From Satellite to Supply Chain: New Approaches Connect Earth Observation to Economic Decisions

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New approaches connect earth observation to economic decisions.

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Abstract: Global supply chains shift environmental and social impacts of consumption to remote locations. This opacity challenges many sustainability goals. To help businesses and governments realize more sustainable supply chains, new approaches are using spatial data and machine learning techniques to connect earth observation data to conventional economic tools.

Supply chains are the lifeblood of the global economy. Their efficiency and omnipresence are a recurring theme in sustainability discussions, for example, on the impacts of globalisation, the socio-environmental trade-offs of local sourcing, pollution associated with production and transportation of goods, or human welfare along complex value chains.

Yet despite broad awareness of the importance of supply chains, currently available tools are still mostly insufficient—whether to inform how specific consumer choices drive environmental impacts along supply chains, or to robustly measure exposure to environmental risk and shocks along specific supply chains. We argue that current tools are insufficient because of their poor spatial and commodity resolution, which does not allow to readily discriminate agents and objects driving or suffering from impacts.

Businesses, consumers, and shareholders increasingly demand robust climate, biodiversity and resource footprint data to inform their economic decisions. Microsoft's carbon-negative pledge, Nestlé's blockchain based supply chain transparency platform, and Black Rock's decision to integrate climate risk into investment analysis are recent examples of this trend. Current tools, which are either limited to broad sectors and country-level analysis or require laborious and narrow-focused life-cycle assessment, are inadequate and do not offer sufficiently detailed and comprehensive coverage[1,2]. Information tools are needed that make supply chains and their impacts more transparent, with low costs for all supply chain participants. Such tools should ideally be third-party and data driven without the need for self-reporting by the supply chain actors themselves.

The latest satellite sensor technologies and hyperspectral image processing approaches can deliver high resolution and almost real-time information on a wide range of ecosystem changes on a world-wide scale. These include crop type and productivity, urban and road expansion based, seasonal surface water availability, and deforestation and biodiversity loss[3,4].

Yet despite this wealth of information, datasets from the natural sciences so far largely miss the connection to the underlying economic production, trade and consumption decisions that drive many of the observed changes. As a result, too much of the corpus of earth observation science is only used to frame a general discussion about sustainability and supply chains but seldom provides concrete information to steer action or inform choices by businesses and policymakers.

New approaches are being developed to provide tools that support better science-based policy and informed decision-making. These are built by combining global economic supply chain data and models with high-resolution spatial datasets on human-driven environmental impacts (Figure 1)[5]. Here we present this emerging area and its challenges vis-a-vis existing gaps. We also reflect on how different knowledge communities can further contribute to improving the connectivity between economic and environmental datasets. We contend that spatially extended economic accounts are a part of the fundamental knowledge infrastructure necessary for maintaining a global economy that operates within planetary boundaries.

Toward Spatially Explicit Supply Chain Data

Global supply chain databases, including economic input-output tables and life cycle inventories, are already used to feed into sustainability dashboards, environmental and economic footprint reports, scenario planning, and shock analyses built on general equilibrium models[6,7]. However most carbon and other environmental impact footprint information has so far only been available at the country and sector level. These results provide a high-level view, but too often lack sufficient spatial and product-level precision to link to on-the-ground dynamics and specific actors.

Integrating spatially explicit supply chain information into financial dashboards would be a game-changer for corporate and finance-sector sustainability. Businesses, traders and investment managers could assess impact hotspots within their complete supply chain footprints and evaluate cost-effective interventions to decrease their environmental impact profile. Supply-chain based economic models could be overlaid with spatially explicit scenarios of disruptions such as climate and disaster shock scenarios evaluating investment risk exposure.

To help enable targeted responses, buying and selling decisions need to be connected to supply chains not just at the country level but at the regional or even local level. A simple example illustrates the value of sub-national resolution: if not modelled as distinct flows, soy exports from farms in Brazil's northern and southern production regions would appear to be identical. Yet in reality the two goods have sharply different environmental profiles (the former is often linked to deforestation, while the latter is mostly grown in existing agricultural areas)[8]. Coupling earth observation and sub-national production data is one way to estimate supply chains at more granular level.

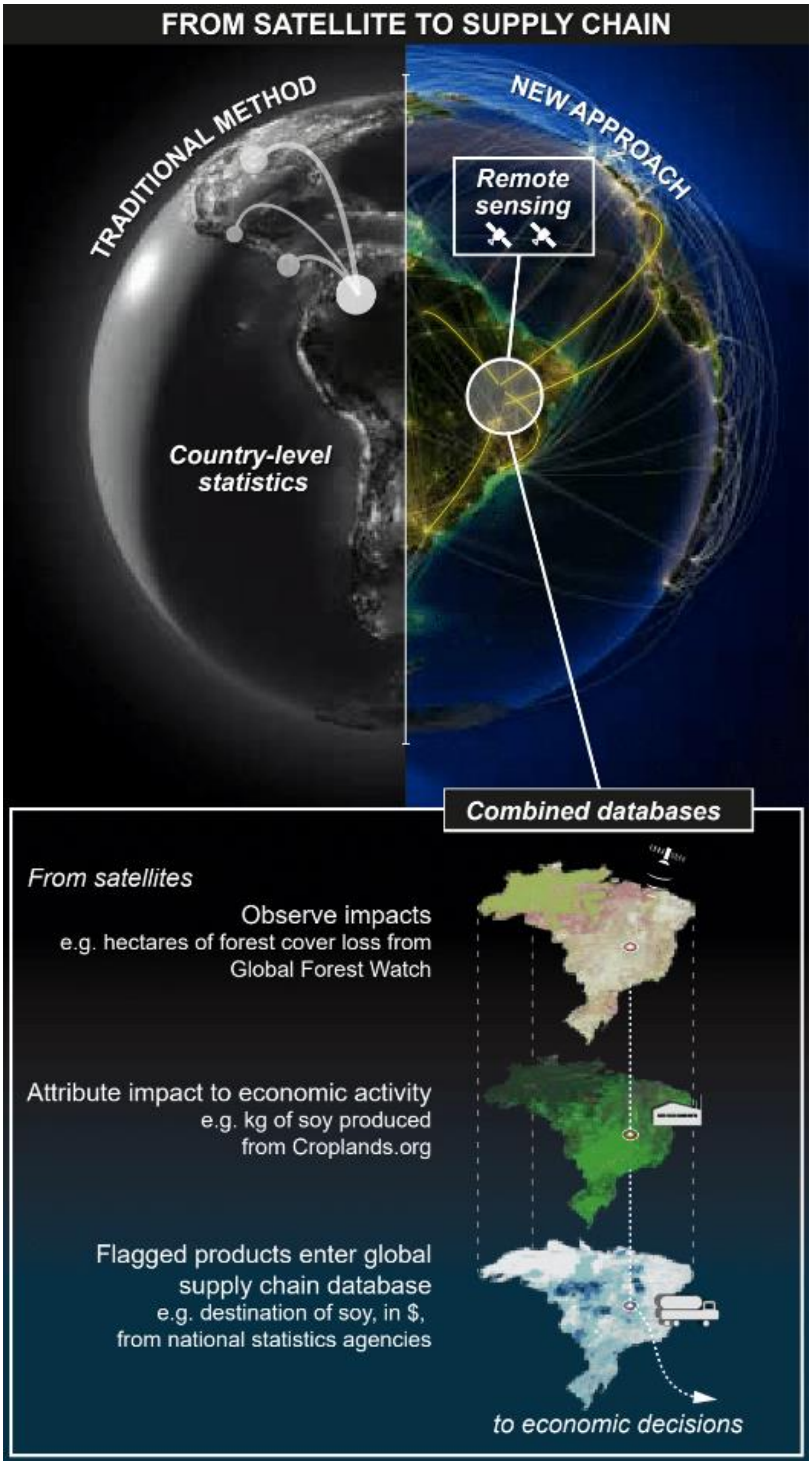

Figure 1: Environmental and economic data can be connected by combining relevant datasets through common spatial features. Spatially detailed observations of environmental health and production activity are increasingly available and new supply chain models strive to incorporate sub-national trade data.

The key to realize this coupling is creating fine-scale inventories of important supply chain steps, such as production, transportation, manufacturing, and consumption[9]. These can be assembled by connecting subnational economic activity data (including regional GDP statistics or trade data from customs agencies that detail the contents of individual transports) with spatial observations or models of supply chain activity, such as from power plants, logging, farming, mining or manufacturing. Tools from information theory such as maximum entropy models or Bayesian methods can be used to combine multiple layers of information into a spatially explicit model integrating both economic activity and environmental impact data.

This approach has already yielded promising results that make environmentally-extended supply chain models more specific and actionable. Several examples that have paved the way for the wider field include studies linking supply chains to global biodiversity hotspots[10] and a project mapping supply chains of tropical forest risk commodities and their embedded deforestation with company-level detail (trase.earth). Other noteworthy examples are fine-scale assessments of Europe's raw material footprint and related global impacts (fineprint.global) and the Industrial Ecology Virtual Lab (ielab.info) infrastructure project with its ambitious aim to house nested multi-resolution models of global supply chains. The methods and databases developed in these research projects, many of them openly available, provide clear evidence of the large potential to move supply chain assessments to a next level using spatially explicit information.

Tools using supply chain information for screening investment portfolios have also been developed. The Soft Commodity Risk Platform (globalcanopy.org), for example, helps banks avoid risk associated with financing deforestation-implicated companies. In a similar vein, the company 427 offers a product evaluating the physical climate risk of a given investment portfolio.

Other projects are using artificial intelligence and machine learning in combination with high-resolution satellite data to estimate gridded activities and their impacts. Several projects are aiming to construct global maps of real-time CO_2 emissions from fossil fuel power plants (carbontracker.org and watttime.org). Similar machine learning based-systems are being used to identify illegality and unsustainable resource use patterns in the global fishing sector (globalfishingwatch.org). It should be cautioned that computational approaches like these will likely be expensive, both for hardware and software development, and many machine learning techniques require training datasets which can be daunting to assemble. An additional hurdle is that the data collection and processing work is still inadequately institutionalized. Despite these practical hurdles, we see clear priorities and pathways to progress, in order to scale these innovative approaches to a broader implementation, as explained further below.

In the modern economy national sustainability goals are often influenced by foreign actors and drivers. International cooperation and transparency are therefore essential to realize targets. Fine-scale supply chain data can help identify the particular foreign actors whose investments or actions may be inducing positive and negative impacts domestically. Industry-specific initiatives for supply chain transparency at the producer end (such as the Extractive Industry Transparency Initiative or the Roundtable on Sustainable Palm Oil) are valuable, but more complete supply chain data would amplify these sector-specific initiatives by catalyzing accountability and change.

At the consumption end of supply chains, for many countries a growing share of their environmental and social impacts occurs abroad[11]. Targeted engagement may thus be the most effective way consuming countries can support the SDGs. Doing this requires a connection to the specific companies which provide the goods people buy. One such potential opportunity to more efficiently allocate resources to support the SDGs is with conservation funding. About 90% of the $6 billion of annual conservation funding originates in and is spent within economically rich countries instead of on potentially more effective protection in more biodiversity-rich regions[12]. For conservation and biodiversity projects knowing the exact location of the sustainability risk hotspots and their specific drivers along a particular supply chain is key for targeting efforts efficiently[13,14].

Individual consumers too are increasingly asking for the locations and magnitude of the impacts associated with their choices. Supply chain tracking is starting to be offered by a handful of retailers. Spatially explicit supply chain data can inform campaigns or product certifications on issues such as biodiversity conservation. Additionally, better supply chain transparency can enable an accountability framework that triggers the adoption of higher environmental and social standards in producing regions. These approaches are technically feasible and have the potential to fundamentally transform supply chain management approaches, thus providing a real chance of meeting SDG 12 on sustainable production and consumption. Implementing these approaches at scale over this decade will be a challenge. It will require establishing economic data with higher geographical detail and fostering multi-disciplinary efforts to better link information from natural science on specific environmental impacts with their underlying socio-economic drivers of production, transport, trade and consumption.

Natural Scientists Can Call Out Economic Drivers

Environmental and economic data can be connected by combining layers of information through common spatio-temporal links (Figure 1) and the use of linked data combined with techniques such as GIS overlay and spatial analysis, semantic and artificial intelligence, matching methods and pattern recognition, to name a few. Progress in connecting natural science data to economic models will come from economic data with increased spatial resolution (adding regional production, domestic trade, and better commodity-level detail in production and trade inventories) and better quality and attribution of observed environmental impact to economic activities or commodities.

To improve economic data on production and trade, customs and national statistics agencies must publish customs declarations and economic production statistics in a disaggregated form. Some countries make customs data available while others do not. In addition to this trade data, comprehensive and reliable subnational production data from national statistical bureaus is vital.

Given that for many sustainability challenges biomass is a good proxy or determinant factor, detailed global maps of agriculture, aquaculture, fishing, and silviculture activity are centrally important. Global croplands data projects, such as GFSAD30 (croplands.org) and the FAO Agro-MAPS, should be robustly supported so they can provide closer to real-time maps of agricultural activity. Maps of aquaculture activity, fishing, and forestry should be similarly prioritized. Although the supply chain community is currently just a user of existing GIS datasets, there are huge opportunities to overcome many challenges if both communities work together and jointly exploit the potential of multispectral and hyperspectral imaging.

Furthermore, those working in the natural sciences and in the field can attribute and tag impacts to their underlying economic drivers. Statistical tools can be used to infer activity-impact relationships, but in practice those gathering primary data on environmental impacts are often close to topic experts and could strive to capture more of this expertise in metadata. Tagging the driving economic activity as precisely as possible (e.g. tagging species threats not just to "agriculture" but to particular crops) is necessary for establishing firm links between impacts, products, and ultimately companies and consumers.

As an alternative to approaches based on combining layers of spatial environmental and economic data, new technologies that break down supply chains into more product detail, such as blockchain, crowdsourcing, and the uses of sensors and trackers provide another approach for supply chain transparency and linking purchase to impact. While these technologies are promising (we watch with particular interest fishcoin.io, which seeks to illuminate the murky global fish trade), their feasibility is still to be tested at large scales. To maximize use and re-use we encourage sustainability initiatives to publish open data tagged with Harmonized System codes or PermID organizational codes as best practice.

Alarm bells are ringing as our economy encroaches on its environmental boundaries. Swift and effective action is needed. From policy and business communities, as well as increasingly from consumers, there is a clear desire for more precise and actionable environmental information that integrates into existing decision-making paradigms. On the science side, those in the earth and environmental sciences may feel frustrated that their work to assemble large-scale observation datasets goes underutilized. Merging supply chain databases with spatial environmental observations is an extremely promising way to add value to these efforts. Building this link will create a *corpus callosum* between the oft-divided worlds of science and economics, allowing timely, fine-grained observations about the health of our planet to feed directly into the common economic tools that are used to guide decisions on a daily basis for most people on earth.

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