Journal article

From teleconnection to telecoupling

Taking stock of an emerging framework in land system science

Cecilie Friis   Jonas Østergaard Nielsen   Iago Otero
Helmut Haberl   Jörg Niewöhner*   Patrick Hostert

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Abstract: Land use change is influenced by a complexity of drivers that transcend spatial, institutional and temporal scales. The analytical framework of *telecoupling* has recently been proposed in land system science to address this complexity, particularly the increasing importance of distal connections, flows and feedbacks characterising change in land systems. This framework holds important potential for advancing the analysis of land system change. In this article, we review the state of the art of the telecoupling framework in the land system science literature. The article traces the development of the framework from teleconnection to telecoupling and presents two approaches to telecoupling analysis currently proposed in the literature. Subsequently, we discuss a number of analytical challenges related to categorisation of systems, system boundaries, hierarchy and scale. Finally, we propose approaches to address these challenges by looking beyond land system science to theoretical perspectives from economic geography, social metabolism studies, political ecology and cultural anthropology.

Keywords: teleconnection, telecoupling, land systems, land use change, globalization, interdisciplinary work

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*joerg.niewoehner@hu-berlin.de; ORCiD: 0000-0002-9034-9761

From Teleconnection to Telecoupling – Taking stock of an emerging framework in Land System Science

Cecilie Friis[ab*], Jonas Østergaard Nielsen[ab], Iago Otero[a], Helmut Haberl[ac], Jörg Niewöhner[ad], and Patrick Hostert[ab]

[a] IRI-THESys, Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany. [b] Geography Department, Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany. [c] Institute of Social Ecology Vienna, Alpen-Adria Universität, Schottenfeldgasse 29 A-1070 Vienna, Austria. [d] Institute of European Ethnology, Humboldt-Universität zu Berlin, Mohrenstraße 41, 10117 Berlin, Germany.

* IRI-THESYS, Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany. Phone: +49 (030) 2093-66343. Email: cecilie.friis@hu-berlin.de

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From Teleconnection to Telecoupling – Taking stock of an emerging framework in Land System Science

Land use change is influenced by a complexity of drivers that transcend spatial, institutional and temporal scales. The analytical framework of *telecoupling* has recently been proposed in Land System Science to address this complexity, in particular the increasing importance of distal connections, flows and feedbacks characterising change in land systems. This framework holds important potential for advancing the analysis of land system change. In this article we review the state of the art of the telecoupling framework in the Land System Science literature. The article traces the development of the framework from teleconnection to telecoupling and presents two approaches to telecoupling analysis currently proposed in the literature. Subsequently, we discuss a number of analytical challenges related to categorisation of systems, system boundaries, hierarchy and scale. Finally, we propose approaches to address these challenges by looking beyond Land System Science to theoretical perspectives from economic geography, social metabolism studies, political ecology and cultural anthropology.

Keywords: Teleconnection, telecoupling, land systems, land use change, globalisation, interdisciplinary work

1. Introduction

During the past three decades, Land System Science (LSS)[1] has consolidated its position as a research field exploring the functioning of land systems and the role of land change in transforming the Earth (Lambin and Geist, 2006; GLP, 2005; Verburg et al., 2013; Aspinall, 2006; Rindfuss et al., 2004; Turner et al., 2007). As the terrestrial component of the Earth System, land systems are analysed as coupled human-environment systems (Young et al., 2006; GLP, 2005; Turner et al., 2003), or socio-ecological systems (Fischer-Kowalski and Haberl, 2007; Folke et al., 2005). Understanding and modelling the dynamics of land system change, the enhanced human pressures on the Earth's limited land resources, as well as the increasingly complex drivers of those changes have been key objectives for LSS (Müller and Munroe, 2014; Rindfuss et al., 2008; Seto and Reenberg, 2014; Dearing et al., 2010; Turner et al., 2007).

Currently, land changes at all spatial levels are influenced by long-distance flows of raw materials, energy, products, people, information and capital creating a need for novel theoretical and methodological approaches to the analysis of causal relations in land system dynamics. Land system scientists have therefore called for the analytical integration of 'classical' place-based land use approaches with more process-based approaches from LSS, as well as other disciplines (Verburg et al., 2013; Meyfroidt et al., 2013; Munroe et al., 2014). The analytical concepts of *teleconnection* and *telecoupling* are central to these efforts (Eakin et al., 2014; Liu et al., 2013; Seto et al., 2012). Building on, expanding and to some extent challenging prominent theoretical notions within LSS, in particular the proximate-underlying drivers framework and the notion of land use transition, the 'tele'-concepts are proposed to direct explicit attention to distal causal interactions between land systems. As such, they offer researchers a heuristic and analytical framework for addressing the increasing spatial decoupling of drivers and outcomes in current land system change. Whereas *teleconnection* is suggested to describe distal environmental and socioeconomic drivers of land system change (Adger et al., 2009; Haberl et al., 2009; Seto et al., 2012), the more recently proposed *telecoupling* is proposed to explicitly capture the feedbacks and multi-directional flows that increasingly characterise interactions between land systems (Eakin et al., 2014; Liu et al., 2013; Liu et al., 2014).

Both 'tele'-concepts are gaining momentum in LSS (Müller and Munroe, 2014; Verburg et al., 2013; Gasparri and le Polain de Waroux, 2015; Seaquist et al., 2014; Carter et al., 2014). However, ambiguities persist regarding the difference between the two concepts, their theoretical content and empirical application. At the 2014 Global Land Project Open Science Meeting (GLP-OSM) in Berlin, for example, teleconnection and telecoupling were

[1] We use the denominator 'Land System Science' instead of 'Land Change Science' to pronounce the systemic character underlying the teleconnection and telecoupling framework. The critical notion of 'change' is inherently embedded in research on Land Systems Dearing JA, Braimoh AK, Reenberg A, et al. (2010) Complex land systems: the need for longterm perspectives to assess their future. *Ecology and Society* 15..

often used interchangeably despite their analytical differences. Furthermore, calls have been made for LSS to engage with theoretical and methodological insights from other disciplines in order to produce new interdisciplinary approaches and a meaningful operationalisation of the telecoupling framework (Liu et al., 2014; Eakin et al., 2014). Eakin et al. (2014) suggest a list of theoretical concepts and analytical methodologies that might facilitate such a development.

This paper therefore aims at summarizing, reviewing and clarifying the conceptual development from 'teleconnection' to 'telecoupling' in the LSS literature. The review then highlights the main strengths of the telecoupling framework for analysing spatial decoupling of land change processes, while pointing at some key challenges facing the application of the framework in particular in relation to categorisation of systems, system boundaries, hierarchy and scale. In order to address these challenges, and in response to the call by Liu et al. (2014) and Eakin et al. (2014), the paper proposes ways to move towards a more interdisciplinary telecoupling framework by pointing to specific theoretical and analytical insights from the fields of economic geography, socioeconomic metabolism studies, political ecology and cultural anthropology. Recent theoretical advancements in these fields offer valuable insights that can help tackle the identified challenges. While an exhaustive account of these large and diverse bodies of literature is outside the scope of the paper, the aim is to illustrate how such perspectives can contribute to pushing LSS research on telecoupling forward.

2. Prominent notions of land system change

The complexity of causes, processes and outcomes of land system change has made it difficult to establish a comprehensive theory of land change (Lambin and Geist, 2006). However, two conceptual notions have been especially prominent in the literature. Firstly, the framework of *proximate causes* and *underlying driving forces* has been widely used to analyse of direct and immediate, as well as broader and more diffuse causal relations in land system change (Geist and Lambin, 2002; Lambin and Geist, 2006). While "proximate" causes are always local, "underlying drivers" may be local, remote or general, i.e. not linked to a particular place. In this sense, the "tele"-concepts are distinguished from the proximate-underlying framework in that they describe distal causal drivers between specific land systems. Secondly, the *land use transition* notion has been influential as a heuristic tool to describe the various stages of land use and land cover change that places or regions are expected to go through in the development from a predominantly agrarian to an industrial or post-industrial society (DeFries et al., 2004; Foley et al., 2005). Land use transitions go along with the past and ongoing biophysical and societal changes related to the overall trajectories of the 'social metabolism' (Fischer-Kowalski and Haberl, 2007; Krausmann et al., 2008a; Haberl et al., 2011), including the changes in 'anthromes', i.e. specific constellations of human-environment systems (Ellis and Ramankutty, 2008).

The framework of proximate and underlying driving forces and the land transition notion have been, and are still, very influential in LSS studies (Ostwald et al., 2009; Caldas et al., 2015; van Vliet et al., 2012; Müller et al., 2014). However, both conceptualisations have been subject to criticism in recent work (Seto et al., 2012; Munroe et al., 2014; Turner et al., 2007). The increasing complexity of the processes shaping land system change challenge the distinction between proximate and underlying drivers, as processes interact across spatial, institutional and temporal scales. The various manifestations of globalisation, e.g. economic, political, technological and cultural, as well as the increasing speed and dimensionality of connectedness, have been key factors in shaping this complexity (Young et al., 2006; Reenberg et al., 2010; Müller and Munroe, 2014). The continued globalisation of the economy and surging international trade have for instance caused increasing spatial separation of places of supply, production and consumption of land based products (e.g. see Yu et al., 2013; Lambin and Meyfroidt, 2011; Erb et al., 2009b). Globalisation of information and knowledge has enabled public responses and policy changes as a result of, for example, media reports of the social and environmental effects of land use practices in faraway places (Nepstad et al., 2006; Garrett et al., 2013). These processes have also been associated with an increasing globalisation of land governance structures (Sikor et al., 2013). Studies illustrate how new policy regimes and regulations in one country have direct consequences for land use in others, for example in relation to forest protection policies resulting in leakages of deforestation abroad (Meyfroidt and Lambin, 2009; Meyfroidt et al., 2010; Meyfroidt et al., 2013) or in REDD+ efforts to mitigate climate change through forest conservation (Fox et al., 2014; Brockhaus et al., 2012).

Rapid land use changes and integration of places around the world have also challenged the conceptualisation of land use transitions. This notion has mainly been criticised for portraying land use change as a unidirectional sequential process that does not encompass the potential for chaotic, discontinuous and multi-directional flows of change including feedbacks, loops and leapfrogging that often characterise land system change (Seto et al., 2012; Lambin and Meyfroidt, 2011; Turner et al., 2007). Moreover, critics have highlighted that the land transition notion essentially adhere to a modernist vision of change that does not account sufficiently for cultural and historical differences across the world (Perz, 2007; Mansfield et al., 2010). Recent work on 'regime shifts', a concept adopted from systems ecology (Scheffer and Carpenter, 2003), in land use change has begun to address sudden transitions in systems between different socio-ecological states in response to unforeseeable events or across thresholds and tipping points (Fischer-Kowalski and Haberl, 2007; Krausmann et al., 2008b; Müller et al., 2014).

In sum the various manifestations of globalisation and the rapid and multidirectional change processes in land systems have facilitated what Reenberg et al. (2010) describe as 'a spatial decoupling of the local land uses from the most important driving forces' (p. 50).

3. Teleconnection

The concept of *teleconnection* has been suggested to capture this spatial decoupling of land change drivers and outcomes. As a concept originating in meteorology and climate change studies teleconnection has been defined as 'any transmission of a coherent effect beyond the location at which a forcing occurred' (Chase et al., 2006: 1). Within the climate change literature, Moser and Hart (2015) have recently proposed the 'societal teleconnection' framework to address distant 'human-created linkages' (2), where a teleconnection is conceptualised as the interaction between a conveying or transmitting physical structure, a process enacted, enabled or constrained by actors and institutions, and the substances, material or immaterial, being transmitted during the course of the teleconnection. As captured in the prefix 'tele', the teleconnection concept invokes a sense of (large) spatial distance between the systems interacting to produce the connection.

In the past 5-10 years, the concept has gained prominence in LSS studies trying to come to grips with both environmental and socioeconomic linkages between distant and seemingly unconnected land systems around the world. Many of these studies focus on international trade flows. Some have analysed teleconnections in relation to the increasing disconnection of production and consumption of land based products using the embodied Human Appropriation of Net Primary Production (eHANPP) (Haberl et al., 2007; Haberl et al., 2009; Kastner et al., 2015; Schaffartzik et al., 2015; Erb et al., 2009a). Others have examined teleconnections between local consumption and global land use patterns using a global multiregional input-output (MRIO) model for international trade flows (Yu et al., 2013; Weinzettel et al., 2013)[2]. Yet others discuss 'economic teleconnection' in, for example, the relationship between deforestation in the Amazon and growing demands for beef (Nepstad et al., 2006), or the land use consequences of global demand for soybean (Reenberg and Fenger, 2011).

The teleconnection concept has also been used to explore distal linkages between local land use change and livelihood transformations in relation to vulnerability and adaptation to global environmental change (Adger et al., 2009; Eakin et al., 2009; Challies et al., 2014). Finally, the teleconnection concept has gained prominence in studies on urban dynamics and land use changes, since urban expansion and the sustainability of cities are now highly dependent on the sustainability of their proximal and distant 'hinterlands' (Seitzinger et al., 2012; Qureshi and Haase, 2014; Seto et al., 2012). Seto et al. (2012) propose the Urban Land Teleconnections framework (ULT), defined as 'a process-based conceptualization that intertwines land use and urbanization by linking places through their processes' (p. 7689). In this framework, the tele-prefix is not merely a question of geographical distance, but also of the processes linking land change in specific urban and rural places, regardless of their

[2] However, see Kastner T, Schaffartzik A, Eisenmenger N, et al. (2014) Cropland area embodied in international trade: Contradictory results from different approaches. *Ecological Economics* 104: 140-144. for a discussion of the limitations of MRIO models.

location (see also Güneralp et al., 2013). The ULT approach captures the importance of recognising the possibility of simultaneous and multi-directional flows when analysing the drivers of land system changes.

4. Telecoupling

The reconfiguration of the teleconnection concept alluded to in the studies on urban-rural relations is captured in the concept of *telecoupling*. Building on the teleconnection concept, telecoupling is put forward in LSS to capture 'not only the "action at a distance" but also the feedback between social processes and land outcomes in multiple interacting systems' (Eakin et al., 2014: 143).

Based on the theoretical work on coupled human-environment systems[3] (Turner et al., 2003; Liu et al., 2007), and recognizing that such coupled systems are increasingly linked over large distances, Liu et al. (2013) initially proposed the telecoupling framework to address a need for 'an integrated framework for advancing our understanding of various distant interactions' (p. 2). Within LSS, Liu et al. (2014) and Eakin et al. (2014) have applied and refined the telecoupling framework to the study of distantly coupled land systems. The latter publications essentially present two approaches for analysing telecoupling. The first can be characterised as a *structured*, or systematic and organised analytical approach focusing on five main telecoupling components, and the second as a *heuristic* approach providing a starting point for analysing the processes involved in creating telecoupling between land systems (Friis and Nielsen, 2014).

4.1. A structured Approach to Telecoupling Analysis

The structured analytical approach follows the telecoupling framework proposed by Liu et al. (2013) closely. It has been further developed within LSS by Liu et al. (2014) and applied by Liu (2014) to the case of forest transition in China. A key feature of this approach is a distinction between *human, natural* and *coupled human-natural* systems. According to Liu et al. (2013) the notion of globalization has been used to analyse distant interactions between human systems, and the teleconnection concept has been applied to long-distance interactions in natural systems. In contrast, telecoupling is proposed to capture both 'socioeconomic and environmental interactions among coupled human and natural systems over distances' (Liu et al., 2013: 3). However, it is worth noting that LSS scholars have long considered land systems as coupled human-environmental systems (e.g. GLP, 2005; Rindfuss et al., 2004), and have already used the teleconnection concept to analyse combined environmental and socioeconomic interactions between land systems, e.g. Adger et al. (2009), Haberl et al. (2009) and Seto et al. (2012).

[3] For consistency, we use the term "human-environment system" throughout the paper to refer to what Liu J, Hull V, Batistella M, et al. (2013) Framing sustainability in a telecoupled world. *Ecology and Society* 18. term "human-natural system".

Liu et al. (2013) describe telecoupled systems as hierarchical, and propose a structured framework with a multilevel analytical approach including five main components of analysis: systems, flows, agents, causes and effects (Figure 1, left). The highest level for analysis is the telecoupling, where multiple coupled human-environment systems interact over (large) spatial distances. A telecoupling arises when an action produces flows between two or more place-based human-environment systems, which create a change and/or response in one or both of the systems – regardless of whether or not these effects are intended. Within each system a variety of agents can create or hinder the flows, and hence set in motion different causes and effects, including feedbacks.

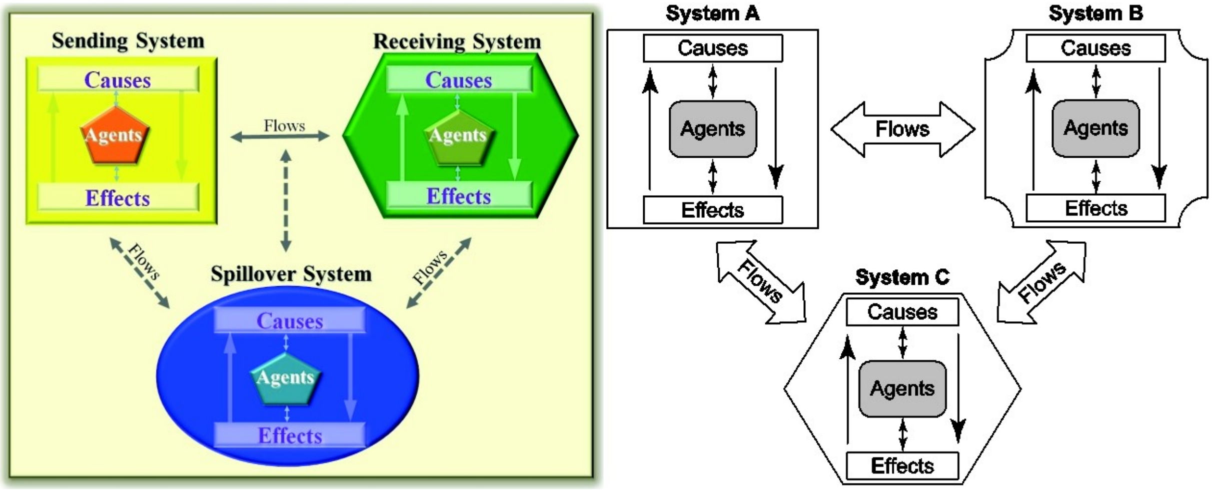

Figure 1. The telecoupling framework as presented in the structured approach by Liu et al. (2013) **(left) and** Liu et al. (2014: 121) **(right) showing the five main components of analysis, namely systems, flows, agents, causes and effects. The figure illustrates the developments made by** Liu et al. (2014) **to highlight that the role of the systems interacting are not determined a priori, but depends on the particular flow under inquiry.**

Systems are classified as sending, receiving or spill-over systems. Sending systems refer to places where the flow originates, whereas receiving systems are the recipients of the flow. Spill-over systems are understood as places that affect or are affected by the flow of interaction between sending and receiving systems, but without direct influence on the nature or direction of the flow. The complexity of the simple schematics increases as multiple sending, receiving and spill-over systems interact over distances. Depending on the particular flow being analysed any system can act as a sending, receiving and/or spill-over system. Although the spatial extent of telecouplings is not explicitly addressed by Liu et al. (2013), telecouplings are implicitly characterised as interactions over (large) geographical distances, e.g. the soybean trade between the US and China.

In the application of the telecoupling framework to LSS, Liu et al. (2014) advance the idea that systems act simultaneously as sending, receiving and spill-over systems illustrated by the second graphic in Figure 1. Emphasis is put on the fact that systems are interacting in multiple telecouplings concurrently, and it is stressed how telecouplings present an increasing challenge for governance in and of land systems.

Liu et al. (2013) and Liu et al. (2014) essentially introduce a comprehensive framework offering a systematic analytical tool for researchers to address each telecoupling component and their relationship with one another. Although the structured approach makes several analytical entry points possible and acknowledges that the same system can hold simultaneous roles, the emphasis on classifying systems as sending, receiving or spill-over systems remains strong and encourages researchers to start by identifying or defining the main flow of interest and its 'direction' between the systems being analysed. The framework's strengths is that it then guides the analysis through a systematic examination of each of the five main telecoupling components, as well as their mutual relations (for examples, see Friis and Nielsen, 2014; Liu et al., 2014).

4.2. A heuristic Approach to Telecoupling Analysis

The second approach for analysing telecoupling is proposed by Eakin et al. (2014) and it elaborates on the processes involved in creating telecouplings between land systems. Specifically, Eakin et al. (2014) add social to spatial distance when analysing telecouplings. As place-based human-environment systems, systems interacting in a telecoupling are assumed to be governed independently. The existence of separated governance structures becomes essential for characterising systems as telecoupled, rather than seeing them as one integrated system. This focus entails that functional distance in terms of governance is equally important as spatial distance in terms of kilometres. Eakin et al. (2014) furthermore stress that the outcome of flows and feedbacks occurs in a way that could not be expected a priori (See Figure 2, where an 'unexpected' flow is illustrated by the arrow #2). An initial flow triggers the telecoupling and is mediated by existing interactions and networks between the two systems, which create a feedback as illustrated in #3 by the bidirectional arrow. Feedbacks or unexpected flows beyond the interaction between the two systems (i.e. effects on or from spill-over systems) are not captured in this figure. Eakin et al. (2014) stress that the outcomes or results of telecoupled interactions are often indirect, emergent or of a second or third order, because different land use systems are governed independently of each other.

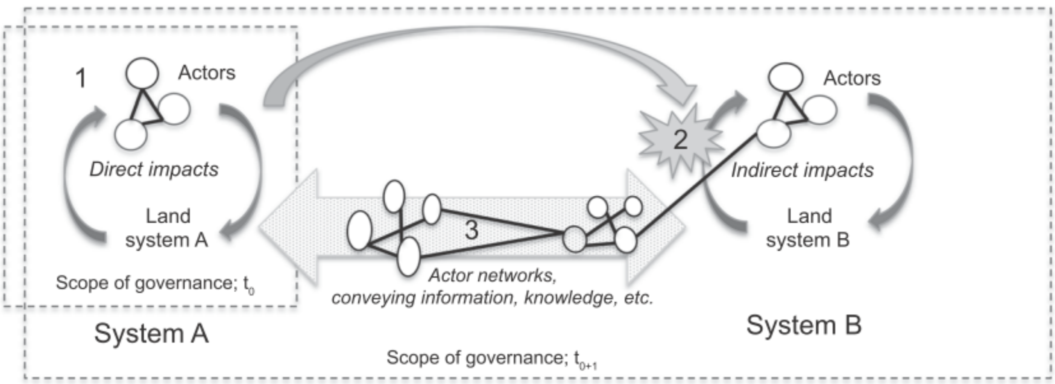

Figure 2. The telecoupling framework as presented in the heuristic approach by Eakin et al. (2014: 147).

This approach suggests that telecoupling can be analysed as the outcome of five key features: the trigger that sets the telecoupling in motion, the direct impacts in the system with the initial change, the indirect/unexpected impacts in the distantly coupled system, the feedback processes that influence the existing governance structures and finally the potential institutional change in both systems.

A further distinction of this approach is the explicit emphasis on the networked interactions across scales in the creation of telecouplings, which substitute the spatial hierarchy and nested scales of analysis featuring prominently in the structured approach. For example, Eakin et al. (2014) note that the rising influence of information technology and social networks have made it possible for actors to '*skip scale*' and interact, influence and create outcomes in telecoupled systems (p. 159). Finally, the question of analytical entry point is left open in the heuristic approach to telecoupling analysis, where the analysis for example could start from an observed land use change, a policy expected to trigger change or in adverse social or environmental impacts.

4.3. Summary

Although based on the same theoretical foundation, two approaches to telecoupling analysis can be distinguished in the literature. The structured approach presented by Liu et al. (2013) and Liu et al. (2014) offers a comprehensive place-based conceptualisation that stresses the systemic nature of coupled human-environment systems, the relations between their components and their interactions over distances. In turn, the heuristic approach presented by Eakin et al. (2014) emphasises the importance of social as well as spatial distance of processes and networks involved in producing telecouplings. This difference is also present in the authors' approach to spatial hierarchy and scale of analysis. Whereas Liu et al. (2013) and Liu et al. (2014) frame telecouplings in a structured spatial hierarchy, Eakin et al. (2014) define them as the outcomes of networked interactions across scales. Furthermore, the structured approach in essence present a type of 'check list' of components to include in an exhaustive analysis that encourages, though does not require, the analysis to begin from the flow of interest, while the heuristic approach focuses on networks, actors and processes with a more open analytical entry point (Friis and Nielsen, 2014). Both approaches highlight the need for continued engagement with different theoretical tools and methodologies in order to capture the full complexity of the dynamics and processes involved in telecoupling.

5. Challenges for Telecoupling Research

The telecoupling framework presents a strong analytical starting point for addressing (new) causal relations in land system change over spatial and social distances. Yet, both approaches to telecoupling analysis face a number of challenges for application within LSS.

The first challenge relates to the structured approach breaking the telecoupling process into five separate, though interrelated, analytical components. While this structured simplicity provides a relatively easy methodological basis, it also to some extent reduces the framework to a 'check list' of components to describe in order to characterise telecoupled systems. The check list does offer a comprehensive scope and starting point for analysis that for example can be used to identify research gaps in the literature (see Liu and Yang, 2013). However, it also risks reducing the complexity of the processes involved to a point where analysis becomes rather thin, e.g. in the example of soybean trade between Brazil and China, where spill-over systems are identified as ‘United States [and] some unknown countries’ (Liu et al., 2013: , Table 1). This introduces a fundamental trade-off between temporal coverage and spatial grain on the one hand, and analytical depth on the other.

A second set of challenges is related to the analytical distinction between sending, receiving and spill-over systems. The categorisation of systems depends to a large extent on the analytical entry point, the scale of analysis and the defined flow of interest in the analysis. Since many of the flows investigated in relation to telecouplings are multi-directional or a matter of exchange, e.g. capital investments for material or information, it becomes an analytical choice whether a system gets categorised as the sender or the receiver in the interaction, as also pointed out by Liu et al. (2013: 5) for the example of soybean trade between Brazil and China. This is an important challenge as it points to an inherent ambiguity in the designation of roles between telecoupled systems. Furthermore, the prominence of feedbacks inherent in the definition of telecoupled land systems would indicate that classifying systems as sending or receiving is problematic and, especially for trade related exchanges, obsolete. Here, it could be relevant to distinguish between strong asymmetrical telecouplings with weak feedbacks, where classifying sending and receiving systems would be appropriate, and balanced telecouplings with more symmetrical flows and feedbacks, where such a classification is more problematic.

The categorisation of systems raises another important issue, as it alludes to an implicit power asymmetry inherent in the distinction of systems based on their role in the interactions. Though the telecoupling framework includes causes and effects in all systems, the sending systems are categorised as origin of the flow and receiving systems as the recipient. This implicitly cast senders as active, while receivers, and especially spill-over systems, are cast as passive. To some extent, the categorisation of systems places the agency in the hands of the actors in the sending system, as they ‘trigger’ the flow that creates the telecoupling. This blurs the complexity of interactions and exchanges between systems and simplifies the role and agency of the actors at both ‘ends’ of the telecoupling with the risk of reproducing preconceived ideas of the distribution of power rather than opening these up to empirical investigation. These caveats would be especially prominent in cases of strong asymmetrical telecouplings. The same type of criticism could be directed towards the distinction between direct and indirect impacts discussed by Eakin et al. (2014), as this also implies a power asymmetry between the telecoupled systems.

The third challenge for both approaches is the need to define spatially and functionally separated systems – the prerequisite for telecoupling analysis. This entails an analytical need to demarcate system boundaries, and a related set of challenges with regards to choosing the spatial and temporal scale of analysis. Six important aspects can be discerned here. First, the demarcation of system boundaries is always problematic in a world characterised by socio-economic, bio-physical and historical interconnectedness – the very same characteristic that has spurred the development of the telecoupling framework in the first place. This renders the separation of systems, at least somewhat, arbitrary. Second, spatial scale choices will influence the nature and extent of the networks of actors, the causes and effects that are attributed to one system as opposed to another. In the structured approach the flow under inquiry, to some extent, becomes a determining factor when separating systems. For the soybean trade example, the nation states of Brazil and China function as delineated systems. A similar delineation could also be imagined in the heuristic approach, where separation in terms of governance is prominent in the definition of a telecoupling. However, such functional separation has in itself become challenging. Recently, scholars have emphasised how land governance structures are transforming from classical place-based to more flow-based arrangements, and thus becoming increasingly de-territorialised (Sikor et al., 2013; Gentry et al., 2014). Land use, it is argued, 'is no longer under a single territorial institution – if it ever was – but is now also the subject of multiple, flow-anchored governance arrangements' (Gentry et al., 2014: 240). From this point of view it becomes challenging to separate systems based on traditional place-based governance structures such as national land management authorities.

Third, the hierarchical understanding of telecouplings prominent in the structured approach builds on classical ideas of nested spatial scales. That is, the telecoupling is understood to operate at a higher spatial level than the relations between the coupled human-environment systems interacting in the telecoupling, and causes and effects are contained within these systems. For example, *transnational* land deals are identified as a telecoupling between *national* land systems. While the heuristic approach seeks to push towards a more networked understanding of space, a question remains as to whether the telecoupling framework reinforces, and is thus limited by, existing ideas of scale (see Marston et al., 2005), or if, and in that case how, it can challenge them?

Fourth, temporal scale choices are important for the way flows and feedbacks are understood. Both versions of the framework emphasise the importance of feedbacks in the creation of telecoupling. However, feedbacks present a challenge in relation to inertia in processes and interactions. While a trigger of change might set rapid responses and feedbacks in motion, some processes work more gradually and only manifest themselves later. The choice of analytical entry points is important here. If the analysis, for example, takes its point of departure in an observed land use transformation, inertia in some processes of exchange might lead the researcher to overlook important elements of the telecoupling process that may only be revealed later. This highlights the challenge for telecoupling research to develop ways to approach contemporary or anticipated land system change. Eakin et al. (2014) propose that taking point of departure in an expected 'trigger' of telecoupling, e.g. the new biofuel targets in the EU, could make it possible to point to potential outcomes in specific land systems elsewhere. As any inquiry into dynamic systems, telecoupling research also faces the challenge of presenting linkages and interactions between the systems as temporal 'snapshots'. An important question associated with this is the degree to which telecoupling requires sustained interaction – can a single exchange across system boundaries qualify as a telecoupling, or is there a need for a longer-term, permanent or at least continuous exchange for systems to be characterised as telecoupled? A question also remains regarding the emphasised requirement for 'unexpectedness' of interactions and outcomes in the telecoupling process – how does one qualify such unexpectedness?

Fifth, spatial and temporal scale choices influence whether the *same* system is attributed to the sending, receiving or spill-over label in the telecoupling process, i.e. the same system may act as the sender of the flow at one point in time or at a certain spatial scale, but the receiver at another. Finally, scale issues also present a challenge in relation to the methodological integration of qualitative and quantitative research. Such integration is often made difficult by scale-mismatches, both spatial and temporal, and continues to challenge LSS studies aiming to bridge the analytical gaps between, e.g. remote sensing derived results and e.g. interview based analysis. Moreover, practical issues related to data availability add to these challenges. Many LSS questions have been researched at particular spatial and temporal resolutions, e.g. using administrative units and decadal censuses, not necessarily because these represent ideal system boundaries, but rather because data is only available at this scale. While such units of analysis do reflect 'traditional' governance boundaries and thus a functional way of separating systems, the increasing interconnectedness and spatial decoupling of drivers and outcomes of land change challenge the separation of systems based on such structures.

6. Ways forward for Telecoupling Research - Looking beyond Land System Science

For LSS to push telecoupling research forward there is a need to engage with the three sets of challenges highlighted above.

Regarding the first challenge of the trade-off between scope and depth of analysis associated with the structured approach, one way to avoid this problem could be to engage in extensive in-depth analysis of all five components and their interrelations. However, such an approach could make the research process both very time and resource intensive, and would require large research groups addressing each of the specific aspects of the telecoupling. Adopting the heuristic approach however to some extent opens up ways to deal with this challenge, as it presents the framework as a less rigorous tool and methodology. With a heuristic approach to telecouplings, the possibility for choosing different analytical entry points becomes more pronounced, thereby allowing researchers to address various aspects of the telecoupling under inquiry, while maintaining a comprehensive view of the entire process. However, in order to fully engage with the complexities of telecoupling and to address the second and third set of challenges, both approaches need to look beyond LSS, as acknowledged by both Liu et al. (2014) and Eakin et al. (2014). To begin this development of an interdisciplinary telecoupling approach, insights from the fields of economic geography, socioeconomic metabolism studies, political ecology and cultural anthropology are explored here. Each of these large and diverse bodies of literature have long histories of engaging with theoretical and methodological questions related to global flows, exchanges and networks that contribute with valuable and alternative perspectives for dealing with global-local interactions, power and scale issues. The aim is to highlight potential beneficial ways for telecoupling research to engage with these fields in order to begin addressing the specific challenges discussed above.

6.1. Economic Geography

One way telecoupling research can engage with the challenges related to scale and system closure is by looking to recent theoretical advancements in economic geography. Perspectives from this field provide means to analyse networks of actors and the distribution of power within these networks in a manner that transcends the implicit power asymmetry associated with the analytical distinction between system functions and with strong asymmetrical telecouplings.

Munroe et al. (2014) discuss how LSS studies often rely on neoclassical framings of markets and the economy more generally that lead, among other things, to an analytical separation of market activities from their historical and cultural context. Moreover, such framings lead to an understanding of space as nested entities, which results in an analytical conflation of spatial scale and agency. In relation to this challenge it is argued that 'adherence to neoclassical framings endures [within LSS] despite growing frustration at their inability to accommodate the world's growing complexity' (Munroe et al., 2014: 12). In turn, Munroe et al. (2014) suggest that analytical approaches from economic geography can help facilitate analyses that recognise how economic activities always depend on their embedding in a particular sphere of social relations and historic context. In particular, the Global Production Networks (GPN) (Henderson et al., 2002; Coe et al., 2008) and Global Value Chains (GVC) (Bair, 2005; Gereffi et al., 2005) approaches are useful. GPN analysis provides specific means to analyse how different actors are connected in complex production and consumption networks, and in turn how economic value flows between actors and is distributed across space. The GPN concept therefore facilitates analyses that 'consider local situations as constituted through their relative positions within processes stretching across varying spatial extents' (Munroe et al., 2014: 19). GVC analysis similarly provides a flow-based methodology focusing on the relative position of actors in terms of their role in governing production processes and value distribution. By acknowledging that actors are embedded differently in a local context, GPN and GVC analyses are able to disentangle the varying positions of actors within a network or chain of production, as well as their degree of power to control the distribution of value. This is particularly relevant for analysis of trade-related telecouplings where GPN and GVC perspectives can open up for new knowledge on how and why telecouplings between specific regions or in particular sectors arise. Furthermore, Nepstad et al. (2014) illustrate how a slowdown in deforestation rates in the Brazilian Amazon is, among other things, associated with intervention in the supply chains of beef and soy producing industries. Here, value chain perspectives reveal how governance of flows in trade-related telecouplings offers an opportunity to manage land system change.

Embracing such understandings of actor relations in telecoupling research can also begin to overcome the potential power asymmetry associated with the analytical distinction between sending, receiving or spill-over systems. Here, one could likewise look to the simple framework for analysing 'societal teleconnection' in the context of climate change mitigation proposed by Moser and Hart (2015) that to some extent transcends the need to assign roles to systems, and instead opens up for empirical investigation of how a 'substance' is transmitted or conveyed by 'processes' through a specific 'structure'. The concepts from economic geography also offer a networked understanding of spatial relations that presents an alternative to the structured hierarchical understanding of scale embedded in the telecoupling framework. Some LSS scholars have already begun integrating the flow-based GVC-approach with more conventional place-based land change analysis. Rueda and Lambin (2013), for example, combine value chain perspectives with land use change analysis in a study of the role of eco-consumers and coffee gourmands in restructuring the Colombian coffee production landscape. This study also presents an approach that combines quantitative methods, i.e. analysing coffee price databases, with qualitative methods, i.e. interview-based narratives and institutional analysis, to facilitate the integration of flow- and place-based approaches.

6.2. Socioeconomic Metabolism

Studies on *socioeconomic metabolism* represent an additional critique of the neoclassical framing of markets and the economy prominent in LSS by giving the material and energetic flows associated with economic interactions a central position within the analysis. In addition, socioeconomic metabolism studies offer ways to deal with temporal perspectives and historical contextualisation of exchange processes involved in creating telecouplings.

Rooted in ecological economics, ecological anthropology, industrial ecology and social ecology (Fischer-Kowalski, 1998), socioeconomic metabolism studies provide a basis for understanding economic flows in terms of material and energetic throughputs. One central insight is that the ever-expanding world economy is based on an increasing amount of energy and material extracted from the environment, circulating around the globe, and released back into the environment as wastes and emissions, thereby contributing to global sustainability problems such as climate change (Martinez-Alier et al., 2010; Krausmann et al., 2009). This translates into an increasing demand for and extraction of land-based resources, and an associated increase in trade within and between countries. As is evident from the existing pool of teleconnection/telecoupling studies, trade is one of the important mechanisms creating telecouplings. In this regard, socioeconomic metabolism studies offer two key insights relevant for telecoupling research; firstly, trade plays an essential role for all human societies' metabolisms in terms of supply of resources and energy; and secondly, although trade is an ubiquitous feature of all human societies, its role for the socioeconomic metabolism has changed fundamentally during major shifts in society-nature interrelations, i.e. so-called sociometabolic transitions (Fischer-Kowalski and Haberl, 2007).

Sociometabolic transitions have implications for the function of land use in socioeconomic metabolism, the spatial structures of societies and the mobility of people and products. In hunter-gatherer and agrarian societies where transport is exceedingly expensive, a large fraction of the socioeconomic metabolism is local, i.e. relatively proximate to human settlements (González de Molina and Toledo, 2014; Krausmann, 2004; Sieferle, 1997). Preindustrial cities could only be supplied through energy-efficient modes of transport, e.g., sailing boats or downhill shipping on rivers, limiting both the spatial reach as well as the biophysical scope of trade-related telecouplings. With the agrarian-industrial transition these conditions fundamentally changed. The availability of fossil energy allowed for labour-saving innovation in agriculture and energy efficient transport technologies have allowed for movement of large amounts of energy and materials across the globe (Sieferle et al., 2006; Fischer-Kowalski and Haberl, 2007). While industrial and post-industrial cities still require enormous hinterlands, the sociometabolic transition imply that these hinterlands need not be proximate, but can extend to distant locations (as also stressed in the Urban Land Teleconnection framework proposed by Seto et al. (2012)). The agrarian-industrial transition is not only a historical phenomenon – for over one-half of the world population it is still ongoing (Fischer-Kowalski et al., 2014). Globally, trade volumes of all products, including agricultural produce (Kastner et al., 2014), are growing faster than the consumption of biophysical resources as a result of ongoing agrarian-industrial transitions combined with increasing economic globalisation and changing consumption patterns. These developments are fundamental for the creation of prominent trade-related telecouplings.

The socioeconomic metabolism perspective thus provides an explanatory framework contributing to a historical as well as contemporary understanding of the factors involved in the spatial decoupling of drivers and outcomes of land system change that give rise to telecouplings. Understanding telecouplings as being at least partly the outcome of specific socio-metabolic 'relations' can provide theoretical as well as methodological input to the examination of global energy and material flows, and in turn land system change. This provides a much needed temporal perspective and historical dimension for the analysis of global flows and telecouplings. Telecoupling analysis would also benefit from methodological developments in this field, e.g. multi-regional studies of socioeconomic metabolism, as they make it possible to deal with questions of indirect or spill-over effects not immediately observable in a given land system. For example, a recent study of the Ukraine has combined material flow and political analyses to examine the importance of the country's regional and global trade and policy relations in driving specific processes in its agricultural and land-use sectors (Schaffartzik et al., 2014).

6.3. Political Ecology

Adding to the perspectives put forward by social metabolism studies, theoretical insights from *political ecology* can offer telecoupling research conceptualizations that are useful in analysing the shifting relationship between society and land-based resources, as well as relations between social groups (Blaikie and Brookfield, 1987). Recently, scholars have emphasised the synergies (and divergences) between political ecology and the wider field of LSS noting in particular how political ecology provides means to address power relations in the processes driving land system change (Turner and Robbins, 2008; Brannstrom and Vadjunec, 2013; Baird and Fox, 2015). For telecoupling research, political ecology thus offers perspectives to address issues of power and agency in the categorisation of system, and historical political ecology presents methods that enable analysis of changing human-environmental relationships through time.

Developed by geographers, anthropologists and environmental sociologists, political ecology combines concerns of ecology with a broadly defined political economy approach (Robbins, 2012; Blaikie and Brookfield, 1987). The process of social metabolic production is central for political ecology, as it advances an intertwined perspective of society and nature that is valuable for understanding an increasingly telecoupled world (Swyngedouw, 2004; see also Swyngedouw and Kaika, 2014). A central focus in political ecology is how uneven power relationships between actors in human-environment systems produce uneven control of resources, and socially uneven landscapes with unequal distribution of the costs and benefits of land use change across class, gender, cast, and (spatially distant) geographical regions (Martinez-Alier, 2002). These power inequalities and a growing socioeconomic metabolism lead to increasingly visible ecological distribution conflicts especially in so-called commodity frontiers, i.e. areas of resource extraction. Such conflicts refer to struggles over the burdens of pollution or over the sacrifices made to extract resources. Distribution conflicts have been documented all along the global metabolic cycle, i.e. in the extractive industries, in biomass extraction, in energy production, and in waste disposal (Martinez-Alier et al., 2010).

These insights from political ecology can provide telecoupling research with the means to address the challenge related to power asymmetries and asymmetrical relations between systems. By analysing interactions between distantly linked systems as (potential) distribution conflicts, actors at both 'ends' of the interaction become active agents with (potential) power to influence the outcome of the interaction. Instead of analysing 'effects' of telecouplings on (passive) receiving or spill-over systems, telecoupling research could ask which actors, regardless of their 'location' in the interaction, have the power to decide on land use outcomes and to shape the interconnectedness of (telecoupled) human-environment systems. The contested nature of the processes of production of (unequal) telecouplings could thus be explored, with particular attention to dynamics of resistance and struggle for alternative telecouplings and political ecological orders across the world.

Historical political ecology studies furthermore add a temporal perspective on these issues that can be useful for telecoupling research. Such studies combine archival research with interviews and biophysical data to analyse how changing power relationships shape land use outcomes through time (see Otero et al., 2011; Davis, 2005; Kull, 2002). Through such a methodology, these studies shed light on historical society-nature relationships and their changes over time and space, explicitly addressing the political and economic forces of environmental change, environmental policy formulation, and environmental narratives associated with such changing relationships (Davis, 2009). This complements the temporal perspective provided by socioeconomic metabolism studies, while offering a research approach that enables integration of qualitative and quantitative data. With a political ecology approach particular telecouplings would be understood as historically produced and transitory social-ecological arrangements that are results of political choices and subject to permanent contestation.

6.4. Cultural Anthropology

The three fields of study presented above offer valuable perspectives on how to analyse and understand spatial and temporal power relationships inherent in the economic, physical and energetic dimensions of telecouplings. Cultural anthropology and wider social science theory adds *culture* to these relations. Engaging with conceptual insights from cultural anthropology and especially the concept of 'scapes' can help telecoupling research address the challenge related to separation of systems, as well as the challenge of defining spatial scales, demarcating system boundaries and dealing with 'unexpected' couplings.

Anthropology has long ceased to understand groups of people as isolated endemic cultures. Instead, most groups are embedded in complex systems of exchange with neighbouring and more distant groups, as well as colonial and post-colonial relations (e.g. Wolf, 1982; Strathern, 1995b). Firstly, such systems of exchange reach far beyond trade. Cultural exchanges are important as they transport knowledge, information, stories and technology, as well as people (Ong and Collier, 2005). Each of these elements tends to follow their own logics of exchange and cannot easily be understood using a single methodological framework. Secondly, systems of exchange rely on and produce social order. Exchange is thus never a simple matter of sender and receiver, but a complex process embedded in existing social relations at both ends (Sahlins, 1972; Mauss, 1954; Lévi-Strauss, 1963). Thirdly, the notion of the 'scape' has been proposed to analyse systems of exchange in a global age (Appadurai, 1996). Different scapes related to various global fluxes have been identified: the ethnoscape captures the migration of people, the technoscape the dispersal of technologies and the financescape the (re)distribution of money and financial derivatives. Scapes precede any process of telecoupling, since scapes always embed the coupled processes under investigation in a global context that cannot easily be reduced to a coupling in the sense of a linear exchange between two separate systems. Furthermore, the theory of scapes does not assume a specific spatial organisation as earlier political-economic theoretical frameworks have done, e.g. world systems theory (Wallerstein, 1974) or centre-periphery concepts (Hannerz, 2001).

Two main aspects to these theoretical insights benefit telecoupling research. Firstly, social and cultural history is important. The literature on scapes suggests that actors as well as the wider social order always have a history. Therefore, analysing the social and environmental history of a region, a people or a set of practices may help to better understand and qualify why particular couplings emerge. Furthermore, acknowledging cultural anthropological insights on 'systems of exchange' would allow telecoupling research to reframe flows and impacts from a clear directional perspective of 'sender' and 'receiver' to address complex exchange processes embedded in existing social, historical and political contexts at 'both ends' of interaction. Telecoupling research adopting these notions of exchange systems would entail a deeper analysis of the social and cultural order within which land use systems and their integration into transnational markets are embedded. This could be achieved by asking the fundamental anthropological question of "what the hell is going on here?" (Geertz in Olson, 1991: 248) in order to reveal the logics of the everyday practices (Bourdieu, 1977) shaping interactions and exchanges over distance. What are the actual communication platforms, transnational alliances, technical and algorithmic infrastructures and social forms that constitute exchanges? (Knorr-Cetina and Bruegger, 2002).

Secondly, anthropology, human geography and wider social science theory suggest a reconfiguration of space and distance that could prove valuable for telecoupling research. The current telecoupling literature points to the need to integrate 'different epistemological perspectives on space and spatiality – one in which Cartesian space is the primary frame and point of departure, and one in which social space and its contingent aspects of agency and power are critical' (Eakin et al., 2014: 153). Whereas the notion of 'tele' or 'distal' is based on a predominantly Euclidian understanding of space, cultural anthropology has long argued for an understanding of space as being both ecological *and* social (Evans-Pritchard, 1940). While Euclidian space is measured in terms of physical distance and ecological space in functional terms, social space refers to the processes of economic, social or cultural distinction that operate between individuals or groups within a society (Bourdieu, 1984). People may be physically close, yet socially distant or vice versa (Sassen and van Roekel-Hughes, 2008). For telecoupling research, this means that it will not suffice to add a social aspect to the existing LSS spatial framework. 'Land' and land use should not be understood in Euclidian spatial and material terms only, but also in its social and symbolic meanings, as some historically informed analysis of social ecology demonstrate (Krausmann et al., 2003;

Gingrich and Krausmann, 2008). This entails a need to engage analytically with the multiple interactions between land as matter, market and meaning and to (re)conceptualise the relationships between physical and social spaces, how they relate to each other and how they are mediated by such factors as infrastructures and institutions. These perspectives on spatiality also problematize neoclassical understanding of scale and spatial hierarchy, since social processes may well overflow geographical scales (Strathern, 1995a; Marston, 2000). Addressing such entangledness of social and material aspects of land use change would enable researchers to address the challenge of 'unexpectedness' in (tele)couplings, since a coupling and/or its effects might seem unexpected from a Euclidian spatial standpoint but when analysed as a social spatial relations this might no longer be the case.

Some LSS scholars have begun to integrate these aspects of space and distance into studies of for example migration and remittances effects on forest transitions and land use change (see Lambin and Meyfroidt, 2011), or the role of e.g. knowledge sharing, capacity building and technology transfer in new South-South telecouplings (Gasparri et al., 2015). However, a deeper theoretical engagement with such perspectives from cultural anthropology could offer LSS a way to understand why actors initiate and sustain (tele)couplings by asking how these operate in everyday social spaces. Combining this epistemological approach with methodological advances, e.g. multi-sited ethnography (Marcus, 1995) or the ethnography of infrastructure (Star, 1999), anthropology and related social sciences have the potential to cast light on many of the challenges currently identified within the telecoupling literature. Here, efforts to engage with multi-cited ethnography and historical political ecology combined with in-depth land use change assessments present examples of promising new avenues (e.g. Baird and Fox, 2015).

7. Conclusion

The telecoupling framework is gaining momentum in Land System Science research. However, there has been some confusion in relation to its theoretical content and analytical application. One aim of this paper has therefore been to clarify the conceptual developments from tele*connection* to tele*coupling*, and to review the current applications of 'telecoupling' within LSS. Furthermore, two analytical approaches, a structured and a heuristic, are identified in the telecoupling literature. The review asserts the strength of the telecoupling framework for addressing the spatial decoupling of causes and outcomes of land change processes, as well as the growing importance of simultaneous and multi-directional flows that challenge classical place-based LSS analysis. However, it is also shown how the telecoupling framework still faces some challenges for empirical application, mainly related to the trade-off between scope and depth of analysis, to the analytical distinction between systems and associated power asymmetries, and to questions of system boundaries, hierarchy and scale. In order to specifically address these challenges, the paper examined four fields of research with long histories of theoretical engagements with questions of human-environment relationships, global-local flows, networks and scale; namely economic geography, socioeconomic metabolism studies, political ecology and cultural anthropology. While this list is not exhaustive in its coverage or depths, all the reviewed approaches offer critical insights that can help LSS scholars begin address and overcome the identified challenges. As such, the paper responds to recent calls within LSS for engagement with other related disciplines. More theoretical, and especially empirical, work that aims to bridge the conceptual and methodological gaps is however needed in order to advance the agenda on telecoupling further.

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