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7

Toolbox: Flow Analysis—Social Metabolism in the Analysis of Telecoupling

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1 Uncovering Underlying Causes of Land-Use Change

Soap and lotion, bread and margarine, and biodiesel: For many of us, not a day goes by that we do not consume palm oil in some form or other. Palm oil is made from the fruit of palm trees grown on plantations in Southeast Asia, Latin America, and sub-Saharan Africa. These plantations exist at the expense of tropical rainforest, subsistence forestry and

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agriculture, and habitats of endangered species. Across hundreds or even thousands of kilometres, our consumption is linked to land-use change elsewhere. Material flows—palm oil exports from Indonesia to the Netherlands, for example—are an important indication of this connection between land systems. Power relations, political ties, and economic investments are simultaneously maintained by and shape material flows across levels of scale, making material flows an integral part of the systems' telecoupling (Chap. 2).

Wherever land-use change occurs—where oil palm plantations expand, for example—empirical trails can lead us to the underlying causes of that change. Studying a system's metabolism and accounting for the material flows it requires for its reproduction leads onto one such trail. The metabolism of a socio-economic system—from community to country—encompasses the material and energy inputs, transformation, stock integration, and outputs required not only for the biophysical but also for the socio-cultural reproduction of that system (Fischer-Kowalski and Erb 2016). Material flow accounting is one tool for the empirical study of social metabolism (Krausmann et al. 2017). Which material flows are considered as inputs or outputs depends on the definition of system boundaries, in particular, the boundary between a socio-economic system and its natural environment and the boundary between two socio-economic systems (Fig. 7.1). In the study of social metabolism, humans, their livestock, and artefacts—from buildings and infrastructures to durable household goods—biophysically constitute a society that is hybrid, a coupled human-environment system, clearly subject to the laws of nature and simultaneously (trans)formed through cultural meaning and purpose. Food and feed, fertilizer minerals, stones and sand, and oil and gas required to build and maintain these hybrids constitute inputs into the socio-economic system. These inputs always initially stem from the natural environment but may be supplied by other socio-economic systems via trade.

Identifying trade flows presents the challenge of defining the humans (as these tend to be most relevant in terms of agency, but possibly also the livestock and artefacts) that biophysically constitute a socio-economic system. For example, if a Dutch company harvests palm fruit in Indonesia, does the corresponding flow cross the nature-society boundary in

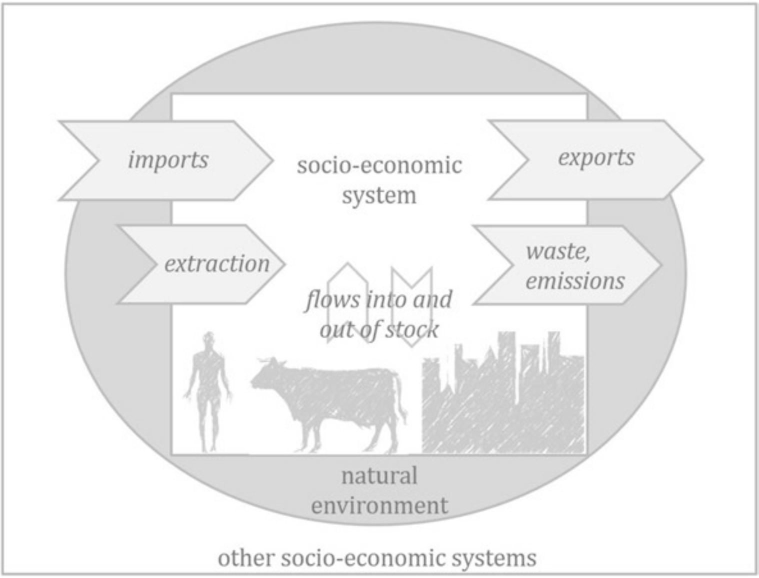

Fig. 7.1 Material flows cross the boundaries between a socio-economic system and its natural environment and between socio-economic systems

Indonesia or the Netherlands? If a Malaysian company ships Indonesian palm oil to Rotterdam, from where it is transported to a German factory that produces cookies eaten in France, then which socio-economic system has caused deforestation in Indonesia? The study of material flows does not provide one definite answer to such questions but, instead, allows for the empirical investigation of possible conceptualizations of what links land-use systems.

Material flow accounting is flanked by two groups of approaches concerned with following the trail from consumption in a socio-economic system to extraction from the natural environment across levels of scale. These approaches differ not only, but especially, in how they empirically operationalize the flows that indicate telecoupling, namely, (1) as material or (2) as monetary flows.

In interpreting the results of these approaches as indications of telecoupling, links between systems are predefined in a manner that may or may not be admissible in terms of how we conceptualize telecoupling and useful for our specific research question. The empirical study of telecoupling through the lens of social metabolism is closely tied to the advancement of our conceptual understanding of functional links across levels of spatial scale.

2 Following the Material Trail

Material flow accounting allows us to empirically investigate material trade as an expression of the links between telecoupled systems. In following this material trail, we may either be led to examine land use in agriculture, forestry, or mining in the exporting country or find that multiple systems are linked through a web of material flows. Malaysia, for example, exports palm oil made from palm fruit harvested on Malaysian plantations and also (re-)exports palm oil imported as crude oil from Indonesia. Countries may also export what they cannot extract domestically at all: We will not find oil palms in Dutch greenhouses, Emirati deserts, or German forests, but the Netherlands, the United Arab Emirates, and Germany are among the world's top ten exporters of palm oil. To link palm oil trade flows to land use and land-use changes through oil palm plantations, material flows are traced back to their origin (Kastner et al. 2011), revealing a web of telecoupled systems between which the steps of extraction, primary and secondary processing, transport, distribution, retail, and final use are divided.

2.1 Heavy Harvest, Traded Lightly

The material trail extends beyond trade flows with their mass as they cross an administrative boundary (Krausmann et al. 2017). From extraction through primary and secondary processing, material flows generally become "lighter". In order to produce one tonne of palm oil, four–five tonnes of oil palm fruit are required, harvested for oil production, but not included in the mass of the exported oil. From the use of land, energy, and auxiliary materials to the machines, infrastructures, and buildings required in the extraction and production processes, material exports additionally depend on manifold upstream inputs. To produce palm oil for export, land must be cleared, roads must be built, plantations fostered; palm fruit must be harvested and transported to constructed mills and possibly onwards to refineries. Construction materials and fossil fuels must be mined or imported. We may know that Indonesia exports almost six million tonnes of palm oil in a year, but this figure alone tells us little about the direct and indirect consequences for the local or the global land system.

2.2 The Land Requirements of Material Flows

Until almost any product reaches its final consumer, myriad materials at sundry sites have been used directly and indirectly requiring land. The land use associated with observed material flows is commonly estimated using coefficients. Material import and export flows are multiplied by a factor representing land required for the production of one unit of that traded good. If, for example, 4.5 tonnes of oil palm fruit yield 1 tonne of palm oil and one Indonesian palm plantation hectare yields an average of 17 tonnes of oil palm fruit, then each tonne of Indonesian palm oil—no matter where in the world it is consumed—requires slightly more than one quarter of a hectare of plantation land.

When one process yields more than one product—in co-production—the total resource use of the process can be assigned to the co-products either according to their relative biophysical (mass, energy content) or according to monetary (value) characteristics. In the production of palm oil, palm kernel cake is produced, sold, and used as animal feed. Oil and cake may be produced at a mass ratio of approximately 3:1, an energy ratio of 19:1, and a value ratio of 15:1. Accordingly, anywhere between 75% and 95% of the land use would be interpreted as required for palm oil production, while between 25% and 5% are required for palm kernel cake production. Consistently addressing co-production in empirical telecoupling analysis is the prerequisite to avoiding double counting. Which manner of representing co-production is most appropriate depends on the specific research question, for example, on the aspects of a telecoupling to be brought into particular focus.

In identifying the relevant material inputs, system boundaries must be defined in accordance with the research question. This decision covers the nodes of the production network taken into consideration as well as to the temporal scope of the analysis. Electricity used in palm oil production, for example, requires a power grid connected to a power plant. Both require their own material inputs, the extraction and processing of which in turn requires further material flows. In theory, each flow could be traced back to extraction as raw material, but this is an endless undertaking in which the relevant material flows become successively smaller and thus have less impact on the overall results. The researcher therefore decides on where to truncate the consideration of the production network, limiting the system boundaries for the telecoupling analysis accordingly (Friis and Nielsen 2017). This truncation may also be based on temporal criteria, that is, to consider, for example, only material flows incurred in the same year as the export flow occurred.

3 Following the Monetary Trail

Material trade flows are generally[1] associated with revenue from exports and spending on imports. Investments in land, either for purchase or for lease, may indicate connections between systems well before extraction and trade materialize. In close conjunction with—although asymmetrically to—material flows, monetary flows link coupled systems.

Environmentally extended input-output analysis has been implemented as a tool for the study of social metabolism, which follows the monetary rather than material trail from consumption to production. This modelling approach is based on input-output tables that may be organized by sectors (e.g. agriculture, production of food, restaurants) or by goods and services (e.g. cereals, flour, restaurant services). For each year, these tables provide information on the purchases made by each sector from all other sectors, the supply of each sector to final demand (e.g. households, government, exports), and the total output of each sector. Multiple input-output tables—commonly representing national economies—can be combined into multi-regional input-output (MRIO) models according to bilateral monetary trade flows.

3.1 Direct and Indirect Monetary Flows

Based on the input-output data, the technical coefficient matrix A indicates the inputs required by each sector per single unit of total monetary output.[2] From this matrix, we would be able to extract the information on the agricultural goods and services, the energy and water supplies, and the transport services that agriculture had to purchase *directly* in order to produce one unit of monetary exports. Of course, each and every of these monetary flows in turn induces other flows. For example, a unit of output from restaurants will require direct inputs from food production. In order to deliver to restaurants, food production will require input from agriculture; hence, restaurants *indirectly* require input from agriculture. In order to produce what it delivers to food production, agriculture requires inputs of fossil energy and fertilizer minerals. The energy and chemical processing sectors that provide these inputs require inputs of energy and water, the provisioning of which in turn requires a specific set of inputs. To calculate all the indirect inputs required by restaurants could be an endless, reiterative calculation, with each successive step adding information on smaller indirect flows. The Leontief inverse, calculated by inverting the difference between the aforementioned technical coefficient matrix A and the identity matrix I $(I-A)^{-1}$, makes it possible to condense this reiteration into one step (for a mathematical explanation of why this is possible, please see Schaffartzik et al. 2014; Miller and Blair 2009).

3.2 The Land Requirements of Monetary Flows

The monetary input-output tables can be extended by matrices or vectors of environmental factors, hence the name *environmentally extended* input-output analysis. The environmental factors can range from land use, material extraction, or energy use to the emission of pollutants or the discharge of waste and must be organized by sector or product group in accordance with the structure of the input-output tables. By extending the input-output tables of an MRIO model with land-use data, the direct land-use requirements per unit of total monetary output of each sector can be calculated as well as—using the Leontief inverse—the direct *and indirect* requirements. Via monetary flows between sectors and countries, final demand in any one country can be linked to land use at the sites of production.

In their study of the global land use related to national consumption, for example, Yu et al. (2013) found that significant levels of use of cropland and forestland in Southeast Asia occurred in sectors directly or indirectly producing for export. The researchers used an MRIO model with 12 agricultural sectors (including rice, vegetables and fruits, oilseeds, and milk) to which they allocated cropland and grazing land data. Forestland was allocated to the forestry sector. Built-up land had to be distributed to essentially all sectors. The economic classifications of flows necessarily subsume high variance in land uses. Indonesian yields of palm fruit, for example, are 44 times higher than yields of cocoa beans, but both types of production are part of the same agricultural sector.

4 Money Or Material: What Makes the World Go 'Round?

Both material and monetary flows can be traced through increasingly globalized production and consumption, revealing vast and changing webs of telecoupled systems. Which type of approach is used in empirical studies or to underpin conceptual advances depends on whether it is the monetary or the material link that is considered more functionally pertinent.

Land use, the colonization of land, the extraction from that land is, of course, a material process. This process can occur independently of monetary flows, as in subsistence agriculture. Monetary final demand for food, in contrast, presupposes some type of material flow. While it may be argued that under the political and economic system of capitalism, production requires investment, no amount of money can ever completely substitute material resources. Systems involved in international monetary production and consumption networks are distinct from those in the corresponding material networks.

Which system is a producer or a consumer may also change, depending on the perspective. In the flow relations within and between systems, money and materials not only flow in opposite directions but are also asymmetrical. The price paid for the same type of material varies over time and by country and also by subnational region and even sector. Depending on whether we follow the material or the monetary trail, we will obtain a different picture of the systems coupled and also by the nature of that coupling. Its monetary production and consumption patterns make China a net exporter of cropland; the country dedicates more land to the production for export than is used globally for Chinese imports. China's material use renders the country a net importer of cropland; more land is required globally to produce for China's imports than is used in China to produce for export (Schaffartzik et al. 2015).

The asymmetries between monetary and material flows that characterize the links between telecoupled systems point to other pivotal characteristics of the underlying relationships: wealth and power differentials, political agreements and disputes, system-specific incentives for production, and trade. Monetary and material trails lead us to these larger issues. In this way, the quantification of material and monetary flows between systems and across levels of scale and the identification of underlying causes of these flows are deeply intertwined. By further operationalizing the concept of social metabolism and its tools for telecoupling analysis, we enter into a highly productive back-and-forth between empirical observations and conceptual advances.

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Notes

1. Food aid constitutes an important exception to the opposing monetary flows associated with material trade flows and can be extremely relevant to the telecoupling of land systems.

2. For an in-depth introduction to input-output analysis, see Miller and Blair (2009). For an overview of environmentally extended input-output analysis focusing on its role in material flow accounting, see Schaffartzik et al. (2014).

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