sustainability

MDPI

Review

Understanding How Smallholders Integrated into Pericoupled and Telecoupled Systems

Yue Dou [1,2,*], Ramon Felipe Bicudo da Silva [1,3], Paul McCord [1], Julie G. Zaehringer [4], Hongbo Yang [5], Paul R. Furumo [6], Jian Zhang [7], J. Cristóbal Pizarro [8,9] and Jianguo Liu [1]

1 Center for Systems Integration and Sustainability, Department of Fisheries and Wildlife, Michigan State University, East Lansing, MI 48823, USA; ramonbicudo@gmail.com (R.F.B.d.S.); mccordpa@msu.edu (P.M.); liuji@msu.edu (J.L.)
2 Environmental Geography Group, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, 1081 HV Amsterdam, The Netherlands
3 Center for Environmental Studies and Research, State University of Campinas, Campinas 13083-867, Brazil
4 Centre for Development and Environment, University of Bern, 3012 Bern, Switzerland; julie.zaehringer@cde.unibe.ch
5 Smithsonian Conservation Biology Institute, Front Royal, VA 22630, USA; yangh@si.edu
6 Department of Environmental Sciences, University of Puerto Rico-Rio Piedras, San Juan 00925, Puerto Rico; pfurumo@stanford.edu
7 School of Life Sciences, Lanzhou University, Lanzhou 730000, China; Jzhang13@lzu.edu.cn
8 Laboratorio de Estudios del Antropoceno (LEA), Departamento de Manejo de Bosques y Medio Ambiente, Facultad de Ciencias Forestales, Universidad de Concepción, Concepción 4030000, Chile; jpizarrop@udec.cl
9 Millennium Nucleus Center for the Socioeconomic Impact of Environmental Policies (CESIEP), Millennium Science Initiative. National Agency of Investigation and Development (ANID)| Science, Technology, Knowledge and Innovation Ministry, Santiago 832 0000, Chile
* Correspondence: yuedou@msu.edu

Received: 31 December 2019; Accepted: 13 February 2020; Published: 20 February 2020

check for updates

Abstract: Increasing connections and influences from near to far have changed social structures, access to natural resources, and essential livelihoods of smallholders (i.e., those with incomes generated primarily from natural resources on small rural properties). However, the potential benefits and negative impacts from these connections to smallholders' livelihoods and social-ecological effects remain understudied. In this paper, we applied the frameworks of pericoupling and telecoupling (human-nature interactions between adjacent and distant systems, respectively) to systematically investigate how the flows linking smallholder systems to other systems affect their livelihoods, and causing varying economic, social, and environmental effects from case to case. We synthesized 12 cases of smallholder systems around the world that are linked to adjacent and distant systems through flows of goods, people, resources, and/or information. In each case, we summarized smallholders' agency, i.e., capability on the formation or operation of these flows, and the changes on livelihoods on the economic, social, and environment effects. Results suggest that strong smallholder agency is associated more with positive than negative effects. Smallholders with medium to high agency have greater overall well-being within the area of interest. Smallholders integrated in pericoupled systems often have strong agency. Being spillover systems in an intercoupled system (e.g., large-scale agricultural investments) can often cause negative outcomes unless smallholders have additional pericoupling flows. Our findings suggest one potential approach to ending poverty and increasing well-being for smallholders is creating and increasing pericoupling flows to empower smallholders for desired livelihood and social-ecological outcomes.

Keywords: smallholder systems; livelihoods; pericoupling; telecoupling; metacoupling

1. Introduction

Smallholder farmers—those with incomes generated primarily from management of natural resources on small rural properties—are a critical target group for ongoing attempts to meet global sustainable development goals (SDGs), such as reducing or ending poverty and hunger [1]. It is estimated that 75% of the world's poor reside in rural areas and that 50% of the poor within developing countries are smallholder farmers [2,3]. Production on these farms, therefore, is critical to food security within impoverished regions [4]. Studying smallholder systems in a globalized world is highly relevant because, after years of decline, world hunger is currently rising because of population growth, social conflicts, and climate change [5].

Smallholders' livelihoods can be highly vulnerable. Their subsistence and income depend on natural resources with limited social and economic capacity to adapt to changing climate and extreme events. At the same time, smallholders also exert very little influence on the global market dominated by large-scale agro-industries or corporations [6,7]. Moreover, it is predicted that climate warming and rainfall fluctuations will be more severe in locations where smallholders are most impoverished [8], and in countries where hunger is already rampant [9].

To address global challenges confronted by smallholders, it is necessary to investigate both the local system in which smallholders are positioned as well as linkages to other systems that may enhance or obstruct sustainable livelihood opportunities and overall well-being. On one hand, access to global markets has demonstrated pathways for smallholders to escape poverty traps, thus highlighting development opportunities from globalization [10,11]. On the other hand, the embedding of smallholders within global markets and trade networks may introduce new power dynamics and vulnerabilities as global commodity price fluctuations influence farmer well-being [12]. Agrifood standards within the global food system are one such example where smallholders are enmeshed in global linkages and, in some cases, may be made worse off due to connections to global markets. Smallholders integrated into global supply chains where large retailers, such as supermarket chains, can dictate cost-cutting measures and production standards result in some smallholders losing out on potential markets if they are unable to satisfy global buyers and standards of production [13]. This scenario was described by Dolan and Humphrey [14] as Kenyan and Zimbabwean farmers struggled to produce vegetables meeting the standards demanded by retailers within the United Kingdom. In other cases, smallholders may be displaced by large-scale land and water grabs as exogenous global forces (e.g., transnational resource demands and land investments) spur acquisition of local-level resources for purposes of production and profit [15–18]. Increasing the share of smallholders' benefits and reducing their vulnerability from being exposed to global markets is therefore vital for ensuring sustainable development of smallholder systems.

Aside from integrating into the global market, smallholder systems are also increasingly interconnected with local and regional markets in various forms. Because of urban consumers' concerns for food safety and demand for organic certified products, smallholders may participate in local farmers markets that have gained popularity in the past decades and other types of alternative food networks (e.g., buyers' club, recreational garden rentals) [19,20]. Moreover, smallholders interact with external systems through flows other than agricultural products, such as flows of people and technology. The availability of technologies and information from outside sources has changed farmers' resilience to climate change [6]. Rural-urban labor migrations have complemented labor shortages in urban areas [21], provided remittances to rural families and thus changed rural land use patterns [22]. Ecotourism operated by smallholder families hosted many visitors [23], however, the revenue was unevenly distributed among participating families and communities besides various uncertain impacts on reduced traditional and subsistence activities (e.g., abandonment of cropland) and on the local ecosystems (e.g., increasing deforestation) [24–26]. These different types of connections and various impacts call for systematic investigation into how smallholder systems are connected with others and why the livelihood, economic, and environmental outcomes vary between different cases. Yet, because of the lack of an integrated flow-based framework, previous studies often considered smallholders as end producers to the global market and failed to comprehensively study smallholders' multi-form interactions with external systems. For example, a systematic review of small-scale fisheries within the global fish market only summarized the variation of local conditions [27], failing to account for the interactions with other nearby markets and the potential spillover effects from these interactions.

The current practice in the literature on the sustainable development of smallholder systems is to frame smallholders in terms of a single focal system with insufficient attention paid to their connections to other systems, such as nearby villages, regional urban centers, or the global market. Several existing frameworks or concepts, while valuable, fall victim to this shortcoming, including the coupled human-natural system concept [28], the sustainable livelihood framework [29,30], and the resilience perspective [31,32]. In the milestone paper on coupled human-natural systems, authors discussed emergent properties within systems, but only showed their ambition to shed light on the interactions between systems in the discussion [28]. Another example is the often applied sustainable livelihoods approach [29,30], which treats these connections from external systems to smallholder systems as "context factors" [33–35]. Most resilience studies on smallholders also focus on approaches of increasing adaptive capacity and reducing risks within the place-based smallholder system itself, such as expanding social networks or implementing incremental adaptations [32,36,37]. Such a framing overlooks the possibilities of transformational adaptations through connecting to other systems.

A new framework, the telecoupling framework, was designed to investigate interactions among coupled human and natural systems (CHANS) across distances [38]. Liu et al. [39] called for synthesis of telecoupling cases in order to systematically assess drivers and patterns of interactions. The authors argued that traditional location-specific studies were unable to pick out the complex cross-system configurations that may underlie human-environment interactions over distances. Further highlighting this tendency to focus on a single location, analytical tools available to social science researchers typically overlook the influences from external systems [40]. For smallholder studies, the integration in the globalized world is often overlooked, and most smallholder perspectives focus on their local context/conditions (place-based) without considering how flows/interactions with external systems affect these location-specific outcomes. Zimmerer, Lambin, and Vanek [41] is a great start that draws attention to study current smallholders' challenges using the lens of telecoupling. With rich literature review and four cases, the authors proposed an integrated multilevel smallholder framework [41]. Their new smallholder framework linked smallholders to a "global receiving system," via the mediation from "public and private institutions" and local spatial interactions. To help explore the range of opportunities and obstacles introduced to smallholders as a result of their local and global interconnections, our study aims to take a step further, and apply the framework of intercoupling (pericoupling and telecoupling) within the metacoupling framework, to systematically categorize the flows and connections that smallholders have that range from adjacent to distant.

The metacoupling framework is designed to investigate various interactions among CHANS, including within a system (i.e., intracoupling), between adjacent systems (i.e., pericoupling), and across distances (i.e., telecoupling) [38,42]. Compared to current approaches utilized in smallholder studies, using the metacoupling framework enables a new perspective that places smallholders in the center of the flow-connected system. Moreover, it provides a new typology that categorize the complexity of flows connecting smallholder systems to different systems based on distance, allowing us to understand the causes and effects within the smallholder systems more comprehensively. Applying the metacoupling framework, particularly the intercoupling (i.e., pericoupling and telecoupling), we demonstrate a broad range of smallholder dynamics under connections to other systems using twelve case studies from across the globe. In doing so, we offer valuable new insights to the challenges and opportunities that smallholders face in the increasingly connected world and, in turn, suggest implications for future metacoupling research of smallholders.

We employ a synthesizing approach and use the metacoupling framework to synthesize selected studies focused on smallholder systems. Building on the insights from existing research such as [27,41], we aim to apply the metacoupling framework to different cases and demonstrate how to use this framework to synthesize smallholder sustainability issues in a larger perspective than the place-based context. Particularly, we want to focus on the following understudied research questions:

1. How do smallholders integrate into the intercoupled systems, as sending, receiving, or spillover systems?
2. At what distances do smallholders engage with other systems in the intercoupled systems (e.g., pericoupling and telecoupling)?
3. What degree of agency do smallholders have in relation to the flows between systems?

2. Methods

The motivation of this paper originates from a symposium "Telecoupling for sustainable development and conservation across local to global scales" at the annual US Regional Association of the International Association for Landscape Ecology (US-IALE) (http://www.usiale.org/symposia2018.html) conference in 2018. A subset of the participants in the symposium focused on the socio-ecological issues for smallholders and volunteered to advance the field by providing cases and insights from their own research. In total, we synthesized 12 cases (Figure 1) which are the work of the participants of this article. These cases include a variety of urgent issues that challenge smallholders' sustainable development. They cover different geographic, ecological, social, demographic, and cultural settings, and they encompass a variety of environmental and socioeconomic problems (Figure 1). More importantly, the cases share four major features: First, they explicitly address complex interactions and feedbacks between smallholder systems and other CHANS. Second, these studies record specifically the flows that connect smallholders to the other systems. Third, these studies consider smallholder livelihoods and their roles in relation with the flows. Fourth, these studies explicitly recorded the social, economic, and ecological effects caused by the flows. In addition, the 12 cases were conducted by co-authors, which are either (1) designed and published to address metacoupling issues or (2) authors have primary data and knowledge can analyze the topic from the perspective of metacoupling.

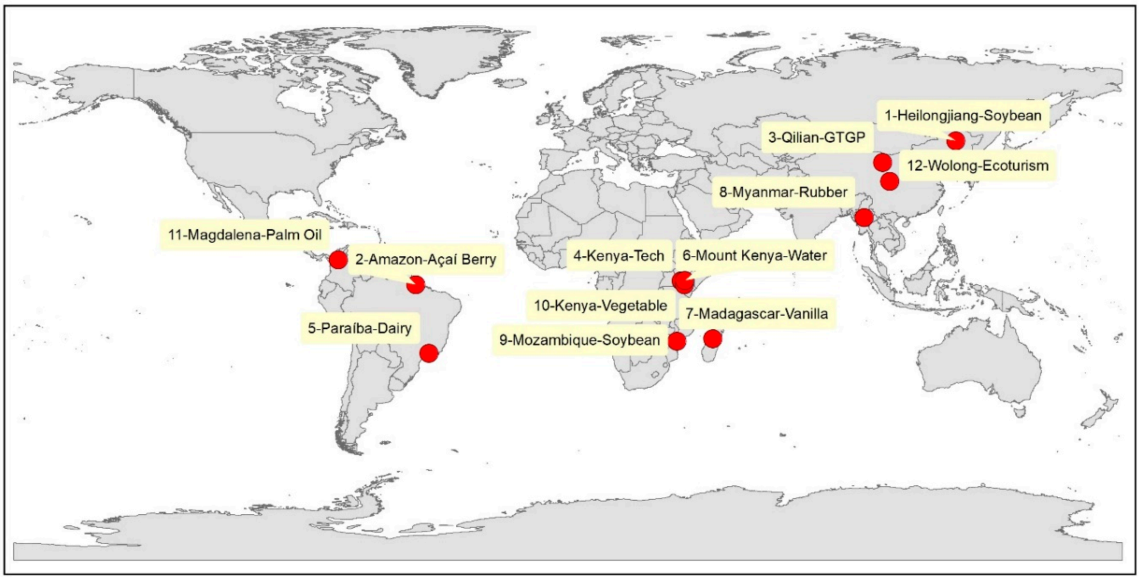

Figure 1. Smallholder case studies, including location and label of region and main elements. Note: The label for each case study corresponds to the identification labels used in Tables 2 and 3.

The metacoupling framework is an umbrella framework that includes intracoupling, pericoupling, and telecoupling frameworks. Interactions that occur within a coupled human and natural system are ***intracoupling***. Interactions that occur between systems are ***intercoupling***, while between adjacent systems are ***pericoupling*** and between distant systems are ***telecoupling***. Telecoupling, among the three, was the first to be designed, and has been quickly adopted by scholars to explore land use changes [43–46], food security, and the role played by international trade [47], water transfer [48,49], and development and sustainability issues [26,50,51], to name a few. Later, pericoupling and intracoupling were proposed along with telecoupling to form the comprehensive metacoupling framework [42]. Several examples have used the different couplings to explore interactions between systems via different ranges of distance [52,53]. Thus, the metacoupling framework has proven effective in studying complex systems and interactions [47,54,55].

We define ***smallholder systems*** as the local coupled human-natural systems that constitute smallholder agents (Figure 2). As the focal system of our analyses, they can be part of a pericoupled or telecoupled system. Our 12 smallholder systems in the case studies (Figure 1) interact with other systems through flows of commodities (e.g., palm oil, açaí berry, soybeans), labor (e.g., off-farm workers), natural resources (e.g., water), and information (e.g., organic certification, technology). Using flows as the analytical point enables us to frame the locally coupled smallholder-natural systems as part of a larger system rather than exclusively within a single CHANS. ***Agency*** is defined as the capacity of smallholders to influence (e.g., form, direct) the flows that integrate them to the overall connected systems [56]. By investigating agency we can evaluate the choices and opportunities smallholders have in the flow-connected systems rather than single CHANS.

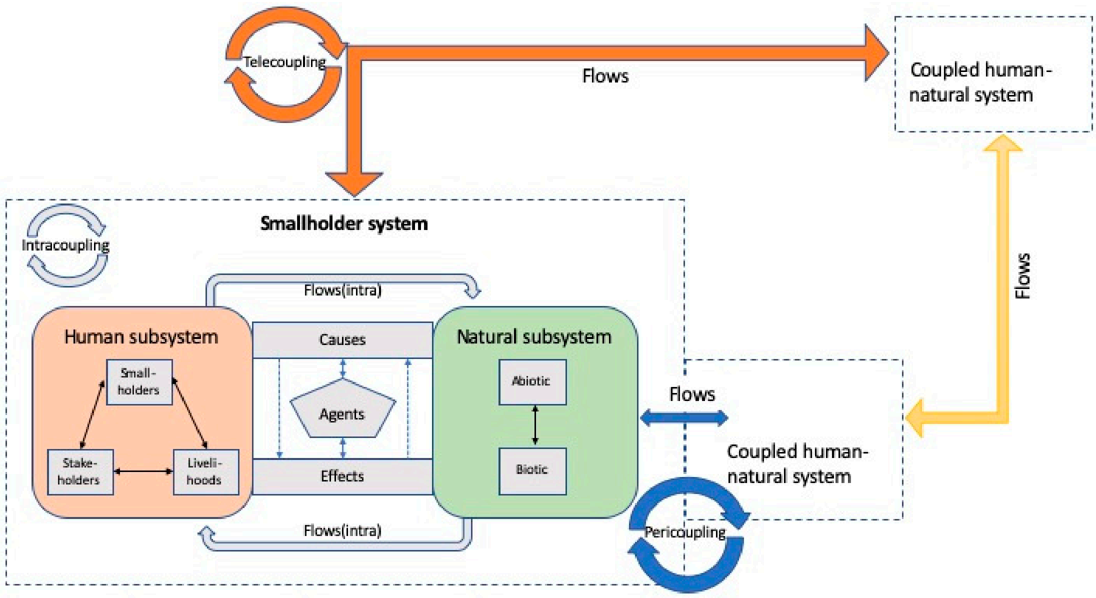

Figure 2. The metacoupling framework using a smallholder system as the focal system (adapted from [34]). Depending on the primary flow, smallholder systems can be receiving, sending, or spillover in the overall intercoupled systems. They are integrated in the intercoupled system via flows connecting them to the other CHANS.

The metacoupling framework has three types of couplings. Here we use two that belong to intercoupling: pericoupling and telecoupling, because we are mostly interested in the dynamics when smallholder systems are connected to other systems. There are five components in pericoupled and telecoupled systems (Table 1). "Systems" are connected to one another by "flows" of commodities, information, people, animals, etc. According to the direction of the flow under evaluation, the smallholder system (i.e., the focal CHANS system in which smallholders are the main agents) can be classified as either a "sending," "receiving," or "spillover" system. Within each system there are "agents," "causes," and "effects" [42] (Figure 2).

We followed the method used by literature to synthesize the cases [28]. We made two explicit tables (i.e., Tables 2 and 3) and asked every co-author to document all five components and answer the three questions. **For the first question**, we synthesized how smallholder systems are integrated into the overall intercoupled system by looking at their relationship to the primary flow in these case studies. The results can be found in Table 2 (primary flow in intercoupled system, type of intercoupled system, and position of smallholders). Flow direction accounts for the role of the smallholder system as a sending, receiving, or spillover system within the broader pericoupled or telecoupled system. The primary flow entering the smallholder system will position it as a receiving system, while if the smallholder system generates and sends out the flows will position them as a sending system. A smallholder system being indirectly affected by the primary flow would be a spillover system. The classifications are based on the research questions and how authors determined the significance of flows and data availability. Often there are multiple flows in an intercoupled system, however, the definition of primary flow depends on the questions researchers want to address. There is no protocol to choose a primary flow because often these flows are completely different in nature and incomparable. In some cases, researchers are interested in the flow with a sizeable volume (e.g., soybeans); while in other cases, the primary flow may not be a commodity, but intangible yet significant (e.g., knowledge transfer, investment). The position of smallholder being sending, receiving, and spillover system is based on the primary flow under investigation. The primary flow integrates smallholders to the intercoupled system directly or indirectly. For example, a research question of a case study asking about the dynamics caused by large agricultural investments (LAIs) would mark the investment as the primary flow. Smallholder systems can be receiving systems if they are the receipt of the investment; they can also be spillover system if affected indirectly in the buffer zone of this investment flow, such as the Cases No. 9 and No.10.

Table 1. Five components in pericoupled and telecoupled systems.

Component	Pericoupled/Telecoupled	Questions and Classification Samples
System	Sending, receiving, spillover	Research Question 1: How do Smallholders Connect to other Systems? For example, if the primary flow enters the smallholder system, this positions smallholder system as a receiving system.
Flows	Movement of material, people, capital, and/or technology between smallholder systems and other systems	Research Question 2: At What Distances do Smallholders Engage in the Intercoupled Systems? For instance, a smallholder adjacent to the connected system can be defined as a pericoupling flow.
Agents	Smallholders, and other stakeholders involved in the metacoupled system	Research Question 3: What degree of agency do smallholders have in relation to the flows between systems? For instance, if smallholders form cooperatives or initialized the flow, the agency is high.
Causes	Reasons behind pericoupling or telecoupling flows	Not applicable
Effects	Social, economic, and environmental consequences of pericoupling or telecoupling flows	Not applicable

For the second question, we summarized the distances and the origins/destinations of flows between smallholder systems and the connected systems (results are indicated in Table 3, Column "Distance of flow integrating smallholders into the intercoupled system"). The classification is based on the distance of the primary flow when the smallholder systems are sending or receiving systems. If smallholder systems are adjacent to the other systems, we classified their interactions with other systems through pericoupling flows (e.g., Case 2, açaí berries sent from Amazon rural sites to family members in the nearby cities); if they are distant from other systems we considered their interactions as telecouplings (e.g., Case 4, knowledge transfer from China to Kenya farmers). Smallholders as spillover systems are connected to other systems through flows other than the primary flow of the intercoupled system (e.g., Cases 9 and 10, smallholders are connected through adjacent flows in the telecoupled systems).

To answer **the last question,** we asked the co-authors to discuss different formats of smallholders' involvement with flows and the sustainability opportunities. We classified the smallholder systems according to the agency of smallholders with the flows. We have ranked the agency of the cases from low, medium, to high. **Low agency** refers to that smallholders engaged in the flows between systems, but they did not initiate the flow and they had little or no ability to transform its characteristics, or there is no strong government and institutional support. This refers to cases without much social development or self-organized collaboration at all. **High agency** refers to that the flow was initiated by the smallholders or the flow has been dramatically transformed because of the involvement of the smallholders. For example, if smallholders formed association or cooperatives on themselves, they are classified as high agency. **Medium agency** is in between low and high agency where smallholders have limited choices and power to shape the flow, but with some levels of collective supports from government (e.g., government cash transfer or conservation programs).

For each of these intercoupling flow traits (i.e., direction, distance, and agent engagement), we provide several examples to: (1) offer the reader an understanding of how the trait influences the intercoupling and (2) describe several causes and effects revealed through usage of the metacoupling framework. Detailed descriptions of each case can be found in Tables 2 and 3. To succinctly refer to each case, we use the following "case number-location-keyword" protocol in the following sections. For example, "No. 1-HLJ-soybean" refers to the first case study in Table 1, which is a smallholder system in Heilongjiang, China where soybeans are grown.

3. Results

3.1. How do Smallholders Connect to other Systems?

Among our 12 cases (Table 2), four focal smallholder systems can be treated as sending systems, four as receiving systems, and four as spillover systems.

One example of sending systems is in Paraíba Valley region of São Paulo State, Brazil (No. 5-Paraíba-dairy), the dairy production is the major rural economic activity focused mainly in the regional market, mostly neighboring cities of the valley and region (e.g., São Paulo city). The flow in this example is the dairy products that are sold from rural farms to the pericoupled market. This regional market is a key source of income for dairy producers but also to maintain other rural practice (e.g., livestock and agriculture) that has deep cultural roots in the valley's history [57]. Although its participation is 14% of the dairy production in São Paulo State, the region suffers a labor loss which jeopardies the maintenance of dairy and other rural practices because of the competitive pressure from the developed urban regions of the valley where wages, labor rights, and amenities (e.g., schools, hospitals) are more attractive to younger generations than in rural areas [58]. While in several cases smallholders sell agricultural products as goods into the regional and international markets, there are also cases that agricultural products are shared between rural smallholders and their relatives dwelling in urban areas (No. 2-Amazon-açaí) [59,60]. Furthermore, the sending systems of smallholders supplied a range of items, including labor and information, which are not always agricultural products to the market.

Four cases are receiving systems based on flows of information, natural resources, and people. One example is the smallholder farmers in No. 1-HLJ-Soybeans. The flow that integrates the smallholder systems in this telecoupled system is the soybean price from the international market. Smallholder soybean farmers traditionally grow soybeans that support domestic demand within China. In the past several decades, China has relied on Brazilian and U.S. growers to supply the bulk of their soybeans, including more than 80% of the soybeans used in China. As a result, Chinese smallholder growers have been integrated into an international commodity market where they receive crop price information (set by the Chicago Board of Trade in the U.S.) that alters their local-level decision-making. For example, 15% of the 673 farmers surveyed in Heilongjiang abandoned soybeans for corns and rice production during the past 10 years as they seek out the most profitable crops (e.g., net profit for soybeans in 2015 was only 236 US$/ha while the profit of corns and rice were 1270 US$/ha and 3493 US$/ha respectively). This shift has produced environmental consequences within the smallholder focal system, including nitrogen pollution [38].

Table 2. Case description of smallholder systems connecting to other systems.

Case No.-Location	Reference(s)	Location of Smallholder Systems	Primary Flow in Intercoupled System	Type of Intercoupled System	Position of Smallholders	Short Description of Dynamics in Smallholder System
1-HLJ-soybean	[45,46,61]	Heilongjiang Province, China	***Price***: soybean price from the global market to local	Telecoupled	Receiving	Chinese soybean farmers (average 6.4 ha) compete with soybeans from Brazil and the United States and receive price signals from the international market which influence land use decisions
2-Amazon-açaí	[59,60]	Tapajós and River region in the state of Pará, and Mazagão River in the state of Amapá	***Food***: açaí berry and other food	Pericoupled	Sending	Smallholders (8–300 ha) in the Brazilian Amazon Delta conduct agriculture, fishing, and agroforestry. They send açaí berry and food to relatives living in the urban areas and receive remittance from these relatives
3-Qilian-policies	[62]	Two counties in Gansu Province, China: Tianzhu, at the eastern end of the Mt. Qilian; Sunan: in the north-west of Mt.Qilian	***Labor***: some family members migrate to nearby cities in other regions of China	Pericoupled	Sending	Smallholders (1–2 ha) in the Qilian Mountains engaging in crop production and husbandry activities receive government ecosystem compensation payment
4-Kenya-tech	[63]	Farms near Kenya Agriculture Research Institute (KARI)-Katumani Research Centre	***Information***: new agricultural technology introduced by Chinese scholars	Telecoupled	Receiving	Smallholders (2–4 ha) in the southeast Kenya, a semiarid tropical climate, have two growing seasons and experiencing water shortages
5-Paraíba-dairy	[57,58]	The Paraíba Valley, São Paulo state, Brazil	***Goods***: dairy products and labor	Pericoupled	Sending	Smallholders (10–500 ha) sell dairy products to urban consumers, and young members migrate to cities
6-Mount Kenya-water	[64,65]	Twenty-five communities in the northern and northwestern slopes of the Mount Kenya region	***Natural resource***: water flow from upstream to downstream	Pericoupled	Receiving	Downstream households (0.1–2.8 ha) negotiate with upstream households and receive irrigation water in order to diversify their seed and crop choices
7-Madagascar-vanilla	[66,67]	The district of Maroantsetra, within the Analanjirofo region of north-eastern Madagascar	***Goods***: vanilla and cloves, high value agricultural products	Telecoupled	Sending	Smallholders grow vanilla and cloves and sell them to Europe and other importing countries
8-Myanmar-rubber	[68,69]	The Tanintharyi Region, in south-eastern Myanmar	***Goods***: cash crops, such as rubber and betelnut	Pericoupled	Spillover	Smallholders (<15 ha) produce cash crops, such as rubber and betelnut, next to externally owned large-scale plantations (e.g., 12,140 ha), and send products to domestic and neighbor country Thailand.
9-Mozambique-soybean	[18]	Guruè and Monapo districts in the Nacala corridor, Mozambique	***Investment***: large-scale investment mostly from foreign countries;	Telecoupled	Spillover	Smallholders grow soybeans individually and sell to South Africa and Europe, or work on foreign (e.g., the Netherlands, South Africa, Norway) plantations of soybeans, macadamia, fruits and vegetables. Smallholders are affected by land-use changes and other socio-environment connections
10-Kenya-vegetable	[70]	The western slopes of Mt Kenya, within the upper Ewaso Ng'iro basin, and includes parts of Laikipia, Meru, and Nyeri counties	***Investment***: large-scale investment producing vegetables and flowers for European markets	Telecoupled	Spillover	Smallholders (<1 ha) practice a combination of crop farming and livestock keeping, mostly for subsistence but partly also for sale on local markets. Smallholders are affected by land-use changes and other socio-environment connections

Table 2. *Cont.*

Case No.-Location	Reference(s)	Location of Smallholder Systems	Primary Flow in Intercoupled System	Type of Intercoupled System	Position of Smallholders	Short Description of Dynamics in Smallholder System
11-Magdalena-palm oil	[71–74]	Northern Colombia	***Policy***: market-based sustainable supply chain certifications	Telecoupled	Spillover	Smallholder oil palm growers (2–55 ha) are becoming certified because of consumer pressure in Europe which originated as a response to deforestation from expanding oil palm plantations in Southeast Asia
12-Wolong-ecotourism	[51,75]	Wolong, Southwest China	***People***: tourists coming from other parts of China, or other countries	Telecoupled	Receiving	A large portion of local cropland was lost because of PES (payments for ecosystem services) programs, earthquake, and post-disaster (2008 Wenchuan earthquake) reconstruction. More and more local households (average 0.20 ha were involved in alternative livelihoods such as work in local tourism industry, out-migrate to work in cities, or expand livestock.

Among the 12 cases, four focused on smallholders as spillover systems. In Colombia, the fourth largest palm oil producer in the world, roughly 35% of palm oil is exported to Europe where consumer pressure creates demand for sustainably certified imports [74]. For instance, the EU market aims to achieve deforestation-free palm oil imports by 2020. While this demand has largely been driven by the environmentally destructive practices surrounding oil palm expansion in Southeast Asia, producers from Latin America are also experiencing this market pressure despite relatively little amount of forest loss from plantation expansion [72]. As a result, commercial producers of palm oil in Colombia are becoming certified to access European markets, and smallholders (2–55 ha) in these supply bases are engaging in market-based certification programs largely at the behest and guidance of mills. The main flow between large producers in Colombia with the EU market is the demand for organic certified products, which is also the primary flow that integrates smallholder systems as spillover to the telecoupled system. The price premium from certified production provides an important motivation for smallholders to join and remain in programs, and these programs have brought positive socio-ecological outcomes on smallholder management practices in Magdalena, Colombia, including better worker pay, less agrochemical use, and larger areas of natural habitat conserved on farms [71]. Smallholder inclusion in market-based certification programs was also enhanced by public policy [76]. However, organic certified smallholders produced less fruit than conventional farmers, risking the financial stability of telecoupled supply chain initiatives if fleeting price premiums cannot be secured in a future market of increased certified palm oil supply.

3.2. At What Distances do Smallholders Engage in the Intercoupled Systems?

Within the intercoupled systems, smallholders are connected to the other systems by pericoupling and telecoupling flows (Table 3).

3.2.1. Pericoupling Flows

Two out of the three cases in Kenya (No.10-Kenya-vegetables and No.6-Mount Kenya-water) share pericoupling flows that are different in content. Domestic or foreign large-scale agricultural investments (LAIs) in the upper Ewaso Ng'iro basin grow and export vegetables and flowers. This investment flow created the overall telecoupled system. However, the focal smallholder system in this case is the spillover system and it is integrated into the telecoupled system through the connection of local water flow to LAIs. The abstraction of river water for irrigation by these LAIs has caused some subsistence-based farmers within a close buffer zone to change their farm management practices [70]. Water is clearly the main factor limiting agricultural production in the region, and the proliferation of LAIs coupled with massive population growth has exacerbated the shortage of this valuable resource. About two-thirds of all interviewed households (67 out of 100) reported a change in the cropland management, of which the main reasons were the water shortage.

In the Mount Kenya region without the presence of LAIs farmers are also entangled in a series of very proximate linkages in which the volume of surface water (i.e., the flow) available to downstream farmers (i.e., the receiving system) is dependent on upstream social and biophysical dynamics [65,77,78]. One set of factors dictating downstream water availability are the institutional arrangements and decision-making of upstream Mount Kenya smallholder farmers. In the past, excessive upstream water use led to shortages in downstream regions and spurred conflicts between water users. A shift in water governance that was initiated by authorities and co-designed by local farmers association since the turn of this century [65], has resulted in more equitable intra-catchment water availability (i.e., an enhancement of the flow entering the downstream system). Logistic regression analysis suggests that stronger governance of community water usage and more interactions between upstream and downstream households will increase the adoption of new seed varieties by 0.437 and 0.251 [65]. This experimentation has led to the cultivation of crops for local and regional markets.

Table 3. Characters of flows connecting smallholders to the intercoupled system.

Case No.-Location	Distance of Flow Integrating Smallholders into the Intercoupled System	Agency	Economic Effects	Social Effects	Environmental Effects
1-HLJ-soybean	Telecoupling: International (~17,000 km)	Low	The profit of growing soybeans dropped significantly	Increased anxious about price fluctuation; emerging of farmer association and looking for sustainable opportunities	Severe environmental damages, including nitrogen pollution; however, soil organic carbons increase
2-Amazon-açaí	Pericoupling: Adjacent cities (~50 km), two competing boats make the daily journey in 2 to 4 h.	High	Rural families receive remittances from urban families, constituting 35% of their total income	Increased land tenure title; poorer families have more out migration than wealthier	Leaving farms to transition to secondary forest cover or be consolidated by agribusiness conglomerates
3-Qilian-policies	Pericoupling: The labors mostly transfer to the nearest city (about 100 km), and some of the labors transfer to Lanzhou, the capitol of Gansu Province (~ 500 km).	Medium	Income of smallholders almost doubled (e.g., average income increased from US $3876 to US $7593)	Increased labor migration (e.g., 74% of families have people migrate for working in the city)	The area of farmland decreased, and area of natural land cover increased
4-Kenya-tech	Telecoupling: International (~8000 km)	High	Increased the yield and profit of maize	Adoption of new agricultural technology, the ridge-furrow mulching system	Water use efficiency of maize, plastic film cost and pollution problem
5-Paraíba-dairy	Pericoupling: Adjacent urban center (~200 km)	High	Profit from dairy product demand of wealth urban residents	Increasing rural migration of young family members	Reduced land use pressure caused the increase of the Atlantic forest cover
6-Mount Kenya-water	Pericoupling: Adjacent villages (<30 km)	High	The adoption of new seed varieties led to cultivation possibilities of crops for local and regional markets	Sustainable water governance association	More equitable intra-catchment water availability
7-Madagascar-vanilla	Telecoupling; International market (Europe, US, Indonesia, China)	Low	Volatile price of vanilla	Lacking institutional arrangement and social development with ties to the global market	Madagascar's high degree of endemic plant and animal species are under threat
8-Myanmar-rubber	Pericoupling: Adjacent to LAIs; Pericoupling, Sell crop products to markets in neighbor Thailand (~500 km), or to the capital (~1000 km)	Low	Smallholders seemed to be in a more favorable position economically now than in 1990. However, they may lose land access to large plantation actors to profit financially	The large plantations had been established by actors of private and military-owned agribusinesses. This contributed to an increasing shortage of land among small-scale farmers	Dominant land uses change from mix of secondary forest and shifting cultivation fallows in 1990s to cashew, betel nut, oil palm, or monoculture rubber plantations. Only 13% of the area was still covered with secondary forest and fallows in 2017, resulting in increasing pressure on remaining biodiversity-rich forests

Table 3. *Cont.*

Case No.-Location	Distance of Flow Integrating Smallholders into the Intercoupled System	Agency	Economic Effects	Social Effects	Environmental Effects
9-Mozambique-soybean	Pericoupling: A one- or two-km buffer around each LAI	Medium	A noticeable portion of the interviewed households currently or previously employed in the LAIs which provided their household with additional income besides agricultural income	Advanced the adoption of new technology from LAIs to smallholders	LAIs also caused land shortage and additional deforestation, as well as shortage of water resources
10-Kenya-vegetable	Pericoupling: A two-km buffer around each LAI	Medium	Overall increased income and market opportunities, along with outgrower contracts	Improved infrastructure, school building, and security; but increased conflicts over water and polluted environment, and problems on people's health.	LAIs mostly caused negative impacts such as over-abstraction of river water, increase in pests, and air pollution with chemicals
11-Magdalena-palm oil	Telecoupling; International (~9000 km)	Medium	Lower yields on certified farms, producing a median of 18.00 tons/ha/year of fresh fruit bunches compared to 21.75 tons on non-certified farms. Certified producers received a price premium of 12–18% of the market price (US$14 per ton) in 2017	Certified producers paid higher wages but employed fewer workers because of lower yields	Better environmental practices among certified producers including the substitution of synthetic fertilizers with organics, less agrochemical use, and larger areas of farms being set-aside for conservation
12-Wolong-ecotourism	Telecoupling; Regional and international	High	Approximately 76.5% of local rural households received income associated with tourism directly or indirectly	The development of tourism has also motivated the community to upgrade local infrastructure (e.g., houses)	Livestock encroachment has become a major threat to panda habitat; negatively influenced vegetation along trails; tourist donation provides support for captive giant panda breeding and research

Pericoupling flows can also include flows that are a bit further than villages but still connect two adjacent systems, such as to the adjacent regional urban centers. Examples include the smallholders in the Qilian Mountain region in Northwest China, where they participate in the Grain-to-Green program (GTGP) and migrate to cities where labor shortages have been going on in recent years [79] (No.3). The GTGP compensates farmers with a stable income for fallowing and reforesting their farmlands that are on slopes [80]. Under the stability from the GTGP, households often send their surplus labor (as the flow integrating smallholders to the overall pericoupled system) to nearby cities for off-farm employment while one or two family members remain on the farm to carry out cultivation activities. In the Qilian Mountains, more than 60% of the households have members migrated to cities because of GTGP, earning a wage higher than the agricultural income. Compared to households without a labor transfer, households with labor migrates have an annual income of $1700 higher per year [63]. The successful implementation of the GTGP facilitated the extra flow of labor migration through farmers' participation in the GTGP, which has also improved water conservation within the Qilian Mountains since the reduction of cropland improved the revegetation of forest and grassland [81].

3.2.2. Telecoupling Flows

Flows connecting smallholders to far-away places have examples of information of technology and commodity price. Kenyan farmers (i.e., in receiving system) have benefited from technological information, or "technology transfers" from China that have improved crop yield (No. 4). In this case, the ridge-furrow mulching system that was passed along to the Kenyan smallholders significantly increased both corn yield and water use efficiency in this semi-arid region where water is the main constraint for agricultural production [82]. Elsewhere, smallholders in Heilongjiang, China, (No. 1) are embedded in the international flow of soybeans where, in this case, they receive soybean price information from the international market which motivates their decision to cultivate soybeans or not, depending on the commodity's price [45].

3.3. What Degree of Agency do Smallholders Have in Relation to the Flows between Systems?

Defined as the capacity of smallholders to influence the flows (e.g., formation, direction) [56] that link them with the intercoupled system, agency is an important property when evaluating smallholders' choices and opportunities in the intercoupled system. As mentioned above, a number of case studies investigate smallholders producing goods that are exported, often to national or international markets. In these three cases, No.1, No.7, and No.8, smallholders have low agency. Often, external forces (e.g., market demand) are so strong that farmers have little ability to shape characteristics of the flow, such as production standards of the goods being traded. For smallholders in the Madagascar vanilla case, there is barely any investment for social development which provides no alternative livelihood options [63,66]. While in the Myanmar case land areas were largely controlled by the military power. With strong government ties, military companies were able to obtain formal concessions and institutional means to exclude smallholders' land use possibilities [68,69].

On the contrary, in some of the cases smallholders have been involved in flows of goods and have medium agency. For example, smallholders in two out of the three LAIs cases (e.g., No. 9-Mozambique-soybean and No. 10-Kenya-vegetable) have medium agency rather than low agency as in the No. 8-Myanmar-rubber. This is because some of these farmers still choose not to work in the large plantations and continue working on their own properties, while their land and other natural resources are affected by the LAIs. Meanwhile, they participate in local and neighboring cities' markets by selling crops which generates a new pericoupling flow that emerged outside of the original telecoupled system.

Certification programs for agricultural commodities are often designed by large industry actors and can risk alienating smallholders. In the case study of Colombian oil palm farmers, smallholder inclusion is driven by the initiative of the mill, as they hold the certification for a group of farmers in their supply base. Smallholders have limited agency in this arrangement, as they do not design the standard but merely implement it. However, smallholder inclusion has been enhanced in Colombia by a public policy that provided incentives for mills to incorporate associations of smallholders into their supply bases [74]. These associations receive credit to plant oil palm but are then required by contract to sell fruit exclusively to that mill. While they receive technical agronomic assistance, they lose agency over the management practices and crop choices on their land.

Alternatively, smallholders may have high agency, as they are directly responsible for initiating or shaping the intercoupling flow. Consider, for example, the Wolong Nature Reserve for giant panda conservation (No. 12-Wolong-Ecotourism), a protected area where people from within and outside of China come to view wildlife and the natural habitat. Smallholder families within the nature reserve have increasingly become more involved in the ecotourism industry in recent years, which, to some extent, has its origins in the reduction of available cropland for smallholders. As land available for cropping and livestock husbandry shrank because of GTGP and the earthquake disaster in 2008 [75], some smallholders migrated to cities while others remained to take part in the ecotourism industry. Recently, smallholders have played a larger role in shaping ecotourism experiences as other off-farm work opportunities have become less lucrative and abundant [83]. These efforts have made Wolong more appealing to outside travelers, increasing the flow of tourists to the nature reserve.

Another high agency example is the *Caboclos*, the riverine rural populations in the Amazon Delta region (No.2-Amazon-Açaí). Owing to increased income gained from the popularity of açaí in national and international markets, these smallholders can have establishments in both rural and urban locations, through which they share flows of cash and food constantly. Some family members have moved out of the remote riverine communities to establish secondary homes in nearby cities for better job and education opportunities. Many of the new migrants to urban areas maintain their rural consumption habits for fish and açaí (a native palm species). Family members from rural locations enlist the help of açaí middlemen to send açaí berries and fish as subsistence food to their urban dwelling relatives [59]. The middlemen will then bring the remittance from urban households to their rural relatives.

Same in the case of No. 5-Paraíba-dairy, the association of dairy farmers and the organization as producers' cooperative systems in the valley is a key factor supporting the local smallholders as group in a competitive market with many sanitary and other standard demands (e.g., quality and varied portfolio of products). Additionally, this agency property is also fostering adoption of innovative production systems, which causes a decrease in pastureland demand (e.g., through intensified dairy systems, high productive cow varieties) with positive effects on forest regeneration, but also improving technological adoption potentially minimizing rural labor scarcity.

4. Discussion

Positioning smallholder systems within an intercoupled system enlarges a researcher's analytical vision by developing an explanatory approach to complex issues that do not always emerge from local dynamics. The metacoupling approach is more holistic as the perspective shifts from focusing only on the smallholder system to inspecting focal CHANS with the flows to and from external systems. It also differs from the dominant paradigm of analyzing smallholder activities within the context of globalization, where smallholder systems are often considered as passive recipients of external pressures, such as price signals from exogenous markets or aid materials from international donor agencies. For example, consider No. 7-Madagascar-Vanilla. In this case study, small-scale farmers in Madagascar grow vanilla and cloves for international markets. Under the traditional analytical perspective, the focus would fall primarily on local well-being and the environmental outcomes resulting from crop production for international markets. Using the telecoupling framework, researchers follow the flow of these spice commodities from the smallholder system to the distant actors across village, district, regional, and even national and international levels, shedding light on the agency of decision-makers and potential paths to improve the environment and economics within the system [67].

This improvement in the conceptualization of smallholders in an increasingly connected world is of paramount relevance addressing SDG of ending poverty by empowering and dealing with challenges smallholders encounter. Table 2, in this sense, shows smallholders as either sending, receiving, and spillover systems in broad intercoupled systems. Table 3 shows pericoupling and telecoupling flows connecting smallholders to other systems from near to far distances. This does not implicate case studies without using the metacoupling framework as failing to account for the dynamism of smallholder systems; each pursuit was indeed focused on multiple complex relationships influencing smallholder livelihoods and well-being. We offer this insight to encourage researchers to consider the multiple forms that smallholders and smallholder livelihoods take as well as the corresponding range of engagement with external systems.

In a previous smallholder telecoupling literature [41], telecoupling is interchangeably used as "global receiving system." Such usage seems to craft research questions from the perspective of the smallholder systems in their most apparent form: acting as the sending system for agricultural goods. However, this view risks overlooking the multi-dimensional nature of smallholders and smallholder systems, such as the multiple positions that smallholders may play as sending, receiving, and spillover systems. More importantly, our paper uses the metacoupling framework to investigate the variety of flows that smallholders connect to other systems, particularly the distance of flows, and thus sheds light on the often overlooked pericoupling that smallholders have.

Particularly, using the flow-based framework can help researchers identify and make visible spillover effects that smallholders face. Spillover effects were often overlooked when flows with adjacent or distant systems were not taken into account because of a tendency to view a system as either driving or being directly impacted by a particular process. When investigating a spillover effect, the focal system is neither a driver nor an intended recipient [55]; however, these "hidden" systems can yield critical insights to the benefits and repercussions resulting from today's global and accelerating network of system linkages. For example, the certified organic palm oil producers in Colombia might have been overlooked if attention was directed solely to large oil palm producers and traders as the initiator or recipient of a telecoupling flow; or to smallholders that have operations within the buffer zone of large agricultural investments in many regions of the world [69,70].

In placing these case studies under the lens of intercoupling, we increase the solution space and opportunities for smallholders' sustainability to the intercoupled systems and reveal the potential impacts from smallholders to linked systems and vice versa. For instance, in order to increase smallholders' share of the benefits from international trade, the specific flows that connect them with actors at different scales were studied to ensure the power balance associated with the flows [68,69]. Moreover, we discovered several trends. Of course, we do not claim that these case studies are representative of all smallholder studies; the case studies discussed in this article were provided by this paper's co-authors following a special session at the 2018 US-IALE conference. A representative sample would require an exhaustive literature review with clearly specified criteria for case selection and removal.

Smallholders integrated in pericoupled systems often experience positive outcomes (Table 2). We see labor migration and food sharing from the regional pericoupled cases that enable smallholders to support their family members in multiple ways. Collaboration of water usage (No. 6-Kenya-Water) is another positive example. The nearby- to regional-adjacent connections seem to likely provide more livelihood options for smallholders than without them. This is also in line with many studies that suggest diversified livelihoods will likely reduce risks and increase resilience for smallholders [36,84]. On the other hand, smallholders in telecoupled systems show a less clear pattern. How to improve the positive effects for these smallholders needs further exploration.

Surprisingly, there was a relatively even split between case studies in which agents were active in shaping the flow and case studies where agents may lack agency (see Table 2). We had expected more cases to consist of smallholders playing passive roles because small-scale farmers are often characterized merely as participants to the kinds of activities associated with globalization [27,32,85,86]. Examples of this type of low agency are those cases where smallholders lose property access or are coerced into altering their traditional cultivation activities because of the actions of large agribusiness mono-plantations funded by external investment (e.g., No.8-Madagascar-Vanilla, No.9-Myanmar-Rubber). These large mono-culture investments may be accompanied by adverse environmental impacts (e.g., deforestation and water contamination), as well as detrimental social and socio-economic impacts (e.g., land conflicts between local communities and dependency on external markets). However, as discussed earlier, if smallholders in the spillover system of the LAIs can still integrate into another pericoupled system (e.g., adjacent urban market), the negative outcomes from the LAIs could be reduced and smallholders seem to enjoy more of the benefits.

The cases in which smallholders with medium and high agency offered valuable insight, one such observation is that smallholders can be transformed into active agents when technological advancement allows them to adjust their cultivation practices. For example, in No. 4-Kenya-Tech, farmers in Kenya's semi-arid agricultural areas were introduced to a ridge-furrow mulching system that saves water and increases corn yield. This agricultural advancement was shared by Chinese agricultural officers (i.e., an incoming flow) and, because of the increase in yields, has allowed the Kenyan smallholders to increase their output for market (i.e., an enhanced outgoing flow). The regional and local flows are both associated with medium and high agency. A supporting observation is that adjustments to resource management institutions (e.g., rules governing water use) can transform a pericoupled flow and increase farmer participation in markets (No. 6-Mount Kenya-water). An additional supporting case is the regional flows that enable smallholders with alternative livelihood options (No. 5-Paraiba-dairy and No. 12- Wolong-ecotourism). We believe this case highlights the need for researchers to identify the key constraints in smallholder systems that, when removed, foster a new flow or enhance an existing one.

However, even in cases we classified as low agency, some farmers may still actively look for new opportunities to increase their livelihood and well-being. For example, in No.1-HLJ-Soybean, some farmers seek new avenues to demand more reasonable contracts with input suppliers and to improve their influence in international markets. These farmers have established farm cooperatives, allowing them to negotiate fair prices for agricultural inputs. With this improved leverage, the farm cooperatives are trying to create new pericoupling flows that would target high-end soybean niche markets in Japan and the European Union, thereby avoiding competition with the genetically modified soybeans from Brazil and the United States. Some soybean farmers follow sustainable and organic agricultural practices to grow soybeans that can sell for a premium price. This offers hope that, in their attempt to improve their own economic well-being, smallholders may adopt best management practices and strategies that benefit local, regional, and global biophysical systems.

5. Conclusions

We synthesized 12 smallholder cases by applying the metacoupling framework to each of them, including smallholders transitioning from subsistence to market-oriented production (e.g., No. 10 Kenya-vegetables), individuals facing substantial market competition (e.g., No. 1-HLJ-soybean), and smallholders facing challenges imposed on them by distant actors (e.g., No. 8-Myanmar-rubber). We showed a wide range of roles that smallholders can perform by initiating, facilitating, receiving, and observing the flows within pericoupled and telecoupled systems. With this exercise, we, as researchers, gained detailed insight and provided sufficient breadth to argue for the benefit of using pericoupling and telecoupling frameworks to assess negative and positive impacts of globalization over smallholders across the world.

By investigating the focal smallholders with flows connecting to other systems, our research broadens the understanding of potential livelihood options for smallholders in a metacoupled world. We have broadened the collective understanding of smallholder systems in at least two ways that are overlooked when applying traditional location-based analysis within a system boundary: (1) smallholders are integrated in pericoupled and telecoupled systems. They are connected to other systems by pericoupling and telecoupling flows. The flows can be of various types, including labor, food, natural resources, policy, or agricultural commodities. (2) Flows that integrate smallholders to a telecoupled system without guaranteeing sufficient agency may be less likely to produce positive outcomes in livelihoods and socio-ecological effects, particularly if the smallholder systems are spillover systems. On the other hand, flows connecting smallholders into pericoupled systems can often increase their options of livelihood choices or facilitating positive socio-economic and environmental effects. Smallholders that are engaged in a telecoupled system, creating additional pericoupling flows with a higher agency may be able to endure less negative effects and create potential livelihood options and fruitful outcomes.

Author Contributions: Conceptualization, Y.D., R.F.B.d.S., and J.L.; methodology, Y.D., P.M., and J.L.; formal analysis, Y.D., R.F.B.d.S., and H.Y.; resources, Y.D., R.F.B.d.S., J.G.Z., P.R.F., H.Y., J.Z., and P.M.; writing—original draft preparation, Y.D., P.M., and R.F.B.d.S.; writing—review and editing, J.G.Z., H.Y., P.R.F., J.Z., J.C.P., and J.L.; visualization, Y.D., R.F.B.d.S., and P.M.; supervision, J.L.; project administration, J.L.; funding acquisition, R.F.B.d.S., J.L., and J.G.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Science Foundation Award [DEB-1518518], Complex Dynamics of Telecoupled Human and Natural Systems, and by National Science Foundation Award [1924111], Uncovering Metacoupled Socio-Environmental Systems; Michigan AgBioResearch; Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), grant numbers 15/25892-7 and 14/50628-9; J.G.Z. was supported by the Swiss Programme for Research on Global Issues for Development (r4d programme), which is funded by the Swiss National Science Foundation (SNSF) and the Swiss Agency for Development and Cooperation (SDC), under Grant No. 400440 152167.

Acknowledgments: The authors would like to thank Sue Nichols and anonymous reviewers who provided valuable comments on an earlier draft, as well as people who participated in all the survey and data collection for every case study used in this article.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. United Nations. *Global Sustainable Development Report 2016*; United Nations: New York, NY, USA, 2016.
2. IFAD. *IFAD Annual Report 2001*; IFAD: Roma, Italy, 2001.
3. Jazairy, I.; Alamgir, M.; Panuccio, T. *The State of World Rural Poverty*; Practical Action Publishing: Rugby, UK, 1992; ISBN 978-1-85339-148-4.
4. Herrero, M.; Thornton, P.K.; Bernués, A.; Baltenweck, I.; Vervoort, J.; van de Steeg, J.; Makokha, S.; van Wijk, M.T.; Karanja, S.; Rufino, M.C.; et al. Exploring future changes in smallholder farming systems by linking socio-economic scenarios with regional and household models. *Glob. Environ. Chang.* **2014**, *24*, 165–182. [CrossRef]
5. United Nations. *The Sustainable Development Goals Report*; United Nations: New York, NY, USA, 2018.
6. Mercer, K.L.; Perales, H.R.; Wainwright, J.D. Climate change and the transgenic adaptation strategy: Smallholder livelihoods, climate justice, and maize landraces in Mexico. *Glob. Environ. Chang.* **2012**, *22*, 495–504. [CrossRef]
7. Morton, J.F. The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19680–19685. [CrossRef] [PubMed]
8. Collier, P.; Conway, G.; Venables, T. Climate Change and Africa. In *The Economics and Politics of Climate Change*; Oxford University Press: New York, NY, USA, 2009.
9. Wheeler, T.; Braun, J. von Climate change impacts on global food security. *Science* **2013**, *341*, 508–513. [CrossRef] [PubMed]
10. Bacon, C. Confronting the coffee crisis: Can Fair Trade, organic, and specialty coffees reduce small-scale farmer vulnerability in Northern Nicaragua? *World Dev.* **2005**, *33*, 497–511. [CrossRef]
11. Barrett, C.B. Smallholder market participation: Concepts and evidence from eastern and southern Africa. *Food Policy* **2008**, *33*, 299–317. [CrossRef]
12. Eakin, H.; Bojórquez-Tapia, L.A. Insights into the composition of household vulnerability from multicriteria decision analysis. *Glob. Environ. Chang.* **2008**, *18*, 112–127. [CrossRef]

13. Lee, J.; Gereffi, G.; Beauvais, J. Global value chains and agrifood standards: Challenges and possibilities for smallholders in developing countries. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 12326–12331. [CrossRef]
14. Dolan, C.; Humphrey, J. Governance and trade in fresh vegetables: The impact of UK supermarkets on the African horticulture industry. *J. Dev. Stud.* **2000**, *37*, 147–176. [CrossRef]
15. Dell'Angelo, J.; D'Odorico, P.; Rulli, M.C. Threats to sustainable development posed by land and water grabbing. *Curr. Opin. Environ. Sustain.* **2017**, *26–27*, 120–128. [CrossRef]
16. McCarthy, D.P.; Donald, P.F.; Scharlemann, J.P.W.; Buchanan, G.M.; Balmford, A.; Green, J.M.H.; Bennun, L.A.; Burgess, N.D.; Fishpool, L.D.C.; Garnett, S.T.; et al. Financial costs of meeting global biodiversity conservation targets: Current spending and unmet needs. *Science* **2012**, *338*, 946–949. [CrossRef] [PubMed]
17. Oberlack, C.; Tejada, L.; Messerli, P.; Rist, S.; Giger, M. Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials. *Glob. Environ. Chang.* **2016**, *41*, 153–171. [CrossRef]
18. Zaehringer, J.G.; Atumane, A.; Berger, S.; Eckert, S. Large-scale agricultural investments trigger direct and indirect land use change: New evidence from the Nacala corridor, Mozambique. *J. Land Use Sci.* **2018**, *13*, 325–343. [CrossRef]
19. Si, Z.; Schumilas, T.; Scott, S. Characterizing alternative food networks in China. *Agric. Hum. Values* **2015**, *32*, 299–313. [CrossRef]
20. Betz, M.E.; Farmer, J.R. Farmers' market governance and its role on consumer motives and outcomes. *Local Environ.* **2016**, *21*, 1420–1434. [CrossRef]
21. Chen, X.; Frank, K.A.; Dietz, T.; Liu, J. Weak Ties, Labor Migration, and Environmental Impacts: Toward a Sociology of Sustainability. *Organ. Environ.* **2012**, *25*, 3–24. [CrossRef]
22. Seto, K.C.; Reenberg, A.; Boone, C.G.; Fragkias, M.; Haase, D.; Langanke, T.; Marcotullio, P.; Munroe, D.K.; Olah, B.; Simon, D. Urban land teleconnections and sustainability. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7687–7692. [CrossRef]
23. Liu, W.; Vogt, C.A.; Luo, J.; He, G.; Frank, K.A.; Liu, J. Drivers and Socioeconomic Impacts of Tourism Participation in Protected Areas. *PLoS ONE* **2012**, *7*, e35420. [CrossRef]
24. Almeyda, A.M.; Broadbent, E.N.; Wyman, M.S.; Durham, W.H. Ecotourism Impacts in the Nicoya Peninsula, Costa Rica. *Int. J. Tour. Res.* **2010**, *819*, 803–819. [CrossRef]
25. He, G.; Chen, X.; Liu, W.; Bearer, S.; Zhou, S.; Cheng, L.Y.; Zhang, H.; Ouyang, Z.; Liu, J. Distribution of economic benefits from ecotourism: A case study of Wolong Nature Reserve for Giant Pandas in China. *Environ. Manage.* **2008**, *42*, 1017–1025. [CrossRef]
26. Yang, H.; Yang, W.; Zhang, J.; Connor, T.; Liu, J. Revealing pathways from payments for ecosystem services to socioeconomic outcomes. *Sci. Adv.* **2018**, *4*, eaao6652. [CrossRef] [PubMed]
27. Crona, B.I.; Van Holt, T.; Petersson, M.; Daw, T.M.; Buchary, E. Using social-ecological syndromes to understand impacts of international seafood trade on small-scale fisheries. *Glob. Environ. Chang.* **2015**, *35*, 162–175. [CrossRef]
28. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J.; et al. Complexity of coupled human and natural systems. *Science* **2007**, *317*, 1513–1516. [CrossRef] [PubMed]
29. Chambers, R.; Conway, G.R. *Sustainable Rural Livelihoods: Practical Concepts for the 21st Century*; Institute of Development Studies: Brighton, UK, 1991.
30. Scoones, I. Livelihoods perspectives and rural development. *J. Peasant Stud.* **2009**, *36*, 171–196. [CrossRef]
31. Barrett, C.B.; Constas, M.A. Toward a theory of resilience for international development applications. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 14625–14630. [CrossRef]
32. Tanner, T.; Lewis, D.; Wrathall, D.; Bronen, R.; Cradock-Henry, N.; Huq, S.; Lawless, C.; Nawrotzki, R.; Prasad, V.; Rahman, M.A.; et al. Livelihood resilience in the face of climate change. *Nat. Clim. Chang.* **2015**, *5*, 23–26. [CrossRef]
33. Dou, Y.; Deadman, P.; Robinson, D.; Almeida, O.; Rivero, S.; Vogt, N.; Pinedo-Vasquez, M. Impacts of Cash Transfer Programs on Rural Livelihoods: A Case Study in the Brazilian Amazon Estuary. *Hum. Ecol.* **2017**, *45*, 697–710. [CrossRef]
34. Vogt, N.D.; Pinedo-vasquez, M.; Brondízio, E.S.; Almeida, O.; Rivero, S. Forest Transitions in Mosaic Landscapes: Smallholder ' s Flexibility in Land- Resource Use Decisions and Livelihood Strategies From World War II to the Present in the Amazon Estuary. *Soc. Nat. Resour.* **2015**, *28*, 1043–1058. [CrossRef]

35. Wright, J.H.; Hill, N.A.O.; Roe, D.; Rowcliffe, J.M.; Kümpel, N.F.; Day, M.; Booker, F.; Milner-Gulland, E.J. Reframing the concept of alternative livelihoods. *Conserv. Biol.* **2016**, *30*, 7–13. [CrossRef]
36. Hanazaki, N.; Berkes, F.; Seixas, C.S.; Peroni, N. Livelihood Diversity, Food Security and Resilience among the Caiçara of Coastal Brazil. *Hum. Ecol.* **2012**, *41*, 153–164. [CrossRef]
37. Kates, R.W.; Travis, W.R.; Wilbanks, T.J. Transformational adaptation when incremental adaptations to climate change are insufficient. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7156–7161. [CrossRef] [PubMed]
38. Liu, J.; Hull, V.; Batistella, M.; Defries, R.; Dietz, T.; Fu, F.; Hertel, T.W.; Izaurralde, R.C.; Lambin, E.F.; Li, S.; et al. Framing Sustainability in a Telecoupled World. *Ecol. Soc.* **2013**, *18*, 19. [CrossRef]
39. Liu, J.; Mooney, H.; Hull, V.; Davis, S.J.; Gaskell, J.; Hertel, T.; Lubchenco, J.; Seto, K.C.; Gleick, P.; Kremen, C.; et al. Systems integration for global sustainability. *Science* **2015**, *347*, 963–973. [CrossRef] [PubMed]
40. Pulver, S.; Ulibarri, N.; Sobocinski, K.L.; Alexander, S.M.; Johnson, M.L.; Mccord, P.F. Frontiers in socio-environmental research: Components, connections, scale, and context. *Ecol. Soc.* **2018**, *23*, 23. [CrossRef]
41. Zimmerer, K.S.; Lambin, E.F.; Vanek, S.J. Smallholder telecoupling and potential sustainability. *Ecol. Soc.* **2018**, *23*, 30. [CrossRef]
42. Liu, J. Integration across a metacoupled planet. *Ecol. Soc.* **2017**, *22*, 29. [CrossRef]
43. Dou, Y.; Millington, J.D.A.; da Silva, R.F.B.; McCord, P.; Vina, A.; Song, Q.; Yu, Q.; Wu, W.; Batistella, M.; Moran, E.; et al. Land-use changes across distant places: Design of a telecoupled agent-based model. *J. Land Use Sci.* **2019**, *14*, 191–209. [CrossRef]
44. Liu, J. Forest Sustainability in China and Implications for a Telecoupled World. *Asia Pacific Policy Stud.* **2014**, *1*, 230–250. [CrossRef]
45. Sun, J.; Mooney, H.; Wu, W.; Tang, H.; Tong, Y.; Xu, Z.; Huang, B.; Cheng, Y.; Yang, X.; Wei, D.; et al. Importing food damages domestic environment: Evidence from global soybean trade. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 5415–5419. [CrossRef]
46. Sun, J.; Tong, Y.; Liu, J. Telecoupled land-use changes in distant countries. *J. Integr. Agric.* **2017**, *16*, 368–376. [CrossRef]
47. Silva, R.; Batistella, M.; Dou, Y.; Moran, E.; Torres, S.; Liu, J. The Sino-Brazilian Telecoupled Soybean System and Cascading Effects for the Exporting Country. *Land* **2017**, *6*, 53. [CrossRef]
48. Deines, J.M.; Liu, X.; Liu, J. Telecoupling in urban water systems: An examination of Beijing's imported water supply. *Water Int.* **2015**, *41*, 251–270. [CrossRef]
49. Yang, W.; Hyndman, D.W.; Winkler, J.A.; Viña, A.; Deines, J.M.; Lupi, F.; Luo, L.; Li, Y.; Basso, B.; Zheng, C.; et al. Urban water sustainability: Framework and application. *Ecol. Soc.* **2016**, *21*, 14. [CrossRef]
50. Da Silva, R.F.B.; Batistella, M.; Palmieri, R.; Dou, Y.; Millington, J.D.A. Eco-certification protocols as mechanisms to foster sustainable environmental practices in telecoupled systems. *For. Policy Econ.* **2019**, *105*, 52–63. [CrossRef]
51. Yang, H.; Lupi, F.; Zhang, J.; Chen, X.; Liu, J. Feedback of telecoupling: The case of a payments for ecosystem services program. *Ecol. Soc.* **2018**, *23*, 45. [CrossRef]
52. Herzberger, A.; Chung, M.G.; Kapsar, K.; Frank, K.A.; Liu, J. Telecoupled food trade affects pericoupled trade and intracoupled production. *Sustainability* **2019**, *11*, 2908. [CrossRef]
53. Liu, J.; Viña, A.; Yang, W.; Li, S.; Xu, W.; Zheng, H. China's Environment on a Metacoupled Planet. *Annu. Rev. Environ. Resour.* **2018**, *43*, 1–34. [CrossRef]
54. Dou, Y.; Silva, R.F.B.; Yang, H.; Liu, J. Spillover effect offsets the conservation effort in the Amazon. *J. Geogr. Sci.* **2018**, *28*, 1715–1732. [CrossRef]
55. Liu, J.; Dou, Y.; Batistella, M.; Challies, E.; Connor, T.; Friis, C.; Millington, J.D.A.; Parish, E.; Romulo, C.; da Silva, R.F.B.; et al. Spillover systems in a telecoupled Anthropocene: Typology, methods, and governance for global sustainability. *Curr. Opin. Environ. Sustain.* **2018**, *33*, 58–69. [CrossRef]
56. Barker, C.; Jane, E.A. *Cultural Studies: Theory and Practice*, 5th ed.; Rojek, C., Ed.; SAGE: London, UK, 2005.
57. Silva, R.F.B.; Batistella, M.; Moran, E.F. Drivers of land change: Human-environment interactions and the Atlantic forest transition in the Paraíba Valley, Brazil. *Land Use Policy* **2016**, *58*, 133–144. [CrossRef]
58. Da Silva, R.F.B.; Batistella, M.; Moran, E.F. Regional socioeconomic changes affecting rural area livelihoods and Atlantic forest transitions. *Land* **2018**, *7*, 125. [CrossRef]

59. Padoch, C.; Brondizio, E.; Costa, S.; Pinedo-vasquez, M.; Sears, R.R.; Siqueira, A. Urban Forest and Rural Cities: Multi-sited Households, Consumption Patterns, and Forest Resources in Amazonia. *Ecol. Soc.* **2008**, *13*, 2. [CrossRef]
60. Oestreicher, J.S.; Fatorelli, L.; Mertens, F.; Lucotte, M.; Béliveau, A.; Tremblay, S.; Saint-Charles, J.; Davidson, R.; Romaña, C.A. Rural livelihood trajectories in the central Brazilian Amazon: Growing inequalities, changing practices, and emerging rural-urban relationships over nearly a decade. *World Dev. Perspect.* **2018**, *10–12*, 34–43. [CrossRef]
61. Tong, Y.; Liu, J.; Li, X.; Sun, J.; Herzberger, A.; Wei, D.; Zhang, W.; Dou, Z.; Zhang, F. Cropping System Conversion led to Organic Carbon Change in China's Mollisols Regions. *Sci. Rep.* **2017**, *7*, 18064. [CrossRef] [PubMed]
62. Zhang, J.; Zhao, X.; Hickey, G.; Tian, T.; Wang, G.; Cui, J.; Zhao, Z.; Xiong, Y. Labor migration and livelihood shift in two social ecotopes with forest conservation: A perspective of coupling human and natural systems (CHANS). in prepared.
63. Jian, Z.; Luo, C.; Zhang, X.; Mo, F.; Xiong, Y. Agronomic strategy to cope with El Nino in semiarid Africa. in prepared.
64. McCord, P.F.; Cox, M.; Schmitt-Harsh, M.; Evans, T. Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya. *Land Use Policy* **2015**, *42*, 738–750. [CrossRef]
65. McCord, P.; Waldman, K.; Baldwin, E.; Dell'Angelo, J.; Evans, T. Assessing multi-level drivers of adaptation to climate variability and water insecurity in smallholder irrigation systems. *World Dev.* **2018**, *108*, 296–308. [CrossRef]
66. Zhu, A. Hot money, cold beer: Navigating the vanilla and rosewood export economies in northeastern Madagascar. *Am. Ethnol.* **2018**, *45*, 253–267. [CrossRef]
67. Andriamihaja, O.R.; Metz, F.; Zaehringer, J.G.; Fischer, M.; Messerli, P. Land Competition under Telecoupling: Distant Actors' Environmental versus Economic Claims on Land in North-Eastern Madagascar. *Sustainability* **2019**, *11*, 851. [CrossRef]
68. Lundsgaard-Hansen, L.M.; Schneider, F.; Zaehringer, J.G.; Oberlack, C.; Myint, W.; Messerli, P. Whose agency counts in land use decision-making in Myanmar? A comparative analysis of three cases in Tanintharyi Region. *Sustainability* **2018**, *10*, 3823. [CrossRef]
69. Zaehringer, J.G.; Lundsgaard-Hansen, L.; Thein, T.T.; Llopis, J.C.; Tun, N.N.; Myint, W.; Schneider, F. The cash crop boom in southern Myanmar: Tracing land use regime shifts through participatory mapping. *Ecosyst. People* **2020**, *16*, 36–49. [CrossRef]
70. Zaehringer, J.G.; Wambugu, G.; Kiteme, B.; Eckert, S. How do large-scale agricultural investments affect land use and the environment on the western slopes of Mount Kenya? Empirical evidence based on small-scale farmers' perceptions and remote sensing. *J. Environ. Manag.* **2018**, *213*, 79–89. [CrossRef] [PubMed]
71. Furumo, P.R.; Rueda, X.; Rodríguez, J.S.; Parés Ramos, I.K. Field evidence for positive certification outcomes on oil palm smallholder management practices in Colombia. *J. Clean. Prod.* **2019**, *245*, 118891. [CrossRef]
72. Furumo, P.R.; Aide, T.M. Characterizing commercial oil palm expansion in Latin America: Land use change and trade. *Environ. Res. Lett.* **2017**, *12*, 024008. [CrossRef]
73. Furumo, P.R.; Mitchell Aide, T. Using soundscapes to assess biodiversity in Neotropical oil palm landscapes. *Landsc. Ecol.* **2019**, *34*, 911–923. [CrossRef]
74. Furumo, P.R.; Barrera-Gonzalez, E.I.; Espinosa, J.C.; Gómez-Zuluaga, G.A.; Aide, T.M. Improve Long-Term Biodiversity Management and Monitoring on Certified Oil Palm Plantations in Colombia by Centralizing Efforts at the Sector Level. *Front. For. Glob. Chang.* **2019**, *2*, 46. [CrossRef]
75. Zhang, J.; Connor, T.; Yang, H.; Ouyang, Z.; Li, S.; Liu, J. Complex effects of natural disasters on protected areas through altering telecouplings. *Ecol. Soc.* **2018**, *23*, 17. [CrossRef]
76. Furumo, P.R. Does certification of oil palm work for smallholders? A case study from Colombia. In *Exploring Inclusive Palm Oil Production*; Jezeer, R., Pasiecznik, N., Eds.; Tropenbos International: Wageningen, The Netherlands, 2019; pp. 10–16. ISBN 9789051131413.
77. Baldwin, E.; Washington-Ottombre, C.; Dell'Angelo, J.; Cole, D.; Evans, T. Polycentric Governance and Irrigation Reform in Kenya. *Governance* **2016**, *29*, 207–225. [CrossRef]
78. Liniger, H.; Gikonyo, J.; Kiteme, B.; Wiesmann, U. Assessing and Managing Scarce Tropical Mountain Water Resources. *Mt. Res. Dev.* **2005**, *25*, 163–173. [CrossRef]

79. Zhan, S.; Huang, L. Rural Roots of Current Migrant Labor Shortage in China: Development and Labor Empowerment in a Situation of Incomplete Proletarianization. *Stud. Comp. Int. Dev.* **2013**, *48*, 81–111. [CrossRef]
80. Li, J.; Feldman, M.W.; Li, S.; Daily, G.C. Rural household income and inequality under the sloping land conversion program in Western China. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 7721–7726. [CrossRef]
81. Chen, S.; Kagatsume, M. Impacts of environmental conservation programs on regional economic structural change in Guizhou, China, from 2002 to 2012: An input–output analysis. *J. Econ. Struct.* **2018**, *7*, 23. [CrossRef]
82. Mo, F.; Wang, J.-Y.; Xiong, Y.-C.; Nguluub, S.N.; Li, F.-M. Ridge-furrow mulching system in semiarid Kenya: A promising solution to improve soil water availability and maize productivity. *Eur. J. Agron.* **2016**, *80*, 124–136. [CrossRef]
83. Liu, W.; Vogt, C.A.; Lupi, F.; He, G.; Ouyang, Z.; Liu, J. Evolution of tourism in a flagship protected area of China. *J. Sustain. Tour.* **2015**, *9582*, 1–24. [CrossRef]
84. Adams, C.; Chamlian Munari, L.; Vliet, N.; Sereni Murrieta, R.S.; Piperata, B.A.; Futemma, C.; Novaes Pedroso, N.; Santos Taqueda, C.; Abrahão Crevelaro, M.; Spressola-Prado, V.L. Diversifying Incomes and Losing Landscape Complexity in Quilombola Shifting Cultivation Communities of the Atlantic Rainforest (Brazil). *Hum. Ecol.* **2012**, *41*, 119–137. [CrossRef]
85. Barrett, C.B. Poverty Traps and Resource Dynamics in Smallholder Agrarian Systems. In *Economics of Poverty, Environment and Natural-Resource Use*; Springer Netherlandsm: Heidelberg, Germany, 2008; Volume 25, pp. 17–40. ISBN 1607255448.
86. Schwarz, A.-M.; Béné, C.; Bennett, G.; Boso, D.; Hilly, Z.; Paul, C.; Posala, R.; Sibiti, S.; Andrew, N. Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. *Glob. Environ. Chang.* **2011**, *21*, 1128–1140. [CrossRef]