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Energy sustainability under the framework of telecoupling

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ABSTRACT

Energy systems, which include energy production, conversion, transportation, distribution and utilization, are key infrastructures in modern society. Interactions among energy systems are generally studied under the framework of energy trade. Although such studies have generated important insights, there are limitations. Many distant interactions (e.g. those due to the Fukushima nuclear crisis) are not in the form of trade, but affect energy sustainability. Even when distant interactions are related to energy trade, they are not systematically analyzed. Environmental impacts of trade are often not integrated with economic analysis of trade. In this paper, to identify and fill important knowledge gaps, we apply an integrated framework of telecoupling (socioeconomic and environmental interactions over distances). The framework of telecoupling, which is more comprehensive and cross-disciplinary than the energy trade framework, is a useful theoretical and methodological tool for analyzing distant interactions among coupled human and natural systems (including energy systems). Telecouplings widely exist in energy systems with various forms and link energy sustainability of different countries closely, so we proposed some methods for energy sustainability analysis under the framework of telecoupling. From the aspect of causes, a method is proposed to judge whether the telecoupling driven by economic factors is conducive to energy sustainability. From the aspect of effects, a method is proposed to assess whether an event is conducive to energy sustainability. The telecoupling framework presents opportunities for more profound and comprehensive understanding of energy sustainability.

1. Introduction

Energy is the foundation of production and socioeconomic development, and all human activities are driven by energy [1,2]. Therefore, it is crucial to ensure energy sustainability [3,4]. In terms of the world's energy sustainability issues, the World Energy Council proposed the 'Energy Trilemma' – energy security, energy equity, and environmental sustainability [5], which is very useful for evaluating the energy sustainability of the region or country [6]. One challenge to achieve energy sustainability is the mismatch between the geographic distribution of energy and the demand around the world. To meet the energy demand, there are increasing distant interactions among places that generate and consume energy. Currently, the main approach to analyzing distant interactions among energy systems and their influences on energy sustainability is the energy trade conceptual framework [7–9], which is an effective tool to analyze economic effects. However, it is not complete or thorough. For example, the Fukushima nuclear crisis, which has nothing to do with energy trade, changed the energy production strategies around the world [10]. The distant interactions, which are critical for energy sustainability, are not adequately analyzed under the framework of energy trade, since they are not trade transactions or their impact goes beyond socioeconomics. Thus, it is necessary to use a comprehensive framework to study energy-related distant interactions.

The framework of telecoupling is a good choice. Telecouplings are socioeconomic and environmental interactions among coupled human and natural systems over distances [11–15]. The framework of telecoupling includes five major interrelated components—systems, flows, agents, causes and effects. The movement

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of energy, which is activated by agents (decision-making entities that directly or indirectly influence telecouplings), may be part of important flows between coupled human and natural systems. Energy can also be part of the causes (reasons why telecouplings appear and change) or effects (socioeconomic and environmental results of distant interactions) of telecouplings. So far the telecoupling framework has been applied to address a number of important issues such as conservation policy and food production [16], global land use [17], trade of goods and products (e.g., food, forest products, palm oil [18,19]), global land grabbing and investment [20], species invasions [15], and payments for distant ecosystem services [21]. In this paper, we compare the framework of telecoupling with the framework of energy trade, apply the framework of telecoupling to several energy systems, and propose some methods for assessing energy sustainability under the framework of telecoupling.

2. Comparisons between the framework of energy trade and the framework of telecoupling

By comparing the framework of telecoupling with the framework of energy trade, we find a number of important knowledge gaps. As shown in Table 1, the differences between two frameworks are listed as follows.

The systems in the framework of energy trade are the suppliers, traders, countries and users. The framework of telecoupling, besides persons and organizations involved in the transactions, brings in many non-energy components, such as air, water, animals, and plants.

The flows between systems analyzed by energy trade tools are limited to money, energy and information. Flows such as movement of persons, plants and animals are neglected. However, energy flows are always accompanied by these relevant flows. For example, invasive species may be transported through energy transportation. The Powder River Basin, Wyoming, is one of the most rapidly expanding areas of coal bed methane. Due to methane mining, there is a significantly greater proportion of non-native species [22].

The agents of energy trade mainly include persons, companies and governments. Under the framework of telecoupling, other creatures, such as animals and plants, are also involved.

The causes of energy trade are limited to socioeconomic factors [23,24]. Under the framework of telecoupling, environmental factors are also emphasized.

In the energy trade framework, effects mainly focus on the socioeconomic, including supply, demand, and price. Environmental impacts are often separately studied, underestimated or even ignored [25,26]. The influence of energy trade on socioeconomic, environmental and biological systems is generally simplified as trade costs and externality (an externality is the cost or benefit that affects a party who does not choose to incur that cost or benefit). For example, when a factory emits air pollutants, its neighbors suffer; in contrast, infrastructure (e.g. roads and power grid) built by a factory may benefits its neighbors [27]. The framework of telecoupling integrates socioeconomic and environmental effects in sending systems (e.g., origins of energy trade), receiving systems (e.g., destinations of the energy trade), and spillover systems (other systems that affect or are affected by interactions between sending and receiving systems, such as energy transport corridors) with comprehensive consideration on feedbacks. Furthermore, the telecoupling framework is methodologically and conceptually superior to the energy trade framework, because it is an interdisciplinary model that not only adequately depicts the complex flow of energy

Table 1
Comparative analysis of energy sustainability using telecoupling framework versus energy trade framework.

		Framework of energy trade	Framework of telecoupling
Systems	Sending and receiving systems	• Energy suppliers • Energy users • Energy countries	• Sending systems including energy suppliers and non-energy components such as air, water, people, and organisms. • Receiving systems—systems including energy users and other components (e.g., air, water, people).
	Spillover Systems (entities that are affected by the distant interactions)	• Focus on transaction itself transportation time and costs	• Other systems beyond receiving and sending systems, such as those along the route of energy transportation
Flows		• Energy and energy-related equipment • Energy related information • Money	• Energy and energy-related equipment • Energy related information • Money • Persons • Organisms
Agents		• Persons • Companies • Governments	• Persons • Companies • Governments • Organisms
Causes		• Socioeconomic factors • Environmental factors	• Socioeconomic factors • Environmental factors
Effects		• Most of the research focused on socioeconomic effects, or environmental effects separately. • Do not attach importance to the effects on other systems • Little consideration on feedbacks • The effects in spillover systems are usually ignored.	• Socioeconomic and environmental effects in sending, receiving and spillover systems are considered together. • Comprehensive consideration on feedback.
Disciplines mainly involved		• Energy • Economics	• Energy • Economics • Biology • Environmental science • Other disciplines