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Methodological and Ideological Options

Towards more accurate and policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of production to consumption

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ABSTRACT

The consumption of internationally traded goods causes multiple socio-environmental impacts. Current methods linking production impacts to final consumption typically trace the origin of products back to the country level, lacking fine-scale spatial resolution. This hampers accurate calculation of trade and consumption footprints, masking and distorting the causal links between consumers' choices and their environmental impacts, especially in countries with large spatial variability in socio-environmental conditions and production impacts. Here we present the SEI-PCS model (*Spatially Explicit Information on Production to Consumption Systems*), which allows for fine-scale sub-national assessments of the origin of, and socio-environmental impacts embedded in, traded commodities. The method connects detailed production data at sub-national scales (e.g., municipalities or provinces), information on domestic flows of goods and in international trade. The model permits the downscaling of country-to-country trade analyses based on either physical allocation from bilateral trade matrices or MRIO models. The importance of producing more spatially-explicit trade analyses is illustrated by identifying the municipalities of Brazil from which different countries source the Brazilian soy they consume. Applications for improving consumption accounting and policy assessment are discussed, including quantification of externalities of consumption, consumer labeling, trade leakages, sustainable resource supply and traceability.

1. Introduction

Sustainability science increasingly recognizes the growing importance of global teleconnections in driving local social–ecological dynamics (Liu et al., 2013; Meyfroidt et al., 2013). A key aspect of these teleconnections is the unprecedented increase in material flows entering international trade in recent decades (Krausmann et al., 2009; Wiedmann et al., 2013), having multiple impacts on ecosystems, biogeophysical cycles, development patterns and resource geopolitics (Burgos Cáceres and Ear, 2012; Le Billon, 2007). Through international trade, policies, consumption patterns and socio-environmental dynamics in one place may be key drivers of land use change, biodiversity loss, poverty or conflict in distant locations (Johnstone and Mazo, 2011). These interconnections may arise from direct causal links or occur indirectly as a consequence of complex chains of apparently unrelated dynamics, such as indirect land use changes stemming from biofuel policies (Ostwald and Henders, 2014), or cascading effects of sectoral policies to other sectors within and across countries, driven by the diversity of socio-economic processes shaping globalization (Lambin and Meyfroidt, 2011). International trade patterns, which depend on the geography of natural resources, levels of producer specialization, trade costs and policies, demographics, geopolitics and political history, shape these distant dependencies (Villoria and Hertel, 2011).

The complex geographies of trade make it increasingly difficult for consumers to trace the goods they consume to the place of production. Meanwhile, ongoing environmental impacts from the unsustainable use of natural resources have raised awareness of the need to understand and mitigate the ecological and social impacts associated with consumption choices (Rautner et al., 2013). As these impacts are ultimately determined by the characteristics of the specific locations where goods are produced, precise information on the origin of a given product is an essential basis for achieving more sustainable resource supply systems, evaluate dependencies, and reduce environmental and social impacts associated with consumption. In recognition of these concerns, trade analyses have evolved greatly from simple models based on bilateral physical trade reports to more sophisticated approaches that take into account transformation of goods and services, complex trade pathways and life cycle impact assessments (Davis et al., 2011).

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However, despite improvements in tracing material flows across sectors and international markets, especially with the recent booming of environmentally extended multi-region input-output (MRIO) studies (Lenzen et al., 2012a; Peters et al., 2011), trade analyses remain highly aggregated, relying on country-to-country trade data and national production data, and assume that the socio-environmental impacts associated with production of a given commodity are homogenous within each producer country. Yet, by their nature, the socio-environmental impacts of production are spatially heterogeneous within countries, depending on the characteristics of local social–ecological and production systems.

The fact that global biophysical accounting approaches currently do not include spatially-explicit information on sourcing locations at scales matching the heterogeneity of the socio-environmental impacts they aim to asses (Erb et al., 2009), decreases their policy relevance. In this context, we argue for a spatial disaggregation down to the scale relevant to the impacts being assessed. More spatially-explicit models could also strongly contribute to an effective understanding of causal links along supply chains, revealing hidden producer-to-consumer linkages. This could improve the understanding of trade-offs and leakage effects resulting from policy interventions in one place, and increase effectiveness in governance of natural resource use and supply chains (Lambin et al., 2014).

Here we present the *Spatially Explicit Information on Production to Consumption Systems* model (SEI-PCS), which aims to overcome some of the shortcomings of current approaches by allocating the socio-environmental impacts that are embedded in the trade of commodities produced in specific regions to the country of final consumption (as well as spatially disaggregated domestic consumption). The objective of the model is to identify the actual locations where the traded goods consumed in any nation are produced. Our main advance is to link data on location and supply chains of domestic production at sub-national scales to data on international trade flows, thereby downscaling and refining country-to-country trade analyses. Subsequently, any socio-economic or environmental impact indicator related to the place of production can be linked to the volume produced, traded and consumed. The scale of what constitutes the “place” of production depends only on the availability of sub-national data. We provide an example based on the trade in agricultural commodities, but the model can be applied to any form of material production and flows from other industrial sectors.

The remainder of the paper is organized into four sections. Section 2 further discusses the shortcomings of current non-spatially explicit (i.e., country-to-country) approaches to mapping trade relations and associated socio-environmental impacts. Section 3 describes the SEI-PCS model, and employs a simple conceptual example to facilitate its comprehension (see also SI 1 for a fuller description, and SI 2 for step-by-step calculations in an Excel workbook). Section 4 showcases the results of a real example — tracing back global and national consumption of Brazilian soy to the individual municipalities where soy is produced—and the advantages of this method versus non-spatially explicit models. Section 5 reflects in more depth on the potential applications and limitations of the SEI-PCS model and discusses how the model can be used to generate crucial insights for impact assessments, the governance of socio-ecological systems and an improved theoretical understanding of international trade and supply chains.

2. Limitations of Non-Spatially Explicit Footprint Accounting and Ways Forward

Current country-to-country assessments of social and environmental impacts embedded in trade do not constrain footprints or impact calculations of a specific consumed unit to the actual location of its production, but instead assume an average impact per unit of primary product at national or even global scales (e.g. national yields for land and water footprints (Hoekstra and Chapagain, 2006; Erb et al., 2009; Saikku et al., 2012; Weinzettel et al., 2013)).

This lack of spatial explicitness across the production-to-consumption system (PCS) can lead to misleading generalizations and unreliable biophysical accounting, especially in countries with high levels of heterogeneity in social and/or environmental conditions, including in ecosystem services provision, resilience and adaptive capacity of local ecosystems. Impacts of production typically depend on region-specific factors such as soil, climate, technological knowledge, infrastructure and the characteristics of production systems, and may thus vary markedly across space. For instance, a country importing Argentinean soy primarily from the Pampa region (almost fully converted to farmland decades ago (Carreño et al., 2012)) will have a much lower land footprint and land use change impacts than a country importing the same amount of soy produced in the Chaco region (where average soybean yields are about half those in the Pampa (SIIA, 2014) and deforestation rates associated with soy expansion are high). On the other hand, because agriculture in the Pampa, where soil P-stocks are almost depleted (Viglizzo et al., 2011), is more input dependent, the impacts of soy consumption on nutrient runoff may be higher there than in the Chaco. These distinctions would be masked by conventional country-to-country trade footprint analyses. Similarly, with country-level analyses, biodiversity losses in a biodiversity-rich and ecologically diverse country such as Brazil are attributed equally to all traded products in one sector and/or to all the consumed units of a given product (Lenzen et al., 2012b) even though the production of certain commodities may actually be concentrated in regions with relatively high or low biodiversity values. Dynamics and modes of production also vary spatio-temporally. For the same amount of new cropland destined to a certain commodity, local pathways of agricultural expansion in different forested areas may imply strikingly different deforestation and environmental impacts (Meyfroidt et al., 2014).

This within-country spatial variability in historical agricultural expansion, modes of production and social and environmental impacts is not considered in global trade data and models, value chain analyses, and biophysical and socio-economic accounting. Thus, causal attribution of socio-environmental consequences to global material and financial flows and to consumers' choices remains poor (Meyfroidt et al., 2013). This misrepresentation of spatial heterogeneity means that such analyses are unable to discriminate the effect of policies in countries, especially where such policies also vary across regions. Understanding the indirect effects of production of a given commodity for a given consumer also requires information on the specific locations of production. For example, although intensification of production in highly suitable areas could theoretically lead to global land sparing, the actual outcome depends on trade geographies. Land intensification in highly suitable areas could produce, by competition, a reduction in the adoption of technological innovations, thus hindering intensification in marginal areas with lower yields (Schmitz et al., 2012). If agricultural expansion in the latter areas would induce high socio-environmental costs, the net effect could counteract the positive effects of intensification in other regions.

There is also a need to better consider the importance of domestic consumption and local dynamics in exporting countries, departing from traditional South–North trade perspectives and reflecting the rise of less developed countries as major consumers of natural resources (Feng et al., 2013). This is especially so in emerging countries, which often are major contributors to total demand for some key products (e.g., Brazilian beef and soy production) (Kastner et al., 2012; Kearney, 2010). Domestic dynamics are often driven by differences in affluence (Weinzettel et al., 2013) and consumption patterns, which are often related to urban–rural divergences (Seto et al., 2012), and thus vary markedly across space. The lack of such domestic perspective on the impacts of globally traded commodities undermines our ability to understand global trade patterns and consumption dynamics and the policy relevance of any recommendations derived from such analyses. To this end, our model also traces production within the country of production to domestic centers of consumption within the same country.