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System boundaries as epistemological and ethnographic problems: assessing energy technology and socio-environmental impact

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Abstract

This article examines an epistemological dilemma at the center of social and environmental impact assessment: where and when the "system boundaries" that define the extent of an energy technology with socio-environmental impact should be drawn. We demonstrate how system boundaries give rise to different epistemological problems, first, when socio-environmental impact is studied across commodity chains, notably in life cycle assessments (LCA), and second, when socio-environmental impact is given a spatial, or areal, dimension. More than just posing epistemological problems, however, we argue that system boundaries present an ethnographic problem and that they should be exposed to cultural as well as political analysis. As cultural artefacts, system boundaries sustain different power-serving worldviews, and the way system boundaries are drawn in discussions on energy transitions calls into question how the existence of energy technologies relies on a geographical displacement of environmental load, including flows of resources, land, and emissions. We observe a human inclination to perceive objects as co-extensive with their physical boundaries, for example through commodity fetishism, but in truncating the global material relations that sustain energy technologies, the socially uneven resource flows that metabolize them are obscured.

Keywords: System boundaries; energy technology; environmental impact assessment; life cycle assessment; epistemology; fetishism

Résumé

Cet article examine un dilemme épistémologique au centre de l'étude d'impact environnemental et social: comment tracer les «frontières du système» pour définir l'étendue d'une technologie énergétique qui a un impact socio-environnemental? Nous démontrons comment les frontières des systèmes donnent lieu à différents problèmes épistémologiques, d'une part, lorsque l'impact socio-environnemental est étudié à travers les chaînes de produits, notamment dans les analyses du cycle de vie (ACV), et d'autre part, lorsque l'impact socio-environnemental prend une dimension spatiale. Plus que de poser des problèmes épistémologiques, cependant, nous soutenons que les limites d'un système posent un problème ethnographique. Les frontières devraient être exposées à l'analyse culturelle aussi bien que politique. En tant qu'artéfacts culturels, les frontières du système soutiennent différentes visions du monde au service du pouvoir. La façon dont ils sont délimités doit tenir compte du déplacement géographique de la charge environnementale, y compris les flux de ressources, de terres et d'émissions. Nous observons une tendance humaine à percevoir les objets comme coextensifs avec leurs limites physiques, par exemple à travers le fétichisme de la marchandise. Cependant, en tronquant les relations matérielles mondiales qui soutiennent les technologies énergétiques, le métabolisme socialement inégal des flux de ressources est obscurci.

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Mots clés: limites du système; technologie énergétique; l'évaluation de l'impact environnemental; l'évaluation du cycle de vie; épistémologie; fétichisme

Resumen

Este articulo examina un dilema epistemológico al centro de la evaluación del impacto social y ambiental: dónde y cuándo deberían trazarse los "límites del sistema" los cuales definen la extensa de una tecnología energética con impacto socio-ambiental. Demostramos como los límites del sistema ocasionan problemas epistemológicos diferentes, primero, cuando se estudia el impacto socio-ambiental a través de las cadenas de productos básicos, particularmente en la evaluación de ciclo de vida (ECV), y segundo, cuando se da el impacto socio-ambiental una dimensión espacial. Sin embargo, más que plantear problemas epistemológicos, sostenemos que los límites del sistema presentan un problema etnográfico y que los límites deben estar expuestos al análisis cultural así como político. Como artefactos culturales, los límites del sistema sostienen cosmovisiones diferentes al servicio del poder, y el modo lo en que se trazan los límites del sistema en discusiones de transiciones energéticas pone en tela de juicio como la existencia de tecnologías energéticas depende de un desplazamiento geográfico de la carga ambiental, incluyendo flujos de recursos, tierra y emisiones. Observamos una tendencia humana a percibir objetos como coextensivos con sus límites físicos, por ejemplo a través del fetichismo de la mercancía. Sin embargo, cuando se truncan las relaciones materiales globales las que sostienen las tecnologías energéticas, se ocultan el metabolismo social desigual de flujos de recursos.

Palabras claves: límites del sistema; tecnología energética; evaluación del impacto ambiental; evaluación de ciclo de vida; epistemología; fetichismo

1. Introduction

What are the social and environmental impacts of carbon and low-carbon energy technologies in different places and at different times? To answer this question, we are faced with an epistemological dilemma. Before measurement takes place, we need to define where and when the phenomenon we are measuring begins and ends—to define its "system boundaries." For instance, one liter of semi-skimmed milk, bought in a British supermarket, has an energy content of 380 kcal. However, to think of the milk in terms of energy also evokes the far-reaching social and environmental contexts that bring milk to the market. Beyond the energy content declared on the milk carton, we can undertake a life cycle assessment (LCA)—expanding the system boundaries—to account for the energy (or the carbon, water, labor, or land) "embodied" in the milk via its production and distribution.[2] We might include the energy content of processed cattle feed, electricity used to run milking machines, cooling tanks, water boilers, and lighting, energy inputs in alkaline and acid detergents, diesel for tractors, and a wide range of other energy technologies used in production. We might expand the system boundaries further to account for the fuels needed to generate the electricity, run the chemical plant, fuel the milk tanker, power the dairy plant, and so on. Arguably, we should also account for the energy expended in the production of the electricity generator, the milking machine, the milk tanker and the tractor, fencing and the batteries storing energy to electrify it. But if an electricity generator and a battery are somehow embodied in a liter of milk, we have culturally come far away from what we normally understand milk to be. Where, then, should we draw the system boundaries around an object in order to gauge its social and environmental impact?

The question has practical implications for LCA, and it is generally recognized that the choice of system boundaries can alter the assessment result significantly (Rebitzer *et al.*, 2004; Finnveden *et al.*, 2009; Dubois-Iorgulescu *et al.*, 2018). In a study of forest products developed to replace carbon-intensive fuels and materials, Peñalosa *et al.* (2019) conclude that the results of their assessment are entirely dependent on the selection of system boundaries. More widely, however, the question challenges the conventional ways in which we define

[2] Howard Odum (1988: 1139 n. 11) reflects on the problem of conceptualizing "embodied energy." From 1967 to 1984, he writes, his concept of "emergy" (spelled with an *m*) was defined as "energy cost" or "embodied energy", but as these terms "proved ambiguous", he revised the definition of emergy to instead signify "energy memory" or "emergent property of energy use." Though the Second Law of Thermodynamics tells us that the quantity of energy expended through the history of an object does not remain "in" the object, this energy may have been essential to its current qualities.

and delineate technological artefacts and other ostensibly bounded objects. This is reflected in studies in urban political ecology. Urban political ecologists demonstrate how urban forms of material circulation produce and reproduce forms of social inequality (Heynen *et al.*, 2006; Newell and Cousins, 2014). Yet the question of *where* the city ends, in metabolic terms, is a highly contentious one in the field (Connolly, 2018; Loftus, 2018; Tzaninis *et al.*, 2020). Noting the socio-material continuities that characterize urban life, Guibrunet *et al.* (2017) argue that material flows analysis and LCA can be tools that facilitate a transition to a city that is at once environmentally sustainable *and* socially just. However, they also demonstrate that the delineation of the "city" as a bounded unit—which is a necessary step to enable the analysis—clouds the multi-scalar patterns of resource distribution that shape the urban metabolism.

In this article, we argue that system boundaries constitute an epistemological problem in assessments of social and environmental impact, but more importantly, that system boundaries should be treated as ethnographic phenomena. The measurement of social and environmental impact depends on how the conceptual boundaries of technologies and other objects are fixed in time and space, and how people draw system boundaries around different phenomena itself differs cross-culturally. System boundaries, we argue, can be studied as cultural artefacts in a comparative perspective, and when exposed to ethnographic analysis, the way system boundaries are drawn in discussions on energy transitions calls into question how the existence of technology relies on socially uneven flows of resources, land, and emissions, implying a geographical displacement of environmental load. By examining system boundaries as part of the epistemological assumptions that enable impact assessment, we seek to conceptualize the "political work of knowledge legitimization" that is linked to the act of measurement (Guibrunet *et al.*, 2017: 353; Barry, 2015).

To develop the argument, we examine how the definition of system boundaries presents epistemological dilemmas in our understanding of socio-ecological systems, as illustrated in assessments of environmental impact. A **first** set of dilemmas occurs when impact is measured across commodity chains—for example through LCA—and system boundaries are defined functionally. A **second** set appears when impact is measured in relation to areal units of different shape and size, and system boundaries are defined spatially. **Third**, we treat system boundaries as an ethnographic problem that can be studied comparatively as cultural artefacts, looking at how system boundaries crystallize in contexts such as Melanesian cargo cults and in what Marx referred to as commodity fetishism in modern capitalism. When viewed as cultural phenomena, system boundaries present not only epistemological but also ontological challenges, doing political work in discussions on green technology and energy transitions. We argue that the way system boundaries are delineated around an energy technology has significant political-ecological implications in that it either exposes or obscures how technologies redistribute flows of land, resources, and emissions unequally between social groups. We illustrate this by comparing industrial and agroecological agricultural systems. Across ethnographic contexts, we discern a pervasive human inclination to perceive the conditions of existence of material objects as co-extensive with their physical boundaries. In truncating the less tangible field of flows which sustains, for instance, an organism or a machine, such perceptions obscure what these objects represent as socio-ecological phenomena.

2. System boundaries as a functional problem

"Objects are boundary projects", Donna Haraway (1991: 201) argues. "What boundaries provisionally contain remains generative, productive of meanings and bodies." Such a perspective on system boundaries is central to a range of methodologies that have been developed in order to measure the social and environmental impact of human activities, including but not limited to LCA (Rebitzer *et al.*, 2004; Finnveden *et al.*, 2009; Dubois-Iorgulescu *et al.*, 2018), ecological footprints (Wackernagel and Beyers, 2019), material flows analysis (Fischer-Kowalski and Hüttler, 1998), and human appropriation of net primary production (Temper, 2016). As one of the most sophisticated frameworks, LCA aims to assess the impact of a product from its development phase and the extraction of resources, via manufacturing and consumption, to end-of-life waste management. LCA has become particularly prominent when the environmental impacts of electricity and transport systems are evaluated, as the demand from energy consumption, given a certain transmission and distribution infrastructure (Cederlöf, 2015), translates in a linear fashion into the demand for energy resources in these systems. This translatability makes it relatively straightforward to compare how different socio-technical systems or commodity chains can deliver the same outcome with different environmental impact (Mulvaney, 2019: 86).

To enable the assessment of environmental impact, LCA operates based on a set of standardized epistemological assumptions. **First**, the life-cycle analyst must define the "functional unit" that is being measured. Rather than a discrete object, the functional unit refers to the practical use-value a product provides, such as "cooling one liter of milk to 4°C for one hour." Different production systems can then be assessed with respect to the delivery of the same use-value. **Second**, the analyst must define the system boundaries that the functional unit exists within. The system boundaries delimit the phenomenon under study from that which it is not (Büchel, 1996). By changing the system boundaries, a study can arrive at significantly different results: "The choices and assumptions made during system modelling", as Rebitzer *et al.* (2004: 705) argue, "especially with respect to the system boundaries and what processes to include within these boundaries, are often decisive for the result of an LCA study." Though LCA is a quantitative tool, the drawing of system boundaries reflects qualitative choices, and life cycle assessment is "therefore mediated by human subjectivity" (Mulvaney, 2019: 87). The United Nations Environment Program's (UNEP) guidelines for social life cycle assessment echo this observation, noting that "[t]here is no such single, *objective* thing as a product life cycle. A product life cycle is an *idea*" (Benoît and Mazijn, 2009: 55, emphases in the original).

Finnveden *et al.* (2009: 5) identify a number of areas where system boundaries raise qualitative issues for LCA, and they argue that these boundary concerns should be approached based on functional considerations. A **first** boundary problem occurs in the space between "the technical system" that enables the functional unit and its "environment." With LCA's cradle-to-grave perspective, Finnveden *et al.* argue that the technical system should be bounded on one end at the point where the extraction of resources is set apart from "raw materials as found in nature", and on the other, where waste management is distinguished from "emissions to nature." Time is a complicating factor as emissions, for example from landfills, can continue over long time spans, even as the impact of emissions depends on the rate of emissivity (cf. Bücher, 1996: 15–18). In comparison, Rebitzer *et al.* (2004: 705–706) show how the boundary between the technical system and its environment often crystallizes through a pragmatic approach in which material and energy flows are traced first from the functional unit upstream, to the point of resource extraction, and then downstream, to the point of final waste disposal. It is then up to the analyst to distinguish between significant and insignificant processes upstream and downstream in an iterative practice of drawing and redrawing the system boundaries. In these terms, both Finnveden *et al.* and Rebitzer *et al.* separate a human-made technological system from a nature external to the functionality of the system, thereby reproducing a dualism in which the cultural contexts and politicized environments in which raw materials and emissions exist (Bumpus and Liverman, 2011; Huber, 2017; Mulvaney, 2019) are severed from the system.

A **second** boundary problem appears in LCA when one product (or functional unit) is part of a commodity chain that it shares with another product—when a system boundary has to be drawn between "the technological system under study and other technological systems" (Finnveden *et al.*, 2009: 5). How then should the environmental impact of the production process be split between the different products? A refinery, for example, is a "multi-output" system in which one process produces several products, while a waste incinerator is a "multi-input" system in which one process incorporates several products. Finnveden *et al.* argue that the analyst has to make a theoretically motivated choice to define the system boundaries in this case, apportioning impact based on variables such as chemical causation, economic value, mass, or any other arbitrary physical variable. It is also possible to expand the system boundaries, they argue, to incorporate other life cycles into the one under study. Gaudreault *et al.* (2010) examine a project in the North American pulp and paper industry, part of which was to replace thermomechanical pulp, which consists of ground wood chips, with deinked pulp made from recycled paper in the production of newsprint. Would the project have a positive environmental impact? The assessment was complicated by the fact that wood chips are a by-product of the timber industry and would be manufactured regardless of demand from the pulp and paper industry. Thus, if the system boundary was drawn around the paper production process alone, the assessment would render a qualitatively—and likely quantitatively—different result than if it included the wider chip market and alternative chip uses. In response to this boundary issue, life cycle analysts often distinguish between "attributional" and "consequential" LCA. The former assesses the impact of a particular product or process while the latter evaluates the effect of a change in process with more extensive system boundaries (Ekvall and Weidema, 2004). Gaudreault *et al.* (2010) find that indirect impacts identified in a consequential study can counteract direct impacts, which are the sole focus of attributional LCA. Given the epistemological issues at stake when system boundary choices are made in LCA, it is evident that the act of measuring the environmental impact of a product's life cycle itself creates the object it measures based on the system boundaries the analyst considers significant from a functional perspective. It is only by measuring an object within selected system boundaries that the object comes into being.

3. System boundaries as a spatial problem

Another kind of epistemological problem occurs when environmental impact is given a spatial dimension. In this case, system boundaries define the areal unit within which impact is measured. Cousins and Newell (2015) argue that LCA and other material flows methodologies generally neglect questions of spatial differentiation, which in turn leaves the uneven socio-political relations that fashion human-environment interactions unassessed. In November 2018, the Swedish Land and Environmental Courts gave the oil company Preem AB permission to expand one of its two refineries in southwestern Sweden to annually process 2.5 million metric tons of crude oil into gasoline and diesel. To provide motorists with fuel, Sweden records some fuel imports, but the domestic market is in large part served by Preem's refineries in Lysekil and Gothenburg. Sweden has no extractive oil industry, but petrochemicals—mainly gasoline and diesel—constitute the country's fourth largest export category (SCB, 2020). In 2014, the Swedish Energy Agency logged net exports of gasoline of around 7.5 million m^3 (Energimyndigheten, 2019). Preem's plans to expand its refinery in Lysekil sparked protests from Swedish environmental activists. The investments would increase the existing refinery's carbon emissions from 1.7 to 3.4 million tons annually—the latter figure representing 17 percent of Sweden's total emissions from industry (Carlén and Wikman, 2020). This resonated poorly with the national goal of reaching net zero emissions by 2045, and in August 2019, the Swedish government announced that it, rather than the courts, would decide on the refinery's future because of its far-reaching political implications (Miljödepartementet, 2019). Citing a slump in petrochemical demand due to the Covid-19 pandemic, Preem later canceled its expansion plans as the project was no longer commercially viable (Gustafsson and Grönlund, 2020).

The conflict surrounding the Lysekil refinery highlights key areal dynamics in the measurement of environmental impact contingent on spatially distributed system boundaries. In a study of voting patterns in the United States, Openshaw and Taylor (1979) noted how changes in the shape and size of the areal units within which votes were aggregated fundamentally changed the result of the vote. The issue, known as the "modifiable areal unit problem" after Openshaw and Taylor's work, has two dimensions. The **first** is a problem of scaling. To measure the spatially distributed environmental impact of a product, the system boundaries have to be drawn at a certain level of abstraction, demarcating a discrete areal unit. However, when a phenomenon is measured over a large area, variations in space diminish (Dark and Bram, 2007: 472; Wong, 2009). This is the boundary problem encountered by urban political ecologists who need to define city limits in order to trace the patterns of material flows at this scale (Guibrunet *et al.*, 2017). In the conflict around the Lysekil refinery, the system boundaries were drawn to coincide with the national boundaries of Sweden: it was at this scale that the expanded refinery would contribute 17 percent of the country's industrial emissions. Yet if the system boundaries were scaled differently, the measurement of environmental impact would render a different result.

If instead of mapping on to Swedish national borders, the system boundaries were drawn around the peninsula where the refinery is located, the refinery would contribute close to 100 percent of the emissions in this areal unit. However, it would not contribute anything to an areal unit of the same size located next to it, even though both units would be nested within Swedish borders. If the system boundaries were drawn around southwestern Sweden rather than the whole country, this would again change the spatially distributed impact of the refinery, leading to a higher figure than the national aggregate. If, by contrast, the boundaries were drawn to include Lysekil in an areal unit incorporating the North Sea, the impact of the refinery would be rather modest given the aggregate emissions from the British and Norwegian oil industries in this area. Thus, when environmental impact is measured with sensitivity to spatial extent, measurement is linked to a certain observational scale (Sayre, 2015: 506–507). It was in relation to a national scale and the Swedish government's net zero emissions target that the refinery became an issue with political ramifications. By measuring the environmental impact of the refinery within certain spatialized system boundaries, the resulting piece of statistical knowledge became an object of government (Barry, 2015) resting on contingent political priorities. The "national" system boundary was politically productive but simultaneously obscured the refinery's environmental impact within areal units scaled otherwise.

A **second** system-boundary dilemma arising from the modifiable areal unit problem is one of zoning; that is, on which side of a boundary a product's impact is measured. In the case of the refinery, Preem's investments in Lysekil would allow the company to turn a profit by satisfying either the Swedish domestic or the Swedish export market with increased gasoline and diesel supplies. However, while some argued that it would be environmentally beneficial to expand the refinery as it would provide the market with cleaner fuels (Värmby, 2020), the political conflict did not concern whether the consumption of fossil fuels would increase in the transport sector overall (though we might argue that increased fossil fuel combustion is a poor start for meeting a net zero emissions target). From a functional perspective, the environmental activists drew the system boundaries around the refinery to exclude its downstream impacts—carbon emissions resulting from increased gasoline and diesel use in cars and trucks—and used Swedish national borders to demarcate the areal unit for the measurement of the refinery's environmental impact. The political conflict, therefore, centered on the extent to which the refinery itself would increase Swedish carbon emissions and whether the refinery should be located within Swedish borders or not.

The modification of system boundaries to include or exclude one or several data points can have significant effects on the measurement of environmental impact. A zoning effect occurs when data is aggregated in areal units whose number remains constant but whose borders change, leading to "different depictions of the region and different analytical results when the data are analysed" (Wong, 2009: 108). A rezoning of the system boundaries to exclude Preem's refinery from the Swedish areal unit would displace the environmental load of energy use from national statistical scrutiny, allowing the government to record a lower environmental impact from the consumption of gasoline and diesel. As Isenhour and Feng (2016) demonstrate in the Swedish case, national efforts to decouple emissions from economic growth generally tend to be counteracted by emissions embodied in imported commodities. Even if all the gasoline and diesel produced in the Lysekil refinery was consumed in Sweden, it would be beneficial for Swedish political purposes to locate the refinery across the national border. If the areal unit was scaled and zoned around the industrial complex "itself", the emissions from the refinery would remain the same regardless of location, but on the national scale, a rezoning of the system boundaries to locate the refinery in another areal unit would have dramatic political implications. The zoning and scaling of system boundaries either internalize (include) or displace (exclude) the environmental impact of a product in/from the analysis of it.

4. System boundaries as an ethnographic problem

Our discussion thus far indicates that system boundaries are generative of technologies and objects with environmental and social impacts. As functional and spatial phenomena, system boundaries are contingent on qualitative judgements and methodological choices with political outcomes. The UNEP's guidelines for social life cycle assessment state that the boundary choices LCA practitioners make tend to reflect three "determinants": **first**, the aims guiding a particular impact study and the questions it intends to answer; **second**, the availability of data and the practitioners' experiences of past modeling; and **third**, "perhaps unknown to the practitioners themselves . . . the *elements of their world-view*" (Benoît and Mazijn, 2009: 55, emphasis added). System boundaries, this would suggest, are essentially *cultural* constructs. At this deeper level, system boundaries are not simply politically strategic instruments but reflections of ontology.

If we consider the diverse ways in which the boundaries of phenomena may be perceived in different cultural contexts, it is evident that system boundaries, more than just posing technical and epistemological problems, are cultural artefacts that express fundamental ontological convictions. The problem of establishing system boundaries is a conundrum not only in the delineation of physical, socio-ecological systems but also in the subjective experience of self. There is an extensive philosophical and anthropological literature probing how experiences of human selfhood can vary in this respect (e.g. Evernden, 1993; Ingold, 2011). The notion of individual humans as bounded entities appears to be particularly associated with the social condition of modernity, whereas "relational" perceptions of selfhood have been identified in many non-modern societies (cf. Bird-David, 1999). In a series of books over the past two decades, Tim Ingold (e.g. 2000, 2011) has contrasted conventional modern perceptions of living and non-living entities as bounded objects with alternative experiences based on the relations that connect them. He aptly contrasts perceptions of such entities as "blobs" versus "bundles of lines" (Ingold, 2018). It seems as if a relational experience of self may be conducive to a relational view of other living and non-living entities. Conversely, experiencing the self as bounded by one's skin may be conducive to a view of the world as composed of clearly delineated objects.

The phenomenological dimension of boundary-drawing is also evident in studies of animal territoriality and human-animal relations. Individual organisms can under specific circumstances subjectively identify with spaces or objects that are external to their physiological boundaries. Neil Evernden (1993: 44) illustrates such expanded identification with the territorial behavior of the stickleback:

> In short, it is as if the boundary of what the fish considers to be *himself* has expanded to the dimensions of the territory. He regards himself as being the size of the territory, no longer an organism bounded by skin but an organism-plus-environment bounded by an invisible integument.

While both animal behavior and human experiences of selfhood confirm that in a subjective, phenomenological sense, the boundaries of an organism may be much wider than its skin, it is more demanding to apply a similar perspective to the objective, *material* constitution of living systems. Yet an organism is clearly a node in a wide network of ecological relations that are both semiotic and material. It represents a continuous net input of nutrients, energy, water, and oxygen that it derives from its environment. The system boundaries of an organism, in other words, coincide with an entire ecosystem and ultimately include even the sun. Cognizant of such entanglement, Haraway (2008: 3–4) problematizes the system boundaries that demarcate the human self when she marvels at the fact that 90 percent of all cells in the human body belong to other species. Co-dependent on bacteria, fungi, and protists, the human body is a multispecies ecosystem.

It would be incorrect to suggest that an overly restricted definition of system boundaries is only a modern affliction. Cultural variation notwithstanding, humans generally appear to have a propensity, at least in the practical contexts of everyday life, to base their conceptions of the world on the sets of tangible objects that present themselves to their senses, particularly their sense of vision. From the perspective of evolutionary biology, such perceptions—often guided by other senses such as hearing or smell—have undoubtedly served the purpose of identifying relevant predators and prey within a given ecological food chain (cf. Ingold, 2000). The cognitive inclination to excise organisms and other entities from the webs of relations that sustain them presumably had a significant survival value for our human and pre-human ancestors through the eons (Maturana and Varela, 1992 [1987]). Philosophical reflection on the intangible system boundaries of the organisms involved would hardly enhance the hunter's chances of success—nor the game animal's chances to escape—in the everyday metabolism of a local ecosystem.

Reification, that is the pervasive "objectification" of the products of intangible flows based on a narrow definition of system boundaries, may thus be a biologically inherited inclination. However, while it no doubt serves a pragmatic purpose in the context of a local community or ecosystem, it risks seriously distorting the conditions of existence in the wider, supra-local social systems integrated by humans. Long-distance resource flows organized by the world market are constitutive of the bodies of modern humans,[3] our animals, and our various artefacts, yet all these bodies and things tend to be visualized as somehow independent of global flows. When increasingly both organisms and artefacts are globally constituted in the modern world, reification is equally problematic in the analysis of ecological and economic systems. The perception of artefacts as excised

[3] Raymond Dasmann (1988) contrasts the constitution and mind frame of what he calls "ecosystem people" with (modern) "biosphere people."

from social and ecological exchange relations results in the kind of ideological mystification that Karl Marx referred to as *fetishism*. David Harvey (1990: 423) calls on us to exercise our "geographical imagination" in order to trace the uneven social and spatial relations that markets conceal through the fetishization of commodities, although this exercise is complicated in everyday life when "[t]he spatial range of our own individual experience of procuring commodities in the marketplace bears no relationship to the spatial range over which the commodities themselves are produced." The spatial reach of our economic transactions far surpasses that of our experience, not to mention our ethics.

Studies that "follow the thing" upstream and downstream across multi-sited ethnographic networks effectively show how commodities—whether papaya (Cook, 2004), Levi's jeans (Brooks, 2019), or photovoltaic solar panels (Mulvaney, 2019)—are manifestations of global relations with social and environmental impacts far removed from circumscribed sites of consumption. Marx's concepts of "commodity fetishism" and "money fetishism" illustrate the propensity to disregard how the system boundaries of artefacts are drawn, and the ideological effects that differently drawn system boundaries have on our understanding and measurement of social and environmental impact. If technologies are conceptualized not as tangible objects but as bundles of globalized lines, machines can no longer be seen simply as local means of saving labor time but must be conceptualized as instruments for displacing workloads and environmental impacts from one place to another in the globalized economy. "Machine fetishism" is a corollary of commodity fetishism in which technology is pictured without regard to the asymmetric global resource flows that keep machines running (Hornborg, 1992, 2001).

A classic illustration of how human perceptions of artefacts can obscure global relations of exchange is offered by the so-called cargo cults of early twentieth-century Melanesia. Upon being integrated in the world economy, Melanesian islanders were amazed by the industrial goods—canned foods, flashlights, rifles, refrigerators, cars—that mysteriously arrived by ships or airplanes from an opaque land beyond the horizon. The islanders believed that the goods were being manufactured by the spirits of their ancestors and conducted rituals to prepare for the prophesied arrival of great quantities of the coveted cargo. Peter Worsley (1970 [1957]: 107) writes:

> Who made these goods, how and where, were mysteries—it could hardly be the idle White men. It was the natives who did all the manual work. If the goods were made in some unknown land, they must, then, be made by the spirits of the dead.

Although many people today may find such misconceptions amusing, the modern consumer is often no less ill-informed about the conditions under which their goods are produced and the socio-environmental impacts they render (Bryant and Goodman, 2004; Evans, 2018). This is now sometimes referred to as "consumer blindness", but as previously observed, it was anticipated in Marx's concept of commodity fetishism. For Marx, the claim that commodities were fetishized in European society was founded on the observation that the decontextualized products of human labor tended to obscure their origins in relations of economic exchange. Through fetishization, commodities were historically and geographically circumscribed as autonomous "things" with inherent value and purpose. Drawing on Marx, Michael Taussig (1980: 36) notes how the phenomenology of modern economic interaction evokes aspects of magic:

> If we "thingify" parts of a living system, ignore the context of which they are a part, and then observe that the things move, so to speak, it logically follows that the things may well be regarded or spoken of as though they were alive with their own autonomous powers. If regarded as mere things, they will therefore appear as though they were indeed *animate* things—fetishes.

A preoccupation with commodities as objects deflects attention from the invisible structures of exchange that make them possible, and hence, the logic of the globalized market complicates the assessment of social and environmental impact. When juxtaposed, the cases of Melanesian cargo cults and globalized commodity production indicate that the definition of system boundaries reflects the observer's positionality in the power geometries of local, regional, and global economic exchange. Regardless of the biological, cultural, or epistemological factors involved, where and when the system boundaries are drawn around a socio-ecological phenomenon exposes or obscures how it redistributes flows of resources and emissions, labor and land unequally between social groups. The more globalized the social and ecological circumstances are in which commodities originate and reach their end-of-life, the more opaque and complicated their political implications become to assess.

5. Conclusion: technology and the political geography of socio-environmental impact

In the context of socio-environmental impact assessment, system boundaries generate technical, epistemological questions, but as ethnographic phenomena, they also reflect potentially conflictual ontological assumptions. The most general conclusion we can draw is that system boundaries are pivotal to conceptualizing the implications of modern human lifestyles and consumption patterns in relation to concerns about distributional inequality and sustainability. In aspiring to assess the global repercussions of our technological and social metabolisms, we encounter a range of obstacles at various levels: functional, technical, spatial, cultural, even biological. These obstacles, which constrain yet enable the analysis of socio-environmental impact, serve political interests by obscuring relations of asymmetric exchange to greater or lesser degrees. To question the delineation of system boundaries must therefore be a basic methodological imperative for political ecologists.

In discussions on green development and strategies for a low-carbon energy transition, there is a strong case made for technologically utopian solutions in which novel, more efficient technologies will enable a decoupling of environmental impact from economic growth. These solutions range from a complete electrification of transport to the mainstreaming of "cultured" meats, milk, and eggs to a wholesale transition to a solar economy (Jacobson and Delucchi, 2011; Sexton *et al.*, 2019; Urry, 2013). Depending on the exponent's political allegiance, they often resonate with teleological imaginaries of technological progress inspired by the American "technological sublime" or the Marxist "development of the productive forces." However, the socio-environmental impact of green technology is contingent on the definition of system boundaries: a technologically utopian solution rests on narrowly defined system boundaries, illustrating how select system boundaries are integral to wider cultural worldviews and visions of political-economic futures (Dove and Kammen, 2015). Whether or not the "indirect", more global impacts of technological change are included in a study changes the assessment result, as exemplified in the case of the North American pulp and paper industry (Gaudreault *et al.*, 2010). If the system boundaries are drawn around a single production process, investments in renewable energy technologies, as well as increases in energy efficiency, are likely to have a positive environmental impact. Yet the investments only contribute to an absolute low-carbon transition if fossil technologies are dismantled in the economy as a whole at the same rate as investments or efficiency gains are made in a particular process. On their own, investments in low-carbon technologies or efficiency gains bring about a relative energy transition, which maintains, or even increases, the net levels of emissions in the economic system (Wackernagel and Rees, 1997: 18–20).

To assess the social and environmental impact of green technologies, it is necessary to define the system boundaries around them. But this is a political act: a system boundary inevitably includes and excludes globalized relations of socio-ecological exchange. A technology can be seen as a node in a wider "bundle of lines" (Ingold, 2018), which in the act of measurement is reified based on specified system boundaries. If we allow the concept of machine fetishism to influence our understanding of technology and socio-environmental impact, the "capabilities" offered by new technologies must be seen to rest on a geographical displacement of environmental load. The coal-fired steam engine was invented in Britain, but it was no coincidence that it appeared at the core of a global empire: the ability to invest in and operate steam engines depended on one's place in the British Empire and one's capacity to access energy and raw materials. Capital to purchase the technology and harness the energy to run it was contingent on exchange relations that involved Welsh collieries, Swedish iron mines, American cotton plantations, African slaves, and a number of other resources and bodies enrolled in a globalized market. Technical knowledge was a necessary condition for the Industrial Revolution, but it was not a *sufficient* condition: industrial development also rested on the ability to spatially displace the socio-environmental load of production and consumption. When impacts are quantified, it is vital to recognize that material flows are maintained through human activities and scale-dependent relations of exchange (Guibrunet *et al.*, 2017; Cederlöf, 2021). While the steam engine often is perceived as co-extensive with its casing, its socio-environmental impacts will vary depending on functional and spatial boundary definitions that compound each other (cf. Cousins and Newell, 2015). To measure the socio-environmental impact of green technology, in turn, we need to expand the system boundaries that define it to include the regional and global flows of raw materials, energy, carbon, labor, and land that make investments in technology materially possible (Hornborg *et al.*, 2019; Roos, 2021). These flows generally remain opaque to the users of technology, "embodied" as they are in artefacts traded on the market. The fact that the energy expended in the production of a commodity does not remain "in" the commodity, even as it is a necessary condition for its existence, leaves the measurement of socio-environmental impact to the qualitative choices and positionality of the observer.

If system boundaries are seen to be cultural products, it follows that they are integral to sustaining different power-serving worldviews. LCA and other methodologies developed to measure socio-environmental impact therefore do political work. Two different approaches to "green" food production illustrate the issues at stake. Industrial farming is often praised for its high returns to land area. Functionally, the environmental impact of production can be traced upstream and downstream, and interestingly, the largest emissions in U.S. industrial agriculture do not occur on the farm but in the production of nitrogen fertilizer, requiring large amounts of natural gas (Huber, 2017). As Dove and Kammen (2015) show, however, the market relations that bring fertilizer to the farmer and later agricultural products to the consumer tend to shroud the socio-ecological continuities that exist between fertilizer plants, farms, and dining tables. If fertilizer is imported from a different state or country, the environmental impact of farming also tends to be displaced to an areal unit removed from the farm and the site of consumption, allowing a statistical displacement of environmental load. In contrast to industrial agriculture, agroecological methods are usually less productive per land area, but they are more productive as a function of energy input (Altieri, 1995), especially when the energy embodied in agricultural inputs are included in the calculation. Industrial agriculture, then, is more productive within narrowly defined system boundaries, but agroecology is more productive within globally defined boundaries.

As a cultural practice, agroecology is an attempt to make system boundaries visible and allow the global boundaries of the productive system to correspond to that of the farm. Through practices of poly-cropping, crop rotation, composting, and integrated pest management (i.e. functional considerations), agroecological farmers aim to internalize the environmental impact of production within the spatial limits of the farm (Cederlöf, 2016). Industrial agriculture, in contrast, works by importing synthetic fertilizers, pesticides, and fuels into the farm through commodity exchange, and the system boundaries thereby extend far beyond the farm boundaries. As different cultural strategies for food production, industrial agriculture and agroecology are associated with different ontological perceptions of system boundaries, and by extension, concepts of productivity and socio-environmental impact. These differences make it difficult to compare the environmental impact of one functional unit based on the two systems, such as the production of one liter of cow's milk, when the two approaches to system boundaries internalize and exclude differently spatialized socio-ecological relations. The choice of system boundaries in an LCA or other study of material flows will reflect a particular worldview and reproduce it. The choice determines which human activities and scale-dependent political-economic relations that are rendered visible. The definition of system boundaries is integral to the measurement of social and environmental impact, yet as cultural artefacts, system boundaries are politically productive, and the measurement of impact is an intervention in an always political ecology.

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