Global Environmental Change xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Enhancing the sustainability of commodity supply chains in tropical forest and agricultural landscapes

Peter Newton [a,*], Arun Agrawal [a], Lini Wollenberg [b]

[a] International Forestry Resources and Institutions (IFRI), School of Natural Resources and Environment, University of Michigan, 440 Church Street, Ann Arbor, MI 48109, USA
[b] CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Gund Institute, University of Vermont, 617 Main Street, Burlington, VT 05405, USA

ARTICLE INFO

Article history:
Received 10 December 2012
Received in revised form 29 July 2013
Accepted 6 August 2013

Keywords:
Climate change
Deforestation
Greenhouse gas emissions
Intervention
Land-use change
Livelihoods

ABSTRACT

The rapid expansion of the production of agricultural commodities such as beef, cocoa, palm oil, rubber and soybean is associated with high rates of deforestation in tropical forest landscapes. Many state, civil society and market sector actors are engaged in developing and implementing innovative interventions that aim to enhance the sustainability of commodity supply chains by affecting where and how agricultural production occurs, particularly in relation to forests. These interventions – in the form of novel or moderated institutions and policies, incentives, or information and technology – can influence producers directly or achieve their impacts indirectly by influencing consumer, retailer and processor decisions. However, the evidence base for assessing the impacts of these interventions in reducing the negative impacts of commodity agriculture production in tropical forest landscapes remains limited, and there has been little comparative analysis across commodities, cases, and countries. Further, there is little consensus of the governance mechanisms and institutional arrangements that best support such interventions. We develop a framework for analyzing commodity supply chain interventions by different actors across multiple contexts. The framework can be used to comparatively analyze interventions and their impacts on commodity production with respect to the spatial and temporal scales over which they operate, the groups of supply chain actors they affect, and the combinations of mechanisms upon which they depend. We find that the roles of actors in influencing agricultural production depends on their position and influence within the supply chain; that complementary institutions, incentives and information are often combined; and that multi-stakeholder collaborations between different groups of actors are common. We discuss how the framework can be used to characterize different interventions using a common language and structure, to aid planning and analysis of interventions, and to facilitate the evaluation of interventions with respect to their structure and outcomes. Studying the collective experience of multiple interventions across commodities and spatial contexts is necessary to generate more systematic understandings of the impacts of commodity supply chain interventions in forest-agriculture landscapes.

1. Challenges in forest-agriculture landscapes

Many agricultural commodities, including beef, cocoa, palm oil, rubber and soybean, are associated with high rates of deforestation in the tropics. The area occupied by these commodities has grown rapidly over the last two decades (Monfreda et al., 2008; Rudel et al., 2009; Table 1) and is likely to continue to expand as the global population and per capita food consumption continue to increase, accompanied by a dietary shift toward meat and processed foods (FAO, 2009; Kearney, 2010). These trends will put greater pressure on remaining forested areas (Nelson et al., 2010; Wirsenius et al., 2010) releasing forest carbon and thereby increasing the role of agriculture as a driver of climate change. At least 12% of total anthropogenic CO_2 emissions can be attributed to deforestation associated with agriculture (van der Werf et al., 2009; Houghton, 2012), which is in addition to agriculture's direct emissions of 10–12% of the global anthropogenic total in 2005 (Smith et al., 2007).

Tropical forest landscapes subject to agricultural conversion therefore present a key conservation and development challenge. Conservation of remaining tropical forests in these landscapes can help to avoid carbon emissions from deforestation and to maintain biodiversity, ecosystem services, and the provision of subsistence and income-generating resources relevant to forest-based local

* Corresponding author. Tel.: +1 734 709 3734.
E-mail addresses: newton.pete@gmail.com, newtonp@umich.edu (P. Newton), arunagra@umich.edu (A. Agrawal), ewollenb@uvm.edu (L. Wollenberg).

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http://dx.doi.org/10.1016/j.gloenvcha.2013.08.004

Table 1
The extent (in 2010) and change (since 1990) of area, yield, and production of key commodities in the top five producing countries globally.

Commodity	Country	Area		Yield		Production	
		Million ha	% change	Hg/ha	% change	Million tons	% change
Cattle[a]	India					210.20	3.8
	Brazil					209.54	42.4
	USA					93.88	(2.0)
	China					83.80	5.4
	Argentina					48.95	(7.4)
Cocoa	Côte d'Ivoire	2.15	37.2	0.06	12.1	1.24	53.8
	Indonesia	1.03	546.0	0.08	(11.9)	0.81	469.1
	Ghana	1.63	134.4	0.04	(8.1)	0.63	115.5
	Nigeria	1.34	88.0	0.03	(6.8)	0.43	75.3
	Brazil	0.65	(1.6)	0.04	(7.4)	0.23	(8.9)
Palm oil	Indonesia	*4.10*	*278.6*			21.53	792.6
	Malaysia	*3.60*	*108.6*			16.99	178.8
	Thailand					1.29	469.7
	Nigeria					1.09	48.8
	Colombia					0.80	217.5
Rubber	Thailand	1.93	37.8	0.16	56.2	3.05	115.2
	Indonesia	3.06	64.3	0.09	33.1	2.79	118.6
	Malaysia	1.29	(20.1)	0.07	(16.8)	0.86	(33.5)
	India	0.45	55.7	0.19	83.9	0.85	186.2
	China	0.69	75.6	0.10	48.8	0.69	161.4
Soy bean	USA	31.01	35.6	0.29	27.5	90.61	72.9
	Brazil	23.29	102.8	0.29	69.8	68.52	244.4
	Argentina	18.13	265.4	0.29	34.7	52.68	392.3
	China	8.52	12.6	0.18	21.7	15.08	37.0
	India	9.21	259.2	0.11	5.0	9.81	277.1

Data: FAO Stat (www.faostat.fao.org), except data in italics: Koh and Wilcove (2008) (period: 1990–2005). Blanks indicate data not available from these sources. Negative numbers in parantheses.
[a] Cattle production measured in head, not tons.

livelihoods. At the same time, higher food production will be needed to feed a larger, richer, global population, provide subsistence and income-generating opportunities for agriculture-based local livelihoods, and support trade in agricultural commodities for higher national incomes. Addressing this challenge requires considered governance of agricultural expansion and intensification, particularly with respect to the spatial configuration of agricultural and forest areas (Angelsen and Kaimowitz, 2001), improved access to and distribution of food, and reduced food waste.

Commodity agriculture production in tropical forest regions can increase independently of deforestation, through intensification or by agricultural expansion in non-forest areas (Angelsen, 2010). Intensification to achieve higher yields (increased production per unit area) is a necessary but insufficient step toward preventing deforestation. First, although higher yields were achieved historically through a combination of investments in labor, technology, fertilizer, seed stock, and irrigation (Naylor, 1996), and enabled reductions in cultivated land areas globally (Burney et al., 2010) the extent to which the future increase in demand can be met from increased yields is unknown. Second, higher local yields and productivity may over time generate profits and efficiencies that stimulate further agricultural expansion, especially where demand for the commodity is growing and labor is available (Angelsen, 2010; Rudel et al., 2009). Agricultural expansion in non-forest areas is therefore also critical, and effective governance across the agriculture and forest sectors will require coordinated efforts by governments of producer and consumer countries, by civil society, and by those directly involved in commodity supply chains (German et al., 2011).

Many policy-makers and market actors are engaged in developing and implementing innovative supply chain interventions that aim to increase the sustainability of commodity production to enhance environmental, economic or social outcomes (Smith, 2008). Many such interventions, including forest policies, certification programs, and payments for environmental services programs, focus on reducing deforestation as a result of commodity agriculture expansion, by promoting either intensification or expansion into non-forest areas (Meyfroidt and Lambin, 2011). While the extent to which forest loss can be directly attributed to different agricultural products is imperfectly defined, such interventions are grounded on the understanding that agricultural commodity production is in many cases closely associated with deforestation.

Despite a recent increase in the number and spatial scope of supply chain interventions, the evidence base for assessing the impacts of these interventions in reducing the negative impacts of commodity agriculture production in tropical forest landscapes remains limited. Further, there has been little analysis of the governance mechanisms and institutional arrangements that best support such interventions (Wollenberg et al., 2011). As a first step to guide analyses of agricultural supply-chain interventions, this paper develops a framework for comparing and explaining the impacts of interventions by different actors. It describes the range of commodity agriculture interventions being developed and implemented in agriculture-forest landscapes, outlines the governance mechanisms associated with different types of intervention and discusses how different actors and interventions can be expected to influence the impact of commodity agriculture production on deforestation, greenhouse gas emissions and livelihoods.

2. Methods

2.1. Literature review

We reviewed the literature to identify emerging or established interventions that affect agricultural commodity supply chains, using a combination of internet searches of Google Scholar and

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consultations with leading experts researching or supporting research on agricultural commodity supply chains. Literature included peer-reviewed journal articles, peer-reviewed reports and working papers published by international organizations (e.g. the Consultative Group on International Agricultural Research, Union of Concerned Scientists, Prince's Rainforests Project, and World Resources Institute), and non-peer reviewed gray literature (for specific factual information). Individuals working in research organizations, non-governmental organizations (NGOs), governmental agencies, funding agencies, and the private sector were informally questioned about their knowledge of the most up-to-date sources of information about more than 30 emerging and established innovative interventions. Individuals selected for informal discussions had specific information about different commodities, countries and interventions, and collectively represented a wealth of knowledge.

2.2. Data on agriculture and deforestation trends

We used publicly available databases to characterize spatial and temporal trends in agricultural production and deforestation on a global scale. Data were principally sourced from FAOstat (http://faostat.fao.org/).

3. Trends and impacts of key agricultural commodities

We focus in this paper on interventions that target five commodities associated with high rates of tropical forest loss: beef, cocoa, palm oil, rubber and soybeans. There is considerable spatial heterogeneity in the production of these commodities in tropical forest regions: beef and soybean production are dominant agricultural commodities in South America; oil palm and rubber are grown largely in forest areas in Southeast Asia; and cocoa is mainly produced in African forest areas, though oil palm expansion is also rapid in Africa (FAO, 2013; Fig. 1). All five commodities have demonstrated rapid growth in production across the countries in which they are principally produced (Fig. 1). Detailed information concerning the trends in commodity production, and the association between these trends and tropical deforestation are discussed extensively in the peer-reviewed literature on cattle (e.g. Nepstad et al., 2006; Barona et al., 2010; Cederberg et al., 2011; Bustamante et al., 2012), cocoa (e.g. Rice and Greenberg, 2000; Gockowski and Sonwa, 2011), palm oil (e.g. Koh and Wilcove, 2008; Butler and Laurence, 2009; Gutiérrez-Vélez et al., 2011; Carlson et al., 2012), rubber (Li et al., 2007; Ziegler et al., 2009), and soybean (Nepstad et al., 2006; Barona et al., 2010; Arima et al., 2011; Macedo et al., 2012).

4. Framework I: commodity agriculture supply chains

Interventions can be broadly defined as novel or modified institutions and policies, incentives, and information and technology designed to influence the behavior of individuals or groups – in this case, in relation to agricultural commodity production (Agrawal and Ribot, 2012; Fig. 2). We define institutions as the formal and informal mechanisms that structure social and individual expectations, behaviors, and interactions (Young, 2001; Luong, 2004). Policies implemented by local, regional, and national government agencies may affect production – for example, by prohibiting activities that encroach on forest land or by creating the legal framework for the development of more sustainable alternatives – or consumption – for example, by reducing demand for commodities from environmentally damaging land uses. We consider incentives to include both rewards and sanctions (Börner et al., 2011). Rewards are represented by financial compensation that encourages land-uses that may not otherwise be economically viable; sanctions are taxes, fines, or other punishments that make lucrative but ecologically damaging activities less profitable. Finally, we define interventions based on information as those involving the creation, dissemination, or adoption of new or moderated information or technology. Producer access to new information or technological innovations could lead to more sustainable and profitable agricultural practices, and consumer awareness of environmental or social impacts of commodity production can significantly alter the demand for that commodity (Raedeke and Rikoon, 1997; Koh et al., 2010).

Agricultural commodity production is responsive to changes in market demand and supply, and so interventions that influence one or more actors or linkages within supply chains have the potential to exert influence on the production of agricultural commodities. These outcomes require changes in the behavior of groups of actors (e.g. producers, consumers). Such influence may be achieved through mechanisms of 'contagion' (actors are influenced by their neighbors), 'common exposure' (actors respond to similar interventions in a similar manner), or 'selection' (an intervention affects a cluster of connected actors) (Franzese and Hays, 2008). Neighbors and clusters in this sense may be actors that are spatially proximate (mediated by roads and rivers) or that are closely connected or interdependent in the supply chain (mediated by markets). Our assessment of how interventions influence producer behavior therefore focuses on the supply chain context.

Supply chains vary in complexity, but can be thought of as involving actors in three principal *sectors*: the market, the state, and civil society (Lemos and Agrawal, 2006). Market actors are directly involved in the supply chain; state and civil society actors are relatively more peripheral stakeholders that can nonetheless exert substantial influence on the chain even without being obligate participants (Smith, 2008). In turn, each sector contains several distinct *groups* (from hereon) of actors. Key groups of actors within the market sector include producers, processors and packagers, distributors and retailers, and consumers (Ericksen, 2008), as well as producer organizations such as cooperatives. Groups of state actors include all levels of government (local, national, and regional) both in producer and in consumer countries. Finally, the principal groups of actors within the civil society sector include NGOs, research institutes and commodity roundtables. Research institutes may be state-funded, but usually maintain a large degree of autonomy. Commodity roundtables are multi-stakeholder initiatives that seek to improve agricultural sustainability, for example by incentivizing producers to adhere to sustainability standards (Brassett et al., 2011). They usually exclude government actors, but convene groups from both the market sector and civil society, including producers, retailers, NGOs, and academics.

5. Framework II: describing the major supply chain interventions

Interventions implemented by civil society, market and/or state actors can influence any one or more market actors in the supply chain (Smith, 2008). They can do so by moderating patterns of behaviors through changed governance structures that target the land-use practices of agriculture commodity producers, the sourcing policies of distributors and retailers, or the purchase decisions of consumers (Fig. 3). A wide variety of specific interventions have been used across tropical landscapes to target deforestation, greenhouse gas emissions and livelihoods. Many interventions rely on more than one of the three possible mechanisms (institutions, incentives, or information): for example, an agricultural certification program offers both an incentive

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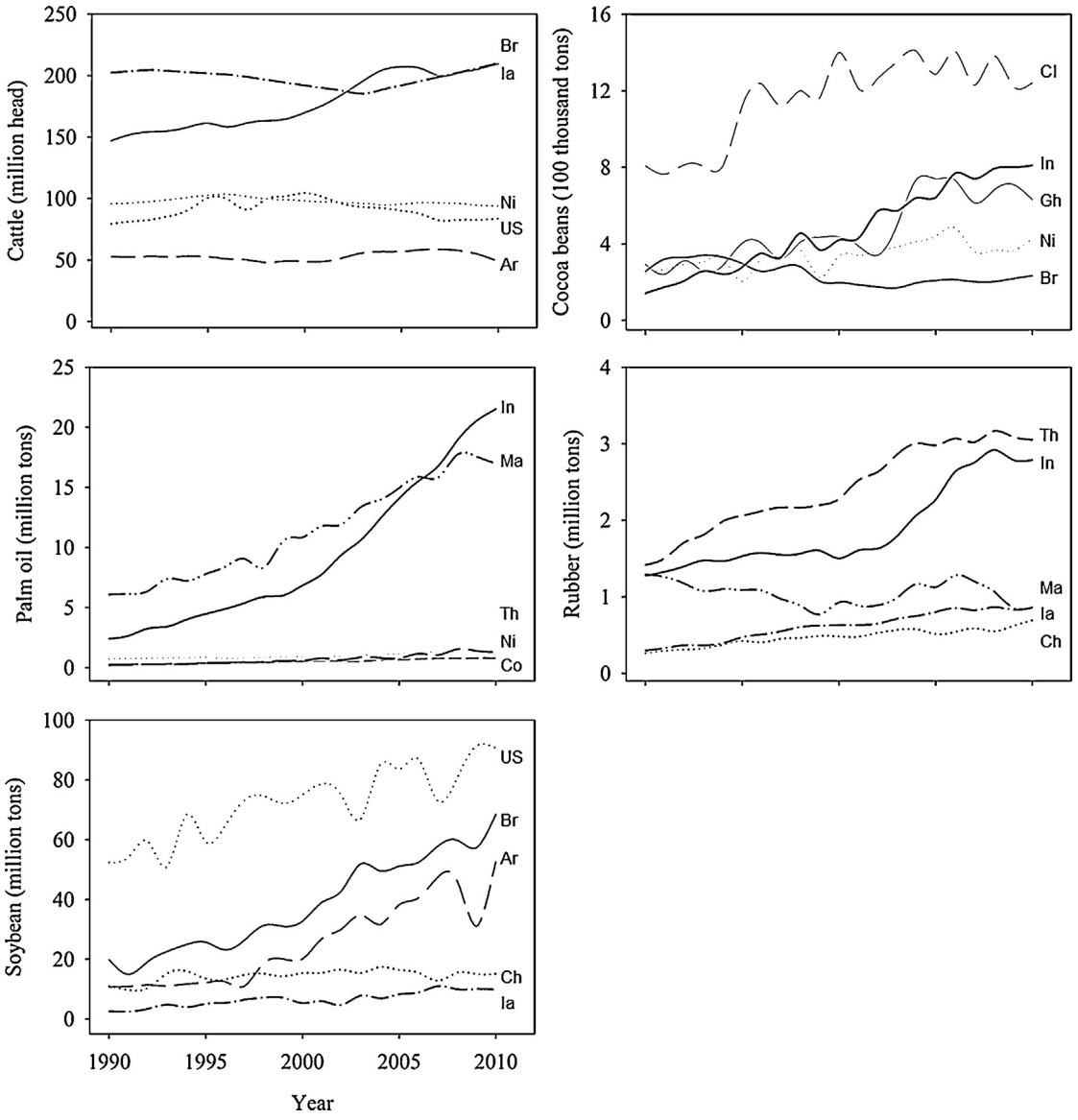

Fig. 1. Temporal trends in the production of five agricultural commodities by the top five producing countries in each case, between 1990 and 2010. Line styles are consistent between graphs: North and South America (dark gray lines; *Argentina*: long dash (Ar); *Brazil*: solid (Br); *Colombia*: short-dash (Co); *USA*: dotted (US)), Africa (light gray lines; *Côte d'Ivoire*: long-dash (Cl); *Ghana*: solid (Gh); *Nigeria*: dotted (Ni)), and Asia (black lines; *China*: dotted (Ch); *India*: dash-dot (Ia); *Indonesia*: solid (In); *Malaysia*: dash-dot-dot (Ma); *Thailand*: long-dash (Th)). *Data*: FAO Stat (www.faostat.fao.org).

to producers (a potential price premium), as well as information to consumers (assurance of lower environmental impact) (Fig. 3). Here, we outline some of the major interventions used in forest-agriculture landscapes, grouped within the three categories according to the relative emphasis on institutions, incentives or information in each case.

5.1. Institutions and policies

5.1.1. Forest policy

Forest policies at both the national and state level can significantly alter deforestation and land-use by producers. For example, Brazil's forest code (law 4.771) requires Amazonian landowners to retain at least 80% of their properties as forest. A proposed revision of the code (April 2012) to reduce this proportion to 50% would have opened the gateway for the clearance of considerable additional forest, including for cattle-ranching, had it not been vetoed by the Brazilian president (Tollefson, 2012). Similarly, a moratorium by the Indonesian government on issuing new permits for oil palm and timber concessions, which began in 2011 and was recently extended until 2015, is expected to directly reduce the extent of legal deforestation within peatland forests (Clements et al., 2010; Austin et al., 2012; Sloan et al., 2012). National forest land-use policy can therefore directly either augment or diminish the potential to control agricultural expansion.

5.1.2. Agricultural policy

Agricultural policy that promotes intensification, expansion or altered practices can also directly affect forest cover. For example, rapid deforestation in Brazilian Amazonia between 1960 and 1980 was in part attributable to federal programs that used tax incentives, credit access and subsidies to encourage investment in large-scale farming and cattle-ranching (Fearnside, 2005). More recently, national policies that promote oil palm development in Indonesia have demonstrated direct conflict with targets for

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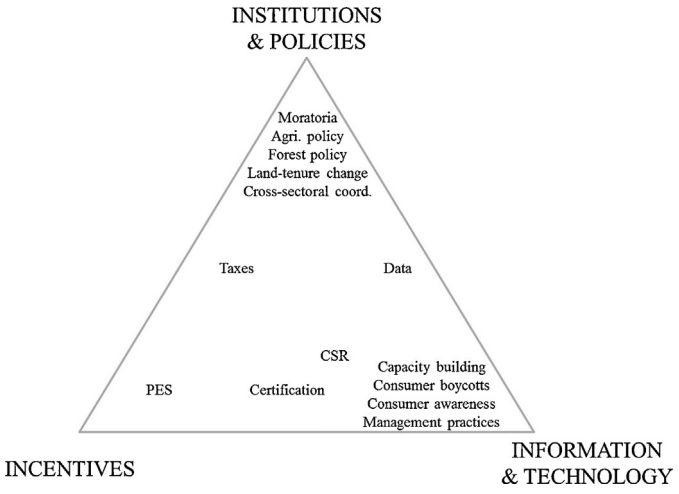

Fig. 2. Interventions in agriculture-forest landscapes, based on combinations of institutions, incentives and information.
Adapted from Agrawal et al. (unpublished data).

reduced deforestation and greenhouse gas emissions (Colchester et al., 2006).

5.1.3. Cross-sectoral coordination

Conflict or coordination between forest and agricultural policy may therefore dramatically enhance or reduce progress toward deforestation goals (Kissinger et al., 2012). Such conflict is evident in Indonesia, where local-government support for oil palm development to provide jobs and income contrasts with national-level goals for reduced deforestation and greenhouse gas emissions. Conversely, actor and policy integration has been successfully demonstrated in two cases in Brazil. First, the Brazilian state of Acre is piloting a sub-national REDD+ program, as part of the Acre Sustainable Development Plan, offering a mix of incentives and payments that encompasses both forests and agriculture, and all scales of producer (Kissinger, 2011). Secondly, the ProAmbiente program engaged smallholders in planning and accounting for their land-use activities, and provides valuable lessons in designing cross-sectoral REDD+ strategies (Moutinho et al., 2011). Coordination requires state and civil society actor groups to agree on objectives and to develop interventions that meet those objectives.

5.1.4. Commodity moratoria

Moratoria may contribute to enhanced sustainability directly, by affecting producer and processor behavior in the long term (e.g. by shifting production onto low-carbon land), or indirectly, by buying time for alternative governance mechanisms (e.g. financial incentives) to be implemented (Austin et al., 2012). A number of commodity-specific moratoria are associated with improved land-use change via the supply chain. For example, the 2006 Soy Moratorium was a pledge by major soybean companies not to trade soybean produced in deforested areas of the Brazilian Amazon. After five years, only 0.13% of the land planted with soybean was in deforested areas (Rudorff et al., 2011). A similar moratorium was begun in 2009 by major Brazilian retailers, slaughterhouses, and distributors who stopped purchases of cattle reared on pasture created by forest conversion (Boucher et al., 2011). Both the soy and beef moratoria were initiated at least partly as a result of pressures from civil society – in significant measure supported by Greenpeace (2006 and 2009) reports and campaigns that highlighted the role of these commodities in Amazonian deforestation. Finally, in an example from consumer countries, the palm oil importer associations of both Belgium and The Netherlands have committed to allowing only sustainable palm oil into those markets by 2015 (Task Force Sustainable Palm Oil, 2010).

5.1.5. Land tenure change and clarification

Poorly defined land-tenure and insecure resource access rights are frequently cited as obstacles to forest conservation and livelihood development, for several reasons (Sunderlin et al., 2009). First, clear land tenure is often a prerequisite to enrollment in incentive initiatives such as REDD+ programs, but such clarity is not frequently associated with the forests used by marginalized groups, including indigenous people and traditional forest populations (Sunderlin et al., 2009). These groups may therefore be excluded from engaging in programs that would increase their capacity to maintain forest quality and to prevent forest conversion by agricultural expansion. Poorer households in South America were less likely to enjoy secure land tenure, to possess a formal land title, or to be able to afford the opportunity or transaction costs, all of which acted as obstacles to participation in payments for environmental services programs (Pagiola et al., 2005).

Secondly, many tropical forest countries contain a large areal extent of land which has been previously deforested and/or which is associated with lower carbon values ('low-carbon' or 'degraded'

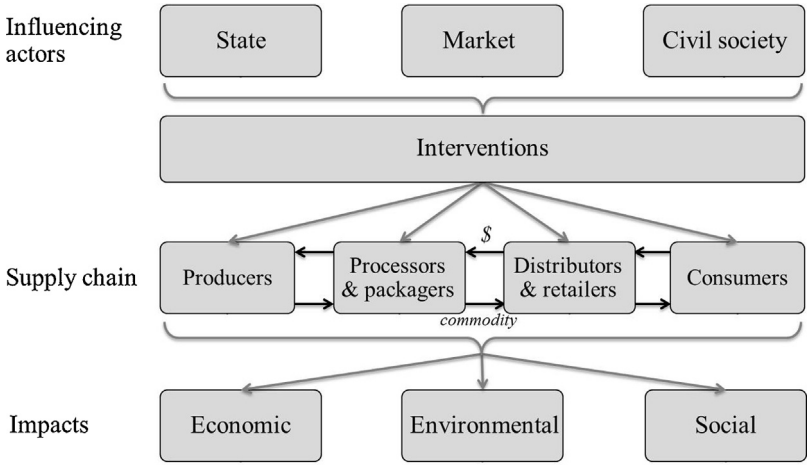

Fig. 3. A framework for analyzing the opportunities for actors to influence commodity supply chains through interventions.

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land) and which may therefore be suitable for more sustainable commodity agriculture and CO_2 emissions mitigation (Fairhurst and McLaughlin, 2009; Smith et al., 2008). However, such 'degraded lands' remain largely unused and new oil palm plantations continue to be established in recently cleared primary or high-carbon secondary forest areas. Agricultural expansion onto degraded land may be constrained both by unclear land tenure (leading to contested land claims), by patchy spatial distribution of such lands, and by higher population densities than in forested areas (Persey et al., 2011). Economic factors are also important: recently converted pasture is more productive than degraded land, and oil palm concessions in primary forest areas carry the benefit of timber sales as an intermediary revenue stream before the plantations become profitable (Buschbacher, 1986; Swarna Nantha and Tisdell, 2009).

In Indonesia, land-tenure uncertainty is expressed both as competing land-use claims from companies and communities and by differences in land-use classification and planning at the levels of national and local government. Similarly, oil palm plantation developers in Peru tend to avoid previously cleared land as it is "frequently under uncertain and disputed tenure; it is simpler to establish tenure over forests, officially owned by the State" (Gutiérrez-Vélez et al., 2011). A number of organizations are attempting to facilitate a shift of commodity agriculture expansion from primary forest onto degraded land. For example, the World Resource Institute's *Project POTICO* began to identify potential 'land-swaps' between peat swamp forest and low-carbon land in Kalimantan (Gingold et al., 2012), but legal and technical barriers prevented completion (Rosenbarger et al., in press).

Legally recognized and enforced land-rights and resource access have the potential to shift land-use away from deforestation and damaging agricultural practices, and to enable forest conservation mechanisms. But undertaking such clarification can be politically costly and government action to clarify tenure has a long history of difficulties (Robinson et al., 2011).

5.2. Incentives

5.2.1. Payments for environmental services

Payments for environmental services (PES) are financial incentives that reward improved land-use and are a direct, conditional mechanism for conservation (Wunder, 2005). Within forest landscapes, the most prominent PES initiative is Reducing Emissions from Deforestation and forest Degradation (REDD+). REDD+ is a set of policies and incentives by which governments in countries with high-greenhouse gas emissions are able to commit funds to countries that demonstrate reduced greenhouse gas emissions from the clearance and degradation of forests (Angelsen, 2008; Parker et al., 2009). Many jurisdictions are also exploring how voluntary carbon market approaches for avoided deforestation that reward individuals, communities and projects on a sub-national scale could nest into national-level REDD+ strategies. In all cases, recipient countries identify contextually appropriate mechanisms to establish baselines for terrestrial emissions and to translate REDD+ funds into avoided deforestation. Financial incentives have largely focused on the forest sector, but the United Nations Framework Convention on Climate Change Cancún Agreement pledged that REDD+ will eventually also address drivers of deforestation.

In addition to multilateral commitments to the REDD+ process, a number of national governments have independently committed funds to support avoided deforestation goals in countries with high pressure to clear forests via bilateral funding arrangements. Norway has agreed to performance-related payments of $0.25 billion to Guyana and $1 billion both to Brazil's Amazon Fund and to Indonesia in return for verifiable emissions reductions from deforestation (Clements et al., 2010; Donovan et al., 2010; Tollefson, 2009). Similarly, in a 2010 agreement with the United Nations Development Program, the government of Ecuador pledged not to extract a vast oil reserve under its Amazonian Yasuni Reserve, if it received approximately US $7 billion raised in emissions credits (Finer et al., 2010). Other innovative arrangements include the formal linkage between California's Global Warming Solutions Act and REDD+-derived emissions offsets from forested states and provinces in developing countries (Agrawal et al., 2011).

5.2.2. Commodity standards and product certification

Voluntary certification programs are experiencing rapid growth in scope, area, and prevalence (Cohn and O'Rourke, 2011). Standards are usually based on a combination of environmental and social objectives, such as operational greenhouse gas emissions, avoided deforestation, or employee working conditions (Steering Committee, 2012). Third-party certification programs have been developed for many products, both by commodity roundtables and by coalitions such as the Sustainable Agriculture Network. The programs themselves are often accredited by an independent body (for example, the ISEAL Alliance) whose code of good practice is seen as a global reference for developing certification standards. Some commodity certification programs are well-established: palm oil certified by the Roundtable on Sustainable Palm Oil (RSPO) accounted for >12% of the global trade in 2011 (RSPO, 2012). Other commodities have only recently become certifiable: the Sustainable Agriculture Network developed a Rainforest Alliance standard for cattle in 2010, which has been implemented in a small number of farms and supply chains in Brazil (SAN, 2010). Certification programs can exert influence at both ends of the supply chain, in the sense that they offer incentives to producers in the form of greater market access, price premiums or protected reputations, and to consumers through assurances of lower environmental impacts of their consumption choices.

5.2.3. Taxes and trade

Governments of consumer countries have the power to affect the supply chain by introducing tax breaks or providing subsidies to certified producers, or by levying taxes on non-certified commodities. For example, in 2011 the European Union proposed to remove import duties on sustainable (RSPO-certified) palm oil to encourage production in producing countries. Conversely, increased taxes on non-certified commodities would drive up their cost, and amplify the demand for sustainable commodities. Trade restrictions, such as the proposed European Union requirement for biofuel producers to pay a fee to offset net carbon emissions, would have a similar effect (Wilcove and Koh, 2010), although such actions are limited by the World Trade Organization. Although a tax also has a regulatory element, its principal effect in these cases is to incentivize behavior associated with greater sustainability.

5.3. Information

5.3.1. Better management practices

Agricultural production may be intensified through the introduction of novel technology, information, or farming practices, collectively termed 'better management practices' (Clay, 2004). However, access to new information and technologies may not be equal across producers, and smallholder farmers particularly may not share the same access to resources as larger-scale producers. Imperfect information and barriers to technology adoption and diffusion may constrain producers' knowledge about, and access to, different production methods, market opportunities, economies of scale, and the trade-offs between

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short- and long-term gains and losses that result from specific land-use decisions (Sunding and Zilberman, 2001).

External actors who facilitate improved flows of information can thus favorably alter producer behavior to yield improved outcomes for both the farmer and the environment. Capacity-building, education, and awareness-raising programs could facilitate the adoption of better practices by producers, lessen their negative impacts, and increase the sustainability of production. Examples include: (1) the Brazilian Agricultural Research Corporation (EMBRAPA), a state organization that aims to "provide solutions for the sustainable development of Brazilian agribusiness through knowledge and technology generation and transfer"; (2) the proposed 'Land-Neutral Agriculture Expansion' mechanism, which could more formally align sustainability and productivity objectives while guarding against leakage (Strassburg et al., 2012); and (3) the 'RSPO Africa Roadshow', which delivers a capacity-building and awareness-raising program across African countries that anticipate a rapid expansion of oil palm plantations. The program could help smallholders transition into sustainable production of this commodity (Proforest, 2012).

5.3.2. Consumer awareness

At the other end of the supply chain, even discerning consumers can only make informed decisions about products that they purchase if the required information is available. Innovative labeling has the potential to inform consumers about the impact of their purchases, and may be introduced as law or as a result of corporate initiatives (Hobbs and Kerr, 2006). For example, in 2011 the European Union introduced Regulation 1169/2011, compelling companies selling products containing 'vegetable oils' (as they were formerly and generically permitted to be listed) to provide a breakdown of every oil contained in the product, including palm oil (EU, 2011). Similarly, the British supermarket chain Tesco piloted a scheme in 2008 to label individual products with an estimated carbon footprint, although the idea was abandoned as too complex to implement (Brenton et al., 2009). But when available, such information may effectively reshape consumer decisions. One study found that consumers who associated margarine made with palm oil with threats to an iconic endangered species such as the tiger, via illustrative product labels, would readily pay a premium for an alternative product that had a lower perceived environmental impact (Bateman et al., 2010).

5.3.3. Consumer boycotts

Information and awareness can manifest themselves not only in individual daily consumption decisions but in the harnessing of collective consumer voices and choices to persuade state and market sector actors to implement further changes to policy or practice. In practice, there are few successful examples of consumer boycotts because it is difficult to mobilize a large enough proportion of the market for the boycott to make a major difference in a large company's revenues. In 2010 Nestlé committed to sourcing only sustainable palm oil by 2015, following a campaign video by Greenpeace that accused Nestlé of using palm oil sourced from deforested regions of Southeast Asia and that encouraged consumers to boycott Nestlé products. The negative publicity from social media pressure may have affected share price, sales or reputation (Khor, 2011).

5.3.4. Corporate social responsibility

Market sector actors can play an important role in the shift toward sustainable supply chains, either in conjunction with or independently of pressure from state or civil society sector actors, or from consumers. Corporate social responsibility (CSR) can lessen the negative impacts of commodity production, particularly if a majority of actors within a given supply chain are engaged, including their subsidiaries, and if those actors view sustainability as a long-term imperative responsibility rather than only a reactionary response to market pressure (Andersen and Skjoett-Larsen, 2009; Kissinger, 2012). Unilever's Sustainable Living Plan (Unilever, 2011) commits to source all of its agricultural raw materials sustainably, and is a business-initiated policy shift toward sustainability (Kissinger, 2012). On a more aggregated scale, the Forest Footprint Disclosure project works with multinational companies to publically assess their impact on deforestation, while the Consumer Goods Forum members pledged in 2010 to sustainably source beef, palm oil, soy, paper and board by 2020. Such initiatives may be small scale relative to overall production, but represent a willingness by businesses to engage and an acknowledgment of the need for sustainability, even if CSR decisions are driven by financial rather than by environmental motivations.

5.3.5. Data

Data on land-use change, from satellite imagery and remote-sensing technologies, and on resource use and production, from collations of national databases (e.g. FAOstat), are increasingly extensive in their precision, accuracy and spatial and temporal coverage (Alves et al., 2009; Hansen et al., 2010). Many of these data are accessible to market, state and civil society actors, enabling them to observe, monitor, analyze and present information about commodity agriculture and deforestation (ISU, 2012), though the privatization and commercialization of some data threatens to constrain this accessibility (Esanu and Uhlir, 2004). Such data may play a role in detecting unsustainable land-use, in spatially targeting interventions, in monitoring and quantifying the impact of those interventions, and in disincentivizing prohibited activities: awareness of the detectability of illegal deforestation may deter potential perpetrators. Extensive monitoring by the PRODES and DETER projects of the Brazilian space research agency (INPE), and near-daily MODIS data from the National Aeronautics and Space Administration (NASA), are jointly credited with helping to detect, respond to and reduce rates of deforestation in Brazil (Alves et al., 2009; Anderson et al., 2005; Kirby et al., 2006). INPE made their data freely available online from 2003, allowing independent research including that which led to the publication of reports (referred to above) associating deforestation with the soy and beef industries (Barona et al., 2010; Greenpeace, 2006, 2009).

6. Framework III: supply chain actor roles

All of the interventions discussed above can contribute to building sustainable commodity supply chains by influencing where and how agricultural production takes place. Some interventions directly target individual producers, while others target different market sector actors (Fig. 3). For example, REDD+ payments to a farmer may directly determine whether that farmer clears a patch of forest. In contrast, an NGO campaign that highlights the negative impacts of commodity agriculture on tropical forests or wildlife may alter consumer-level demand, causing sensitive retailers or processors to alter their sourcing policies, in turn pressuring producers to conform to new sustainability standards to prevent loss of sales and revenue.

6.1. Producers

Commodity supply chains are characterized by varying numbers of market actors within each group; for example, palm oil production in Indonesia is dominated by a few large commercial

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operatives, whereas cocoa production in Côte d'Ivoire is characterized by a large number of smallholder producers. Such differences in supply chain structure mean that state and civil society actors seeking to influence supply chain processes need to use strategies modulated to the specific context of their intervention. Instigating a change in production methods for a commodity dominated by a small number of large-scale producers may justify specific strategies targeted at individual producers. State and civil society actors may have to engage large businesses which have the power to resist unprofitable change but which, if successfully engaged, can alter the nature of the markets rapidly and dramatically.

In contrast, altering land-use behavior within commodity supply chains characterized by a large number of smallholders entails high transaction costs since it is challenging to engage and influence all the different actors. However, ecologically damaging land-use options such as forest conversion are usually more marginally profitable for smallholders and so the opportunity costs to overcome are lower. Therefore, each individual landowner may be less resistant to policy change and there may be greater potential for incentives to tip the balance in favor of more sustainable land-use practices.

6.2. Distributors and retailers

A small number of major distributors and retailers dominate several major commodity supply chains. These companies have strong incentives to protect their market share and reputations, and so are sensitive to consumer pressure. If these companies adopt codes of good practice or implement assurances of sustainability in sourcing commodities, substantial pressure can be exerted on producers to comply with these standards. Examples where the market influence of large retailers has been leveraged include McDonalds' Sustainable Land Management Commitment, which pledged to move toward buying five commodities, including beef and palm oil, from sustainable sources (Mongabay, 2011). Another example is the commitment by Nestlé, Proctor & Gamble and Unilever to source only sustainable, RSPO-certified palm oil by 2015 (Laurance et al., 2010).

6.3. Consumers

Patterns of consumption are determined both by individual decisions, which may be influenced by dynamic societal or cultural norms, and by policies affecting consumer choice of commodities, and their access to them. However, the potential for interventions that target consumers to affect supply chains is limited to the extent of influence of that consumer group in the total market. For example, the United Kingdom consumes just 1% of palm oil traded internationally: as an individual country it can only have a limited impact on the palm oil industry, even with tough legislation and controls against imports and sales of unsustainably produced oil. In contrast, European Union countries collectively account for 22% of consumption. Policy changes at this level thus offer much greater scope for influencing the market (DFID, 2012). Even so, 78% of production remains unaffected by any European Union mechanism that encourages better production methods, and >50% of palm oil is consumed in China and India. These countries have so far shown less inclination to make discriminatory choices and, unless consumers in those markets can be persuaded to buy into sustainably sourced oil, the demand for cheap (and unsustainable) palm oil will continue to grow. The success of roundtables and certification programs may be limited if the biggest markets for commodities do not demonstrate a demand for such programs.

7. Discussion

Diverse and innovative interventions have been developed by civil society, market, and state actors to enhance the sustainability of agricultural commodity supply chains. These interventions are based on new or adapted institutions, incentives, and information (Fig. 2). Metrics of enhanced sustainability include reductions in deforestation and greenhouse gas emissions associated with commodity agriculture expansion, and improvements in livelihoods in forest-agriculture landscapes. A growing body of literature characterizes individual interventions and their impacts, and documents the challenges of implementing these interventions. This paper outlines a subset of these interventions that illustrates their diversity.

Research has focused largely on individual commodities, cases, and countries, with relatively little comparative analysis across contexts. But interventions and their impacts on commodity production can be analyzed comparatively with respect to the spatial and temporal scales over which they operate, the groups of supply chain actors they affect, and the combinations of mechanisms upon which they depend. Studying the collective experience of multiple interventions across commodities and spatial contexts is necessary to generate more systematic understandings of the impacts of a given intervention, as also of the conditions under which different interventions lead to trade-offs and synergies between goals.

One constraint to comparing the governance of commodities is that there are no encompassing conceptual frameworks through which to integrate the aggregate experiences of a range of interventions globally. Our approach enables diverse interventions to be mapped through a general framework that includes relevant actors and interventions, their interaction in supply chains, and their impacts on commodity agriculture production (Fig. 3).

In the context of forest-agriculture landscapes, all of the interventions discussed above aim to alter producer behavior either directly or indirectly through the supply chain. However, the complexity of commodity supply chains and the spatial variation in the drivers of deforestation at local, national, and global scales mean that no single intervention type will effectively alter patterns of land-use change globally. The social-ecological and policy-institutional contexts in which interventions are implemented clearly play an important role in shaping the impacts of interventions. But comparison is still necessary because many processes, challenges and solutions are similar across commodity landscapes. For example, commodity roundtables and certification programs have emerged as interventions in cattle, soy, palm oil and biofuel systems across countries. REDD+ funding is proposed as a mechanism to protect forests and also to reduce the impact of commodity agriculture in forest areas globally. Outcomes from the study of one context may well be relevant outside that system. In sum: interventions may appear disparate, but the governance arrangements, the mechanisms by which interventions influence supply chains, and the impacts of those interventions on deforestation, greenhouse gas emissions and livelihoods share properties that are critical to identify generalizable lessons as also to attribute causal effects.

Our proposed framework for considering intervention characteristics, mechanisms and impacts is less a device for generating testable hypotheses about causal effects (Ostrom, 2009), and is more an analytically useful tool that serves three other purposes (Fig. 3). First, the framework provides the language and structure to characterize the configuration of an intervention vis-a-vis other interventions. Second, it aids the planning and analysis of interventions. Understanding the relationships among different actors and processes is critical for designing new interventions as well as for modifying the structure of existing ones, many of which

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are still evolving. Third, it facilitates the evaluation of interventions with respect to their structure and expected outcomes: (1) the nature of the intervention and associated governance structures; (2) the expected impacts of the intervention on environmental, economic and social outcomes; and (3) the degree to which these impacts can be measured, monitored, and are sustainable. It has been difficult to attribute causality to specific interventions, and common metrics for assessing intervention successes and shortcomings have yet to be adequately explored. Impact evaluation and monitoring may be facilitated by the development of indicators based on an encompassing framework that can be used across contexts.

We discuss below in detail these latter two ways in which our framework may help to evaluate the relationship between interventions and outcomes.

7.1. Intervention planning

7.1.1. Intervention complementarity

Frequently, interventions are not implemented in isolation, but as composite projects that employ multiple, complementary interventions. An initial intervention creates 'enabling conditions' necessary for the subsequent successful implementation of another. In either case, the relationship may be catalytic or obligatory. We offer three examples of interdependent approaches:

(1) The Katingan Project, in Central Kalimantan, aims to conserve forest and to resist oil palm development both by generating carbon credits through an Ecological Restoration Concession, and by meeting the needs of rural communities through a suite of income-generating opportunities (Mazars Starling Resources, 2012). Project implementers anticipate that this combination of activities will maintain local support for forest conservation and will meet environmental, social and economic objectives.
(2) The Brazilian soy and beef moratoria were catalyzed by earlier interventions by civil society organizations, including awareness-raising reports by an international NGO (Boucher et al., 2011). It is uncertain that the political will for such a rapid and dramatic policy commitment would have existed without the pressure and attention generated by earlier reports.
(3) The REDD+ bilateral funding arrangement between Norway and Indonesia is conditional on the successful enforcement of the moratorium by Indonesia on new concession permits for conversion of peat lands and national forest (Clements et al., 2010).

In sum, the combinations of institutions and policies, incentives, and information and technology, matched to the context of the intervention to influence supply chains actors, is critical in determining the degree to which commodity production can be more sustainable, and to which alternatives to the business-as-usual scenario will be feasible.

7.1.2. Intervention inclusivity

A large number of emerging interventions are initiated, elaborated, and implemented by multi-stakeholder partnerships of actors that combine individuals or organizations from two or more of the three main actor sectors: market, state and civil society. Such partnerships may benefit from the combined expertise, political leverage, perceived legitimacy, and human and physical capital of their constituent members.

Intervention programs that have broadly embraced the idea of multi-stakeholder collaboration include: (1) the roundtables that are closely associated with many commodity certification programs, and (2) many REDD+ dialogs, which include both government and civil society actors such as community forest user groups.

Specific examples of multi-stakeholder approaches include:

(1) The Forest Conservation Policy developed to reduce deforestation within concessions of the palm oil company Golden Agri-Resources was the product of a collaboration between Golden Agri-Resources and the non-profit organization TFT, with input from NGO stakeholders including Greenpeace (GAR, 2011).
(2) The world's first voluntary, independent cattle certification program has been developed by the Sustainable Agriculture Network (SAN) and implemented in farms in Brazil by a Sustainable Agriculture Network partner, the Institute of Forestry and Agricultural Management and Certification (Imaflora) (SAN, 2010). The consultation and development process included representatives from the private sector (e.g. cattle farms and slaughter-houses), state sector (e.g. the Brazilian Agricultural Research Corporation (EMBRAPA)) and civil society (e.g. Imaflora, Amigos da Terra).
(3) The development of the soy moratorium in Brazil was led by the Brazilian Association of Vegetable Oil Producers (ABIOVE) and the National Association of Cereal Exporters (ANEC), in collaboration with NGO and state actors (Boucher et al., 2011).

Further, these three examples also demonstrate that many interventions formally include private sector actors: the roundtables, certification programs, soy moratorium and the Golden Agri-Resources Forest Conservation Policy are all examples of interventions coordinated in part by market actors.

These examples suggest that despite higher coordination costs, commodity chain interventions or suites of interventions may be more effective and sustainable if they (a) include a greater diversity of actor groups, and (b) ensure a greater representativeness of stakeholders affected by decisions within the commodity landscape.

7.1.3. Intervention capacity to influence the supply chain

The potential impact of an intervention or suite of interventions can be calculated as a function of (a) the proportion of the local or global commodity production influenced by the intervention, and (b) the additionality achieved by the intervention (a combination of permanence and avoided leakage). The actual impact will depend on the structure of the supply chain, the relationships among actors, and those actors' responses to an intervention. However, these factors vary according to the scale at which those actors operate. Smallholder decision-making, for example, may differ considerably from that of a large-scale commercial operator, who may respond to a different set of incentives.

An example from the oil palm context illustrates how the position and influence of actors in the supply chain may determine the potential impact of interventions. Golden Agri-Resources is the second-largest producer of palm oil in the world. The development of the Forest Conservation Policy (see above) followed a sustained period of campaigning in 2009–2010 by the environmental NGO Greenpeace, which highlighted alleged environmental malpractice by Golden Agri-Resources. As a consequence, a significant number of large retailers canceled palm oil contracts with Golden Agri-Resources. The subsequent development and adoption of the Forest Conservation Policy committed Golden Agri-Resources to improved environmental and social standards that superseded RSPO standards and national laws (GAR, 2011). Golden Agri-Resources was targeted by Greenpeace because of its prominent position in the industry; the impact on producer land practice was relatively rapid because the incentives to preserve reputation and sales were high; and the Golden Agri-Resources' large market

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share meant that this single campaign and forest policy influenced a relatively large land area of oil palm plantations.

We identify two lessons from the above. First, interventions that target groups of actors with a relatively large influence over the total demand and supply for a commodity may be more efficient at producing positive outcomes than those that target less influential actor groups. Second, it may be that a combination of interventions that variously target the behavior of both consumers (e.g. the Greenpeace campaign) and producers (e.g. the Golden Agri-Resources Forest Conservation Policy) are more likely to achieve permanence than those which target just one end of the supply chain. By targeting consumers, an intervention creates strong market incentives for actors further up the supply chain to respond quickly, and so supply chain linkages can be exploited to exert pressure on distributors and retailers, on processors and packagers, and on producers. However, temporal fluctuations in market dynamics and shifting consumer preferences mean that even if a consumer-targeted intervention currently influences a significant proportion of the total commodity market, there is little certainty that demand will not alter in the future. For this reason, a producer-levied intervention may support greater permanence. Together, these approaches may contribute to the development of more sustainable commodity agriculture supply chains.

7.2. Intervention evaluation

7.2.1. Impacts and trade-offs

The impact of any one intervention may be characterized by trade-offs between (1) economic, environmental, and social outcomes, (2) the extent of those outcomes on different spatial and temporal scales, (3) the extent to which those outcomes are felt by different actor groups, and (4) the relative emphasis on effectiveness, efficiency and equitability. A complete discussion of how these trade-offs vary between different sorts of interventions is beyond the scope of this paper, but the importance of monitoring and evaluation in establishing the magnitude and nature of such trade-offs is briefly considered, as are the challenges associated with attribution and causality.

7.2.2. Monitoring and evaluation

The absence of established methods for comparing the relative and absolute influence of interventions on supply chains is a significant barrier to the extraction of more empirical lessons from disparate interventions. The attribution of impacts to specific interventions is notoriously difficult in contexts where multiple programs and policies are simultaneously acting to promote similar or conflicting outcomes, emphasizing the need for well-designed monitoring protocols. An important early step is to identify indicators and metrics of improved environmental, economic and social outcomes that are comparable across space and time. Such indicators will be more powerful if combined with either 'natural experiments' or direct interventions (e.g. randomized control trials).

In all cases, the impact metrics chosen will reflect research priorities. We highlight the objectives of reduced deforestation and greenhouse gas emissions, and the reduction of poverty and development of better socioeconomic conditions for rural forest- and agriculture-dependent people in tropical landscapes. However, we believe our framework can be equally useful to the evaluation of intervention impacts on other outcomes and is a useful point of departure from which to begin this important assessment.

7.2.3. Attribution and causality

Although there is broad consensus that commodity agriculture in tropical forest regions is associated with deforestation, consistent empirical evidence is not always available to accurately determine which agricultural products are the principal drivers of forest loss in a given place or time. Complex sequences of causality characterize the relationship between agriculture and forests in many cases, such as in the ongoing debate regarding the relationship between deforestation and both soy and cattle in Brazilian Amazonia (Barona et al., 2010). The absence of clear and consistent methods to attribute deforestation to specific agricultural products and events may constrain the effectiveness of interventions that aim to improve the governance of commodity supply chains.

8. Conclusion

Changes in land-use in forest-agriculture landscapes present both threats and opportunities to forests, people and the climate. A growing array of innovative interventions based on institutions, incentives and/or information aim to influence how and where commodity agriculture occurs in relation to forests. But comparative assessments and evaluation of different interventions, their impacts, and their lessons are rare. In this paper, we present a general framework to help characterize different interventions, assess the governance structures associated with disparate interventions, and identify common pathways along which different actor groups interact with commodity supply chains. Understanding how interventions affect different parts of the supply chain and how they ultimately exert influence on agricultural production practices is critical to design and develop effective interventions to improve environmental, economic, and social outcomes.

Acknowledgements

This work was supported by the CGIAR research program on Climate Change, Agriculture and Food Security (CCAFS). We thank Alemayehu Ayana, Catherine Benson, David Edmunds, Edward Davey, Andréanne Grimard, Gabrielle Kissinger, Nathalie Walker and two anonymous reviewers for comments on an earlier draft.

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Please cite this article in press as: Newton, P., et al., Enhancing the sustainability of commodity supply chains in tropical forest and agricultural landscapes. Global Environ. Change (2013), http://dx.doi.org/10.1016/j.gloenvcha.2013.08.004

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Please cite this article in press as: Newton, P., et al., Enhancing the sustainability of commodity supply chains in tropical forest and agricultural landscapes. Global Environ. Change (2013), http://dx.doi.org/10.1016/j.gloenvcha.2013.08.004

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