COUPLED

OPERATIONALISING TELECOUPLINGS FOR SOLVING SUSTAINABILITY CHALLENGES FOR LAND USE

Deliverable D5.2

Methods to analyze trade-offs

Report on the outcomes of VMS 6 (trade-offs)

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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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Role of this deliverable in the wider COUPLED research strategy

Within its wider research strategy, COUPLED seeks to explore three overarching, interrelated research questions:

1. Processes: How inter-dependent are land and resource systems in today's world, and what are new or unexpected actors and processes creating the telecouplings that produce these dependencies?

2. Distance: How is sustainability governance of land use and land-based products affected by differences in the type of linkages and telecouplings and the scale at which they operate?

3. Impacts: Which enabling conditions are required to generate opportunities for a more sustainable allocation of resources in a telecoupled world?

COUPLED addresses these three questions in three Work Packages (WPs) that relate to one research question each: WP 3 Processes, WP 4 Distance, and WP 5 Impacts. These WPs generate knowledge, via the individual PhD projects of Early Stage Researchers (ESRs) as well as various synthesis activities, that then flow into the WP Synthesis. Thus, all WPs provide a platform for collaborative, comparative and cross-sectoral research. Concretely, WP 3 enables ESRs 1-5 to understand which kinds of processes and flows characterise telecoupled land systems and explore methods such as commodity chain analysis, material and energy flow analysis, and qualitative following techniques in order to identify and measure flows, to recognise and categorise actors, and to capture different types of spill-over flows. WP 4 focuses on the role of spatial and temporal distance in telecouplings. ESRs 6-10 explore sending, receiving and spill-over systems by focusing on how to methodologically and conceptually define system boundaries and distance in telecoupled systems. Specifically, the ESRs will explore how to establish a unit of analysis and a workable definition of distance, how to incorporate insights from the social and natural sciences, and how to develop methodologies for measuring the strength and direction of flows across institutional, governance, social, and Euclidian distances. This will enable these ESRs to assess mismatches in flows between systems, providing entry points for policy interventions. In WP 5 ESRs 11-15 qualify and assess systemic couplings in terms of their impacts. Using methods such as participant observation, remote sensing, supply chain analysis, and policy charting over distance, these ESRs explore causal relations, such as whether or not an observed land-use impact is the result of a particular telecoupling. Understanding actual outcomes of telecouplings enables these ESRs to identify winners and losers of specific couplings, facilitating governance discussions regarding how to mitigate trade-offs and how to allocate resources and impacts more justly.

Virtual Meeting Series are a central tool in WPs 3 to 5 to enable discussions, knowledge consolidation and synthesis across the individual ESR projects. This deliverable 5.2 documents the outcomes of the second Virtual Meeting Series (VMS6) within work package 5 IMPACTS which reviewed the trade-offs and synergies between targets humans are seeking from land systems. Moreover, VMS 6 defined a conceptual framework, reviewed existing methods and discussed a case study to analyse how existing trade-offs analysis should be extended to telecoupled processes.

Executive Summary

Land systems and their management are crucial for the satisfaction of basic needs and also for achieving wider objectives set by societies. These include improvements in human well-being, economic development, food production, as well as nature conservation or carbon storage, and may take the form of politically agreed targets, such as the 1.5 to 2°C of the Paris agreement, the sustainable development goals, or the Aichi conservation targets. These targets are subject to systemic effects such as trade-offs and synergies: pursuing one target may indeed either enhance or hamper the achievement of other targets.

Research on trade-offs and synergies has already reached a certain maturity. Nevertheless, existing studies have mostly focussed on trade-offs and synergies occurring within a given place, or system. The growing literature on telecouplings highlights the relationships between human and natural systems across large distances, through trade, flows of information, capital, or people. The telecoupling framework posits that these distal links need to be considered for comprehensively assessing the sustainability of land use. The telecoupling framework has also stimulated the scientific community to engage further with complexity and global interconnectedness when analysing the drivers, processes and consequences of land use and land-use change, including trade-offs.

The telecoupling framework, therefore, suggests that pursuing targets in one system may not only enhance or hamper the achievement of other targets in that same system, but in other systems as well; these may potentially be very remote. This deliverable explores the need for further scientific endeavour to understand trade-offs and synergies between distant land systems. We first define a framework which enables the analysis of trade-offs and synergies between distant systems and discuss its relevance for telecoupling research. We then explain how existing methods can be extended to analyse trade-offs and synergies across scales and illustrate our argument with a case study about trade-offs and synergies in biodiversity conservation and global environmental governance. This deliverable is meant to encourage future research about impacts on land systems to include potential trade-offs and synergies occurring across large distances.

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1 Introduction

All types of land use generate multidimensional impacts which may be environmental, social, economic or cultural. Improved trade relationships, information flows and communication channels have brought together distant places across the world in an unprecedented manner. Whilst countless benefits are derived, a variety of challenges can be observed, resulting from the increased complexity of global networks. These evolve quickly through time, creating different cause-effect pathways that can multiply unforeseen direct and indirect impacts on other actors, systems, flows or places in positive (synergies) or negative (trade-offs) ways. Identifying the total set of impacts caused by any action is difficult as many direct and indirect trade-offs and synergies can arise at multiple times and locations. Nevertheless, to achieve sustainability in all its dimensions it is necessary to have a deep understanding of the potential outcomes of the actions to maximize potential synergies and minimize trade-offs, in a world where human exchanges between distant places (telecouplings) are becoming the norm rather than the exception. We refer to the telecoupling framework to theoretically contextualize the rise of multiple causal pathways of impact when two or more geographically distant systems exchange flows due to defined causes (Liu et al., 2013).

Trade-offs and synergies have been extensively studied in various fields related to sustainability, such as corporate social responsibility (Hahn, Figge, Pinkse, & Preuss, 2010), ecosystem services (Cavender-Bares, Polasky, King, & Balvanera, 2015), and more recently, in relation to the goals of the 2030 Agenda for the Sustainable Development Goals (SDGs) (Weitz, Carlsen, Nilsson, & Skånberg, 2018). The study of trade-offs and synergies applies different perspectives according to their foreseen applicability, for instance, trade-offs and synergies of goals vs. outcomes or profit vs. sustainability, trade-offs and synergies across time or different sectors or stakeholder groups. Whilst various classifications of trade-offs and synergies are proposed, they do not offer the possibility of analyzing trade-offs in telecoupled systems that interact across multiple geographic locations and temporal scales. Extending analysis of trade-offs to telecoupled systems is urgently needed due to the pace and number of global trade and societal exchanges with current and foreseeable consequences that threaten the wellbeing of nature and people.

The goal of this report is to provide initial ideas that contribute to the extension of existing analytical frameworks of trade-offs to one that can be applied to telecoupled systems. To do this, we first conducted a targeted review of existing studies on trade-offs in different disciplines related to sustainability. Building from the existing narratives, we suggested a preliminary conceptualization of the currently available frameworks for telecoupling research. Subsequently, we selected and described the most suitable tools that could allow for analysis of trade-offs within telecoupling systems. We then illustrated the application of telecoupling framework to analyzing trade-offs in biodiversity conservation and more broadly in global environmental governance. Finally, we discussed the challenges and limitations of applying existing trade-offs analytical tools to telecoupling systems.

2 Methodology

We gathered some literature based on ESRs expertise, literature search and snowballing. The chosen articles had to either contribute to the conceptual development of trade-offs and synergies in sustainability science, explain methods to analyze trade-offs and synergies, or be applications in the field of land-use science. Although our sources have not been selected systematically, they provide insights into what is commonly done to study trade-offs and synergies. An overview of the reviewed literature can be found in the appendix.

We hence reviewed a bundle of articles in the fields of economics, ecology and land system science literature. We coded the results according to the topic, the type of trade-offs analyzed, the temporal and geographical scale, and the method used. These observations framed our discussions on which changes in concepts and methods should be made to analyze trade-offs and synergies in telecoupled systems. We finally illustrated our ideas for the case of telecoupled trade-offs and synergies related to biodiversity conservation.

3 Results

3.1 Findings from the reviewed literature

Reviewing the literature, we found that despite focussing on different scales (local to global, different time periods), no study analyzed the trade-offs and synergies across these scales, for example between two different locations (e.g. different countries), years (e.g. trade-offs between current and future generations), or actors (e.g. between investors and local communities). Studies often focused on the landscape scale in a given year (Nelson et al., 2009). A few studies mentioned the spatial scale of trade-offs and synergies in their theoretical concepts (Rodríguez et al., 2006), but they rarely referred to trade-offs and synergies between distant locations. The only concrete example of trade-offs and synergies across space was the positive externalities of agro-ecology to the neighbouring farmers through more pollination (Power, 2010). This neglects trade-offs and synergies between distant actors and systems, or between present and future generations. We argue that this omittance is first due to a vague conceptualization of targets, a missing telecoupling perspective, and lagging methods to analyze trade-offs and synergies across scales.

3.2 Towards a concept of trade-offs and synergies across scales

It is vital to sketch an appropriate conceptualization of trade-offs and synergies, which takes into account processes at different spatial and temporal scales. The way we identify and frame problems, define goals and predict their mutual interactions with one another (e.g. inhibiting or enhancing) will eventually determine whether we will be able to solve any of the underlying problems. This observation is important, since maintaining a rather superficial approach to possible trade-offs is likely to favour cosmetic interventions over more structural transformations (Hornborg, 2009). To conceptualize trade-offs arising from decisions made about land-use systems, we have to acknowledge that due to their characteristics as complex socio-ecological systems, there will be non-linear interactions and emergent features, apparent when observed through a trans-disciplinary perspective.

A notable observation from reviewing the literature is that trade-offs are conceptualized as inherent to different stages of formulating and implementing solutions, depending on which approach to follow. According to Deng, Li, and Gibson (2016), trade-offs (in the realm of ecosystem services) occur when “human interventions enhance the output of an ecosystem service while negatively affecting the provision of other services”. Accordingly, Gill et al. (2019) base their analysis of trade-offs in conservation impacts on the outcomes from specific interventions. However, some conceptualizations rather place potential trade-offs at an earlier stage of the schematic: at the level of the formulation of goals or targets. For example, Weitz et al. (2018) analyze trade-offs as inherent features between individual SDG targets, independent of the type of intervention implemented. Taking a stance between these two approaches, one could conceptualize trade-offs as being potentially inherent in different targets to varying degrees, but only manifesting themselves and becoming observable through specific interventions.

While certain narratives at times debate trade-offs in terms of entire dimensions (e.g. nature conservation vs. social well-being), these mono-consequentialist imaginaries fail to account for complex interactions between individual targets or goals (Gill et al. 2019). Further, trade-offs may occur between different domains and goals, but also (simultaneously or exclusively) between different scales (e.g. temporal and spatial), at different magnitudes or levels (e.g. as shades between the trade-off vs. synergy binary) (Gill et al., 2019; Weitz et al., 2018; Deng, Li, and Gibson, 2016).

To accommodate the proposals from these various contributions, we suggest the following integrated conceptualization, aimed at providing a unifying terminology. We propose that trade-offs and synergies can occur between different targets. Targets belong to a specific domain (e.g. “no poverty” in the SDGs), follow a certain goal (e.g. reduce extreme poverty) to a certain extent (e.g. to zero) in a certain time-frame (e.g. by 2030) at a given spatial level of organization (e.g. globally) and potentially with explicit reference to certain groups or communities (e.g. for all people).

Trade-offs and synergies hence refer to the relationship between one or several targets. In this way, a target is sufficiently determined, so that a trade-off or synergy cannot occur for one and the same target, but only between different targets, which may or may not belong to the same domain or to the same goal (e.g. when referring to different territorial units). Such a specific definition of a target is indeed needed to allow for trade-offs and synergies across different scales. For example, the relation between one goal in a given country and the same goal in another country can just be defined as a trade-off or synergy if the two are considered as distinct targets. The same holds for different actors or time periods (*Figure 2*).

This conceptualization allows us to identify the relevance of telecoupling research in providing a framework to identify and analyze those trade-offs that occur between targets, which do not share the same spatial level of organization. This may refer to two different targets based on the same goal (e.g. reducing deforestation in Brazil and in China) or to different goals (reducing emissions in Europe and increasing food security in South-East Asia). Further, rather than a binary distinction between trade-offs and synergy, we suggest to apply a more nuanced scale of types of interactions between different targets, such as the one originally proposed by Nilsson, Griggs, and Visbeck (2016) for the SDGs and detailed in *Figure 1*.

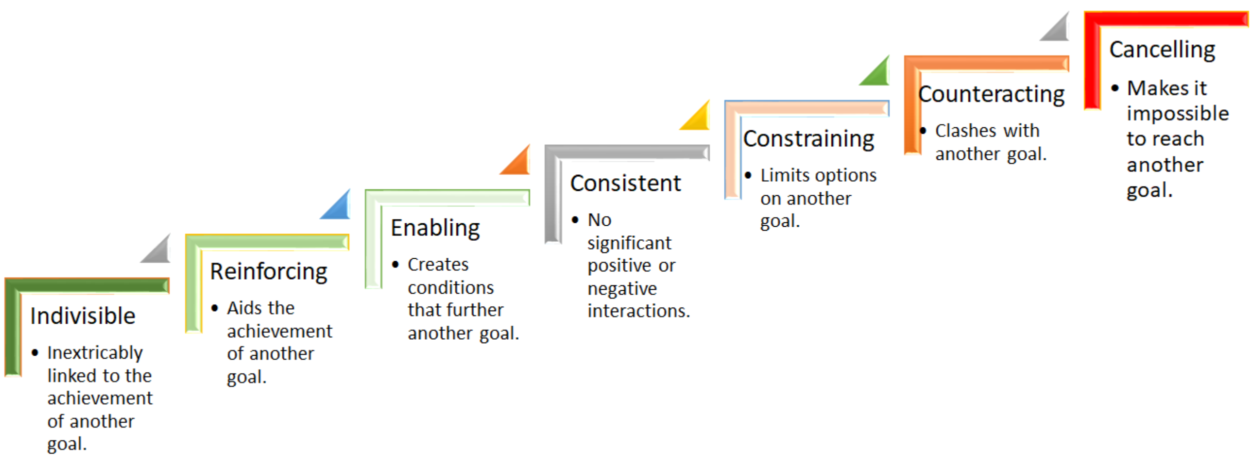

Figure 1. Types of interactions between different targets (from Nilsson, Griggs, and Visbeck, 2016)

3.3 A telecoupling lens upon trade-offs and synergies

The telecoupling framework identifies five elements for the study of socio-ecological systems: systems, agents, causes, impacts and flows. Telecoupled systems are composed of at least one sending and receiving system, which are operated by agents that exchange specific flows (e.g. materials, energy, ideas, information, etc.) under certain motivations (causes) that lead to certain intended consequences (impacts). Unintended consequences can occur (spillovers) over systems that are not directly involved in the original exchange (spillover systems) (Liu et al., 2013).

The telecoupling framework highlights the importance of the complex interconnectedness emerging between systems across temporal and geographic scales. Consequently, it argues that sustainability can only be achieved in all its dimensions when the geographically distant impacts are recognized and mitigated across scales.

Due to the extent of global interactions, many geographically distant systems are directly or indirectly telecoupled, whether this connection is explicitly acknowledged or not. These connections might be purposefully or un-purposefully created, but its identification is a first vital step to identify what trade-offs and synergies arise from those interactions. One could guide the identification of potential elements based on the general components of a telecoupled system as described by the telecoupled framework (Liu et al., 2013): systems, agents, causes, impacts and flows (*Table 1*).

Table 1. Elements in Telecoupling Framework relevant to trade-off/synergies analysis

Trade-off/synergies concept framework	**Telecoupling Framework elements**
Domain	Impacts (causes, flows, spillovers)
Goal	
Extent	
Timeframe	Dynamic
Spatial level	Systems
Certain groups or communities	Agents

Guiding questions might include: What are the actors that might be impacted by decisions taken in the system of study? Are the agents in my system exchanging any type of flow with other systems too? Which other systems depend on the dynamics occurring in my system(s) of study? Which sectors might be indirectly affected by the decisions taken in my system(s) of study?

This exercise causes the expansion of the system boundaries initially considered in traditional studies (Liu et al., 2013). By applying the telecoupling framework we acknowledge that it is virtually impossible to isolate the impacts of actions in an increasingly interconnected world. The more one expands the boundaries of a system, the more indirectly linked systems and unintended consequences (spillovers) will be detected. This systemic approach could end up in an endless expansion of system boundaries that, due to limited resources available, may be unfeasible. However, it is the only way to include a more complete spectrum of impacts and identify the complete set of drivers playing in the system or dynamic under study.

It is important to highlight that there are multiple enabling factors facilitating the creation of telecoupled systems. Two geographically distant places have different levels of proximity depending on their similarity and connectedness in the environmental, social, institutional or economic dimensions. As a consequence, the identification of trade-offs and synergies between telecoupled systems needs first the identification of potential telecoupled elements (actors, impacts, causes, flows and other systems) as explained above, which in turn needs a multidimensional analytical approach to be conducted (environmental, social, institutional or economic).

The study of trade-offs and synergies in the telecoupling framework has been somehow included in the analysis of spillover systems and leakage effects (Liu et al., 2018). The latter are negative unintended consequences that affect systems that are indirectly linked to the original sending and receiving systems. The study of spillovers in the telecoupling framework inherently incorporates the notion of geographic and temporal distances but it could benefit from the large body of literature developed to analyze trade-offs and synergies in other disciplines. Therefore, in this report, we recommend complementing the diverse methodologies to analyze trade-offs with the telecoupling perspective by identifying the telecoupling elements that might be interacting with the original system of study but might be geographically disconnected. In the following section, we detail the methods and tools that can be used together with the telecoupling framework to perform a holistic analysis of trade-offs and synergies across scales (*Figure 2*).

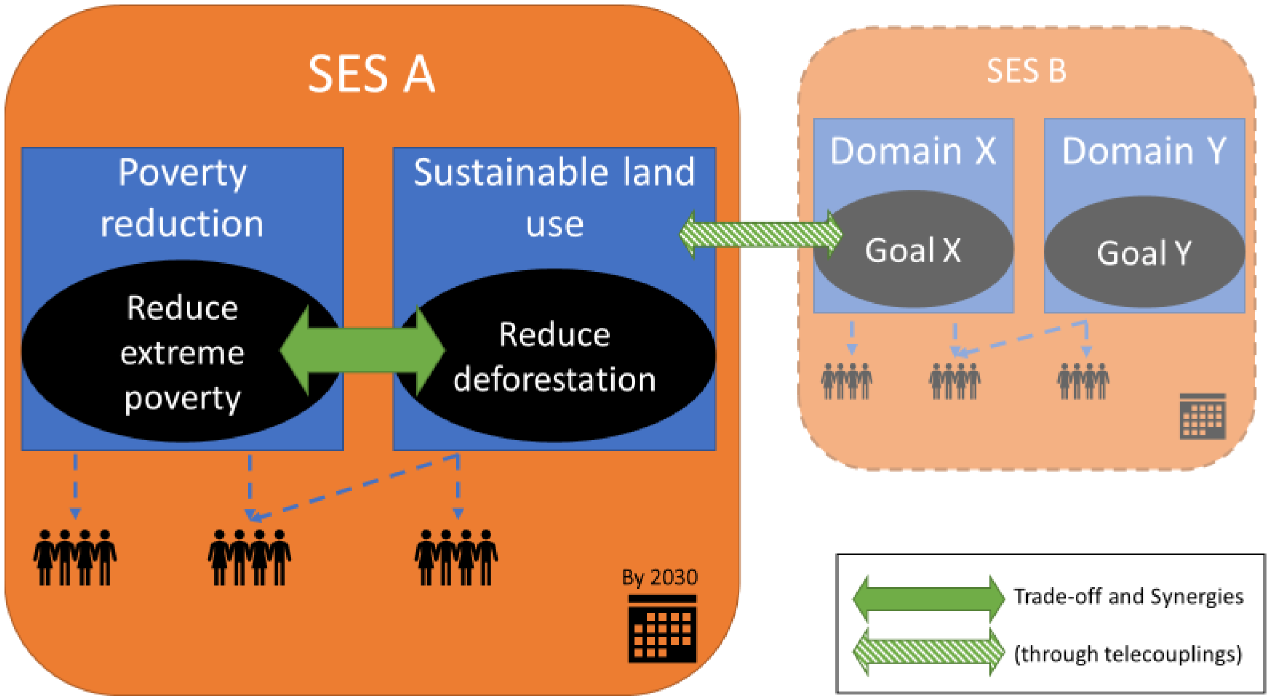

Figure 2: Trade-off/Synergies concept framework through telecoupling lens: In order to define trade-offs and synergies across scales, targets must be fully defined by their domain, goal, extent, time-frame, spatial level, and affected community. Trade-off and synergies are often analyzed between different goals in the same Social-Ecological System (SES). Applying telecouping lens helps to reveal the trade-off between goals/outcomes between telecoupled SESs.

3.4 Methods/Tools to analyse trade-offs and synergies

Many methods originating from different academic disciplines have been developed to explicitly quantify trade-offs in socio-economic and ecological systems (Deng et al, 2016). Although many of these methods are well suited to analyze trade-offs at either a local or global scale, very few are able to capture socioeconomic and environmental interactions occurring at multiple geographical and temporal scales. Recent years have, however, witnessed an increased interest in methods able to analyze such telecoupled effects (Parra Paitan and Verburg, 2019). In the case of trade-offs, these methods can be broadly classified into integrated assessment models, multi-criteria analyses, efficiency frontier methods, and spatial econometric analyses. Below, we give a brief description of these four different approaches, their pros and cons, and we provide examples of how they could be applied in telecoupling research. An overview of all approaches can be found in *Table 2*.

Multi-scale, multi-model approaches

Multi-scale, multi-model approaches are characterized by large computational-intensive models linking local pixel-based models that capture local processes with regional or global socio-economic models that capture underlying processes defined at larger scales. The rationale for adopting such a stepwise modelling approach is that interactions between socioeconomic and environmental systems typically occur at multiple scales, meaning they cannot be accurately explained by a single model (Verburg et al., 2008). By using the output of a global model as input for a local model, these models are deemed to better describe trade-offs relevant to telecoupling research. A recent example is Johnson et al. (2020), who linked the results of a Computable General Equilibrium model (e.g. GTAP) with a spatially explicit ecosystem model (InVEST) to analyse trade-offs between different global policy-scenarios in terms of their resulting economic prosperity and environmental degradation. The benefit of this approach is that it provides a well-developed framework to account for effects occurring at multiple scales. A drawback of this approach is that these models are usually very data-intensive, requiring datasets that are not always available, or exceeding computational limitations. Another potential drawback of these models is that they are based on assumptions (e.g. households maximizing utility) that do not necessarily reflect observed behaviour.

Multi-criteria decision analyses

Multi-criteria decision analyses (MCDA) compare alternative courses of action in terms of their costs and benefits to rank policy alternatives across multiple dimensions (Huang et al., 2011). To do so, MCDA approaches typically assign weights to pre-defined criteria (although alternative approaches exist that respect the incommensurability of different criteria). For example, Fontana et al. (2013) compared three land-use alternatives in the central Alps based on a range of weighted criteria indicators. This approach could be appropriate for telecoupling research to weigh the outcomes of a certain outcome across multiple scales, dimensions and time horizons. The benefit of such an approach is that it is very transparent in how different indicators are weighted against each other, making it a highly suitable approach for policymakers. The downside is that the assignment of weights is typically based on subjective arguments, which could lead to very contentious outcomes.

Efficiency frontier methods

Efficiency frontier methods are based on economic production theory and are well-equipped to analyse trade-offs between different targets, given a certain optimization function and the limited amount of inputs (Deng et al., 2016). The efficiency frontier also demonstrates the degree of inefficiency of outcomes, thus providing insights into how inputs can be optimally allocated. These methods have often been applied in a telecoupling context as they can be used to analyse the efficiency of different land-use patterns across different scales (Polasky et al., 2008). A benefit of this approach in the context of analysing trade-offs in telecoupling research is that it is well suited to identify the most efficient allocation of inputs, even if these inputs are not defined at the same scale. A downside is that the production frontier is often subject to deep uncertainty, especially when analysing trade-offs relevant at local scales.

Spatial econometric analysis

Spatial econometric analysis builds on conventional econometric analysis by incorporating state-of-the-world regression models with spatially lagged (in-)dependent variables. Such regression methods typically rely on a pre-defined spatial weight matrix that describes the interconnections between the different units of analysis. The main advantage of this approach is that spatial spillovers can be explicitly measured, meaning this type of analysis is well-suited for analysing spatial trade-offs. As an example, Arima et al. (2011) used this approach to link the expansion of mechanized agriculture in Brazil to pasture conversions on distant, forest frontiers. A drawback of this approach is that it requires prior knowledge of the appropriate spatial weight matrices, which are often defined arbitrarily.

Table 2: Examples of approaches to analyze trade-offs

Approach	Example	Pro	Con
Multi-scale, multi-model approaches	Johnson et al (2020)	Well-equipped to account for effects occurring at multiple scales	Very data intensive

Multi-criteria decision analyses	Fontana et al. (2013)	Very transparent in how different indicators are weighted against each other	Assignment of weights is typically based on subjective arguments
Efficiency frontier methods	Polasky et al. (2008)	Well suited to identify the most efficient allocation of inputs	Subject to large uncertainty, especially when analysing trade-offs relevant at local scales
Spatial econometric analysis	Arima et al. (2011)	Spatial spillover effects can be explicitly measured	Requires prior knowledge on the appropriate spatial weight matrices

3.5 Applying telecoupling framework to trade-off analyses for biodiversity conservation and global environmental governances

Center of conservation planning and investment decision-making is analyzing the trade-offs and synergies, mostly within the domain of biodiversity, ecosystem services, and economic development under certain conditions (Lee and Lautenbach, 2016; Ruijs et al., 2013; Deng, Li, and Gibson, 2016; Xu et al., 2017). However, the spill-over effects were mostly only considered within neighboring areas (Power, 2010). Meanwhile, within the telecoupling research, several works discussed the impact of international trade flows on conservation outcomes (Carrasco et al., 2017; Chaudhary and Kastner, 2016; Lenzen et al., 2012), yet the trade-off and synergies of such conservation outcomes between these distal systems remain to be fully discussed. Combining these two frameworks can hence help identify and measure the tradeoffs and synergies between conservation targets/outcomes in distal systems and for groups of communities.

By applying the lens of telecoupling on forest conservation efforts, for instance, Dou et al. (2019) suggested that the conservation of forest in the Amazonia may be at the cost of accelerated deforestation in other biomes (e.g., Cerrado) under similar threats (e.g., expansion of soy and beef production). At global level, similarly, successful reduction of deforestation in many developed countries can be attributed to imported commodities leading to increased deforestation in the sourcing countries (Pendrill et al., 2019), suggesting forest conservation efforts in developed countries may be at the cost of habitat loss elsewhere. Specifically, as telecoupling research has identified the link of land use and land cover (LULC) changes between systems (Pendrill et al., 2019), such information can inform the analysis of trade-offs and synergies related to biodiversity and ecosystem services in telecoupled systems.

Including telecoupling aspects in trade-off analysis can also better reflect the heterogeneity of nature and society. Traditional trade-off analysis builts on the fundamental assumption of replaceability – that it does not matter where one ton of carbon is emitted or one ton of soy is produced. However, one species extinct here often cannot be substituted by another species conserved somewhere else, nor will the economic loss of one local community be compensated by the gain of another community somewhere else. By identifying the agents and members of the specified social-ecological systems, the telecoupling framework helps reveal the winners and losers of conservation decisions and actions beyond location differences.

As we move beyond the debates between conservation and development and gradually reach the consensus of conserving the world's biodiversity and ecosystems, decision-making requires an improved understanding of trade-offs/synergies between conservation targets/outcomes within the same domain but different places and communities. International conservation investments and plans themselves can be the flows that enable and respond to telecouplings (Boillat, 2018; Kuemmerle, 2019). Domestic and regional conservation policies may also have impacts on conservation in distal systems. A recent example is that the conservation and sustainability targets in the EU may have perverse outcomes for tropical forests and the inhabitants (Fuchs et al., 2020). Integrating the telecoupling lens and traditional trade-off analyses may be a way forward in achieving a more equal and just distribution of burdens and benefits of conservation.

More broadly, considering telecouplings when studying trade-offs and synergies is essential for the achievement of environmental justice. Trade-offs between geographically or culturally distant actors may indeed not be revealed and dealt with equitably, if the rights of one of the parties are not recognized or if they cannot participate in decision-making processes because of the distance (Boillat et al., 2020; Corbera et al., 2019).

Recognizing these telecoupled trade-offs and synergies is hence essential for the governance of global land systems (Challies, Newig, and Lenschow, 2019; Lenschow, Newig, and Challies, 2016; Oberlack, Sebastien, and Heinimann, 2018; Liu et al., 2018). For example, some global policies targeting the development of infrastructure to enhance export-oriented agriculture in the Global South may enhance trade-offs between local needs and foreign demand for agricultural commodities (Hanspach et al., 2017). Newig et al. define three types of governance affecting telecouplings (Newig et al., 2019): governance inducing telecouplings, governance coordinating telecoupled flows, and governance directing telecouplings towards sustainability. Stakeholders involved in “governance inducing telecouplings” need to be aware of the trade-offs generated between all involved systems. For example, EU biofuels directives need to make sure they take into account the trade-offs and synergies between cheaper biofuels for European refineries, and socio-ecological impacts in producing countries as Indonesia. Stakeholders involved in “governance coordinating telecoupled flows” should make sure all actors along a telecoupled network have the same power to participate in decision processes. This may include roundtables and discussions between all actors of an international supply chain, as suppliers, retailers or consumer associations, to mitigate trade-offs between the goals of these different actors. Stakeholders involved in “governance directing telecouplings towards sustainability” should as well recognize the needs of all actors potentially affected. For example, participatory approaches with local communities should be considered when a foreign donor wants to implement a conservation area, to mitigate potential trade-offs and enhance synergies between the goal pursued by the donor and the local communities.

4 Discussion and conclusions

We found that although the reviewed literature has already revealed various trade-offs and synergies between goals, most of the existing studies failed in accounting for trade-offs and synergies across geographic and temporal scales. Indeed, most of them studied trade-offs and synergies between different domains (e.g. poverty reduction and biodiversity) in a given location (or pixel) at a given time. However, we argue that trade-offs and synergies can as well occur for the same domain but between two different and potentially distant locations, communities or points in time, which we here referred to as scales. Recent conceptual frameworks started including different scales of trade-offs and synergies. Nevertheless, their empirical applicability is still lagging. Therefore, we discussed how the recent developments in telecoupling research could help better understand trade-offs and synergies across scales.

We first built upon existing concepts to define a concept that can be applied to telecoupled trade-offs and synergies. We found that some existing concepts defined trade-offs and synergies as inherent to specific targets, while others defined it concerning a given intervention. We argued that in order to define trade-offs and synergies across scales, we needed to adopt a very sharp definition of a target, which should be specific to a given domain, goal, location, time, and actors. If not fully defined, for example, if the target is solely vaguely defined by a domain (e.g. poverty reduction), one might miss potential trade-offs and synergies across one of these scales. For example, researchers may overlook important trade-offs and synergies between producers in an exporting country and consumers in an importing country, between donors of conservation funds in western countries and local producers in developing countries, between various stakeholders along a global supply chain, between poverty reduction in one community to the expense of another community, or between welfare in one generation to the expense of future generations.

The telecoupling lens can improve existing work, by including trade-offs and synergies affecting distant systems, time periods, and actors. The telecoupling framework is indeed an attempt to upscale the system boundaries (Friis and Nielsen, 2017) and to consider spillovers on tierce systems (Liu et al., 2018) to analyse the relationship between targets across scales. Another input of the telecoupling literature is that researchers should not only consider trade-offs and synergies separated by geographical distance, but as well by cultural, institutional, economic, environmental, social distance as explained by COUPLED Work Package 4. For example, trade-offs between socially distant actors may include costs and benefits endured by investors, middlemen and agricultural workers in a given cash crop plantation (Friis and Nielsen, 2017).

Not all methods used in conventional trade-off analysis can directly be applied to study trade-offs and synergies across scales. However, we identified how these methods have already been improved to allow for telecoupled impacts. Nevertheless, further research is needed to develop new methods able to detect and analyse telecoupled trade-offs and synergies.

Finally, researchers dealing with telecouplings should not only attempt to reveal trade-offs and synergies between distant systems, but as well find just solutions to govern these telecoupled trade-offs and synergies. Especially, research should focus on how to mitigate trade-offs and foster synergies (Hanspach et al., 2017). For example, at the local scale, some agricultural landscapes as mixed crop-livestock farming are able to mitigate trade-offs between harvest and environmental properties (Tilman et al., 2002; Billen, Le Noë, and Garnier, 2018). Trade-offs between local needs and global demands for agriculture commodities can as well be mitigated through education and the support of local grassroots smallholder initiatives (Hanspach et al., 2017). Trade-offs can finally be mitigated by supporting a shift of activities towards regions where trade-offs are lowest and synergies highest. For example, agriculture production could be supported where the trade-offs between production and carbon storage, biodiversity or water quality are the least important (Johnson et al., 2014; West et al., 2010). Nevertheless, much work is still needed to better understand how to govern and mitigate trade-offs and foster synergies occurring across distant places, actors and generations.

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Annex

Table S1: Overview of the reviewed literature

Article citation (APA style please)	Type of article: Conceptual or methodological or case study	Method used or discussed	Domains analyzed
Weitz, N., Carlsen, H., Nilsson, M., & Skånberg, K. (2018). Towards systemic and contextual priority setting for implementing the 2030 agenda. *Sustainability Science*, *13*(2), 531–548. https://doi.org/10.1007/s11625-017-0470-0	methodological		i.e. economic vs environtmental
Hahn, T., Figge, F., Pinkse, J., & Preuss, L. (2010). Trade-offs in corporate sustainability: you can't have your cake and eat it. Business Strategy and the Environment, 19(4), 217–229. https://doi.org/10.1002/bse.674	methodological		
Delmas, M., & Blass, V. D. (2010). Measuring corporate environmental performance: the trade-offs of sustainability ratings. Business Strategy and the Environment, 19(4), 245–260. https://doi.org/10.1002/bse.676	methodological		
Cavender-Bares, J., Polasky, S., King, E., & Balvanera, P. (2015). A sustainability framework for assessing trade-offs in ecosystem services. Ecology and Society, 20(1). https://doi.org/10.5751/ES-06917-200117	methodological		
Angus-Leppan, T., Benn, S., & Young, L. (2010). A sensemaking approach to trade-offs and synergies between human and ecological elements of corporate sustainability. Business Strategy and the Environment, 19(4), n/a-n/a. https://doi.org/10.1002/bse.675	case study		
Smith, P., Calvin, K., Nkem, J., Campbell, D., Cherubini, F., Grassi, G., Korotkov, V., Hoang, A.L., Lwasa, S., McElwee, P., Nkonya, E., Saigusa, N., Soussana, J.-F., Taboada, M.A.,	systematic review		climate mitigation, climate adaptation, food, degradation and desertification

Manning, F., Nampanzira, D., Arias-Navarro, C., Vizzarri, M., House, J., Roe, S., Cowie, A., Rounsevell, M., Arneth, A., n.d. Which practices co-deliver food security, climate change mitigation and adaptation, and combat land-degradation and desertification? Global Change Biology n/a. https://doi.org/10.1111/gcb.14878			
Gill, D.A., Cheng, S.H., Glew, L., Aigner, E., Bennett, N.J., Mascia, M.B., 2019. Social Synergies, Tradeoffs, and Equity in Marine Conservation Impacts. Annual Review of Environment and Resources 44, 347–372. https://doi.org/10.1146/annurev-environ-110718-032344	conceptual		
Cabral, R.B., Halpern, B.S., Costello, C., Gaines, S.D., 2016. Unexpected Management Choices When Accounting for Uncertainty in Ecosystem Service Tradeoff Analyses. Conservation Letters 10, 422–430. https://doi.org/10.1111/conl.12303	methodological	simulations. utility and expected utility (Von Neumann & Morgenstern, 1944; Varian, 2009)	mangroves nursery function and aquaculture prodection; yield and biomass;
Dawes, J.H.P., 2019. Are the Sustainable Development Goals self-consistent and mutually achievable? Sustainable Development 0. https://doi.org/10.1002/sd.1975	methodological	network analysis	between SDGs
Fontana V, Radtke A, Bossi Fedrigotti V, Tappeiner U, Tasser E, Zerbe S and Buchholz T 2013 Comparing land-use alternatives: Using the ecosystem services concept to define a multi-criteria decision analysis Ecol. Econ.			
Klapwijk C J, van Wijk M T, Rosenstock T S, van Asten P J A, Thornton P K and Giller K E 2014 Analysis of trade-offs in agricultural systems: Current status and way forward Curr. Opin. Environ. Sustain.	conceptual	Pareto-frontiers	ecosystem services, land use, and biodiversity
Van Meensel J, Lauwers L, Van Huylenbroeck G and Van Passel S 2010 Comparing frontier methods for economic-environmental trade-off analysis Eur. J. Oper. Res.	methodological	conventional parametric (SFA) and non-parametric (DEA) frontier approaches	economic-environment
Schwenk W S, Donovan T M, Keeton W S and Nunery J S 2012 Carbon storage, timber production, and	methodological	multiple	trade-offs around the use of crop residues in smallholder farming

biodiversity: Comparing ecosystem services with multi-criteria decision analysis Ecol. Appl.			systems
Seppelt R, Lautenbach S and Volk M 2013 Identifying trade-offs between ecosystem services, land use, and biodiversity: A plea for combining scenario analysis and optimization on different spatial scales Curr. Opin. Environ. Sustain.	conceptual	multi-criteria decision analysis	three land-use alternatives resulting from land-use change caused by socio-economic pressures: traditional larch (Larix decidua) meadow, spruce forest (abandonment) and intensive meadow (intensification)
Deng, Xiangzheng, Zhihui Li, and John Gibson. "A Review on Trade-off Analysis of Ecosystem Services for Sustainable Land-Use Management." Journal of Geographical Sciences 26, no. 7 (July 1, 2016): 953–68. https://doi.org/10.1007/s11442-016-1309-9.	methodological	simulations	carbon storage, timber production, and biodiversity
Sabatini, Francesco Maria, Rafael Barreto de Andrade, Yoan Paillet, Péter Ódor, Christophe Bouget, Thomas Campagnaro, Frédéric Gosselin, et al. "Trade-Offs between Carbon Stocks and Biodiversity in European Temperate Forests." Global Change Biology 25, no. 2 (2019): 536–48. https://doi.org/10.1111/gcb.14503.	empirical	correlation - cluster Boosted Regression Trees	
Groot, Jeroen C. J., Walter A. H. Rossing, André Jellema, Derk Jan Stobbelaar, Henk Renting, and Martin K. Van Ittersum. "Exploring Multi-Scale Trade-Offs between Nature Conservation, Agricultural Profits and Landscape Quality—A Methodology to Support Discussions on Land-Use Perspectives." Agriculture, Ecosystems & Environment, Multifunctionality of Agriculture: Tools and Methods for Impact Assessment and Valuation, 120, no. 1 (April 1, 2007): 58–69. https://doi.org/10.1016/j.agee.2006.03.037.	empirical	multi-objective design problem (Pareto) spatially explicit land-use optimization methodology heuristic search method (i.e., differential evolution)	agronomic, economic and environmental
Petz, Katalin, Rob Alkemade, Michel Bakkenes, Catharina J. E. Schulp, Marijn van der Velde, and Rik	empirical	modelling	

Leemans. “Mapping and Modelling Trade-Offs and Synergies between Grazing Intensity and Ecosystem Services in Rangelands Using Global-Scale Datasets and Models.” Global Environmental Change 29 (November 1, 2014): 223–34. https://doi.org/10.1016/j.gloenvcha.2014.08.007.			
Gerecke, Madleina, Oskar Hagen, Janine Bolliger, Anna M. Hersperger, Felix Kienast, Bronwyn Price, and Loïc Pellissier. “Assessing Potential Landscape Service Trade-Offs Driven by Urbanization in Switzerland.” Palgrave Communications 5, no. 1 (September 24, 2019): 1–13. https://doi.org/10.1057/s41599-019-0316-8.	empirical	statistical models	
Nelson, Erik, Guillermo Mendoza, James Regetz, Stephen Polasky, Heather Tallis, DRichard Cameron, Kai MA Chan, et al. 2009. ‘Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production, and Tradeoffs at Landscape Scales’. Frontiers in Ecology and the Environment 7 (1): 4–11. https://doi.org/10.1890/080023.	empirical	modelling	ecosystem services, biodiversity conservation, commodity production
Rodríguez, Jon Paul, T. Douglas Beard, Elena M. Bennett, Graeme S. Cumming, Steven J. Cork, John Agard, Andrew P. Dobson, und Garry D. Peterson. „Trade-offs across Space, Time, and Ecosystem Services“. Ecology and Society 11, Nr. 1 (2006). https://www.jstor.org/stable/26267786.	conceptual		ecosystem services