COUPLED

OPERATIONALISING TELECOUPLINGS FOR SOLVING SUSTAINABILITY CHALLENGES FOR LAND USE

Deliverable D5.1

Exploring impacts and causality in telecoupling research: Emerging evidence and knowledge gaps

Report on the outcomes of VMS 5 (causality)

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About COUPLED

Human consumption of food and agricultural products has a significant impact on the environment and the societies in the regions where they are produced. Different sectors, consumers, businesses and politicians are increasingly demanding more environmental and social sustainable land use both inside and outside Europe. Yet, there is increasing recognition of the limitations of current research approaches to adequately understand and address the increasing complexity of land system dynamics, which are often characterized by strong non-linearity, feedback mechanisms, and local contexts, and where places of production, trade, and consumption of land-based products are increasingly separated.

Coordinated by the Humboldt-Universität zu Berlin, COUPLED is a European training network in order to better integrate research, innovation and social responsibility framed around the concept of telecouplings.

COUPLED trains Early Stage Researchers capable of:

- understanding processes and actors that influence land use in an increasingly interconnected world
- considering distant, unexpected feedbacks and spillovers and to account for their social and environmental impact
- fostering new and enhanced governance measures that can shape land-use couplings to deliver more sustainable outcomes of land-use decisions

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Executive Summary

The EU-ITN COUPLED Work Package 5 (WP 5) aims to explore causality across scales and distances in telecoupling research, and to determine why a particular impact occurs and quantify trade-offs across and within telecouplings. This report constitutes a first step in this direction, and it draws upon the discussions held among WP5 members in the context of the project's Virtual Meeting Series 5 (VMS 5). As noted in the COUPLED's project proposal, the objective of VMS 5 was to analyse "methodologies to attribute impacts to drivers in telecoupled human-environment systems" and to assess "the strengths and weaknesses of approaches to impute causality, and thus to quantify sustainability in telecoupled systems" (pp. 22).

Telecoupling offers a framework for understanding the world as a large interconnected system while breaking its constituent parts into manageable units, enabling situated analysis that accounts for local level details while acknowledging transboundary flows and interactions across places and scales. Therefore, research aimed at engaging with causality issues, for instance what drives a given land-use change process, or what determines the outcomes of such a process, will be challenging given the cross-scalar and variegated nature of the social, environmental, political and economic interactions that make up the world today. That said, telecoupling researchers should take up this challenge because the identification of drivers of a given land use, or land-use change process, is crucial to develop relevant and realistic policy recommendations that can lead to more sustainable land uses.

To our understanding, impact assessment, trade-off analysis, and methods for identifying causal relationships are areas that have not yet been widely explored from a telecoupling perspective.

The research questions guiding this report are:

1. How do existing theoretical and conceptual approaches to telecoupling understand and analyse impacts, trade-offs and causality?
2. How do empirical telecoupling research papers approach impacts, trade-offs and causality?

We addressed the first question through a review of landmark conceptual articles in the growing telecoupling literature and the second through a systematic review of empirical telecoupling research. The former supports existing attempts to qualify and expand concepts and methodologies in telecoupling, while the latter illuminates current knowledge gaps in terms of impact assessment, analysis of trade-offs, and methods for identifying causality.

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1. Introduction

The EU-ITN COUPLED Work Package 5 (WP 5) aims to explore causality across scales and distances in telecoupling research, and to determine why a particular impact occurs and quantify trade-offs across and within telecouplings. This report constitutes a first step in this direction, and it draws upon the discussions held among WP5 members in the context of the project's Virtual Meeting Series 5 (VMS 5). As noted in the COUPLED's project proposal, the objective of VMS 5 was to analyse "methodologies to attribute impacts to drivers in telecoupled human-environment systems" and to assess "the strengths and weaknesses of approaches to impute causality, and thus to quantify sustainability in telecoupled systems" (pp. 22).

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To our understanding, impact assessment, trade-off analysis, and methods for identifying causal relationships are areas that have not yet been widely explored from a telecoupling perspective. Only Carlson et al. (2018) have examined the state of causal attribution in telecoupling literature and offered suggestions for improved rigor in analysis of causal relationships. However, in contrast with our report, they have not examined the types of impacts arising from causal processes.

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2. Theory development and conceptualisation in telecoupling research

This section is based on a review of seminal articles in telecoupling research which have aimed at advancing telecoupling theory, specifically definitions and terminology relevant to the design of "telecoupling-informed" land use (social) science (Table 1 - Source column). Our reading of these articles was driven by questions such as: how is telecoupling understood? What is understood by impacts, causality, and trade-offs? Which other relevant concepts appear in this literature and how are these defined or understood? The observations that follow are either informed by literal transcriptions of the reviewed articles or by our own interpretation of the articles' content.

The first issue to notice in Table 1 is that the articles reviewed diverge in their understanding of telecoupling. The latter can be understood as an ontological given (see Liu et al. 2015), as a heuristic (Friis et al. 2017a; Niewöhner et al. 2016) or as both (Carlson et al. 2018). For Carlson et al. (2018), for example, the causes for an observed land-use or environmental change can have their origin in a different location, sector, time or institution, which makes it difficult to establish a single cause of such change, or to establish the relative

influence of these potentially distinct origins. In this regard, the literature identifies a number of concepts that in one way or another denote the complexity of causal attribution. As shown in Table 1, these concepts include scalar, temporal and spatial patterns that characterise land-use and environmental systems, as well as a variety of effects that can accompany land-use or environmental change.

Table 1. Patterns and effects that complicate the attribution of 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
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
Underlying (or indirect) causes	Fundamental forces that underpin the more proximate causes.	Geist & Lambin, 2002
Effects		
Cascading effect	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; Parra Paitan & Verburg, 2019
Cumulative effect	Impact on the environment which results from the incremental 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

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
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
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
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

Source: Own elaboration based on listed references.

The majority of the reviewed articles provide clear definitions of the different types of effects that potentially emerge in telecoupled systems. As shown in Table 1, these include direct effects, indirect effects, cascading effects, legacy effects and feedback effects (Liu et al,, 2014; Niewöhner et al., 2016). However, we have noted that the term “effects” is often understood differently by the authors; for example, while Carlson et al. (2018) refer to them as “events”, “variables”, or even “facts”, Liu et al. (2013) point to effects as being the results of flows, including both positive and negative, socio-economic and environmental effects.

In the reviewed articles, the impacts in telecoupled systems also vary in their characteristics: form (direct or indirect), direction (positive, negative or undetermined), duration (short, medium or long-term, temporary or permanent), reversibility (reversible or irreversible), spatial scale (local, regional, national or global), and magnitude (high, medium, low). Spillovers are generally considered a particular form of impact, which occur in a system that is not central to the interactions between the sending and receiving systems. While it is difficult to delineate relevant spillover systems, it is even more demanding to accurately and comprehensively evaluate causes, effects and associated causal mechanisms of spillovers (Table 2).

Table 2. Definitions for spillovers and related concepts in telecoupling research.

Displacement	Geographical shift of land use from one place to another. It can result in spatial separation between the land used for agricultural or wood production and the place of consumption of these products, as it occurs with trade; it can also result from population movements.	Meyfroidt et al., 2013
Indirect land-use change	Indirect land-use change is a land-use change in one place caused by a land-use change in another place. Indirect land-use change is a form of spillover.	Meyfroidt et al., 2018
Land-use spillovers	Land-use spillovers refer to situations where land-use changes or direct interventions on land use (e.g., policy, program, new technologies) in one place have impacts on land use in another place.	Meyfroidt et al., 2018
(Land-use) Leakage	Leakage refers to a displacement of the environmental impact, thereby counteracting the intended effects of the initial policy or intervention. Land-use leakage occurs when a land-use intervention, such as an environmental conservation policy, which triggers land-use change elsewhere that reduces the overall benefit of the local intervention. A leakage is a form of spillover.	Meyfroidt, Lambin, Erb, & Hertel, 2013; Meyfroidt et al., 2018
Rebound effect	A rebound effect occurs when technological improvements create decreased costs, subsequently leading to increased demand. A rebound effect can occur when a technological change leads to an increase in efficiency, thereby increasing profits and leading to more agricultural expansion. A rebound effect is a form of spillover.	le Polain de Waroux et al., 2017; Nilsson, Bergquist, & Schultz, 2017
Spillover effects	A spillover is an effect of an intervention (e.g. policy, campaign, program) on subsequent behaviors not targeted by the intervention. Spillover effects can be both positive and negative.	Truelove et al., 2014
Spillover systems	Spillover systems are those that affect, or are affected by, local, regional, or international interactions between sending and receiving systems.	Liu et al., 2013

Source: Own elaboration based on listed references.

In the reviewed articles for developing Tables 1 and 2, causes are the socio-economic, political, cultural or ecological processes that drive the flows (Liu et al., 2015), and such causes are considered the source of dynamism in the flows of telecoupled systems, which often have multiple and interacting causes (Niewöhner et al., 2016). Carlson et al. (2018) define causes from six criteria: sector, system of origin, agent, distance, response time and direction. To them, the cause is what explains the effect. Causality is, they argue, a temporal component that links cause and effect empirically (Carlson et al., 2018).

All these contributions taken together suggest that researchers have developed multiple typologies and categories to break down telecoupled impacts into graspable units for analysis. They also imply that different methods or epistemologies will be required to analyze such multiplicity of possible impacts resulting from telecoupling(s).

3. Review of telecoupling research: data collection and analysis

As noted above, this report addressed its second research question through a systematic review of telecoupling *empirical* literature. We aimed to investigate how empirical analyses have to date approached impacts, tradeoffs and causality. Through a broad search string in the scientific database Scopus looking for all published material up until April 2019 containing the term 'telecoupl*', we were able to identify 106 articles. We then read all abstracts and selected only those which included at least one empirical case, which rendered 87 articles.

Subsequently, we selected randomly 15 articles among the second sample, and we read the articles in full in order to develop a codebook which guided the remaining of the systematic review. A principal observation and consequence of this process was realizing that telecoupling empirical research was highly disciplinarily and methodologically diverse, and often incomparable, which meant that the codebook had to be flexible enough to accommodate both qualitative and quantitative insights from the published articles.

The review of these 15 articles was organized as a preparation for the systematic review. It was rather informal: each author read four papers selected randomly and took individual notes guided by questions reflected upon during the preparatory group meetings including, how authors qualify an impact, which type of impact they are talking about (e.g. social, economic, ecological, etc.), which measurement indicators they consider, at which scale they measure and consider such impact(s) (individual, community, municipality or the like, region, country etc.). We annotated applied methods and took notes on which chains of causality the authors identify, which trade-offs they consider, and whether these are quantified and with use of which indicators.

However, during this preliminary review, such details were not appearing in the telecoupling research and the aspects were broadly found to represent a knowledge gap in the literature.The findings were added to a common worksheet on google drive and discussed continuously during several Skype meetings. We also used the preliminary review to reflect on the literature search protocol in terms of criteria on which papers to include and exclude in the systematic review. It turned out to be quite challenging to make a clear distinction between 'empirical' and 'conceptual' papers, which was the initial idea. Even though it added a certain complexity to the review and selection of papers, it was decided to look through all papers and make the decision on inclusion/exclusion paper by paper. The criteria for inclusion and the resulting codebook can be found on the provided link in this report's Appendix 1.

After this preliminary review process, we started the systematic review which – as of June 2019 – we have not yet concluded. We have reviewed so far 27 of the 87 articles found, with each of us reading an average of 5 papers. We strived to avoid subjective interpretation of the articles' content and, for this reason, we only documented impacts, trade-offs and causality links identified by the author(s), and not those that we could think of from reviewing the paper, if any. This meant that we only inserted information included in the articles reviewed, as shown in the data-entry guide we developed (see Appendix 2).

We also strived to achieve triangulation between reviewers by letting at least every fifth paper be reviewed

by two people who review the paper individually and then crosscheck for differences. When differences were observed, these were discussed among the reviewers and a consensus response was found. We argue that this leads to findings that better reflect the actual trends in the literature. In cases where the reviewer had further comments and observations, these appear in the “comments” column. This information is as valuable as the systematic codes but will be processed more qualitatively in the future – when the review is concluded in the form of an academic article.

4. Review of telecoupling empirical research

This section synthesizes the main findings of our review of 27 articles, which will be expanded in the coming months to incorporate the remaining 60 articles. We structure the analysis on five parts that distill the articles’ focus, theoretical and methodological lenses; the ecological, social, economic impacts identified; and their approach to understanding and analysing causality and trade-offs.

4.1. Articles’ analytical focus, theoretical framing, data and methods

The analytical focus of the reviewed articles is diverse: a large share of contributions analyze telecoupling(s) arising from farming systems (e.g. soybean, bananas) (e.g. Lenschow et al., 2016; Baird et al., 2015; Garrett et al., 2013) and fisheries (e.g. Carlson et al., 2018); some focus on telecouplings arising from different forms of conservation policy and practice (e.g. Boillat et al., 2018), and others look at water, species, timber and other ecosystem services flows (e.g. Parish et al., 2018). One third of the articles are global in scope, which does not necessarily mean that their level of empirical observation is global per se. Some of these articles, for example, draw global lessons from the analysis of telecoupled systems that span across two or more countries (e.g. Pace et al., 2017). Four articles focus only on a specific region of the world, i.e. Asia, North America, collecting data across two or more countries from these regions (e.g. Pezzoli et al., 2014), while the rest of the articles rely on empirical data collection from sending or receiving system at national or sub-national levels (e.g. Chen et al., 2019).

The theoretical framework or conceptual lenses of the reviewed articles refer to the main concepts, frameworks, theories used to frame the research and/or explain the empirical observations of the particular study. As expected, due to the cross-disciplinary nature of researchers in telecoupling, there is a wide range of theories applied. However, a large proportion of studies in the sample seem to be grounded in the post-positivist tradition of land system science, either not referring to any theoretical framework or using the Coupled Human and Natural Systems (CHANS) framework or an equivalent, such as Ecosystem Services. Only a few studies ground their work in social sciences using, for instance, theories related to polycentric governance and human geography. Moreover, all use or refer to the telecoupling framework (or at minimum, apply the terminology) for some part of the article. There is a wide range of terminology used by authors to describe, explain and qualify impacts arising from telecouplings. This suggests that the use of a standardised language for the systematic analysis of distant socioeconomic and environmental interactions has not yet been established, which for some might result problematic since it might foreclose fruitful and richer interdisciplinary research (Nielsen et al., 2019).

Methodologically, we see a roughly equal spread across qualitative, quantitative and mixed data types in the reviewed articles. Papers using a single method dominate our sample (12 out of 27), with six of these employing quantitative or spatial methods. The other six used non-systematic literature reviews as their sole method, while another four combined a literature review with one or more other methods, indicating a preference for using secondary literature to develop new insights using the telecoupling framework. Qualitative methods were always used in congruence with other methods, apart from literature reviews. There are four qualitative multi-method studies including interviews, focus-group discussions, household surveys and participant observation.

Generally, we see a spread of methods across our sample, ranging from geospatial modelling, choice

experiments, carbon calculations and regression analysis to the suite of qualitative methods. It was often challenging to extract useful information about the specific details of the data collection, including the number and size of where and how data was collected, as well as the size of the sample (number of people, archival data, datasets, etc.) consulted by the authors. The use of multiple methods often implies multiple sampling strategies and approaches, and authors are not always clear in distinguishing the sampling approaches for the various methods employed. This lack of detail has been acknowledged for interdisciplinary research in climate change, for example (Nielsen and D'haen, 2014). In our sample, the articles using only literature review, being non-systematic, often did not record their sampling approach for the literature. For nine articles, it is not clear what the sample size or source is.

However, for the papers with details that indicate the scale and source of data collection, we see a wide spread of sample sizes and approaches to sampling. Sampling based on geospatial characteristics was prominent (typically administrative boundaries), and so was the use of national-level statistics. Overall, we can categorise the sampling as follows: household level (1); village-level (3); one or more protected areas (2); one or more sub-national regions (spatial and/or administrative) area (in Mexico-US, Brazil, Germany, China, and Indonesia) (5); sub-national land parcel (in one case land concessions); country statistics (exporting-importing countries) from e.g. FAO for certain commodities (fish, soy bean) (3); certain animal species (1); and literature using a certain string of words and criteria (e.g. 38 peer-reviewed papers). In the following sections, we are more explicit on the methodologies used by different authors to identify different types of impacts and to establish causality and trade-offs in telecoupled systems.

4.2. Ecological impacts

All reviewed articles describe at least one ecological impact of the studied telecoupled system, including land-use changes (e.g. deforestation, afforestation, fragmentation, intensification), or changes in soil conditions, water quality and quantity, air quality, climate, biodiversity, species dynamics, nutrient cycling or biomass changes. Most articles describe negative impacts, whereas some also refer to positive impacts. For example, Parish et al. (2018) describe that the telecoupled transatlantic wood pellet trade has many observed positive environmental effects, such as the preservation of European Union forested land and associated ecosystems or the reduction in toxic air emissions related to coal combustion. In addition, other studies refer to positive impacts such as reduced pest infestation and pollination (López-Hoffman et al., 2017), reduction in flood risks (Quan et al. 2016), or afforestation (Yang et al. 2018).

Telecoupling research assesses impacts in four different ways: (1) descriptions in other literature, (2) observations from the field, (3) quantitative measurements or estimations, and/or (4) models. First, many studies on telecoupling quote other secondary literature. Our literature review reveals that many articles on telecoupling use descriptive evidence to portray impacts, but do not conduct empirical assessments (e.g. Baumann & Kuemmerle, 2016; Gasparri & de Waroux, 2015; Liu et al., 2015; Pace & Gephart, 2017). Lenschow et al. (2016), for example, summarize the environmental implications of the interregional soybean trade by referring to secondary literature. If studies refer to environmental impacts described in other literature, it often remains unclear whether the depicted impacts are empirically established or only hypothetical. Many articles describe the potential present and future ecological impacts of a certain commodity trade in very general terms, which entails the risk of attributing the observed effects of a certain process to the telecoupling under investigation without assessing causality. For instance, Parish et al. (2018) claim that the preservation of European Union forestland and associated ecosystems is an effect of the telecoupled transatlantic wood pellet trade, without conducting any causal analysis or investigating any causal mechanisms.

Second, scholars describe impacts by referring to direct observations from the field (e.g. Andriamihaja et al., 2019; Baird & Fox, 2015; Friis & Nielsen, 2017b; Tapia-Lewin et al., 2017). Case studies that rely on field research for impact assessments often do not make causal claims about the observed impacts because they rely on descriptive qualitative statements, but do not employ rigorous methods to identify impacts. While some researchers describe the actual observed effects made during fieldwork, such as rapid landscape

changes (e.g. Baird & Fox, 2015), other researchers illustrate potential impacts based on their field research. For example, Friis and Nielsen, (2017b) show that banana cultivation in Laos can potentially lead to land and soil degradation if a banana fungus infects the plants. Likewise, Tapia-Lewin et al. (2017) describe that human gathering and trade of sandhopper has potential detrimental effect on the trophic chain by affecting the intertidal sandy beach food web and community structure.

A third group of reviewed papers identify ecological impacts on the basis of quantitative measurements or estimations. Studies may use descriptive statistical indicators to assess environmental impacts, such as Liu et al. (2015) who illustrate the environmental effects of panda loans by estimating the CO_2 emissions associated with the transportation of pandas and their feed, as well as with the travel of tourists to see the pandas. Two commonly used methods to measure environmental impacts are life cycle assessments and environmental footprints. For example, Marston and Konar (2017) calculate the virtual water footprints and water transfers from the Central Valley of California during the drought, indicating that drought may strengthen the telecoupling between groundwater withdrawal and distant consumers of agricultural commodities. Additionally, deforestation is commonly quantified using remote-sensing-based approaches (e.g. Sun, Tong, & Liu, 2017), which can be combined with participatory approaches based on workshops and field walks (Zaehringer et al., 2018).

Finally, a fourth group of studies calculate ecological impacts using modelling techniques. Examples include scenario development (e.g. Norder et al., 2017), statistical models (e.g. Fuller et al., 2018) and/or land system models (e.g. Rulli et al., 2019). Parra Paitan & Verburg (2019) present a comprehensive overview of various different models to account for the direct and indirect environmental impacts caused by agricultural production (e.g. agent-based models, system dynamics models, equilibrium models and land-use models).

In sum, we find that very few publications on telecoupling make use of rigorous causal analysis to determine ecological impacts. In addition, most telecoupling research makes no or vague assertions about the form (direct or indirect), direction (positive, negative or undetermined), duration (short, medium or long-term, temporary or permanent), reversibility (reversible or irreversible), spatial scale (local, regional, national or global) and magnitude (high, medium, low) of environmental impacts.

4.3. Social impacts

Most of the papers reviewed identify social impacts of telecoupled systems, but only four specify whether these are direct or indirect impacts. The impacts identified in the review papers are various and include both positive and negative ones. The majority of the negative impacts relate to loss of accessibility and scarcity of resources, particularly limited access to and increased competition for food (Pace et al. 2017; Friis & Nielsen 2017b) and land (Alexander et al. 2018; Andriamihaja et al. 2019; Baird & Fox 2015; Bolliat et al. 2018). Other negative impacts include changing economic conditions (Boillat et al. 2018; Cease et al. 2015; Carlson et al 2018; Baumann & Kummerle 2016), issues of justice and equity (Bolliat et al. 2018), exclusion (Boillat et al. 2018), poor management of resources (Quan et al. 2016), illegal activities (Boillat et al. 2018; Baumann & Kummerle 2016), issues of labour (Carlson et al 2018; Baird & Fox 2015), migration (Baumann & Kummerle 2016), displacement (Baird & Fox 2015) and health issues (Lenschow et al. 2016; Cease et al. 2015; Friis & Nielsen 2017b).

However, it is not only negative impacts that are identified in telecoupled research: 14 of the 27 papers identify certain positive impacts. These include improved knowledge, awareness and participation (Liu et al. 2015; Tapia-Lewin et al. 2017; Yang et al. 2018; Carlson et al. 2018) and better access to capital, labour and natural resources for certain groups (Marston & Konar 2017; Quan et al. 2016; Liu et al. 2015; Bolliat et al. 2018; Friis & Nielsen 2017b; Parish et al. 2018; Carlson et al. 2018; Bagstad et al. 2019).

In 9 out of 27 papers, literature review and use of secondary data are the main methods used to identify impacts. The second most common methodology for identifying social impacts is field research including surveys, interviews and observation (5). Also modelling (2) and choice experiments (1) are methods that have been employed in the papers reviewed. Only 5 papers refer directly to the indicators of the impacts

mentioned. These are either statistical indicators, or a referral to criteria of equity.

4.4. Economic impacts

As regards economic impacts, which we acknowledge constitute a subset of social impacts, almost two-thirds of the articles identify both positive and negative economic impacts associated with the telecoupling interaction(s) under observation, which are classified in the form of either direct or indirect impacts. Positive economic impacts identified include: job creation, increased income, investments in new technologies, and overall economic growth of regions or countries. Most of these were largely related by the authors to the social wellbeing, while some of them linked these impacts to environmental aspects as well. For example, Pezzoli et al. (2014) identified interconnectedness between socioeconomic conditions and environmental health, whilst Garrett et al. (2013) identified the incentives for environmental certifications by producers. Hence the review also revealed the interlinkages among the environmental, social and economic impacts of telecoupled interactions and processes. Among the negative impacts identified, there are detrimental effects on income and terms of trade for specific social groups. Cease et al. (2015), for example, highlight how coupled agricultural markets have, in some contexts, resulted in locust outbreaks which have in turn damaged crops, reduced productivity, farmers' income and threatened regional food supply.

In the reviewed articles, the methods to qualify and/or quantify economic impacts include: literature reviews, interviews and surveys, secondary data analysis, quantitative analysis and modelling, and field observations. Only a few studies are based on data collected through interviews or surveys to collect data (e.g. Boillat et al., 2018; Friis & Nielsen, 2017b; Baird & Fox, 2015; and Tapia-Lewin et al., 2017), while the rest of the articles are based on either literature review or secondary data. Some articles rely on mixed methods to identify economic impacts: Baird & Fox (2015) use both interviews and field observations; Boillat et al. (2018) combine a literature review with expert interviews; Friis & Nielsen (2017b) rely on both interviews and secondary data; and Baumann et al. (2016) combine a literature review with spatial data analysis.

4.5. Causality and trade-offs

Telecoupling research strives to explore how things are connected across distances. Demonstrating these connections through links of causality thus represents a key task. From the sample of 27 papers included for the early review, 14 papers deal with attribution of causality. However, they do so with very different levels of detail, methodology and analytical focus. In an early version of the codebook, we asked if the authors were attributing causality systematically. We changed the entry to 'causality attribution' to capture authors who attributed causality more argumentatively and less systematically.

By *systematically*, we understand the appliance of methods specifically directed at demonstrating links between drivers and impacts. By *argumentatively*, we mean that the authors discuss drivers and argue for causation, albeit in a less systematic and more speculative manner. In practice, the distinction is however far from straightforward. The term 'systematically' does not in itself guarantee higher level of detail or accuracy. An example is Alexander et al. (2018), where causation between global land management intensity and changes in climate and atmospheric carbon dioxide is explored through modelling and probability analysis. This approach permits to visualize and quantify broad trends in a systematic way and point to relevant study objects for future research, but it does not capture the less direct, less predictable, or more complex cause-effect relations.

A more qualitative approach is represented by Friis and Nielsen (2017b), who examine the main causes of a banana plantation expansion in Laos, and how this expansion is influenced by telecouplings. The authors map causal relations based on knowledge from interviews, fieldwork, and personal experiences. The approach is more argumentative than systematic but is based on empirical evidence and considers aspects not captured by those of the quantitative systematic approaches, such as influence from 'elusive and immaterial interactions'.

Several of the other papers were difficult to categorize as either or in terms of attributing causality. One of the reasons is that the telecoupling language strive to embed causation when framing 'drivers', 'impacts', and the influence of different 'flows' between different systems. Therefore, it can be difficult to discern when a research paper does not establish or assess causality as such but does apply a terminology and/or visualization tools to the case of study that indirectly argues for causal links; for example the reviews and flow charts presented in Pace and Gephart (2017) or Bolliat et al. (2018).

Finally, out of the 27 articles reviewed so far, 11 addressed trade-offs directly or indirectly as part of their discussions, but none of them did so systematically and through quantification. An example of a very indirect account of trade-offs is Andriamihaja et al. (2019) who discuss pros and cons in relation to how immediate positive impacts such as livelihood improvement through better access to cash crops can lead to deforestation because of expansion of cash crop cultivation. This relationship of potential trade-offs between conservation and livelihood improvement through forest use could benefit from more systematic assessment e.g. by quantifying the change in stock of different forest resources when different groups of people get access to extraction. Liu et al. (2015) address trade-offs more explicitly in relation to telecoupling by pointing out how they may offset each other. They highlight, for example, in relation to trade of agricultural and industrial products that "the decrease in the amount of plastic film used may in part be due to an over 50% reduction in an average household's agricultural land as a result of the Grain-to-Green Program. Tourism also provides a source of nonfarm income that may discourage agricultural development, and in turn, agricultural trade." (Liu et al., 2015).

It is also sometimes challenging to distinguish between trade-offs and other types of impact categories. For example, Yang et al. (2018) explore the case of a payments for ecosystem services (PES) program and argue that more deforestation will lead to more crop raiding, which in turn will lead to more off-farm activity, including tourism, which over time will lead to a potentially negative ecosystem health in the long run. These could be looked at as trade-offs but could also be considered as cascading effects. We argue here, that the terminology is not important in itself but we advocate that telecoupling research is explicit about which impacts are assessed, how the impacts are categorized and why.

5. Conclusion

Our literature review shows that current assessments of impacts, causality and trade-offs in telecoupling research have been mostly descriptive, which is in line with the findings by Carlson and colleagues (2018). The impacts observed from telecoupled systems are several, and span across ecological, economic, and social considerations. The analysis of causality in telecoupled systems is challenging because telecoupled systems are usually characterized by a decoupling of drivers and impacts, meaning that causes and effects can be spatially, temporally, institutionally and sectorally separated. This also explains why the analytical boundaries of the telecoupled system(s) are usually set at country or multi-country level, rather than taking an empirically global perspective where patterns of a given trade flow, for example soybeans, are analyzed in their full spatial complexity.

In this report, we have been able to identify a number of research challenges and gaps, which will be further qualified and explored when we conclude the review. First, we observe that telecoupling research needs to distinguish more clearly between the assessment of empirically observed or measured impacts and the assessment of the risks of the occurrence of impacts. Second, it also needs to improve the rigour of causality attribution for the different impacts identified, by for example explaining in detail what kind of data is used to establish causality, and how this data is collected, and thus give an idea of the empirical evidence and the validity of the argued causation. Our own assessment of such causation was challenging because of the many variations and level of detail in which authors dealt with impacts and at what level they were detected and assessed. Third and finally, telecoupling research has not yet considered trade-offs a central aspect of enquiry, with most analyses addressing these qualitatively rather than quantitatively and with grounded data.

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Appendices

Appendix 1: Weblink for codebook

https://docs.google.com/spreadsheets/d/1-AE2LdThqDB5-HA4_FITRd-P_Rl1Gvx-relIZ-UjWiI/edit#gid=0

Appendix 2: Review Code Procedures

Analytical focus

This refers to the main system, process, issue or research problem addressed in the article. It is usually referred to in the article's research objective, and/or the Introduction of the paper.

Research objective

This indicates the objective of the article as stated in the publication, i.e. copy-paste sentence from the research objective, usually found in Introduction/Abstract. It is necessary to have the research objective in mind before judging a certain impact focus and vice versa, focus on certain impacts in a certain way might be explained by a broader tendency in research focus.

Reference to a flow

Reference or not to a "flow" in the studied system, process, issue, or problem addressed in the article. The flow can be explicitly defined by the authors in the paper, or interpreted by the reviewer based on the paper contents.

Countries of analytical focus

These columns list the countries which are directly or indirectly part of the paper's analysis, as they are relevant for the studied system, process, issue, or research problem. These countries are usually found in the Introduction and Methods sections, or in the Results when the findings are presented. When papers refer to multiple countries that are affected by specific telecouplings, but these are not part of the analysis, i.e. they are only mentioned using secondary data or the like, should not be listed in these columns.

Analytical scale

This refers to the geographies of the authors' empirical engagement, i.e. where they conduct their empirical research or what is the geographical scope of the data they use in their article.

We have defined 5 categories: local, sub-national, national, regional (more than one country from a larger region/continent, e.g. Asia), and global (from multiple countries from around the world). This information can be directly found in the Introduction and/or Methods section, and it can also be interpreted by the reviewer. For example, an article that involves interviews at community, regional and federal levels to understand sugarcane trade in a given country would be classified here as "national". An article that looks at a given global teleconnection relying on global datasets would be classified as "global".

Data type

This refers to the type of data collected by the authors to write their article. We have identified four broad categories: qualitative, quantitative, spatial, and mixed (if the former are somewhat combined). Surveys designed to collect only quantitative data have been considered a quantitative approach, and when used to

collect both qualitative and quantitative data have been considered a mixed approach.

Number of methods

This refers to the plurality of methods used by the author(s) in the article. We have identified two broad categories: multiple, if the author(s) use more than one method, and single if they only use one.

Methods

These columns specifically describe each of the methods used in the article.

Sample size

This refers to the specific details of the data collection methods, specifically regarding the number of locations where research has been conducted and the number of people, archival data, datasets, etc. the authors have liaised with to write the article.

Theoretical framework or conceptual lenses

This refers to the main concepts, frameworks, theories used to frame the research, if any.

For example, an article might be using Liu et al's telecoupling framework, while another might be using value chain analysis or more broadly concepts like Coupled Human and Natural Systems. This information is usually present in the Introduction or in a dedicated theoretical section, and this column should describe here the theoretical approach highlighting the principal theoretical framework or concepts used.

Terminology for impacts

This refers to the term(s) used by the author(s) to qualify the impacts directly or indirectly resulting from the system, process or issue being studied. These can include terms like "impact, outcome, effect, consequence, etc."

Impacts (ecological, social, economic)

This refers to the impacts in these three domains as identified by the author(s). These columns should list the identified impacts, with the correspondent qualifications, e.g. increased soil erosion, enhanced knowledge, or reduced income. This information is usually found in the Results and Discussion sections of the article.

Types of impacts

This refers to the qualification of the impact by the author(s) in relation to how tightly connected such impact is to the system, process or issue being analysed, i.e. how strong the relation of causality actually is. We can distinguish here between direct and indirect impacts, between first and second order impacts, etc. If the author(s) do not make such distinction, the column can be left blank. This distinction between impacts of different kinds might not be made, or might be noted somewhere in the manuscript, more likely in the Introduction, Results and/or Discussion section(s).

Methods and indicators

This refers to the author(s) employed methods to qualify the identified impacts, and the indicators used for such qualification (if any).

Causality attribution

This refers to whether the author(s) establish a direct causality relationship between the system, process or issue being studied and a specific impact. For example, this should indicate if the author(s) attribute certain level of income change to a specific land-use change process being studied. If so, this column should also indicate how such attribution is made.

Trade-offs analysis

This refers to whether the author(s) analyse trade-offs of some kind, between processes, impacts, or the like. For example, a paper might note that increased land-use change has driven increased local income, at the expense of local forest cover, whilst reducing deforestation elsewhere through market-based interactions. Trade-offs should be identified and described in this column.

Institutions

This refers to whether the author(s) include institutions -in the more general sense of the term, i.e. both formal and informal rule-making, government, policy and the like- as part of their understanding of a telecoupled system, or as part of their analysis. If so, this column should indicate in which way institutions are part of the analysis.

Review notes

This column can include any reflection of the reviewer about the paper that might be relevant for the purpose of the review.

Author(s) understanding of telecoupling

This column can include a reflection of the reviewer about how author(s) seem to understand telecoupling(s), teleconnections, or the like in the reviewed paper.