to prevent advanced economies from displacing their emissions to others through trade. Here, we reflect on the future of carbon-footprint accounting for complex and rapidly shifting global trade networks.

Although many advanced economies are stabilizing or reducing their territorial emissions, these victories rest substantially on the effects of outsourcing.[1–3] High-income countries are making use of a "carbon loophole" in the Paris agreement: they can meet the targets by simply displacing emissions rather than reducing them. For most advanced economies, emissions embodied in imported goods and services represent 20%–50% of their total global greenhouse gas (GHG) footprint. This is problematic for two reasons. First, production often shifts to less carbon-efficient producers. Second, because it is difficult to precisely calculate embodied emissions, it is hard to set fair targets or evaluate each country's true contributions to reducing global emissions.

Future Emission Growth Can Come from New Countries

Embodied carbon flows have so far predominantly been due to the rise of China, but this is changing. Signs indicate that the era of China as "the world's factory" is drawing to a close and that future growth will come from a new set of post-China countries.[4,5] Today, flows of embodied emissions are dominated by south-south and south-to-north transfers (Figure 1). As China's per-capita gross domestic product (GDP) increases and its industrial partnerships expand through the Belt and Road Initiative, it is not unreasonable to expect that primary production industries (such as textiles, plastics, and heavy manufacturing) will migrate to new countries with lower labor costs. A new group of post-China countries is poised for substantial growth in emissions as a result of a combination of growing populations, rising affluence, urbanization (which might not drive higher footprints but is associated with them[6]), poor carbon efficiency of production, and protectionist tariffs, which encourage domestic production (Figure 2). Although India is the largest, other key post-China economies include Pakistan, Indonesia, the Philippines, Bangladesh, Cambodia, Ethiopia, Kenya, Myanmar, Nigeria, Russia, South Africa, and Vietnam.

Currently, roughly one-third of GHG emissions are embodied in goods and services traded internationally. These embodied imports are not yet included in the reporting guidelines of the United Nations Framework Convention on Climate Change (UNFCCC), but they are tracked by established global carbon-footprint models. These models provide robust top-level results but currently are not timely or granular enough to make specific policy or purchasing decisions. Carbon-footprint accounting models need to improve their level of detail and improve timeliness to keep up with the shifting trade and production patterns in order to provide timely and accurate information to support fair and actionable climate policies.[8]

Tracking GHGs Embodied in Trade

To track embodied emissions in trade, databases of global supply chains (formally multi-region input-output [MRIO] models) along with carbon-footprint accounting can be used. MRIO models document global supply chains by tracing primary production and emissions from each production sector through multiple trade and transformation steps to final consumers. Assembling an MRIO model involves linking the national input-output tables (IOTs) published by national statistics agencies together by using international trade data and applying interpolation and balancing to produce a unified, consistent account of economic flows between all sectors globally. The most detailed of these models today tracks 15,000 sectors across 190 countries (see, among others, Moran and Wood[9] or Inomata and Owen[10] for an overview of the available models from universities and the Organisation for Economic Co-operation and Development [OECD]).

MRIO models are powerful tools for tracking embodied carbon flows, but several factors limit their ability to accurately track embodied emissions under shifting global trade and manufacturing patterns.

Overarching Challenges for MRIO Models

Beyond the quotidian desires typical of modeling efforts of higher-resolution data and more computer, staff, and funding resources, we see two overarching challenges to maintaining timely and accurate accounts of embodied emissions. These center around missing or stale economic data and inadequate emission inventories.

The compilation of supply-and-use tables (SUTs) or IOTs by national or regional

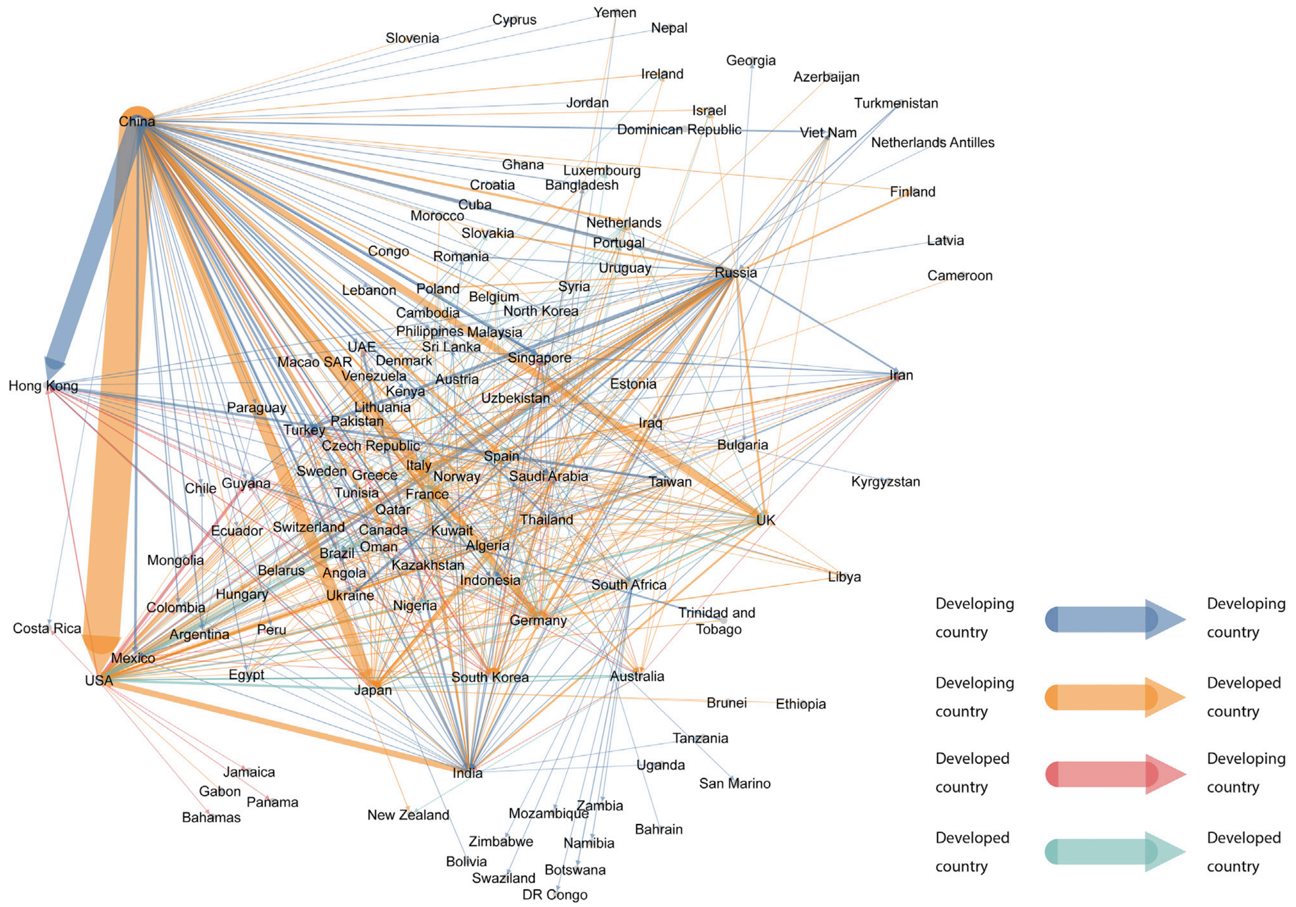

Figure 1. Global Net Displaced Carbon Emissions via International Trade in 2015

Flows from developing countries to developed countries dominate the network. Recently, flows among developing countries have also grown. Net outflows from developed countries are rare in the network. Flows < 5,000 Gg CO_2 are not shown. Arrow widths are scaled linearly in proportion to flow size. The net embodied emissions are 430 Tg CO_2 from China to the US, 140 Tg CO_2 from China to Japan, and 70 Tg CO_2 from India to the US. This figure uses data from the Eora MRIO (https://worldmrio.com/footprints/carbon).

statistical agencies is of primary importance. Most developed countries maintain detailed and reliable SUTs and/or IOTs. However, many countries lack satisfactory sector resolution or even any IOT at all. Despite documentation and instructional guidelines, there is often simply a lack of adequate human resources to produce and maintain these tables. Training and assistance programs for national statistical agencies are available, yet these still prove to be insufficient. Furthermore, IOTs must be kept up to date. Although we are cognizant that producing a complete IOT is a substantial undertaking, we strongly urge national statistics agencies to prepare annual updates as well. Best practice is to publish a full IOT every 5 years and offer a lower-resolution or rescaled dataset in each intermediate year. Grant and training programs for national statistics agencies are probably less sexy than other sustainability-themed projects, yet without trustworthy and up-to-date basic data on how the economy functions, many quantitative sustainability initiatives will be all foam and no beer.

Given the urgency of the climate challenge, although we do not want to disparage past accomplishments, we maintain that the state of GHG-emissions accounting is far behind where it needs to be. The largest sources of uncertainty in current MRIO-based footprint results come not from the trade or MRIO model but simply from uncertainty in the total national direct emissions and the attribution of those emissions to economic sectors.[9,10] Emissions are recorded in broad categories (e.g., "stationary combustion" according to the guidelines of the Intergovernmental Panel on Climate Change) or by activity rather than by industry. This makes it is difficult to recommend which companies, which products, or which government institutions should be involved in their reduction. Emissions need to be attributed much more precisely to emitting industries, e.g., individual crops and specific heavy manufactures, in order for subsequent models to support more granular policy recommendations.[11] Although UNFCCC Annex I countries provide relatively detailed emission inventories, more than half of global emissions come from non-Annex I countries (e.g., China, India, South Africa, Saudi Arabia, and Iran), and the non-Annex I inventories detail only a few dozen categories, compared with the several hundred or thousand data points of a full inventory. China, for example, has a UNFCCC inventory only for 1994, 2005, and 2012. Complementing these reports, independent, real-time observations should be used to avoid misreporting.[12]

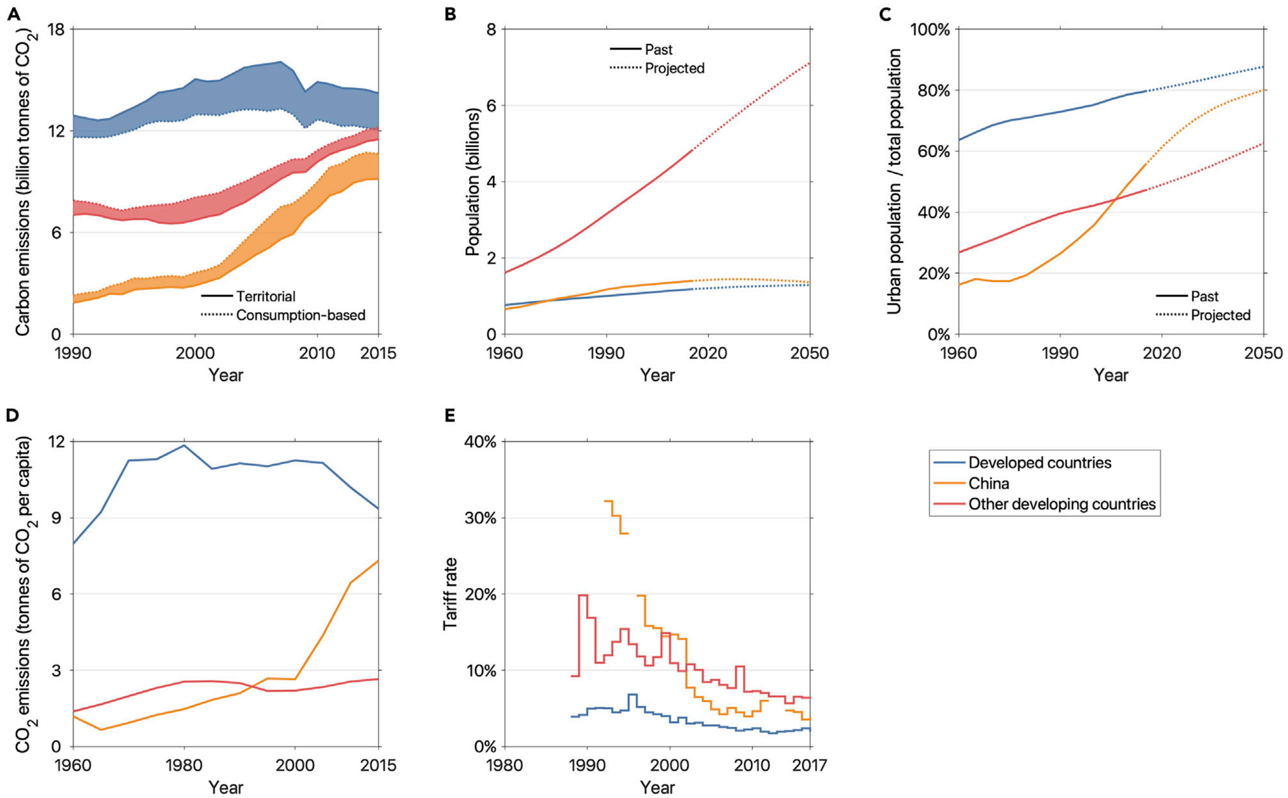

Figure 2. Emissions Growth Is Poised to Grow in Developing Countries

Emissions have stabilized in the advanced economies and are decelerating in China (A). In developing countries, population and urbanization rates are rising (B and C), per-capita carbon emissions are low (D), and higher tariffs (E) protect domestic production. The category "other developing countries" includes all developing countries except China. Sources include territorial and consumption-based emissions from the Eora MRIO[7] (https://worldmrio.com/footprints/carbon), population and urbanization rates from the 2017 UN World Population Prospect (https://population.un.org/wpp/), and tariff rates from the World Bank (https://data.worldbank.org).

Opportunities for Advances

In addition to addressing the aforementioned challenges, we also see promising areas for future development. The next steps we identify are admittedly broad and challenging, so we offer these as an aspirational vision. Although we recognize that these suggestions are ambitious, we believe they are basically feasible and will indeed be part of the basic furniture in a smoothly operating <2°C-consistent global economy.

Nowcasting

With further improvements in MRIO assembly methods, including more automation and machine-readable data, it should be feasible to link MRIO models to annual or even quarterly announcements of nowcasted economic statistics. As with economic data, these nowcasted estimates are provisional, but nowcasted results should still provide basically correct signals. Even at an aggregate level, nowcasted values can help us understand the evolution of supply chains.

Make Bills of Lading Public

Bills of lading are public records collected by national customs agencies, and they document the contents of most commercial traffic. These records are a valuable information resource that could help reveal global supply chains in higher detail. These records are ostensibly public information but are often held by customs agencies and sold at high prices. Making these public would provide an enormously valuable dataset for monitoring global supply chains.

Engagement by Large Companies

Equally important to, and in the future potentially even surpassing, current MRIO models is the work of the Carbon Disclosure Project (CDP; https://www.cdp.net) in encouraging companies to produce and publish transparent estimates of their whole supply-chain emissions. Hundreds of companies are responsible for more embodied emissions than small countries, and these large companies also oversee a large share of global trade. Providing guidance and validation for companies to self-report their supply-chain and complete-footprint (sometimes called scope 3) emissions would be a revolutionary new source of information about embodied carbon in imports and exports. In addition to the CDP efforts, there could be other facets of corporate engagement, such as the corporate engagement on soy and beef production in Brazil from the Trase.Earth supply-chain-transparency project (https://trase.earth/), voluntary efforts (such as Walmart's exploration of product-level RFID tracking), and pressure from investors, given that today nearly $30 trillion is held in "sustainability"-branded portfolios.

Double-Entry Bookkeeping in COMTRADE

Reports of bilateral trade are critical inputs to MRIO models. The current international trade system asks countries to individually report their trade in goods and services; however, significant discrepancies are still frequent, e.g., the US's total reported exports to China do not match China's reported imports from the US (*The Economist* describes this net global trade imbalance as "trade with Mars"). To resolve this model, builders must either estimate a new compromise value or dismiss conflicting data. Yet, understandably, national policymakers can be skeptical of results that do not match their country's IOT or trade statistics. It should be possible to advance the trade reporting system so that every export record is matched to an import record. With a unified international trade reporting system, official country-level IOT and SUTs could be linked directly into a global MRIO model without any adjustment.

Link Economic Accounts to Remote Sensing of GHG Emissions

Satellite observation can help monitor GHG emissions. Flying or planned satellites include NASA's OCO-2 satellite, China's TanSat,[13] Japan's GOSAT, and the EU's upcoming SCARBO project. Advances in artificial-intelligence technology and statistical models, such as machine-learning algorithms, could help link remote measurements to industrial sectors and companies. Several promising initiatives exist already. The VULCAN[14] and ODIAC (http://odiac.org/) models use spatial-disaggregation techniques, such as maximum entropy models, to locate emissions; the World Resource Institute's Global Power Plant Database[15] has assembled a dataset of most large fossil-fuel power plants globally, and a Google-funded Carbon Tracker Initiative (https://www.carbontracker.org/) aims to extend that with satellite-based, real-time, per-plant utilization rates, and the WattTime initiative (https://www.watttime.org/) has announced plans to combine multiple data sources by using machine learning and advanced algorithms to build a global map of real-time emissions from every fossil-fuel power plant. Such detailed emission inventories should be linked to MRIOs, as described above.

Regular Maintenance to Carbon-Footprint Models

Currently, MRIO databases are largely grant supported, and continued updates are perpetually precarious. The OECD recently began offering an MRIO database, and we commend this step. Building MRIO models requires a modest investment on the order of tens to hundreds of researchers worldwide. This is a far smaller investment than is put into physical climate models or integrated assessment models, for example. Further investment in economic models will pay dividends quickly: MRIO models provide useful real-world results by informing about the GHG-emission consequences of specific purchasing decisions.

To have any chance of achieving the <2°C target, we need carbon accounting that is as sophisticated as financial accounting. Major advances are needed from where we stand today. Above, we have outlined areas where the science, technology, business, and policy and governance communities can contribute to realizing the vision of having a detailed and real-time map of how the global economy uses carbon.

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