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Telecoupling as a framework to support a more nuanced understanding of causality in land system science

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ABSTRACT

This article illustrates the potential of the telecoupling framework to improve causal attribution in land system science (LSS). We shed light on the distinct analytical approaches that have characterized telecoupling research to date, how these can contribute to LSS with new insights, and whether such insights can improve causal attribution. By reviewing 45 empirical telecoupling studies, we firstly demonstrate how telecoupling is applied in a broad variety of ways within LSS and across different disciplines and research topics, albeit with qualitative data and assessments being underrepresented. Secondly, we show that telecoupling is clearer in its contribution to causal attribution when applied explicitly in framework integration or empirical application, rather than when it is included more indirectly as a narrative. Finally, we argue that telecoupling can complement existing LSS theory with a flexible and holistic approach to dealing with the uncertainties and complexities related to attributing causality in a globalized world.

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Telecoupling; causality; land system science; social-ecological systems

1. Introduction

Understanding how relationships between people and their environment make up land systems is key to supporting more sustainable land use and reducing the negative environmental impacts of land-use change (Rounsevell et al., 2013). Today, there is broad scientific awareness about the interconnectedness of these relationships, and this is reflected in the land system science (LSS) literature, which seeks to understand and model land-use change through analytical approaches that emphasize relativeness, complexity, and context-dependency of causes and effects. This includes frameworks such as coupled human-environment (Turner et al., 2003) and social-ecological systems (Schlüter et al., 2012), coupled human-natural systems (Liu et al., 2007), and most recently, the telecoupling framework (Liu et al., 2013).

Systems and actors influencing and/or being influenced by land-use change are increasingly both linked and globalized. This implies that processes influencing land-use change outcomes, including the actions by individual actors, can be physically distant while at the same time being causally connected. For example, deforestation can be caused by consumption in

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a distant country (Torres et al., 2017), and modifications in ecosystems in one place can be fuelled by trade relationships and multinational corporations in another place (Pace & Gephart, 2017). In LSS, it is key to disentangle this causal interconnectedness to understand the social-ecological drivers of land-use change and better target interventions for more sustainable land systems (Meyfroidt, 2016).

In this article, we undertake a literature review to understand how the telecoupling framework can address this challenge of causal attribution in LSS. Specifically, we ask: 1) Which analytical approaches characterize telecoupling research? 2) How can the different approaches to telecoupling contribute to LSS with new insights? and 3) Can these insights help clarify the influence of the telecoupling framework for causal attribution in LSS?

Telecoupling emerged as an analytical tool to help account for socio-economic and environmental interactions across large distances by examining the systems of interest, the flows that connect them, the causes and effects of those flows, and the actor-networks that mediate them (Eakin et al., 2014; Friis & Nielsen, 2017; Liu et al., 2013). Thus, telecoupling recognizes the complexity and interconnectedness of causes and effects in land-use systems. In this regard, existing research and reviews of the telecoupling literature have provided insights into how telecoupling can improve our understanding of human-environment interactions and contribute with applicable terminology and techniques for analyzing such interactions in a globalizing world (Corbera et al., 2019; Friis et al., 2016; Kapsar et al., 2019; Sonderegger et al., 2020). There have been a few flagship contributions highlighting techniques for explaining cause-effect relationships through a telecoupling lens (Carlson et al., 2018; Meyfroidt, 2019). However, we still know little about how existing research has benefitted from applying the telecoupling framework to understand causal relationships within LSS and how telecoupling is influencing research designs and the interpretation of research findings. This is critical to avoid the risk of pursuing a conceptual idea that is not any different from what is already available in the LSS literature on causality (Lambin et al., 2001; Meyfroidt, 2016; Meyfroidt et al., 2018).

While telecoupling research has gained momentum since 2013 (Eakin et al., 2017; Friis, Cecilie, & Nielsen, 2019; Liu et al., 2013), the interdisciplinary and empirical application of the framework is still novel. The attention to proximate and underlying causes is not new to the LSS community (Scheidel & Gingrich, 2020), but the telecoupling conceptualization introduced a terminology and framing for disentangling the complexity that arises when both proximate and underlying causes are coupled over social, institutional, and geographical distances.

These conceptual debates on the utility of telecoupling for establishing causal relationships are presented in the following section. Then, we present our approach to data collection, data processing, and our literature review. We elaborate on the review findings in three separate but interlinked sections corresponding to the three research questions. We then discuss the findings through a critical lens and recommend future pathways for telecoupling application.

2. Telecoupling and the challenge of attributing causality

Telecoupling is the process that connects social-ecological systems across time and space. In its original framing, telecoupling is understood through the analysis of five major components: systems, agents, flows, causes, and effects (Liu et al., 2013). *Systems* are categorized as either sending-, receiving-, or spillover systems, meaning that they either 'send', 'receive', or are indirectly impacted by material and immaterial flows (of money, commodities, information, etc.) from other systems (Hull & Liu, 2018). *Agents* can be humans, organizations, animal species, or any actor at any scale whose actions are consequential to the studied phenomenon (Liu et al., 2014). Examining the *flows* between agents helps trace distal drivers of land-use change and the connections between causes and effects at different scales, between distant locations, and beyond the regulatory context of the studied phenomenon. By analytically following material and immaterial flows, causes can be discovered that are not immediate, obvious, or place-bound (Friis & Nielsen). In this article, we define material flows as physical measurable units such as commodities, people, or biophysical elements, and immaterial flows as more intangible flows such as information, discourse, and social interactions (Friis & Nielsen). We understand information flows as including knowledge and money, but other literature such as Eakin et al. (2014) defines money as part of the physical material flows. Both material and immaterial flows are important for the identification of causes behind telecoupled land-use change processes. For example, soybean expansion is connected to the increase of a material flow (i.e. international trade of soybeans) and is driven by proximate causes such as agricultural technology. In turn, the adoption of new technologies is strongly linked to immaterial flows like information about technologies and production schemes, dissimilated through personal experiences, social networks, workshops, meetings, and social media (Henderson et al., 2021). Thus, the flow-based analysis draws attention to the spatial and temporal complexity of causes and effects which characterize telecoupled systems (Eakin et al., 2014). We understand *causes* in relation to telecoupling as the factors that determine the emergence and strength of telecoupled relationships, and the *effects* as the environmental and socioeconomic consequences of such relationships (Liu et al., 2014). Furthermore, we refer to the analysis of causal mechanisms, which is what distinguishes causation from correlation (Meyfroidt, 2016).

To our knowledge, the initial conceptualization of the telecoupling framework did not claim an ability to identify causal mechanisms. Still, research grounded in the idea of telecoupling often assumes or analyzes a (telecoupled) relationship between a given land-use phenomenon occurring in a specific location and its distal drivers and feedback mechanisms. In so doing, telecoupling researchers apply a variety of approaches to establish causality between phenomena, by, for example, qualitatively exploring information and discursive flows across distance (Eakin et al., 2014) or quantitatively tracking and measuring the flows of commodities between regions (Yao et al., 2018). Liu et al. (2013) highlight how land-use telecouplings can have various economic, technological, political, environmental, or cultural causes, and how these causal mechanisms influence the emergence, dynamic, and strength of the relationship. Eakin et al. (2014) exemplify this process by showing how telecoupling entails effects on livelihoods or land systems that are caused (indirectly) by spatially distant (but connected) actors.

While telecoupling can provide new perspectives on the interconnectedness of the global economy and its social-ecological consequences, this interconnectedness implies some fundamental challenges for causal attribution. For example, a given specific land use, or land-use change process, cannot be explained by a single phenomenon (e.g. increased international demand for a certain crop) but by a combination of drivers (e.g. increased international demand, coupled with local economic incentives), which in turn may be products of different political, social and/or cultural forces. It becomes increasingly difficult to disentangle the causal relationships driving land-use change processes since causal factors can rarely be understood in isolation from each other, and they often transcend institutional, spatial, and temporal scales (Norder et al., 2017).

Causal effects in telecoupled systems will often be created by multiple and overlapping causal variables. Some causal processes work more gradually, and some work more rapidly, often depending on a number of factors connecting sending and receiving systems (Friis et al., 2016). For example, Nepstad et al. (2014) argue that several mutually reinforcing factors, including temporally and spatially overlapping policy and supply chain interventions, decreased demand for new deforestation in the Amazon. Leisz et al. (2016) analyze a case of telecoupled land use and land cover change in Vietnam and show how this is linked to a multitude of both distal causes in the form of historical political decisions, immediate causes, and causes at both higher and more local scales.

Even though the debate between quantitative and qualitative causal analysis has become more integrative in acknowledging that causes can be validated both quantitatively and qualitatively (Beach & Pedersen, 2016; Carlson et al.), researchers still tend to avoid making direct causal claims

Table 1. Terms related to the complexity of attributing causality in telecoupled land-use systems.

Term	Definition	Source
Causes		
Multi-causality	Any given pattern may be caused by several different processes, and the action of each is dependent on context.	Chapman et al., 2017; Lambin et al., 2001
Confounders	A variable that influences explanatory (independent) and response (dependent) variables. Confounding variables can be both observable and unobservable.	Carlson et al. (2018)
Proximate (or direct) causes	Human activities or immediate actions at the local level that originate from the observed change and directly impact the observed change.	Geist & Lambin, 2002; Meyfroidt, 2016
Underlying (or indirect) causes	Fundamental forces that underpin the more proximate causes.	Geist & Lambin, 2002; Meyfroidt, 2016
Effects		
Cascading effect	The process by which a system affects other multiple systems in sequence as a result of telecoupling dynamics; occurs when a change of one element of a system drives a chain of events leading to many other changes in the system.	Baird & Fox, 2015; Paitan & Verburg, 2019
Cumulative effect	impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency [. . .] or person undertakes such other actions.	Clark, 1994
Legacy effect	Effects that do not disappear until many years to decades after the emergence of a telecoupling.	Liu, 2014; Norder et al., 2017; Paitan & Verburg, 2019
Non-linearity	Social and ecological patterns do not gradually change as a linear function of relevant processes but rather display thresholds, time lags, and generally complex behavior (including regime shifts).	Chapman et al., 2017; Paitan & Verburg, 2019
Threshold effects	Seemingly stable systems can suddenly undergo comprehensive transformations into something entirely new, with internal controls and characteristics that are profoundly different from those of the original. Small events might trigger changes that are difficult or even impossible to reverse.	Duit & Galaz, 2008
Time lags (or inertia)	Effects that do not emerge until years or even decades after the initiation of a telecoupling.	Liu, 2014; Norder et al., 2017; Paitan & Verburg, 2019
Multifinality	Similar combinations of causal factors result in substantially different outcomes, for example, due to small variations in contextual factors or contingent events.	Bennet and Elman 2006; Meyfroidt, 2016
Equifinality	Different combinations of causes that end up in similar outcome.	Bennet and Elman 2006; Meyfroidt, 2016
Temporal spillover	Conducting behavior A in time 1 affects the probability of conducting behavior A in time 2.	Nilsson et al., 2017
Cause and effect		
Feedback	Feedbacks occur between systems when effects of the first system on a second system feed back to affect the first system. Feedbacks can be negative (damping) or positive (amplifying).	Liu et al., 2013; Rotmans & Loorbach, 2009
Feedback loop	Feedback loops, or reverse causality, can be related to bidirectional causation and implies that events in a nonlinear causal chain can be both causes and effects,	(Carlson et al., ; Meyfroidt, 2016; Sugihara et al., 2012)
Multi-scalarity	Relevant processes are simultaneously operating at a diversity of scales, manifesting in patterns at multiple scales (both temporal and spatial).	Chapman et al., 2017
Path dependence	Positive feedback loops or self-reinforcing sequences i.e. chains of chronologically ordered and causally connected events which are more tightly connected and less contingent than in typical causal chains.	Mahoney, 2000; Pierson, 2000
Unobserved heterogeneity	The unmeasured third factors that may affect the relation between the causal factor and the outcome.	Meyfroidt, 2016
Spatial decoupling	The decoupling of drivers and outcomes which gives rise to telecouplings.	Friis et al., 2016

unless quantitative analyses are included (Efroymson et al., 2016; Rounsevell et al., 2013). Altogether, the literature highlights that attributing causality to telecoupled land-use systems is a complex endeavor. Such complexity stems from the fact that causes and effects in land-use systems can be approached from different scalar, temporal, and spatial perspectives, which involve specific conceptual and methodological challenges. We highlight examples from the literature on terms related to this challenge in Table 1.

3. Methods

3.1 Data collection

This paper builds on data from a review of 45 articles that draw on telecoupling to empirically study land systems. Conceptual and literature-based articles were thus excluded from the review. The sample articles were collected through Scopus, using the search string: telecoupl* OR tele-coupl* AND 'land use' OR 'land-use' OR 'deforestat*' OR 'land system' OR 'land-system' in the title, abstract or keywords. The search yielded 77 results, containing articles published up until September 2020. Subsequently, we made sure that each article in the sample had a) been peer-reviewed; b) written in English; c) analysed an empirical case; d) mentioned telecoupling at least once, and e) made explicit reference to land use or land cover change in the title or abstract. This resulted in a sample of 45 articles which we acknowledge is substantially smaller than, for example, the sample in Sonderegger et al. (2020) who, due to a broader screening, identified 137 articles roughly within the same search period. It is beyond the scope of our review to address the entirety of research topics engaging with telecoupling, and our search string and inclusion criteria have left out some flagship contributions as a consequence (e.g. Boillat et al., 2018; Eakin et al., 2017; Ringel, 2018). The aim of our review is not to exhaustively document the breadth of the research field, but rather to pinpoint the variety of opportunities that the telecoupling framework offers for causal attribution in relation to different research agendas within LSS. The sampling process is visualized through the PRISMA flow chart below (Figure 1), which is an acknowledged method for reporting sampling strategies in systematic reviews (Moher et al., 2010).

When the final sample of the 45 articles was identified, we conducted a content analysis to analyze how the relationships between telecoupling approach, research design, data collection, and methods for data analysis are investigated. We employed a mixed approach, using elements from both the systematic review tradition (Moher et al., 2010) and qualitative content analysis (Mayring, 2014). We used a systematized coding scheme to review and critically appraise the selected research (Moher et al., 2010). We analyzed the articles by looking at relationships in coded content in NVivo rather than applying statistical methods (meta-analysis), inspired by a qualitative content analysis tradition and guided by the following review steps (cf. Mayring, 2014).

(1) Identification of knowledge gaps in existing telecoupling reviews (exploring review strategies and supplementary materials) and LSS literature on causality.
(2) Formulation of the research question to inform identified knowledge gap;
(3) Linking research question to theory (state of the art, theoretical approach, preconceptions for interpretations);
(4) Definition of the exploratory research design and development of the codebook;
(5) Defining the literature sample supported by the PRISMA approach;
(6) Codebook and methods of data collection pilot-tested and revised;
(7) Inter-coder reliability established, processing of the study in NVivo and organization of node hierarchies;
(8) Presentation of results in response to the research question; and
(9) Discussion concerning quality criteria.

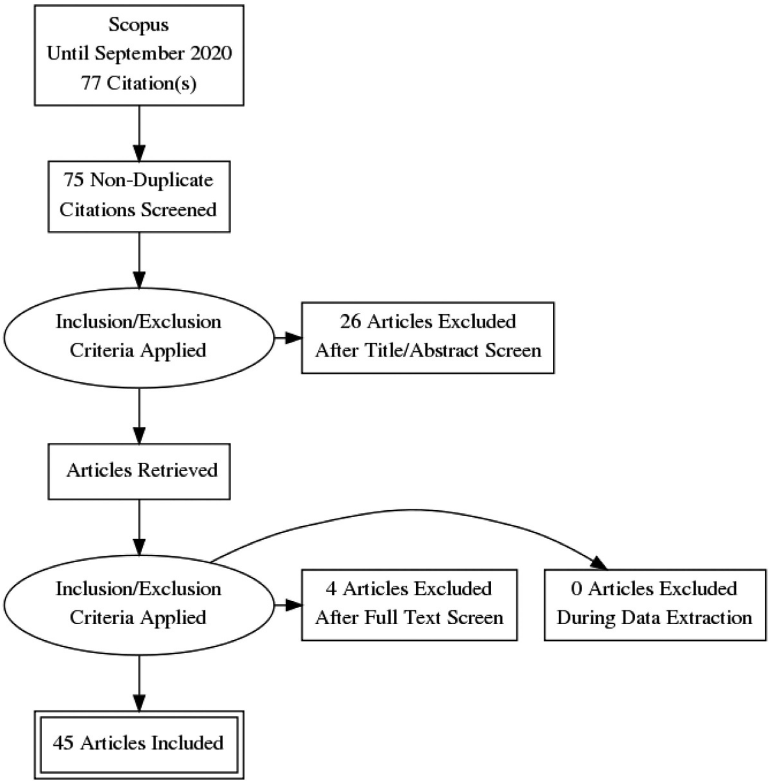

Figure 1. PRISMA of literature included for review. *Source: Figure generated from own data in http://prisma.thetacollaborative.ca/.*

The coding protocol combines deductive and more open-ended inductive categories, each assigned a code in the review (supplementary material_1). Inductive category development consists of formulating broad categories such as 'causal relations' and working through the text line by line, formulating code categories directly from the text at the decided level of abstraction (i.e. how detailed or general categories are formulated). In the deductively formulated category system, categories are predefined (such as 'material' or 'immaterial' analytical focus), and text segments are coded to illustrate examples of the character of the category.

The predefined codes were developed based on first readings of the review sample, theoretical insights from the telecoupling literature, and existing reviews (Eakin et al., 2014; Friis et al., 2016; Kapsar et al., ; Liu et al., 2013; Liu et al., 2014; Meyfroidt, 2016). The inductive codes facilitated an exploratory inquiry of how telecoupling provides both opportunities and pitfalls in causal attribution. These codes refer primarily to the identification of authors' statements on their application of telecoupling. The deductive codes contributed with information on research characteristics such as data collection and processing approaches and to what extent these strengthen causal statements. An example is our distinction between 'material' and 'immaterial' analytical focus, through which we try to identify which aspects of the study object are in primary focus. This is different from the distinction between material and immaterial flows. A study might analyze a material flow (such as commodities) but focus on the immaterial aspects of this commodity flow (such as local attitudes in the receiving system or political incentive structures in the sending system) (supplementary material_1).

3.2 Data coding and analysis

The articles were not examined in terms of how well they attribute causality since causal analysis is not an explicit objective of all reviewed articles. Rather, we analyzed if and how telecoupling influences the way causal relationships are identified and we reviewed the methods and methodological approaches used to make causal attributions. The different research designs are discussed in their relation to one another and with regards to the causal statements made in the article and the telecoupling approach applied (i.e. discerning between heuristic and structured approaches and the application of telecoupling as either a narrative, empirical application, or operationalization through existing concepts and tools see also supplementary material_1).

Since the analysis included some elements of latent content (the underlying meaning of the text), coding reliability became particularly important. Intercoder reliability was enhanced by conducting a series of pilot tests during the development of the codebook and conducting continuous and collective meetings to evaluate results. Moreover, each article was reviewed by a minimum of two authors with the use of the same coding scheme, and the first author was in charge of merging reviews, aggregating and analyzing the coded text segments.

With regards to causality, the coders were asked to code all statements made that captured cause-effect relationships were coded, including statements that were not explicitly claiming to attribute causality. Codes were then labeled with direct reference to authors' terminology to avoid unstructured and layered interpretation by individual coders. The analysis was conducted in NVivo, relying on the codebook to investigate the articles' causal statements, analyzing their relationship to other codes, and organizing node hierarchies.

4. Results and discussion

4.1 Analytical approaches in telecoupling research

The reviewed articles represent a broad variety of research topics and types of flows, albeit a majority focus on land use, land-use change, or international trade since we limit the sample to studies within LSS. In turn, the flows mostly analyzed are financial flows, commodities, and trade flows, but there are also several examples of more immaterial flows such as information, knowledge, and policy (supplementary material_1). Generally, the contributions reviewed in this paper shows how a relatively simple idea like telecoupling can support a broad variety of research inquiries addressing a high level of complexity.

An overview of the causal statements and key research attributes is presented in the supplementary material. These statements vary in scale from specific country-level inquiries such as how Chinese imports from the Congo basin are driven by the US demand for Chinese furniture (Fuller et al., 2018), to broader discussions of the multiple drivers of global and regional land-use change (Creutzig et al., 2019). Nine articles justify causal statements by referring to findings from field observations, whereas the majority of the causal statements are justified by using evidence from existing literature, models, and quantitative measurements or estimations (Figure 2). The figure presents broader categories while a breakdown of specific tools applied is available in supplementary materials. Two articles are excluded from the figure as we did not identify any specific causal claims (Seaquist et al., 2014; Zimmerer et al., 2018).

In 30 of the 45 articles, data is included on the same topic over a given time period (years or decades, past or future) (supplementary material_1,4). Twenty-three of these deal with spatial data (including forest cover data), while the others are spread across biophysical, economic, and trade data, among others. The use of longitudinal data is not equivalent to an explicit focus on causal temporal couplings (e.g. legacy effects and time lags), such as the historical interactions between deforestation and soil loss (Norder et al., 2017), as there is a much stronger focus on the spatial connections (supplementary material_1).

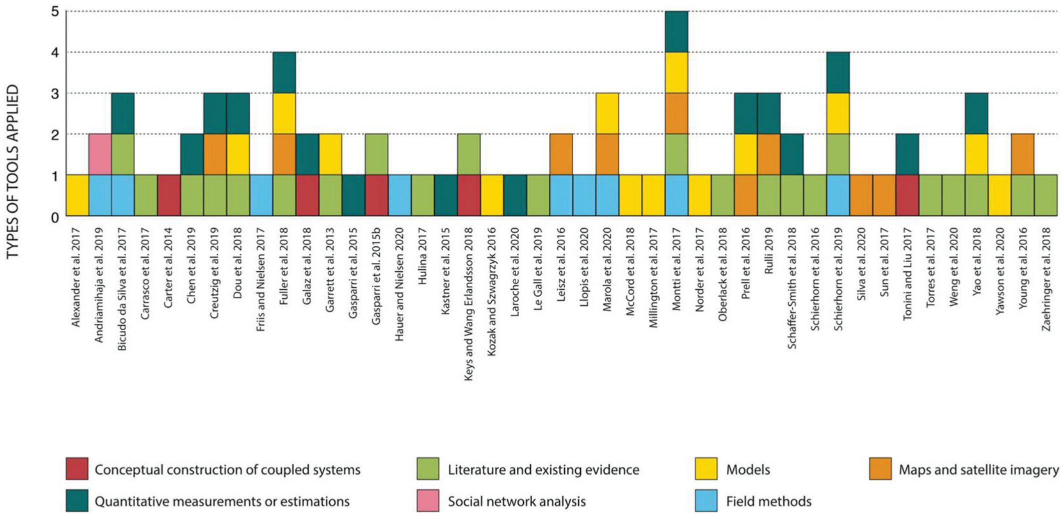

Figure 2. Type of tools applied to justify causal statements. Source*: Figure generated from own data.*

The articles that primarily use quantitative assessments tend to frequently approach their research from a deductive approach, testing a predefined explanatory theory or exploring the effects of a top-down rule or policy, whereas the mixed methods and qualitative approaches are more exploratory (see supplementary material_1). Generally, qualitative and mixed methods approaches together with temporal perspectives seem to be an underrepresented combination in the sample. Qualitative approaches are important to pursue since some flows in telecoupled systems are difficult, if not impossible, to quantify. Discursive or knowledge flows cannot easily be measured in quantitative terms. Generally, due to the context-dependent, complex, and dynamic nature of land systems, and the (partial) lack of relevant knowledge and data (Newig et al., 2020), it is challenging to isolate causal factors and measure and quantify them. More interpretative analyses are required to explain the less tangible dimensions of causal relationships.

For example, REDD+ is an official framework for reducing emissions from deforestation and forest degradation, but in terms of understanding the drivers and effects of related interventions, it is important to examine the various incentives and values of the governing actors (Eakin et al., 2014), as they pursue different aims and strategies for implementation, which will affect the outcome of the interventions (Andriamihaja et al., 2019). Thus, in a REDD+ case, it is relevant to map and quantify the direction of material and financial flows. However, to understand the full nature of causal mechanisms, it is essential to investigate, through more qualitative inquiry, the more immaterial flows of ideas and values, and the actions and behaviors of actor-networks mediating these. A relevant and frequently referenced but rarely applied approach in telecoupling research is process-tracing. The process-tracing method breaks down flows and causal chains observed in case studies into analyzable units and validates each link in causal graphs as well as invalidates counter-hypotheses (Beach & Pedersen, 2016; Bennett & George, 2005).

In the review sample, the use of secondary data is more common in studies with primarily quantitative interpretation rather than qualitative interpretation (Figure 3). In two studies, qualitative secondary social data is used (Carter et al., 2014; Keys & Wang-Erlandsson, 2018). This finding is related to the tendency that most of the examples of temporal perspectives are conducted with quantitative (22 articles) rather than qualitative (two articles) assessment. The two examples that combine a qualitative assessment with some degree of quantitative and

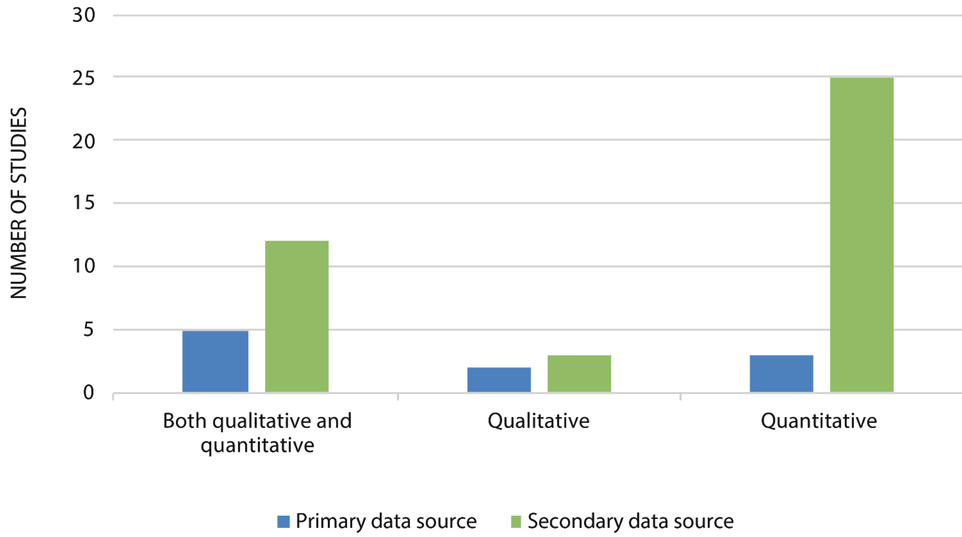

Figure 3. Data source within qualitative and quantitative studies. Source*: Figure generated from own data.*

longitudinal analysis include Oberlack et al. (2018) who provide a stylized timeline from 2007 to 2016 of a bioenergy project case in Sierra Leone that led to significant land-use changes. The timeline provides an overview of major activities and events associated with the project in the set-up phase, the operational phase, and the scaling down and termination phase. While the authors do not claim to present more than a process overview, we argue it is a useful tool for a telecoupling analysis as it provides a context for knowledge and value generation and allows for the consideration of links between concrete events in time (temporal couplings) that might be decisive for the outcome of the intervention. Another example is Hauer and Nielsen (2020) who do not explicitly adopt a longitudinal design, but they provide an example of how questions in qualitative interviews can be tailored to focus on organizational evolution and changes over time.

There appears to be a reluctance to engage more explicitly with the implied temporal dimension of the telecoupling framework and to move beyond quantitative approaches more familiar in traditional LSS. Due to the few examples in our review that combine qualitative and mixed methods approaches with a temporal perspective, we present a few cases beyond our sample to illustrate the value of conducting comparative longitudinal studies on topics that are often subject to telecoupling research. Vicol et al. , for example, apply a temporal perspective on the implications of global value chain upgrading for coffee producers in Indonesia. They select secondary qualitative-quantitative survey data from case studies at three different geographical sites where village-level field visits and household surveys had been carried out at least annually between 2008 and 2016. This allows them to make a longitudinal assessment of local attitudes and analyze how coffee value chain relationships emerge, evolve, and break down. These are dynamics that would be difficult to capture using a single-sited snapshot of an isolated case. Petursson and Vedeld (2017) present an approach to analyzing the development and manifestation of conservation policy discourse over time by analyzing qualitative data from interviews in the same case-study region in Uganda for a period of eight years from 2003 to 2011. This enables them to generate new insight into how changing actor interests and power relations can contribute to explaining the gap between rhetoric and reality in protected area governance. Another approach is presented by Liu et al. (2014), who suggest that information about transnational land deals could be documented in a relational database and categorized according to sending, receiving, and spillover systems, with each system including a list of agents, flows, causes, effects, and their linkages to other telecouplings such as species invasion. This would provide future telecoupling analyses with information on how land deals evolve and are connected in time. As pointed out by the authors, a promising database to enable such research inquiries is the LandMatrix, an independent land monitoring initiative to improve transparency in decisions over large-scale land acquisitions (Land matrix, n.d.).

We do not find any evidence that the interaction with telecoupling prescribes a specific type of analysis. Still, we do find that the application of the telecoupling influences the analytical perspective and contributes to generating new insights by specifying distal system dynamics, as we elaborate on in the following sections.

4.2 Different approaches to telecoupling

In the literature, the word 'telecoupling' is on the one hand used to describe the phenomena of globalization, and on the other hand, used as a conceptual framework to study these phenomena. We echo the argument that telecoupling research needs more consistent language, as proposed in (Meyfroidt, 2016) and, equally important, to be clear about how telecoupling is understood. We find that the potential of telecoupling to directly support more nuanced causal attribution in LSS depends on this variety in telecoupling application and operationalization.

A distinction between telecoupling as a phenomenon, a concept, and a framework has been identified in previous reviews (Kapsar et al.). However, our review reveals examples where all three types are applied simultaneously, which makes it difficult to clarify the difference it makes for causal attribution to adopt a telecoupling lens in the analysis. For the sake of consistent wording, from here onwards we refer to telecoupling as a framework in our conceptual discussions and recommendations for future research. To categorize and discuss the variety of approaches to telecoupling across the articles in our review sample, we offer a modification of the typology proposed in Kapsar et al. (2019) by discerning between 1) research that applies telecoupling implicitly as a phenomenon or research context (telecoupling as a narrative), and 2) research that directly applies the telecoupling framework on an empirical case in combination with another framework (telecoupling operationalized through existing concepts and tools), and 3) research that directly applies the telecoupling framework to an empirical case (empirical application of telecoupling). These three archetypes are not mutually exclusive but provide a constructive categorization for the discussion of the value added by the telecoupling framework.

Telecoupling as a *narrative* constitutes much of what we already know from research on multifaceted sustainability challenges about system interconnectedness but makes the interconnectedness more explicit by zooming in on the linkages involved in global processes. We identified 24 articles applying telecoupling as a narrative for research context rather than operationalized through existing concepts and tools or empirical application, and 16 of those articles focus primarily on material aspects (Figure 4). For instance, Rulli et al. (2019) apply telecoupling as a narrative in their analysis of potential environmental impacts of the expansion of oil palm production in Indonesia, where they focus primarily on observable, measurable, and material aspects such as quantifying forest loss, fragmentation, CO2 emissions, and freshwater pollution. They refer to the interconnectedness of drivers (bioenergy and palm oil consumption) and the multitude of environmental impacts, as an argument that policymakers should develop strategies that consider the complexity of telecoupled systems and spillovers.

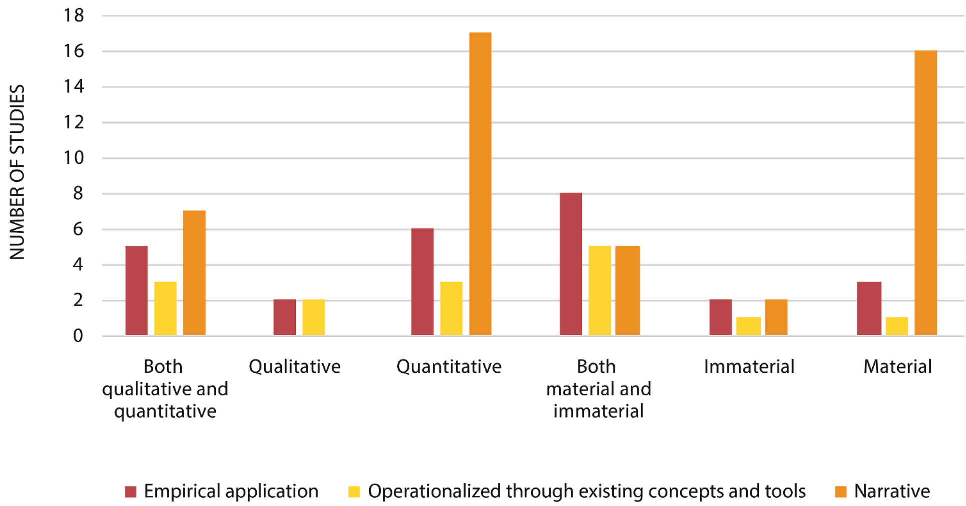

Figure 4. Telecoupling application and analytical focus. Source*: Figure generated from own data.*

Applying telecoupling as a narrative can help move beyond seeing globalization as a diffuse process and towards attending to specific global linkages and identifying the underlying distal drivers of environmental and social problems that manifest in a particular place. However, the analytical influence of telecoupling in studies that do not refer to any of the framework components, but only briefly mentions the term as an empirical phenomenon, is unclear (see for example, Creutzig et al., 2019; Fuller et al., ; Galaz et al., 2018; Kastner et al., 2015; Kozak & Szwagrzyk, ; Schierhorn et al., 2019).

In several research articles applying telecoupling as a narrative, telecoupling is understood broadly as a globalization process that has various impacts on land use and land cover, rather than operationalized as a tool to identify causal relationships. For example, Llopis et al. (2020) explore two telecoupling dynamics (protected areas and cash crop price boom) as drivers of the state of local well-being in a context of agricultural intensification in a biodiversity hotspot in Madagascar, or Bicudo da Silva et al. (2020) who consider telecoupling processes such as ecological tourism connecting urban and distant populations as the driver of direct and indirect land changes in Brazil. As such, telecoupling as a narrative can work as a way to describe the phenomenon of multiplex and intertwined causes rather than disentangling the complexity through the operationalization of the telecoupling framework components.

In contrast, the remaining 21 articles apply telecoupling more explicitly in either operationalization through existing concepts and tools or direct empirical application with reference to some or all of the telecoupling elements of the original framework: systems, causes, effects, actors, and flows (Liu et al., 2013). These more explicit telecoupling applications are frequently carried out with a combined material and immaterial analytical focus (13 articles out of 21). Telecoupling as operationalized through existing concepts and tools and empirical application is also associated with more examples of qualitative interpretation (four articles) and integrated qualitative/quantitative interpretation (eight articles) than the 'telecoupling as a narrative' application where 17 articles apply quantitative interpretation, 7 articles engage with both quantitative and qualitative interpretation, and zero articles appear purely qualitative (Figure 4). In turn, analyses of information-based flows such as discourse, knowledge, policy, and social dynamics are found primarily within empirical application or operationalization through existing concepts and tools (supplementary material_1).

Telecoupling as *operationalized through existing concepts and tools* shows how telecoupling can support an extension or modification of existing conceptual frameworks from various disciplines to better capture the interlinkages and interdependencies in a globalizing world. Hauer and Nielsen (2020) combine telecoupling with geographies of marketization. The marketization perspective supports attention towards everyday practices and actor behavior in the study site while telecoupling provides a structured way of accounting for the systemic position of the studied phenomenon. Using this approach, they show how rice markets, rice cultivation and landscapes are intertwined and co-evolving in Burkina Faso rather than one causing the other. The iteration between a systemic and practice-oriented analysis enables a move beyond isolated descriptions of causes and effects and towards an understanding of the causal mechanism and broader causal relationships influencing the rice sector.

Another example is Andriamihaja et al. (2019) who combine the telecoupling framework with a social network analysis (SNA) approach to capture the drivers of more immaterial flows by showing how the interests of distant actors influence and accelerate local land competition in Madagascar. They inform this theoretical approach by qualitative field observations at a regional and national level and qualitative-quantitative survey information on, amongst other things, product prices, and less tangible and informal information flow. They visualize this variety of data in a network graph showing the intensity, scale, frequency, and complexity of flows and interactions that comprise the evidence for the variety of land-use change drivers. They note how the application of telecoupling enabled them to better understand the links between distant drivers and local effects. In this example, telecoupling provides a framework for the application of SNA by prescribing the domains for analytical inquiry (systems, actors, causes, effects, flows), and SNA offers a way of carrying out this inquiry in a structured and quantifiable way. The articles within this category engage directly with telecoupling and deal with an empirical case but the focus is on how empirical application is operationalized through either integration or combination with existing theory (Hauer & Nielsen, 2020), conceptual integration (Oberlack et al., 2018; Zimmerer et al., 2018), the extension of existing frameworks (Keys & Wang-Erlandsson, 2018), or models (Yao et al., 2018), or through specific methodological tools (Andriamihaja et al., ; McCord et al., 2018; Millington et al., 2017). We cluster these together in one archetype because they all primarily focus on developing the idea of telecoupling through explicit interaction with existing concepts and methods.

Finally, the application of telecoupling for direct *empirical application* reveals how the telecoupling framework can be used as an analytical tool to disentangle actors, systems, flows, causes, and effects in situations where the analytical boundaries are inherently challenging to draw due to the transcending nature of the research problems studied. Friis and Nielsen (2017), for example, break up the banana production network into separate units of analysis (sending and receiving systems, actors, feedback, flows, etc.) and show how qualitative data and an empirical application of telecoupling can help expand the understanding of agency and power between distant actors. They show how this analytical approach better captures the complexity of causal relations behind the banana boom rather than limiting the analytical focus to a particular production system or place. Hulina et al. (2017) also show how telecoupling supports their analysis of migratory species by accounting holistically and systematically for the multitude of interrelated components (systems, flows, agents, causes, effects), in a way that provides a full picture of issues related to species migration and conservation, without losing sight of important but more underlying factors such as public perceptions of land use and cultural acceptance of the need for species conservation. Gasparri et al. (2015) combine a focus on both material and immaterial aspects in their empirical application of telecoupling to show how knowledge transfer, direct investment, and cooperation with South America are crucial elements of the soybean expansion in Southern Africa, which can result in similar deforestation and biodiversity loss as in South America

We propose these three distinct ways of understanding and applying the telecoupling framework as a way to structure the discussion that follows, even if aware that there are examples of more ambiguous applications. For example, Marola et al. (2020) refer to telecoupling as a phenomenon and emphasize that their objective is 'not so much to see what telecoupling can tell us about environmental certification as what we can learn from environmental certification about crafting information flows to govern telecoupled systems.' (p. 2). Still, they apply the idea directly to an empirical case. As they refer to telecoupling as a phenomenon and a globalization effect rather than an analytical framework, we have categorized their application as a narrative. The article is atypical for the sample in that it shows that telecoupling as a narrative can also be applied more directly to explore an empirical case, and thus contribute to the theory development of the framework components even if they are not explicitly included in the analysis. They do so by providing a structured way to analyze and distinguish between information flows between distant places in terms of bandwidth, which can support empirical theorizing on telecoupling governance (Marola et al., 2020).

4.3 The analytical influence of telecoupling for causal attribution

Nineteen of the 45 articles in the reviewed sample report in different ways how the telecoupling framework contributes to their analysis. Articles belonging to the empirical application of the telecoupling framework more often report on such contributions, followed by studies that combine telecoupling with other theoretical frameworks. Studies that employ telecoupling as a narrative rarely do so (Figure 5).

The statements in Figure 5 suggest that the umbrella conceptual framing of telecoupling (*mapping distant connections* and *multiple systems interactions*) is the most broadly reported contribution of the framework across all three types of application. In a globalized and interconnected world, it

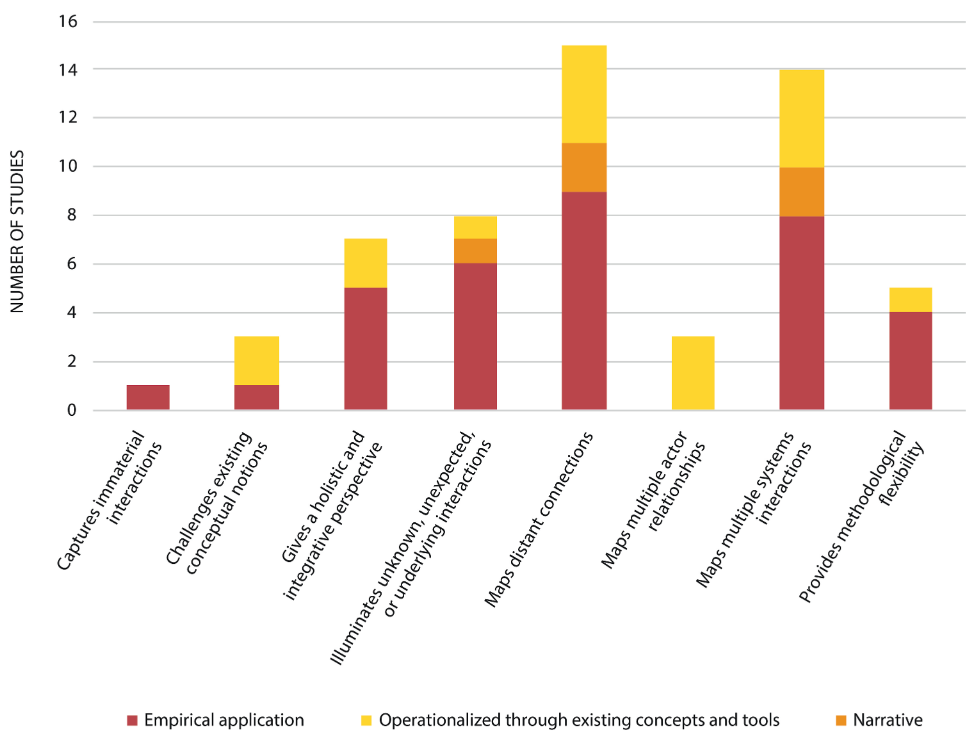

Figure 5. Reported contributions of the telecoupling framework. Source*: Figure generated from own data.*

can be difficult to determine which variables should be accounted for as a cause, and which should be accounted for as the effect (cf. the challenge positive feedback loops presented in Table 1). By mapping distant connections between multiple system components, the telecoupling framework disentangles this multitude of possible cause-effect relationships. It does so in a structured manner that makes it possible to focus on investigating specific linkages, causes, and effects, while acknowledging the wider system and other potential explanations. Thus, telecoupling does not ask what can be seen as a cause for the object of study, but what might have an interaction with the object of study. Hauer and Nielsen (2020) argue that the emphasis on systems connections through the analysis of flows results in less attention towards the question of how systems emerge, and how causal mechanisms play out. From another perspective, it could be argued that the telecoupling framework supports exactly such inquiry by showing *how* systems are created, maintained, or dissolved, by the direction and strength of flows between actors. In that sense, telecoupling maps the challenge of inferring causality, while at the same time providing a way to meet this challenge.

Mapping multiple actor relationships is also key in the original framing of telecoupling, but a less frequently reported contribution in the reviewed sample (3 articles; Figure 5). This speaks to the argument by Sonderegger et al. (2020), that the embedded network aspect of telecoupling deserves further testing and operationalization. Telecoupling research can contribute to shedding light on the interconnectedness between systems, actors, processes, and flows, but inevitably falls short in depicting all the dimensions of such complexity at once. Acknowledging the telecoupling framework as a type of network approach would also imply acknowledging this premise, and that the framework can map multiplex causal relationships that can then be subject to narrower inquiries in integration with other theoretical frameworks and/or by tapping into the telecoupling toolbox. This growing toolbox contains script tools for the assessment of potential causes and effects between social-ecological telecoupled systems through both statistical assessment and qualitative description (Nielsen et al., 2019; Tonini & Liu, 2017).

The objective of telecoupling research does not need to be to identify *all* causes and effects related to a given empirical case of land-use change but to identify which telecoupled relationships generate the largest socio-economic and environmental impacts (Liu et al., 2014) and to discover more unanticipated, intangible or underlying driving forces (Geist & Lambin, 2002). This is related to the reported strength that telecoupling contributes to *illuminating unknown, unexpected, or underlying interactions* (Figure 5). Telecoupling can help identify otherwise overlooked drivers by following flows between agents across systems with complex and fuzzy institutional boundaries. The inherent uncertainty related to causal attribution in LSS should be acknowledged as part of telecoupled systems rather than as a barrier to causal analysis. Uncertainty is not necessarily an analytical shortcoming but can be a valuable finding if it is explicitly discussed and integrated with the analysis. Some land-use changes require an acceptance that there will always be uncertainty because of the difficulty of attributing one factor as a cause and another one as an outcome (Rauschmayer et al., 2009).

In principle, causality can never be fully proven, only inferred. It has been a long while since science started to attribute causality beyond what can be directly observed, but there are not many holistic analytical frameworks within LSS that manage this accepted uncertainty about causal mechanisms. Whether applied directly and empirically, through existing concepts and tools, or as a narrative, the telecoupling framework does not prescribe any theory or methods to analyze causal mechanisms. Still, the framework's approach to relationships between causes and effects as complex linkages and pathways (cf., Eakin et al., 2017), provides a heuristic framing for the data collection on processes, actors and flows that can contribute to a more nuanced understanding of causality and causal mechanisms. As put by Eakin et al. (2017), the phenomenon of unexpected outcomes can in part be explained by the intangible nature of linkages such as values, political dynamics and information flows in telecoupled systems. For example, in the classic case of the causal relationship between increased meat demand in China (cause) and deforestation in Brazil (effect), analysis of the direction and strength of trade flows provides information on the interdependency of distant actors and land use processes which contributes to revealing the mechanisms through which the cause produces the effect (Torres et al., 2017). As such, and especially when approached through integrated toolboxes, telecoupling facilitates consideration of the agency of causal linkages which is essential to guide the different types of land use policy interventions that different causal mechanisms call for (Meyfroidt, 2016).

Integrated approaches to telecoupling causality are enabled through the framework because it provides *methodological flexibility* (Figure 5). The telecoupling framework gives analytical direction for the identification of specific causal relationships between systems and actors through material and immaterial flows, while at the same time providing flexibility to discover alternative patterns (Figure 5). As noted in Friis and Nielsen (2017), it allows to flexibly set the institutional and analytical boundaries of the study, while always keeping a focus on the local issue at hand. For example, Eakin et al. (2017) use telecoupling as a heuristic and draw system boundaries based on the different values and interests of actors associated with a telecoupled food production system. Moreover, the telecoupling framework provides flexibility in the sense that what makes a cause and what makes an effect will change depending on the analytical entry point i.e. which flows and actors that are in focus and what is interpreted as sending, receiving, and spillover systems.

Telecoupling does not prescribe *where* to look for specific drivers and effects, but it provides a framework for *how* to look, and from where a decision on an analytical entry point can be made without losing sight of the bigger picture. This is associated with the reported strength that overall, telecoupling *supports a holistic and integrative perspective*. As put by Lambin et al. (2001), what drives land-use change are 'peoples' responses to economic opportunities, as mediated by institutional factors' (p. 261), opportunities that are created by local, national, and international markets. This underscores well why an integrative holistic perspective on concrete interactions across scales and geographic distance is paramount. Moreover, the argument supports the need to further tap into the reported contribution regarding *demonstrating immaterial flows and interactions* to illuminate the beforementioned more intangible factors (e.g. incentive structures and institutional logics), which is key to fully understanding the complexity of causes behind land-use change.

For example, underlying economic incentive structures among government actors or discursive flows between institutions in a given land-use setting can over time contribute to environmental degradation if local and positive attitudes towards conservation progressively weaken (Geist & Lambin, 2002). While challenging to go beyond the acknowledgement of their presence and towards structured causal analysis, these underlying and discursive structures make up enabling causal factors for the phenomenon in focus (e.g. environmental degradation) and should be explored in both their quantitative (e.g. volume or frequency) and qualitative (e.g. motivation or subjectivity) characteristics and the context of the telecoupled systems. Boillat et al. (2018) present a good example of telecoupling operationalization through existing concepts and tools in combination with more qualitative inquiries, in this case, a telecoupling analysis in an environmental justice framing to map power asymmetries in four different cases of protected area governance. Underlying causal mechanisms are also more far-reaching than the effects they from time to time generate. An example from the review is the observable trade of commodities (material flows), which can be linked to more underlying reciprocal flows, policy, and discourses (immaterial flows; Gasparri et al., 2015; Leisz et al., 2016). In addition, the biological state of a forest can be influenced by cultural values, institutions, and social capital even though a direct causal link to physical traits such as resource extraction cannot be easily attributed with concrete measures and numbers (see, Gibson et al., 1999 or Geist & Lambin, 2002).

We did not identify any direct reports on the potential and strength of the telecoupling framework in terms of supporting analysis of complexities related to the temporal dimension such as facilitating the identification of non-linearity, time-lags, or inertia (Table 1). As noted earlier, 30 of the

45 reviewed articles include some level of temporal perspective. However, the ability of the telecoupling framework to identify temporal couplings is not reported in the articles applying the framework more explicitly (Figure 5). The temporal dimension is addressed in the original conceptualization of the telecoupling framework (Liu et al., 2015). However, as our review indicates, not much telecoupling research aims at moving beyond the presentation of system interactions as temporal snapshots and towards addressing both temporal and underlying flows behind multiple interacting causal mechanisms. Such information is relevant for policy intervention as it informs about the permanency and institutionalization of the telecoupled system. Relevant tools for more integrated inquiries have already been discussed in relation to telecoupling research including socioeconomic metabolism (Friis et al., 2016), process-tracing (Carlson et al., ; Meyfroidt, 2016), hybrid telecoupling models (Millington et al., 2017), agent-based modeling (Dou et al., 2019) or system dynamics models (Paitan & Verburg, 2019), and networks of action situations (NAS) approach (Oberlack et al., 2018), amongst others. Moreover, there are visualization techniques to show temporal order and development within social-ecological systems (Banitz et al., 2022; Sonderegger et al., 2020). However, accounting for temporal dynamics such as latency effects or slow-moving variables remains a challenge.

A telecoupling framework that supports longitudinal and mixed methods assessments would strengthen its contribution to causal analysis, not least because underlying drivers that require qualitative inquiry tend to reveal themselves over time. For example, increased timber logging is a proximate cause of the decline in biodiversity. The direct effect of timber logging in terms of habitat destruction can be measured and mapped quantitatively. However, looking at the cause of increased timber logging in more detail would require attention to the underlying driving forces (Geist & Lambin, 2002) at broader governance scales, and a consideration of the cumulative causes and more slow-moving variables (Pierson & Brown University, Rhode Island, Dietrich Rueschemeyer, Brown University, 2003). Moreover, underlying driving forces such as individual incentives related to increasing incomes from logging, and slow-moving variables such as attitude change require more qualitative inquiries.

Addressing causal mechanisms in an exploratory and hypothetical manner does not necessarily mirror a lack of structural approach to causality (cf., (Carlson et al.). Rather, it can be seen as an acknowledgement of the challenges associated with causal attribution (Table 1). Tapping into the strengths reported in Figure 5, the telecoupling framework becomes particularly suited to meet some of these challenges as it disentangles the interconnectedness associated with environmental and social problems involving multiple actors, scales, and locations (multi-causality), the immaterial and indirect flows between actors (potential underlying causes or confounding variables), and the spillover systems of such problems (cumulative and cascading effects).

5. Conclusion

Attributing causality in LSS is a challenging endeavor in today's interconnected world. In this article, we have demonstrated how the empirical telecoupling literature has taken up the challenge. First, we have shown that such literature is characterized by a broad variety of disciplines and analytical approaches. While most studies applying telecoupling do so with the use of quantitative methods, as identified in earlier reviews, qualitative and mixed methods studies and perspectives on temporal couplings are underrepresented. Consequently, we have suggested that qualitative and mixed-method longitudinal approaches to telecoupling research can complement quantitative analyses and provide a promising pathway for strengthening causal assessments in complex system interactions.

Second, based on the review, we have argued that telecoupling applications are most explicit in their contribution to providing a more nuanced understanding of causality in LSS when approached through either empirical application or operationalization through existing concepts and tools, rather than as a narrative. The empirical application of telecoupling shows that using telecoupling directly as an analytical tool to map and visualize actors and flows between distant systems can reveal unexpected impacts, spillovers, and significant causal relationships that are surrounded by complexity and uncertainty. Telecoupling operationalized through existing concepts and tools, in turn, demonstrates that conceptual frameworks from other disciplines can be enriched with a telecoupling lens and subsequently contribute to better capturing interconnectedness across distance. Altogether, the explicit interaction with the telecoupling framework seems to facilitate a more holistic focus on both material and immaterial aspects of causal relationships.

Third, the analysis of the review findings and the authors' reports on the benefits of engaging with the telecoupling framework, reveal that the analytical contribution of applying the framework is broad and ranges from its methodological flexibility to the holistic mapping of multiple systems and distant interactions. While it is rarely elaborated in detail how telecoupling contributes to causal attribution, there is evidence that telecoupling supports the identification of causal relationships that explicitly address, and thereby overcome, the analytical challenge related to the inherent complexity, unpredictability, and uncertainty of causes and effects which can complement existing LSS theory. Providing a flow-based and agency-focused perspective on causality can if operationalized through relevant qualitative and quantitative methods, guide the direction of interventions to target the processes and actors responsible for the most decisive causal mechanisms.

Overall, this article has demonstrated that telecoupling can push otherwise unobservable driving forces to the empirical domain through the conceptualization of multiple system components. In research advocating for better causal attribution in LSS, however, there is often a focus on the need to have causality proven with solid evidence from rigorous and triangulated methodological approaches. In this regard, we conclude that a telecoupling perspective does not necessarily make research better at proving causality, but it provides a structured framework for better understanding the complexity in the variety of ways causes and effects can be linked and unfold in a hyperconnected world. Finally, the telecoupling framework offers terminology and a toolbox for structuring and communicating such complexity in a way that shows applicable in various disciplines and methodological approaches, which makes it suitable for trans- and interdisciplinary research and collaboration. It is the analytical process that the telecoupling framework supports, which we argue can ensure a more nuanced understanding of causal attribution within LSS and beyond.

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Data availability statement

Raw data were generated in NVivo. Derived data supporting the findings of this study are available from the corresponding author upon request.

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References

Andriamihaja, O.R., Metz, F., Zaehringer, J.G., Fischer, M., & Messerli, P. (2019). Land competition under telecoupling: Distant actors' environmental versus economic claims on land in North-Eastern Madagascar. *Sustainability (Switzerland)*, *11*(3), 851. https://doi.org/10.3390/su11030851

Baird, I., & Fox, J. (2015). How Land Concessions Affect Places Elsewhere: Telecoupling, Political Ecology, and Large-Scale Plantations in Southern Laos and Northeastern Cambodia. *Land*, *4*(2), 436–453. https://doi.org/10.3390/land4020436

Banitz, T., Hertz, T., Johansson, L.-G., Lindkvist, E., Martí-nez-Peña, R., Radosavljevic, S., Schlüter, M., Wennberg, K., Ylikoski, P., & Grimm, V. (2022). Visualization of causation in social-ecological systems. *Ecology and Society*, *27*(1):31. https://doi.org/10.5751/ES-13030-270131

Beach, D., & Pedersen, R. (2016). Causal Case Study Methods: Foundations and Guidelines for Comparing, Matching, and Tracing. University of Michigan Press, 14-62 and 302-337. https://doi.org/10.3998/mpub.6576809

Bennett, A., & Elman, C. (2006). Qualitative research: Recent developments in case study methods. *Annual Review of Political ScienceAnnual Review of Political Science*, *9*, 455–476. https://doi.org/10.1146/annurev.polisci.8.082103.104918

Bennett, A., & George, A. (2005). *Case studies and theory development in the social sciences*. The MIT Press.

Bicudo da Silva, R.F., Millington, J.D.A., Moran, E.F., Batistella, M., & Liu, J. (2020). Three decades of land-use and land-cover change in mountain regions of the Brazilian Atlantic Forest. *Landscape and Urban Planning*, *204* (August), 103948. https://doi.org/10.1016/j.landurbplan.2020.103948

Boillat, S., Gerber, J.-D., Oberlack, C., Zaehringer, J., Ifejika Speranza, C., & Rist, S. (2018). Distant Interactions, Power, and Environmental Justice in Protected Area Governance: A Telecoupling Perspective. *Sustainability*, *10*(11), 3954. https://doi.org/10.3390/su10113954

Carlson, A., Zaehringer, J., Garrett, R., Felipe Bicudo Silva, R., Furumo, P., Raya Rey, A., Torres, A., Gon Chung, M., Li, Y., & Liu, J. (2018). Toward rigorous telecoupling causal attribution: A systematic review and typology. *Sustainability*, *10* (12), 4426. https://doi.org/10.3390/su10124426

Carter, N.H., Viña, A., Hull, V., McConnell, W.J., Axinn, W., Ghimire, D., & Liu, J. (2014). Coupled human and natural systems approach to wildlife research and conservation. *Ecology and Society*, *19*(3):43. https://doi.org/10.5751/ES-06881-190343

Chapman, M., Klassen, S., Kreitzman, M., Semmelink, A., Sharp, K., Singh, G., & Chan, K.M.A. (2017). 5 Key Challenges and Solutions for Governing Complex Adaptive (Food) Systems. *Sustainability (Switzerland)*, *9*(9), 1–30. https://doi.org/10.3390/su9091594

Clark, R. (1994). Cumulative effects assessment: A tool for sustainable development. *Impact Assessment*, *12*(3), 319–331. https://doi.org/10.1080/07349165.1994.9725869

Corbera, E., Busck-Lumholt, L.M., Mempel, F., & Rodríguez-Labajos, B. (2019). Environmental justice in telecoupling research. In C. Friis & J.Ø. Nielsen (Eds.), *Telecoupling: Exploring land-use change in a globalised world* (pp. 213–232). Palgrave Macmillan.10.1007/978-3-030-11105-2.

Creutzig, F., Bren D'Amour, C., Weddige, U., Fuss, S., Beringer, T., Gläser, A., Kalkuhl, M., Steckel, J.C., Radebach, A., & Edenhofer, O. (2019). Assessing human and environmental pressures of global land-use change 2000-2010. *Global Sustainability*, *2*, e1–17 doi:10.1017/sus.2018.15.

Dou, Y., Millington, J.D.A., Bicudo, R.F., Silva, D., Mccord, P., Viña, A., Song, Q., Yu, Q., Wu, W., Batistella, M., Moran, E., Liu, J., Felipe, R., & Da Silva, B. (2019). Land-use changes across distant places: Design of a telecoupled agent-based model) Land-use changes across distant places: Design of a telecoupled agent-based model Land-use changes across distant places: Design of a telecoupled agent-based model. *Journal of Land Use Science*, *14*(3), 191–209. https://doi.org/10.1080/1747423X.2019.1687769

Duit, A., & Galaz, V. (2008). Governance and complexity - Emerging issues for governance theory. *Governance*, *21*(3), 311–335. https://doi.org/10.1111/J.1468-0491.2008.00402.X

Eakin, H., DeFries, R., Kerr, S., Lambin, E.F., Liu, J., Marcotullio, P.J., Messerli, P., Reenberg, A., Rueda, X., Swaffield, S.R., Wicke, B., & Zimmerer, K. (2014). Significance of telecoupling for exploration of land-use change. In *Rethinking global land use in an urban era* (MIT Press) (Issue March, pp. 141–161). https://doi.org/10.7551/mitpress/9780262026901.003.0008.

Eakin, H., Rueda, X., & Mahanti, A. (2017). Transforming governance in telecoupled food systems. *Ecology and Society*, *22* (4):32. https://doi.org/10.5751/ES-09831-220432

Efroymson, R.A., Kline, K.L., Angelsen, A., Verburg, P.H., Dale, V.H., Langeveld, J.W.A., & McBride, A. (2016). A causal analysis framework for land-use change and the potential role of bioenergy policy. *Land Use Policy*, *59*(October), 516–527. https://doi.org/10.1016/j.landusepol.2016.09.009

Friis, C., Nielsen, J.Ø., Otero, I., Haberl, H., Niewöhner, J., & Hostert, P. (2016). From teleconnection to telecoupling: Taking stock of an emerging framework in land system science. *Journal of Land Use Science*, *11*(2), 131–153. https://doi.org/10.1080/1747423X.2015.1096423

Friis, C., & Nielsen, J.Ø. (2017). On the system. Boundary choices, implications, and solutions in telecoupling land use change research. *Sustainability (Switzerland)*, *9*(6), 1–20. https://doi.org/10.3390/su9060974

Fuller, T.L., Narins, T.P., Nackoney, J., Bonebrake, T.C., Sesink Clee, P., Morgan, K., Tróchez, A., Bocuma Meñe, D., Bongwele, E., Njabo, K.Y., Anthony, N.M., Gonder, M.K., Kahn, M., Allen, W.R., & Smith, T.B. (2018). Assessing the impact of China's timber industry on Congo Basin land use change. *Area*, 51(2), 340– 349. https://doi.org/10.1111/area.12469

Galaz, V., Crona, B., Dauriach, A., Scholtens, B., & Steffen, W. (2018). Finance and the Earth system – Exploring the links between financial actors and non-linear changes in the climate system. *Global Environmental Change*, *53*(September), 296–302. https://doi.org/10.1016/j.gloenvcha.2018.09.008

Gasparri, N.I., Kuemmerle, T., Meyfroidt, P., le Polain de Waroux, Y., & Kreft, H. (2015). The emerging soybean production frontier in Southern Africa: Conservation challenges and the role of south-south telecouplings. *Conservation Letters*, *9* (1), 21–31 doi:10.1111/conl.12173.

Geist, H.J., & Lambin, E.F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, *52* (2), 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Gibson, C., Williams, J., & Ostrom, E. (1999). Social capital and the governance of forest resources. *Conference on the creation and returns of social capital*, *812*, 12.

Hauer, J., & Nielsen, J.Ø. (2020). Making land-use change and markets: The global-local entanglement of producing rice in Bagré, Burkina Faso. *Geografiska Annaler, Series B: Human Geography*, *102*(1), 84–100 doi:10.1080/04353684.2020.1723121.

Henderson, J., Godar, J., Frey, G.P., Börner, J., & Gardner, T. (2021). The Paraguayan Chaco at a crossroads: Drivers of an emerging soybean frontier. *Regional Environmental Change*, *21*(3):72. https://doi.org/10.1007/s10113-021-01804-z

Hulina, J., Bocetti, C., Campa, H., III, Hull, V., Yang, W., Liu, J., Kapuscinski, A.R., Hellmann, J.J., & Locke, K.A. (2017). Telecoupling framework for research on migratory species in the Anthropocene. *Elementa: Science of the Anthropocene*, *5*, 5. https://doi.org/10.1525/elementa.184

Hull, V., & Liu, J. (2018). Telecoupling: A new frontier for global sustainability. *Ecology and Society*, *23*(4). https://doi.org/10.5751/ES-10494-230441

Kapsar, K., Hovis, C., Bicudo da Silva, R., Buchholtz, E., Carlson, A., Dou, Y., Du, Y., Furumo, P., Li, Y., Torres, A., Yang, D., Wan, H., Zaehringer, J., & Liu, J. (2019). Telecoupling research: The first five years. *Sustainability*, *11*(4), 1033. https://doi.org/10.3390/su11041033

Kastner, T., Erb, K.H., & Haberl, H. (2015). Global human appropriation of net primary production for biomass consumption in the European Union, 1986-2007. *Journal of Industrial Ecology*, *19*(5), 825–836 doi:10.1111/jiec.12238.

Keys, P.W., & Wang-Erlandsson, L. (2018). On the social dynamics of moisture recycling. *Earth System Dynamics*, *9*(2), 829–847. https://doi.org/10.5194/esd-9-829-2018

Kozak, J., & Szwagrzyk, M. (2016). Have there been forest transitions? Forest transition theory revisited in the context of the modifiable areal unit problem. *Area*, *48*(4), 504–512. https://doi.org/10.1111/area.12267

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., . . . Xu, J. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change*, *11*(4), 261–269. https://doi.org/10.1016/S0959-3780(01)00007-3

Land matrix. (n.d.). https://landmatrix.org/

Leisz, S.J., Rounds, E., An, N.T., Yen, N.T.B., Bang, T.N., Douangphachanh, S., & Ninchaleune, B. (2016). Telecouplings in the east-west economic corridor within borders and across. *Remote Sensing*, *8*(12), 1–30 doi:10.3390/rs8121012.

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., Hertel, T.W., Izaurralde, R.C., Lambin, E.F., Li, S., Martinelli, L.A., McConnell, W.J., Moran, E.F., Naylor, R., Ouyang, Z., Polenske, K.R., Reenberg, A., de Miranda Rocha, G., Simmons, C.S., & Zhu, C. (2013). Framing Sustainability in a Telecoupled World. *Ecology and Society*, *18*(2), 26. https://doi.org/10.5751/ES-05873-180226

Liu, J., Hull, V., Luo, J., Yang, W., Liu, W., Viña, A., Vogt, C., Xu, Z., Yang, H., Zhang, J., An, L., Chen, X., Li, S., Ouyang, Z., Xu, W., & Zhang, H. (2015). Multiple telecouplings and their complex interrelationships. *Ecology and Society*, *20*(3):44. https://doi.org/10.5751/ES-07868-200344

Liu, J., Hull, V., Moran, E., Nagendra, H., Swaffield, S.R., & Turner, B.L., II. (2014). Applications of the telecoupling framework to land-change science. *Rethinking Global Land Use in an Urban Era*, *14*(June 2018), 119–140. https://doi.org/10.7551/mitpress/9780262026901.003.0007

Llopis, J.C., Diebold, C.L., Schneider, F., Harimalala, P.C., Patrick, L., Messerli, P., & Zaehringer, J.G. (2020). Capabilities under telecoupling: Human well-being between cash crops and protected areas in North-Eastern Madagascar. *Frontiers in Sustainable Food Systems*, *3*(January), 1–20. https://doi.org/10.3389/fsufs.2019.00126

Mahoney, J. (2000). Path dependence in historical sociology. *Theory and Society*, *29*(4), 507–548. https://doi.org/10.1023/A:1007113830879

Marola, E., Schöpfner, J., Gallemore, C., & Jespersen, K. (2020). The bandwidth problem in telecoupled systems governance: Certifying sustainable winemaking in Australia and Chile. *Ecological Economics*, *171*(July 2019), 106592. https://doi.org/10.1016/j.ecolecon.2020.106592

Mayring, P. (2014). Qualitative Content Analysis: Theoretical foundation, basic procedures and software solution. *Advances in Bioethics*, *11*(January), 39–62. https://doi.org/10.1016/S1479-3709(07)11003-7

McCord, P., Tonini, F., & Liu, J. (2018). The Telecoupling GeoApp: A Web-GIS application to systematically analyze telecouplings and sustainable development. *Applied Geography*, *96*(March), 16–28. https://doi.org/10.1016/j.apgeog.2018.05.001

Meyfroidt, P. (2016). Approaches and terminology for causal analysis in land systems science. *Journal of Land Use Science*, *11*(5), 501–522. https://doi.org/10.1080/1747423X.2015.1117530

Meyfroidt, P. (2019). Explanations in telecoupling research. *Telecoupling*, 69–86. https://doi.org/10.1007/978-3-030-11105-2_4

Millington, J., Xiong, H., Peterson, S., & Woods, J. (2017). Integrating modelling approaches for understanding telecoupling: Global food trade and local land use. *Land*, *6*(3), 56. https://doi.org/10.3390/land6030056

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D.G. (2010). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *International Journal of Surgery*, *8*(5), 336–341. https://doi.org/10.1016/j.ijsu.2010.02.007

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., Bezerra, T., DiGiano, M., Shimada, J., Da Motta, R. S., Armijo, E., Castello, L., Brando, P., Hansen, M.C., McGrath-Horn, M., Carvalho, O., & Hess, L. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. *Science*, *344*(6188), 1118–1123. https://doi.org/10.1126/science.1248525

Newig, J., Challies, E., Cotta, B., Lenschow, A., & Schilling-Vacaflor, A. (2020). Governing global telecoupling toward environmental sustainability. *Ecology and Society*, *25*(4), 1–17. https://doi.org/10.5751/ES-11844-250421

Nielsen, J.Ø., Hauer, J., & Friis, C. (2019). Toolbox: Capturing and Understanding Telecoupling through Qualitative Research. In C. Friis, J. Nielsen (Eds.), *Telecoupling. Palgrave Studies in Natural Resource Management* (pp. 303–312). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-11105-2_16

Nielsen, J.Ø., Hauer, J., & Friis, C. (2019). Toolbox: Capturing and understanding telecoupling through qualitative research. In *Telecoupling*, (Issue January). https://doi.org/10.1007/978-3-030-11105-2.

Norder, S., Seijmonsbergen, A.C., Rughooputh, S.D.D.V., van Loon, E.E., Tatayah, V., Kamminga, A.T., & Rijsdijk, K.F. (2017). Assessing temporal couplings in social–ecological island systems: Historical deforestation and soil loss on Mauritius (Indian Ocean). *Ecology and Society*, *22*(1), 29. https://doi.org/10.5751/ES-09073-220129

Oberlack, C., Boillat, S., Brönnimann, S., Gerber, J.D., Heinimann, A., Speranza, C.I., Messerli, P., Rist, S., & Wiesmann, U. (2018). Polycentric governance in telecoupled resource systems. *Ecology and Society*, *23*(1):16. doi:10.5751/ES-09902-230116).

Pace, M.L., & Gephart, J.A. (2017). Trade: A Driver of Present and Future Ecosystems. *Ecosystems (New York, N.Y.)*, *20*(1), 44–53. https://doi.org/10.1007/s10021-016-0021-z

Paitan, C.P., & Verburg, P.H. (2019). Methods to assess the impacts and indirect land use change caused by telecoupled agricultural supply chains: A review. *Sustainability (Switzerland)*, *11*(4):1162. https://doi.org/10.3390/su11041162

Petursson, J.G., & Vedeld, P. (2017). Rhetoric and reality in protected area governance: Institutional change under different conservation discourses in Mount Elgon National Park, Uganda. *Ecological Economics*, *131*(January), 166–177. https://doi.org/10.1016/j.ecolecon.2016.08.028

Pierson, P. (2003). Big, slow-moving, and . . . Invisible: Macro-social processes in the study of comparative politics. In R. I. James Mahoney, Brown University, Rhode Island, Dietrich Rueschemeyer, Brown University (Ed.), *Comparative historical analysis in the social sciences* (pp. 177–207). Cambridge University Press. https://doi.org/10.1017/CBO9780511803963.006.

Rauschmayer, F., Berghöfer, A., Omann, I., & Zikos, D. (2009). Examining processes or/and outcomes? Evaluation concepts in European governance of natural resources. *Environmental Policy and Governance*, *19*(3), 159–173. https://doi.org/10.1002/eet.506

Ringel, M. (2018). Tele-coupling energy efficiency polices in Europe: Showcasing the German governance arrangements. *Sustainability (Switzerland)*, *10*(6):1754. https://doi.org/10.3390/su10061754

Rotmans, J., & Loorbach, D. (2009). Complexity and transition management. *Journal of Industrial Ecology*, *13*(2), 184–196. https://doi.org/10.1111/j.1530-9290.2009.00116.x

Rounsevell, M.D.A., Pedroli, B., Erb, K., Gramberger, M., Busck, A.G., Haberl, H., Kristensen, S., Kuemmerle, T., Lavorel, S., Lindner, M., Lotze-Campen, H., Metzger, M.J., Murray-Rust, D., Popp, A., Pérez-Soba, M., Reenberg, A., Vadineanu, A., Verburg, P.H., & Wolfslehner, B. (2013). *Challenges for Land System Science. Land Use Policy*, January . https://doi.org/10.1016/j.landusepol.2012.01.007

Rounsevell M DA *et al*. (2012). Challenges for land system science. Land Use Policy, 29(4), 899–910. 10.1016/j.landusepol.2012.01.007

Rulli, M.C., Casirati, S., Dell'Angelo, J., Davis, K.F., Passera, C., & D'Odorico, P. (2019). Interdependencies and telecoupling of oil palm expansion at the expense of Indonesian rainforest. *Renewable and Sustainable Energy Reviews*, *105*, 499–512. https://doi.org/10.1016/j.rser.2018.12.050

Scheidel, A., & Gingrich, S. (2020). Toward sustainable and just forest recovery: research gaps and potentials for knowledge integration. One Earth, 3(6), 680–690. https://doi.org/10.1016/j.oneear.2020.11.005

Schierhorn, F., Kastner, T., Kuemmerle, T., Meyfroidt, P., Kurganova, I., Prishchepov, A.V., Erb, K.H., Houghton, R.A., & Müller, D. (2019). Large greenhouse gas savings due to changes in the post-Soviet food systems. *Environmental Research Letters*, *14*(6), 65009. doi:10.1088/1748-9326/ab1cf1

Schlüter, M., McAllister, R.R.J., Arlinghaus, R., Bunnefeld, N., Eisenack, K., Hölker, F., Milner-Gulland, E.J., Müller, B., Nicholson, E., Quaas, M., & Stöven, M. (2012). New horizons for managing the environment: A review of coupled social-ecological systems modeling. *Natural Resource Modeling*, *25*(1), 219–272. https://doi.org/10.1111/j.1939-7445.2011.00108.x

Seaquist, J.W., Johansson, E.L., & Nicholas, K.A. (2014). Architecture of the global land acquisition system: Applying the tools of network science to identify key vulnerabilities. *Environmental Research Letters*, *9*(11), 114006. https://doi.org/10.1088/1748-9326/9/11/114006

Sonderegger, G., Oberlack, C., Llopis, J.C., Verburg, P.H., & Heinimann, A. (2020). Telecoupling visualizations through a network lens: A systematic review. *Ecology and Society*, *25*(4), 1–15. https://doi.org/10.5751/ES-11830-250447

Sugihara, G., May, R., Ye, H., Hsieh, C.H., Deyle, E., Fogarty, M., & Munch, S. (2012). Detecting causality in complex ecosystems. *Science*, *338*(6106), 496–500. https://doi.org/10.1126/science.1227079

Telecoupling toolbox. (n.d.). https://telecouplingtoolbox.org/

Tonini, F., & Liu, J. (2017). Telecoupling toolbox: Spatially-explicit tools for studying telecoupled human and natural systems. *Ecology and Society*, *22*(4):11.

Torres, S.M., Moran, E.F., & da Silva, R.F.B. (2017). Property rights and the soybean revolution: Shaping how China and Brazil are telecoupled. *Sustainability (Switzerland)*, *9*(6). https://doi.org/10.3390/su9060954

Turner, B.L., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Hovelsrud-Broda, G.K., Kasperson, J.X., Kasperson, R.E., Luers, A., Martello, M.L., Mathiesen, S., Naylor, R., Polsky, C., Pulsipher, A., Schiller, A., Selin, H., & Tyler, N. (2003). Illustrating the coupled human-environment system for vulnerability analysis: Three case studies. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(14), 8080–8085. https://doi.org/10.1073/pnas.1231334100

Vicol, M., Neilson, J., Hartatri, D.F.S., & Cooper, P. (2018). Upgrading for whom? Relationship coffee, value chain interventions and rural development in Indonesia. *World Development*, *110*, 26–37. https://doi.org/10.1016/j.worlddev.2018.05.020

Yao, G., Hertel, T.W., & Taheripour, F. (2018). Economic drivers of telecoupling and terrestrial carbon fluxes in the global soybean complex. *Global Environmental Change*, *50*, 190–200. https://doi.org/10.1016/j.gloenvcha.2018.04.005

Zimmerer, K.S., Lambin, E.F., & Vanek, S.J. (2018). Smallholder telecoupling and potential sustainability. *Ecology and Society*, *23*(1 30). https://doi.org/10.5751/ES-09935-230130