Telecoupling

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The world is increasingly interconnected through a variety of distant processes such as international trade, foreign investment, migration, and species invasion. Such interconnections have enormous impacts on human wellbeing and the environment worldwide. For example, China's soybean imports from Brazil have drastically increased as a result of the ongoing trade dispute between the United States and China, which severely hurt US farmers economically and promoted the conversion of Brazil's natural lands (e.g., tropical forests and *Cerrado*) for more soybean production to meet the rising demand from China and elsewhere. These and other impacts in turn affect the prospects for achieving the United Nations Sustainable Development Goals and addressing other global challenges. Traditionally, distant processes were often studied – and governed – in isolation even though they often co-occur and can amplify or offset each other's impacts. Studying and governing them together would need an umbrella concept that encompasses various distant processes. To address such a need, the umbrella concept of telecoupling was proposed, which refers to human–nature interactions over distances (Liu *et al*. 2013).

The interest in telecoupling research and governance has been growing rapidly (Kapsar *et al*. 2019). For example, the Global Land Programme (https://glp.earth/) has designated telecoupling as a research priority. The global assessment of biodiversity and ecosystem services organized by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has featured telecouplings (Díaz *et al*. 2019). Many other UN reports have also highlighted telecouplings (e.g., UN Environment 2019). Telecoupling has also been widely featured in global news media outlets (e.g., *Time* magazine – Walsh 2011; Thomson Reuters Foundation News – Thiaw and Steiner 2019). A number of PhD students have conducted their dissertations on telecoupling. The European Commission has supported a new PhD program on telecoupling with 15 doctoral students across nine countries in its first cohort (http://coupled-itn.eu/). In addition, several dozen symposia, workshops, training sessions, and other sessions on telecoupling have been organized in a variety of venues (Liu *et al*. 2019).

This entry provides background information about the concept, illustrates the framework that helps understand telecoupling, and provides example applications of the telecoupling concept and framework. It also demonstrates telecoupling research methods, outlines governance approaches, and ends with critical knowledge gaps for future telecoupling research and governance.

Concept of telecoupling

The telecoupling concept was introduced in 2008 by the author (Liu *et al*. 2019). It builds on relevant disciplinary concepts such

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Figure 1 Icons of example telecoupling processes. Source: Reproduced with permission of the Center for Systems Integration and Sustainability at Michigan State University.

as teleconnection (interactions between distant climatic systems) and globalization (interactions between distant human systems; Sassen 1999). Teleconnection is a climatological concept (Wallace and Gutzler 1981) and includes the oceanic-atmospheric cycle referred to as the El Niño Southern Oscillation. Although El Niño phenomena originate in the tropical Pacific, their impacts extend to many distant parts of the world (e.g., increased precipitation in southwest US states such as California). By simultaneously integrating humans and nature as well as their interactions, the telecoupling concept goes beyond separate human or environmental interactions, such as climatic interactions. Such integration is crucial because it can help address the most challenging dilemma facing humanity and civilization, that is, the conflict between socioeconomic development and environmental protection. It can also help us understand human–nature synergies and tradeoffs. Also, it is a natural extension of relevant concepts, including coupled human and natural systems, which usually focus on human–nature interactions within a specific place.

Telecoupling is an umbrella concept that seeks to take account of the interrelationships over long distances among disparate socioeconomic and biophysical processes, such as international trade, foreign investment, water transfer, transnational land tenure transfer, species invasion, knowledge transfer, technology transfer, tourism, payments for ecosystem services, species dispersal, and atmospheric circulation, that are typically considered in disciplinary isolation (Liu *et al.* 2013). These long-distance interactions can be viewed as telecoupling processes after they are expanded in scope (Figure 1). For example, studies on human migration often focus on demographic and socioeconomic dimensions, but human migration has environmental impacts too. So human migration can be viewed as a telecoupling when both socioeconomic and environmental dimensions are considered. In contrast, studies on animal migration often emphasize ecological dimensions, but animal migration also has various socioeconomic impacts. Therefore, animal migration can also be viewed as a telecoupling when both ecological and socioeconomic dimensions are accounted for.

Telecoupling is related to, but more comprehensive than, established concepts. Teleconnection, for instance, focuses on distant climatic connections, while telecoupling encompasses both socioeconomic and natural (including climatic) connections. When teleconnection has socioeconomic impacts, it can be expanded to be viewed as telecoupling. Concepts such as globalization, foreign direct investment, and international trade focus on global and international scales, but telecoupling can go further by including distant interactions at other scales, such as national and regional scales. Telecouplings emphasize feedbacks between different systems, while other concepts usually do not do so explicitly.

Telecoupling framework

The telecoupling framework is developed to holistically understand patterns, mechanisms, and consequences of telecoupling (Liu *et al.* 2013). It consists of five major interrelated components (Figure 2). Two or more coupled systems and their connections constitute the most basic structure of a telecoupled system. These connections are represented by "flow," which is movement of matter, energy, information, people, organisms, and/or capital between systems. The system where the flow originates is the "sending system," while the system where the flow ends is the "receiving system."

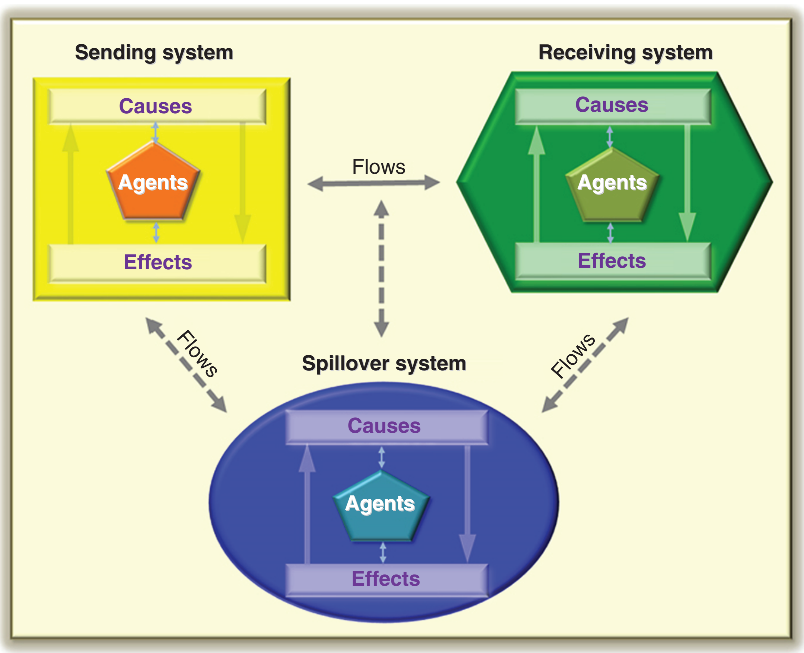

Figure 2 Five major and interrelated components of the telecoupling framework. A telecoupled system consists of coupled human and natural systems interacting through flows. Each coupled system includes three interrelated components: causes, effects, and agents. Causes are reasons behind the flows, effects are consequences of the flows, and agents are decision-making entities that facilitate or hinder the flows. A system can be a sending, receiving, and/or spillover system, depending on the direction of a flow. Local couplings within a coupled system are not displayed to make the figure simple. Source: Liu *et al.* 2013.

Other systems that affect or are affected by the interactions between sending and receiving systems are "spillover systems."

In each coupled system, there are three components: causes, agents, and effects. The reasons for or drivers of a given flow are "causes," including socioeconomic, cultural, political, environmental, and other factors. Effects resulting from flows may be diverse, ranging from socioeconomic to environmental consequences. Feedbacks are an important kind of effect, which may arise due to flows from receiving to sending systems, including positive and negative feedbacks that enhance or weaken the flows themselves, respectively. The final major component of the telecoupling framework is "agents"; these are decision-making entities such as human or nonhuman agents that facilitate flows. Human agents may include individuals (e.g., farmers, ranchers, tourists), households, and organizations (e.g., governments, nongovernmental organizations, companies). Nonhuman agents include animals such as migratory birds and bats.

The major components can be illustrated by applying the telecoupling framework to soybean exports from Brazil to China (Liu *et al.* 2013). The main flows are movement of soybeans from Brazil (sending system) to China (receiving system) and feedbacks via cash (for purchasing soybeans) from China to Brazil. The major agents include soybean farmers in Brazil who plant soybeans, traders who facilitate the sale and purchase of soybeans, consumers in China who are the forces behind the demand for soybeans, government officials in both Brazil and China who develop and implement relevant trade policies, and nongovernmental organizations, such as The Nature Conservancy, that advocate environmental conservation throughout the soybean supply chain. Causes range from good climate and abundant land for soybean production in Brazil to Chinese traditional preferences for soybean products and increased demand for meat production using soybeans as animal feed. Effects in Brazil include the conversion of Amazonian rainforest and *Cerrado* into soybean lands, loss of biodiversity and ecosystem services, increased use of agricultural chemicals such as herbicides and fertilizers, and increased income; and, in China, conversion of soybean lands into corn fields and rice paddies due to less competitive prices for domestically produced soybeans, and more nitrogen pollution, because soybeans can fix nitrogen while production of corn and rice requires more fertilizers, which are usually overused by farmers. Both soybean production and transports emit greenhouse gases that contribute to climate change. Thus, the rest of the world is a spillover system.

Applications of the telecoupling concept and framework

The telecoupling concept and framework have been widely applied in diverse fields. By the end of 2019, more than 520 publications had cited the foundational paper on telecoupling (Liu *et al.* 2013). Based on the analysis by Kapsar *et al.* (2019), the applications have informed various important scientific and policy issues, including conservation, land use, ecosystem services, food security, energy, natural resources, urbanization, economic development, and sustainability. The types of flows in telecoupling studies ranged from trade, knowledge transfer, species dispersal, tourism, water transfer, human migration, waste transfer, technology transfer, investment, and animal migration to ecosystem service flows (Kapsar *et al.* 2019). Almost three-quarters of the papers studied trade (e.g., agricultural and timber products), one-third addressed knowledge transfer, and almost one-fifth involved species dispersal, followed by tourism, water transfer, and other flows (each accounting for less than one-tenth of the papers analyzed). In terms of geographical scales, they ranged from international, to national and regional, and to local scales. Many studies involved multiple scales. The number of countries in a single study ranged from 1 to 172, but most studies focused on one or several countries each (Kapsar *et al.* 2019).

The applications of the telecoupling framework have made substantial contributions to a variety of scientific disciplines, such as geography, Earth science, ecology, economics, environmental science, fisheries, wildlife, and political science. The contributions can be divided into several major areas: identification of knowledge gaps; generation of fundamental hypotheses; detection of spillover systems; and assessment of feedbacks, tradeoffs, and synergies of telecoupled systems (Kapsar *et al.* 2019). Through systematic comparisons between existing knowledge and the telecoupling framework, knowledge gaps can be readily identified. Such identified gaps can help set up research priorities and determine future research directions. The telecoupling framework also inspires the development of novel hypotheses that challenge conventional wisdom. For instance, the framework suggests that telecoupling can generate both positive and negative effects on sending, receiving, and spillover systems. Applying the framework led to the proposition and confirmation of the hypothesis that importing countries also suffer environmentally, in contrast to the widely held conclusion that importing countries enjoy environmental benefits from imports while exporting countries have negative environmental burdens due to production for exports (Sun *et al.* 2018). Unlike sending and receiving systems, spillover systems are mostly overlooked and are thus the least studied and least understood. Detecting them is often a challenging but important first step toward understanding and governing them. Finally, integrating human and natural interactions over distances embedded in the telecoupling framework helps effectively evaluate feedbacks, tradeoffs, and synergies among sending, receiving, and spillover systems.

An example application of the telecoupling framework to geography is to test Tobler's First Law of Geography. Introduced by Waldo R. Tobler in 1969, the first law states that things nearby are more related than things far away. However, analyses using the telecoupling framework indicate that a country has more trade with distant countries than with adjacent (neighboring) countries (Schaffer-Smith *et al.* 2018). So it can be argued that Tobler's First Law does not apply to the international trade examined.

Telecoupling research methods

Guided by relevant theories, telecoupling research has benefited from a variety of methods used in multiple disciplines, such as remote sensing, geographic information systems, and computer modeling. Telecoupling researchers have also begun to develop some specific tools and models. Below are a couple of examples.

A telecoupled agent-based model (TeleABM) has been developed to simulate telecoupling processes and quantitatively understand the dynamics of complex telecoupled systems (Dou *et al.* 2019). It is an important expansion of traditional agent-based models that focus on individual systems and ignore interactions among different systems. Through calibration and validation with empirical data, TeleABM produces simulation results that reflect the reality.

A software program, Telecoupling Toolbox (http://telecouplingtoolbox.org/), incorporates socioeconomic and environmental analytic methods to study telecoupled systems. There are two versions: ArcGIS Toolbox (desktop-based) and Telecoupling GeoApp (web-based). Both are useful platforms with a set of mapping, virtualization, and geospatial analysis tools that can be used to explore major components (systems, flows, agents, causes, and effects) of telecouplings and their interactions.

Telecoupling research is more challenging than research focusing on a particular system in one place, as it often requires more resources, time, and expertise. However, it can be feasible, as demonstrated in previous telecoupling studies. A telecoupling research project should be placed under the telecoupling framework and, if necessary, divided into two or more trackable tasks, which can be tackled by different researchers or by the same researchers over time, and then integrated after the tasks are completed (Liu 2017). For instance, the first five papers can each focus on one major component of the telecoupling framework and the sixth paper can integrate the results on all five major components from the first five papers (Liu *et al.* 2019).

Telecoupling governance

Telecoupling poses new challenges for governance, compared to local couplings within a coupled system. This is because telecoupled systems are more complex as a result of interactions between two or more coupled systems through various flows and often across conventional political and administrative boundaries. Thus, coordination among different coupled systems is key for telecoupling governance. One approach for effective coordination is to shift from place-based governance (i.e., governance of individual places separately) to flow-based governance (i.e., attention to the relationships of a focal place with other places, including flows between them), because flows are the essential linkages among coupled systems. There are successful examples of flow-based governance. For instance, regarding the migratory Kirtland's Warbler (*Setophaga kirtlandii*), collaboration (e.g., through targeted timber harvest and tourism) among the sending (breeding) and receiving (wintering) systems has led to increases in the population sizes of and suitable habitats for this songbird of conservation concern (Hulina *et al.* 2017). However, to sustain the success, it is necessary to expand flow-based governance by incorporating spillover systems (e.g., migratory stopover sites, hometowns of tourists visiting the breeding sites), because important conservation funds can be generated from tourists visiting wintering and breeding sites, and this is especially important in the light of reduced federal funding for warbler conservation.

Perspectives

In the past several years, applications of the telecoupling concept and framework have made remarkable progress in advancing multiple scientific disciplines and addressing a number of the world's most challenging issues. Despite the challenges in telecoupling research and governance, more opportunities are emerging to address critical knowledge gaps. These gaps include tracing of flows and feedbacks among systems, detection of hidden spillover systems, understanding of telecoupling emergence and dynamics, and uncovering unexpected positive and negative impacts of telecoupling on sustainability and human wellbeing across local to global scales (e.g., impacts of telecoupling on synergies and tradeoffs among United Nations Sustainable Development Goals). Further development of geospatial analytical tools such as the Telecoupling Toolbox can help speed up the operationalization of the telecoupling framework and bridge these and other knowledge gaps.

Telecoupling is embedded in an even broader concept, that is, metacoupling, which consists of intracoupling (human–nature interactions within a system) and pericoupling (human–nature interactions between adjacent systems), in addition to telecoupling (Liu 2017). Such embeddedness reflects the real world. Uncovering the interrelationships between telecoupling and other types of coupling in the context of metacoupling is crucial for a holistic understanding of interactions across different scales and for achieving United Nations Sustainable Development Goals everywhere around the world.

SEE ALSO: Agent-based modeling; Climatic modes and teleconnections; Environment and migration; Environment and trade; Geography and the study of human–environment relations; Spatial interaction; Sustainability science; Tobler's first law of geography; Tourism; Trade, FDI, and industrial development

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