Achieving sustainable development in rural areas in Colombia: future scenarios for biodiversity conservation under land use change

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Abstract

Agricultural expansion is a complex land use change phenomenon with deep environmental and socio-economic consequences, especially across tropical countries where most of this expansion is occurring. Here we use scenario and network analysis combined with sustainability assessment to understand the drivers of landscape change and their effects on sustainable development in Colombia's rural areas, using the Central Magdalena region as a case study, and ultimately informing strategies to reconcile agricultural expansion with biodiversity conservation and rural development. Using this approach we investigated three environmental and agricultural policy scenarios: the Business as Usual scenario, enforcing a stronger regulatory framework, and adopting incentives. Our analysis show that the Business as Usual scenario is not supported by stakeholders and negatively affects most sustainability objectives with the predominant agricultural sectors in the region (cattle ranching and oil palm) not improving social inequality, and threatening biodiversity, natural resources, and food security. Both alternative scenarios improve overall sustainability, including biodiversity. Therefore to reconcile agricultural expansion, biodiversity and sustainable development, it is important to adopt a stronger regulatory and enforcement framework at different administrative levels, as well as incentive schemes focusing on small holders. Our study also shows that history cannot be ignored when thinking about the future and sustainability especially in areas with legacies of strong inequalities caused by armed conflict. Finally, we suggest that combining scenario analysis, network analysis, and sustainability assessment is a useful methodology for studying land use changes holistically, exploring complex systems at different scales, and informing locally-relevant strategies and recommendations, ultimately enabling science to be proactive.

Keywords: Neotropics, oil palm, network analysis, environmental policy, pastures, agriculture.

Highlights

1. We carried out sustainability assessment of agricultural policy scenarios in rural Colombia.
2. Scenarios: Business as Usual (BAU), Regulatory-based (REG), Incentives based (INC)
3. REG and INC achieve more sustainability objectives than BAU including biodiversity
4. Legacies of strong inequalities - armed conflict cannot be ignored in scenario analysis
5. Network analysis and sustainability assessment of scenarios are useful tools to explore complex systems

1. Introduction

With an increasing human population and consumption reconciling agricultural expansion with biodiversity conservation and sustainable development is an ever increasing challenge, especially in the tropics where most of this expansion is occurring (Foley et al., 2005; Gibbs et al., 2010; Tscharntke et al., 2012). Increasing agriculture is a complex land use change phenomenon, being a key driver of both environmental and socio-economic change: it increases food production and stimulates economic development, but it comes at a high environmental cost, particularly in areas with weak and dysfunctional governance such as the tropics (Foley et al., 2011, 2005; Gibbs et al., 2010). Agricultural expansion leads to habitat loss and fragmentation, which in turn are the main causes of biodiversity decline worldwide (Fahrig, 2003; Green et al., 2005). It also accounts for one-third of global greenhouse gas emissions, thus contributing to climate change and is the largest user of fresh water (Foley et al., 2005; Rockström et al., 2009); while its intensive use of oil synthesised fertilizers (+700% in the last 40 years) has altered global nutrients cycles and impacted water quality, ecosystems, and fisheries (Rockström et al., 2009; Tilman et al., 2001). Since agriculture is expanding, both biodiversity conservation and sustainable development will ultimately depend on understanding the different forces (socio-political and economic) acting in these systems and on strategies to achieve integrated landscape management where environmental and socio-economic objectives can be met in the same region (Gardner et al., 2009; Grau et al., 2013; Harvey et al., 2008; Perfecto and Vandermeer, 2008).

Historically traditional shifting agriculture, illegal crops, and extensive cattle ranching, have been the main drivers of deforestation and habitat conversion in South America, including Colombia (Etter et al. 2006; Grau & Aide 2008). However new land uses are now causing landscape conversion, driven by export-oriented industrial agricultural policies and strong market conditions (Grau & Aide 2008, Pacheco 2012). This is primarily related to the expansion of soybean cultivation in Brazil, Argentina, Paraguay and Bolivia, as well as the expansion of oil palm in Colombia, and to lesser extent, in Ecuador and Peru (Pacheco, 2012). The expansion of oil palm has led to the conversion of natural ecosystems, landscape homogenisation, pollution, biodiversity loss, and carbon emissions both across the tropics and in Colombia (Castiblanco et al., 2013; Danielsen et al., 2009; Fitzherbert et al., 2008; Pacheco, 2012; Savilaakso et al., 2014; Turner et al., 2011; Wicke et al., 2011). While the sector can contribute to countries' economic growth and income generation, it can also exacerbate problems associated with social inequalities and concentrate land ownership by favouring industry owners (Castiblanco et al., 2015; McCarthy, 2010; Mingorance, 2006; Vermeulen and Cotula, 2010).

In Colombia extensive cattle ranches still occupy as much as 70% of the agricultural land (Etter et al. 2006a; McAlpine et al. 2009). However oil palm cultivation has been expanding since the 1970s supported by the National government with tax exemptions, subsidised credits, and mandatory consumption through biodiesel blends (Castiblanco et al., 2013), turning the country in the 4th largest oil palm producer worldwide. Such land use changes can impact sustainability in multiple ways; hence it is challenging to design strategies to ensure both biodiversity conservation and socio-economic development across regions where complex land use transitions are occurring.

Scenario analysis combined with sustainability assessment can be a great tool for strategy development and for providing future recommendations because it is a way of investigating future pathways as well as the consequences of different policies within complex systems (Alcamo & Henrichs 2008; Spangenberg 2007, Tzanopoulos et al. 2011). To guide sustainable development, assessment of future scenarios should include all dimensions of sustainability, i.e. environmental, social, and economic aspects, as well as the relations between them (Pope et al., 2004; Reidsma et al., 2011). Strategy development also requires understanding of the drivers of change acting on a system and their impact, which can be achieved with Network Analysis (Wasserman and Faust, 1994).

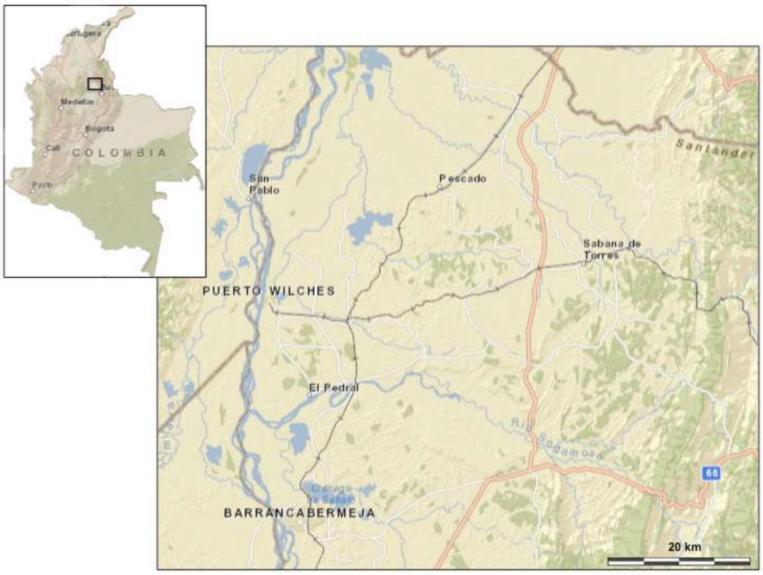
Here we deploy scenario and network analysis combined with sustainability assessment to understand the drivers of change and their effects on sustainability under different environmental and agricultural policy scenarios in the Magdalena region of Colombia, ultimately informing strategies to achieve biodiversity conservation while fostering sustainable development across an agricultural area. This is particularly timely in the country considering it aims to achieve a sustainable and green growth (DNP, 2014) and it is undertaking a peace process, which will open new investment and development opportunities. Finally, our study will demonstrate how combining scenario analysis, network analysis and sustainability assessment is a useful methodology to understand systems in which multiple drivers interact at different scales affecting different aspects of sustainability, to study complex phenomena such as land use changes in a holistic way, and to inform locally-relevant strategies and recommendations.

2. Material and methods

2.1 Study site

The study took place in the Middle Magdalena region of Colombia, which covers the central area of the inter-Andean Magdalena River valley, in the Department of Santander and in the municipalities of Sabana de Torres and Puerto Wilches, extending over 3000 km^2 (Fig.1). The region is part of the rainforest biome; it is naturally characterized by humid tropical forests and wetlands and has a tropical climate with mean annual temperature of 27 ℃ and bimodal rainfall of 2100-2600 mm annually (IDEAM et al., 2007). It hosts endangered and endemic species and it is considered an important genetic corridor as well as an important site for migratory bird species (Hernández-Camacho et al., 1992).

Fig. 1. Map of the study region.



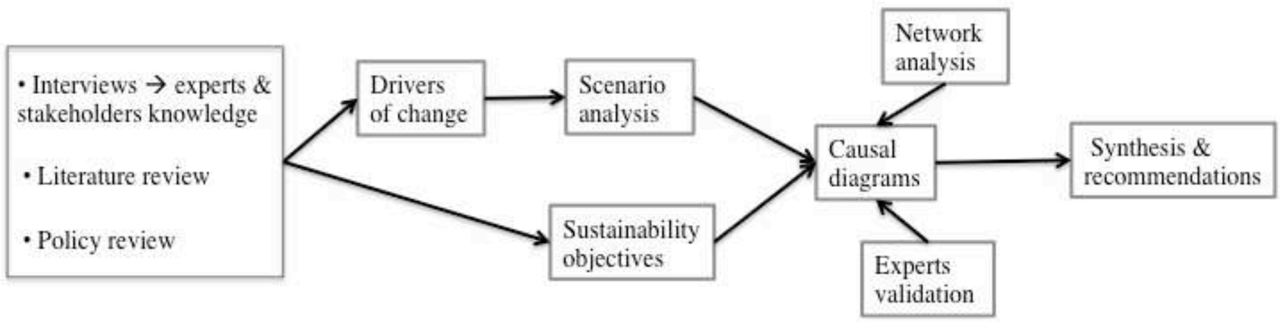
However, the majority of its natural ecosystem has been converted into cattle ranches and oil palm plantations while the remaining natural habitats are threatened by further agricultural conversion (Castiblanco et al., 2013; Etter et al., 2006). Extensive and low productivity cattle ranching and increasing oil palm plantations are the dominant land uses in the region, which has the second largest amount of suitable land for oil-palm conversion in the country (Etter et al. 2006a; Molano 2009; Castiblanco et al. 2013). Other economic activities are gold mining and oil extraction (Molano, 2009).

The economic and social context has been characterised by violence, uneven development, and lack of government presence and institutions, which led to a coercive context of powerful elites, unofficial authorities, and poor participation (Molano, 2009). Poverty is still widespread with all municipalities except Barrancabermeja displaying unmet basic needs indexes greater than 60% (PDPMM-CINEP, 2007). Peace arrived in the region less than ten years ago but land inequality and power imbalance persist, making sustainable rural development challenging to achieve (Molano, 2009).

2.2 Data collection and analysis

We used an integrated methodology that combines scenario analysis and sustainability assessment (Pope et al. 2004; Sheate et al. 2008; Partidário et al. 2009) with network analysis (Tzanopoulos et al., 2011) to investigate the drivers of change in the region, their effect on sustainability under different scenarios, and to define management and policy recommendations for sustainable development (Fig. 2). Scenario analysis is often used in environmental research topics such as land use and biodiversity (Berkel and Verburg, 2012; Sala, 2000) and combined with sustainability assessment can help policy makers to understand the impact of potential policies or management plans (Westhoek et al., 2006). Such assessments can be conducted against a baseline to verify how acceptable the impacts of a proposal would be or against a series of aspirational objectives (Pope et al. 2004). We used the latter because it focuses on positive change, instead of merely minimizing any negative effects (Pope et al. 2004).

Fig. 2. Diagram of the methodological framework employed.



We further integrated network analysis to understand the relationships between drivers, impacts, and sustainability, and to inform management and policy recommendations to reconcile agricultural expansion and rural development with biodiversity conservation in the region. Network analysis is based on graph theory and focuses on the causal relationships (links) among different entities (nodes) (Wasserman and Faust, 1994). It is particularly helpful to explore real world systems in which drivers do not act in isolation and may have multiple consequences, and to identify which entities are key within such systems (de Nooy and Mrvar, 2005).

The research involved a number of stages. First, we conducted a literature review on the region and on Colombian agricultural policy to understand the changes that have occurred in the area and its social, economic, and environmental issues. We then interviewed experts and stakeholders (N=42) to understand further the drivers of change acting in the area and their impact on sustainability, to explore potential future scenarios and interviewees' views on them, and to identify important sustainability objectives. Through the interviews we also wanted to incorporate local knowledge, explore trade-offs, and consider different perspectives of landscape change and views for the future, as recommended by previous studies (Mitchley et al., 2006; Sheate et al., 2008). In order to achieve a comprehensive portrait of the region we ensured that different administrative levels and stakeholders groups were represented in the interviewees sample including: farmers and landowners (N=10), of which three were large holders (>1000ha), and seven were medium and small holders (<1000ha); researchers/experts within ecology, agriculture, and social sciences (N=13); conservation practitioners/NGOs representatives (N=12); politicians and/or authorities (N=11). The interviews were semi-structured and the questions dealt with the main drivers of landscape change in the region in the last 40 years and their impact; objectives that would be important to achieve in the area; visions of the future; and potential solutions to reconcile agricultural expansion and rural development with biodiversity conservation. Through both processes (interviews and literature review) we identified the main drivers of change acting in the system at different scales and their consequences. We then developed a list of sustainability objectives under which the different scenarios would be assessed, incorporating the following aspects: biodiversity conservation, natural resource management, and socio-economic development. The objectives were informed by a review of policy documents, including the National Development Plan for Colombia (DNP, 2014), and by the interviews to ensure their relevance at the local level.

In the following stage we conceptualised the scenarios. Because the focus of the study is how to achieve biodiversity conservation across agricultural landscapes the scenarios were centred on that. We formulated the scenarios with a 25 year the time horizon and based them on the knowledge gathered during the interviews, an extensive literature review on conservation in tropical agricultural regions, current agricultural policies, and desired future states for biodiversity in the region. We considered both peer-reviewed articles as well as reports and policy documents that focused on: tropical agriculture; Colombia's land use, policy trends and consequences, history and armed conflict; sustainability; and strategies to achieve biodiversity conservation in agricultural landscapes. We investigated three alternative scenarios and their implications for overall sustainability: the business as usual scenario (BAU), an incentive based one (INC) and a regulatory one (REG). Both incentive-based conservation approaches vs. regulatory ones are established strategies to achieve conservation outcomes in agricultural landscapes (Arima et al., 2014; Harvey et al., 2008; Kumaraswamy and Kunte, 2013; Lambin et al., 2014; McAlpine et al., 2009; Phalan et al., 2011). Under the INC scenario, the national government increases spending on the environment and provides incentives to landowners to maintain natural habitats and establishing food security crops areas through changes in fiscal policies. Also, we designed the incentives to be even more advantageous and easily available for small farmers. Under the REG scenario increased monitoring and enforcement would ensure that current environmental legislation is enforced and adequate land use plans are developed through a participatory approach. In addition the agricultural sector would be required to perform Environmental Impact Assessments (EIAs), and the current agricultural subsidies would become conditional to maintaining existing natural habitats and meeting social standards (e.g. no land grabbing or displacement).

Following this, we produced network diagrams depicting the causal relationships between drivers of change and their impacts on the previously identified objectives under the three scenarios. We then explored the scenarios, the sustainability objectives, and the diagrams with experts (an ecologist, two social scientists, a land-use planning researcher, and two conservation practitioners), five of which were part of the 42 interviewees at the initial stage. In these network graphs the drivers of change, their consequences, and the sustainability objectives are the nodes, while the causal relationships between them are represented with arrows. The assessment of stakeholders/experts views on each scenario was carried out through discussion on potential scenarios and ways forward during the initial stage interviews and at a later stage through the experts input on the conceptualised scenarios and network graphs. We further investigated these graphs with network analysis and the Pajek software (de Nooy and Mrvar, 2005). This enabled us to identify the central nodes in the graphs, which correspond to the entities that have a primary effect on the system and therefore on the sustainability objectives. We treated the network as an undirected one and used degree centrality. The latter consists in assigning to each node/entity a value that corresponds to the number of lines that are connected to it. We then define as key entities the four nodes with the highest degree centrality (de Nooy and Mrvar, 2005). Finally, we developed a comparison matrix from the network graphs validated by the experts to summarize the positive or negative effects of the three scenarios on each sustainability objective, reporting the driver(s) directly responsible for those effects. Both understanding what entities have a central role in this system and the comparison matrix particularly informed on which measures/strategies should be adopted to achieve the sustainability objectives.

3. Results

3.1 Business as Usual Scenario: drivers of change and effects on sustainability

This scenario describes the process and drivers of change that have been occurring in the region for the last 40 years and projects them and their consequences in the future (25 years). The causal relationships between the drivers of change (D1-D6), their impact, and the sustainability objectives (Obj. 1-18) (Table 1) are represented in Fig. 3 and explained here. The drivers, their impacts, and their effects on sustainability are also listed in Table 2.

Table 1. Sustainability objectives for the study area.

	Study Area Objectives
Rural-economic development	
Obj. 1	Develop a tourism sector
Obj. 2	Improve infrastructures
Obj. 3	Increase employment and income
Obj. 4	Increase small holders potential and competitiveness
Obj. 5	Increase sustainable farming practices
Obj. 6	Increase municipalities income
Social development	
Obj. 7	Achieve better healthcare, education, and housing conditions
Obj. 8	Improve security and human rights
Obj. 9	Improve social equity
Obj. 10	Maintain food security and farming cultural heritage
Institutional capacity	
Obj. 11	Strengthen institutions and law enforcement
Obj. 12	Increase local participation into policy and decision making
Obj. 13	Encourage and increase small farmers alliances/cooperatives
Biodiversity and natural resources	
Obj. 14	Conserve native habitats and connectivity
Obj. 15	Maintain ecosystem services provision
Obj. 16	Conserve species richness and diversity
Obj. 17	Maintain ecosystem resilience to climate change and natural disasters
Obj. 18	Increase environmental awareness and connections between people and biodiversity

Fig. 3. Network graph representing the causal relationships between the drivers of change (D1-D6), their consequences and their positive (green dotted lines) and negative (red dotted lines) effect on the sustainability objectives (1-18) under the BAU scenario. Thicker boxes represent central nodes in the graph.

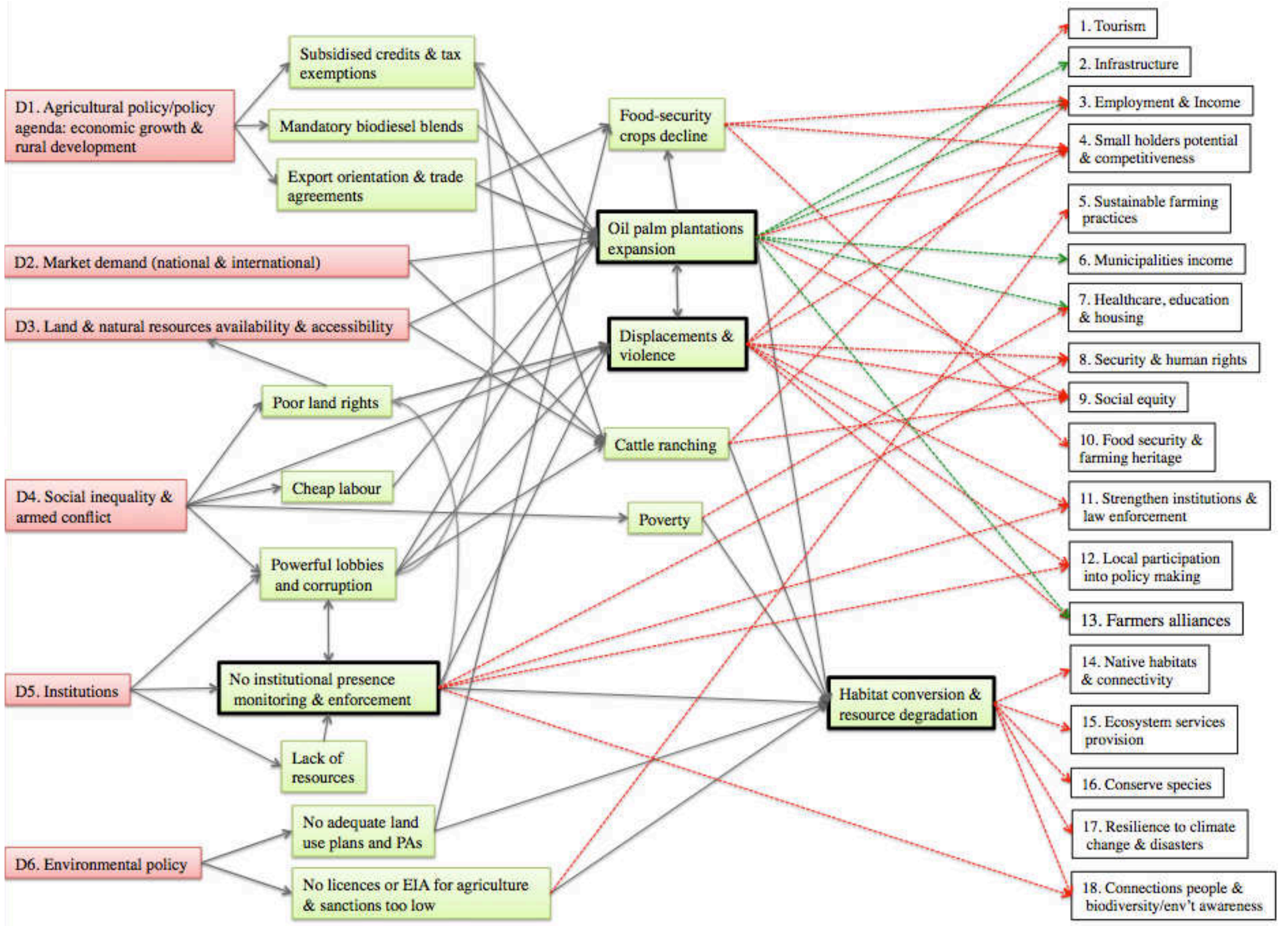


Table 2. A comparison matrix of the drivers and/or their impacts and their positive (+) or negative (-) effect on the sustainability objectives under the tree scenarios (Obj. 1-18).

Obj.	**BAU Scenario**		**Regulatory Scenario**		**Incentives Scenario**	
Rural-economic development						
Obj. 1	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
Obj. 2	(+)	Oil palm expansion	(+)	Oil palm expansion	(+)	Oil palm expansion
Obj. 3	(+)	Oil palm expansion	(+)	Oil palm expansion	(+)	Oil palm expansion
	(-)	Cattle ranching	(-)	Cattle ranching	(-)	Cattle ranching
	(-)	Food security crops decline	(+)	Food security crops area	(+)	Food security crops area
					(+)	Small holders credit access
Obj. 4	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
	(-)	Oil palm expansion	(-)	Oil palm expansion	(-)	Oil palm expansion
	(-)	Food security crops decline	(+)	Food security crops area	(+)	Food security crops area
					(+)	Small holders credit access
Obj. 5	(-)	No licenses/EIA for agriculture	(+)	Licenses/EIA/Sanctions for agriculture	(-)	No licenses/EIA for agriculture
			(+)	Conditions on subsidies	(+)	Incentives for natural habitats and food security crops
Obj. 6	(+)	Oil palm expansion	(+)	Oil palm expansion	(+)	Oil palm expansion
Social development						
Obj. 7	(-)	Poverty	(-)	Poverty	(-)	Poverty
	(+)	Oil palm expansion	(+)	Oil palm expansion	(+)	Oil palm expansion
Obj. 8	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
	(-)	No institutional presence	(+)	Institutional presence	(-)	No institutional presence
Obj. 9	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
	(-)	Cattle ranching	(-)	Cattle ranching	(-)	Cattle ranching
	(-)	Oil palm expansion	(-)	Oil palm expansion	(-)	Oil palm expansion
					(+)	Small holders credit access
Obj. 10	(-)	Oil palm expansion	(-)	Oil palm expansion	(-)	Oil palm expansion
	(-)	Food security crops decline	(+)	Food security crops areas	(+)	Food security crops areas
	(-)	No land use plans				
Institutional capacity						
Obj. 11	(-)	No institutional presence	(+)	Institutional presence	(-)	No institutional presence
	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
Obj. 12	(-)	No institutional presence	(+)	Institutional presence	(-)	No institutional presence
	(-)	Displacements & violence	(-)	Displacements & violence	(-)	Displacements & violence
			(+)	Adequate land use planning		
Obj. 13	(+)	Oil palm expansion	(+)	Oil palm expansion	(+)	Oil palm expansion
	(-)	No institutional presence	(+)	Institutional presence	(-)	No institutional presence
					(+)	Small holders credit access
Biodiversity & natural resources						
Obj. 14	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation
			(+)	Secure natural areas	(+)	Natural habitats
Obj. 15	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation
			(+)	Secure natural areas	(+)	Natural habitats
Obj. 16	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation
			(+)	Secure natural areas	(+)	Natural habitats
Obj. 17	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation
			(+)	Secure natural areas	(+)	Natural habitats
Obj. 18	(-)	No institutional presence	(+)	Institutional presence	(-)	No institutional presence
	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation	(-)	Habitat conversion & resource degradation
			(+)	Secure natural areas	(+)	Natural habitats

The region has two predominant agricultural sectors: cattle ranching and oil palm cultivation, which are supported by the agricultural policy (D1), national and international market demand (D2), and land and natural resource availability (D3). They also have benefitted from social inequalities, the armed conflict (D4) and lack of institutions (D5) through very powerful supporting lobbies. These trends are expected to continue in the years to follow, as well as the sectors' environmental and socio-economic consequences.

Cattle ranching negatively affects the environmental sustainability objectives (Obj. 14-18), social equity (Obj. 3), and does not generate employment (Obj. 9) because of its high inefficiency and its low labour force requirements (Vergara, 2010). Rates of natural habitat conversion for cattle ranching are estimated at 150,000-250,000 ha/year for forest and 50,000 ha/year for savannahs at the national level (Etter et al. 2006). The sector has played an important role in the Colombian society and in shaping the country landscapes since the 1500s, when it was used to gradually gain control over indigenous land during the colonisation (McAlpine et al., 2009). Nowadays the industry is still responsible of land appropriation through habitat clearing later secured by the planting of introduced grasses and used as pasture (Etter et al. 2006).

Oil palm cultivation has been expanding in the area favoured by national policy (D1) through subsidized credit, mandatory biodiesel blends (20% by 2020), and tax exemptions such as the biodiesel sale tax or producers income tax (Law 939 of 2004 and 1970 of 2005) and there are no signs of policy shifting. Although at the national level the oil palm industry only represents 2.6% of the agricultural GDP (MADR, 2013) when it is present in an area, such as our study region, it has important effects. Oil palm plantations cause habitat and biodiversity loss and affect soil quality and water resources through the use pesticides, fertilisers and the draining of water bodies (Obj. 14-18). They also cause forced displacements, violation of human rights, loss of traditional farming practices and local food security, thus negatively affecting Obj. 4, 9, and 10. All these effects are expected to continue into the future. Although not all palm plantations establishment happened through violence and forced displacement, different authors documented the connections between oil palm plantations, armed groups, and violence (Mingorance 2006; Ocampo-Valencia 2009; Segura 2008; Castiblanco et al. 2015). A decrease in food security in the region happened as a consequence of both oil palm expansion, which increase land prices and displaces subsistence crops to more marginal lands, and trade agreements affecting the small farm economy (Salamanca et al. 2009; Infante & Tobón 2010).

On the development side, oil palm plantations increase infrastructure (Obj. 2), employment (Obj. 3) and can achieve lower rates of unmet basic needs and higher municipalities income (Obj. 6 and 7), as also reported by Castiblanco et al. (2015). However, interviewees' views on the quality of employment provided by the sector were not always positive: because of the lack of labour unions as a consequence of violence in the region (Molano, 2009) contracts are often temporary, with few workers' benefits and rights. Oil palm plantations also have a positive effect on the establishment of farmers "productive alliances" (Obj. 13) where the company owning the plantation outsources the production to local farmers, but there is scepticism of how beneficial they really are for farmers because companies retain control over the fruit price (Ocampo-Valencia, 2009). Overall the oil palm sector tends to negatively affect social equity (Obj. 9) because of the differences between farmers earnings and the income generated at the industrialization and commercialization stage (Castiblanco et al., 2015) and it is generally a mean of land concentration because large holders are more likely to access credits and can afford the 4-year wait until the first yield. There seem to be no signs of changes in these trends in the future.

Social inequality and the resulting armed conflict (D4) have long been part of Colombian history with over 60% of land owned by 0.4% of landowners (Albertus and Kaplan, 2012). Land grabbing and forced displacement are also severe issues and affected almost 5 million people in the country from 1985 to 2008 (Fensuagro, 2012). Even if violence and displacement ceased in the region in the last 10 years their numerous consequences are still present. They foster powerful lobbies and corruption and negatively affect tourism (Obj. 1), security and human rights (Obj. 8), social equity (Obj. 9), institutions and law enforcement (Obj. 11), local participation into policy making (Obj. 12), and farmers' alliances (Obj. 13). Displacements can also have positive and negative effects on natural habitat cover (Sánchez-Cuervo and Aide, 2013).

This regional and national context is further aggravated by the lack of institutions (D5), monitoring and enforcement. Because of power imbalance and corruption, politically powerful groups such as large oil palm growers and cattle ranchers blocked most large-scale reforms and have been key factors in influencing agricultural policies by means of providing statistical support, lobbying, and allowing public officials to be part of their board of directors (Albertus and Kaplan, 2012). The same power dynamics apply to the environmental sector: authorities lack resources and power to actually make a difference, while excessive bureaucracy and corruption hinder they credibility and efficiency.

Finally, the environmental policy (D6) is insufficient or not applied, thus failing to protect habitats and biodiversity. Municipalities are required to have land use plans, but these are often out dated, not integrated at different scales and administrative levels, and not applied. Furthermore no Environmental Impact Assessment (EIA) is required for the agricultural sector, sanctions are too low, and not all Departments require companies to have environmental management plans.

Overall, if current policies and drivers of change persist, all trends described are also expected to continue into the future. It is also possible that if the system was to reach unknown thresholds and tipping points it could precipitate into unforeseen environmental states.

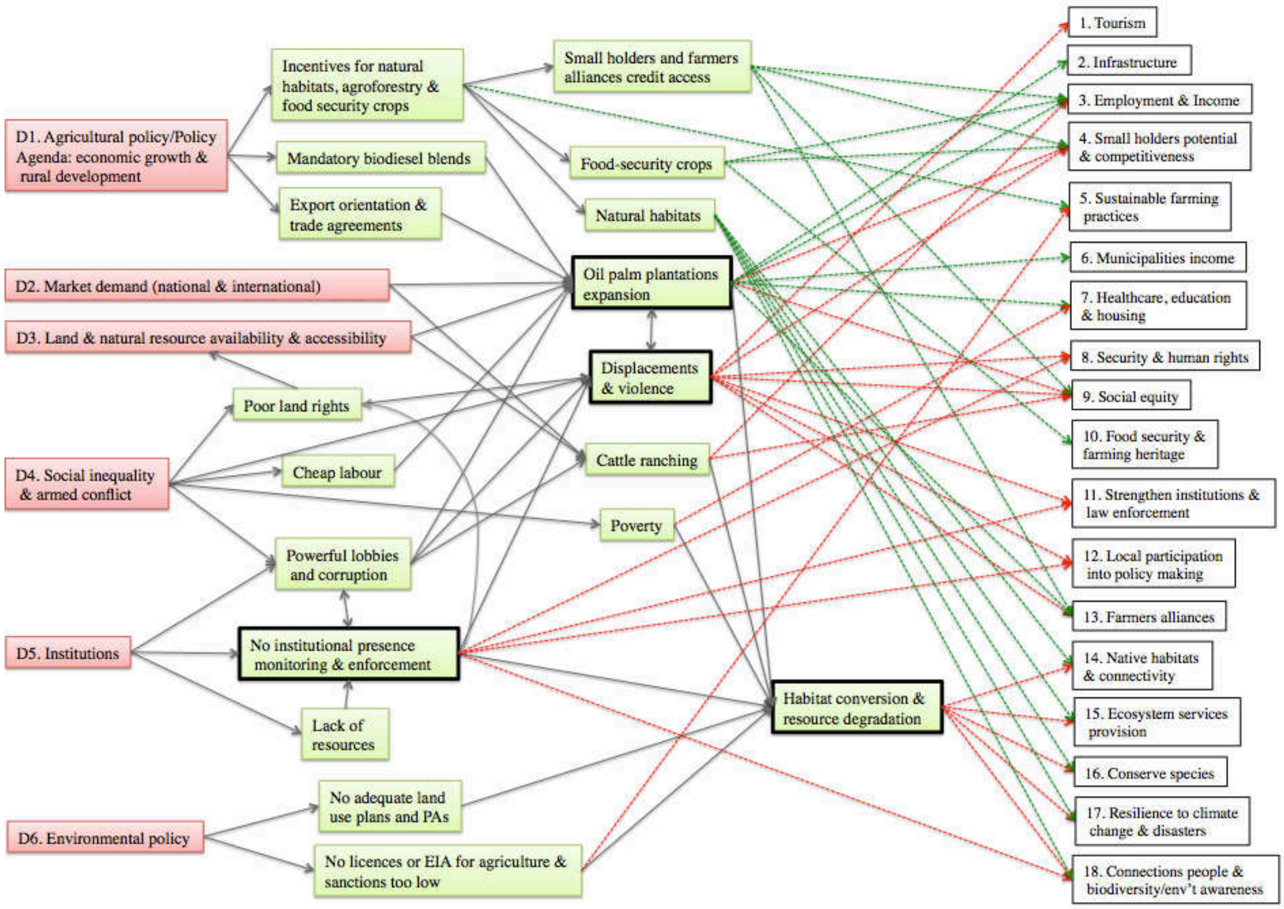
3.1.1 Stakeholders' views

Stakeholders generally held negative views on this scenario as it is producing more negative than positive effects on sustainability. Some of the issues they raised were that the BAU is not improving land and social inequality issues, while it is threatening key natural resources such as biodiversity and water. They claimed that national policy agendas and trade agreements were beneficial for strongly profitable land uses (e.g. oil palm cultivation) at the expenses of small-scale producers, ultimately worsening their condition and exacerbating social inequality. They also reported that institutional weakness and corruption has hindered significant socio-economic improvements.

3.2 Incentives based scenario: drivers of change and effects on sustainability

In the INC scenario, the national government increases its spending on the environment and provides incentives to landowners to maintain natural habitats and establishing food security crops areas with a focus on small farmers alliances/cooperatives. Under this scenario many of the causal links remain the same but we would expect an increase in food security crops production, persistence of some natural habitats in the landscape, and increased credit accessibility for small holders and farmers alliances (Fig. 4). This in turn would impact positively several sustainability objectives: employment and income (Obj. 3), small holder potential and competitiveness (Obj. 4), social equity (Obj. 9), food security and farming heritage (Obj. 10), the establishment of farmers alliances (Obj. 13), and the environmental ones (Obj. 14-18) (Fig. 4). Overall this scenario would represent an improvement to the BAU since more sustainability objectives are positively affected (Table 2).

Fig. 4. Network graph representing the causal relationships between the drivers of change (D1-D6), their consequences and their positive (green dotted lines) and negative (red dotted lines) effect on the sustainability objectives (1-18) under the INC scenario. Thicker boxes represent central nodes in the graph.



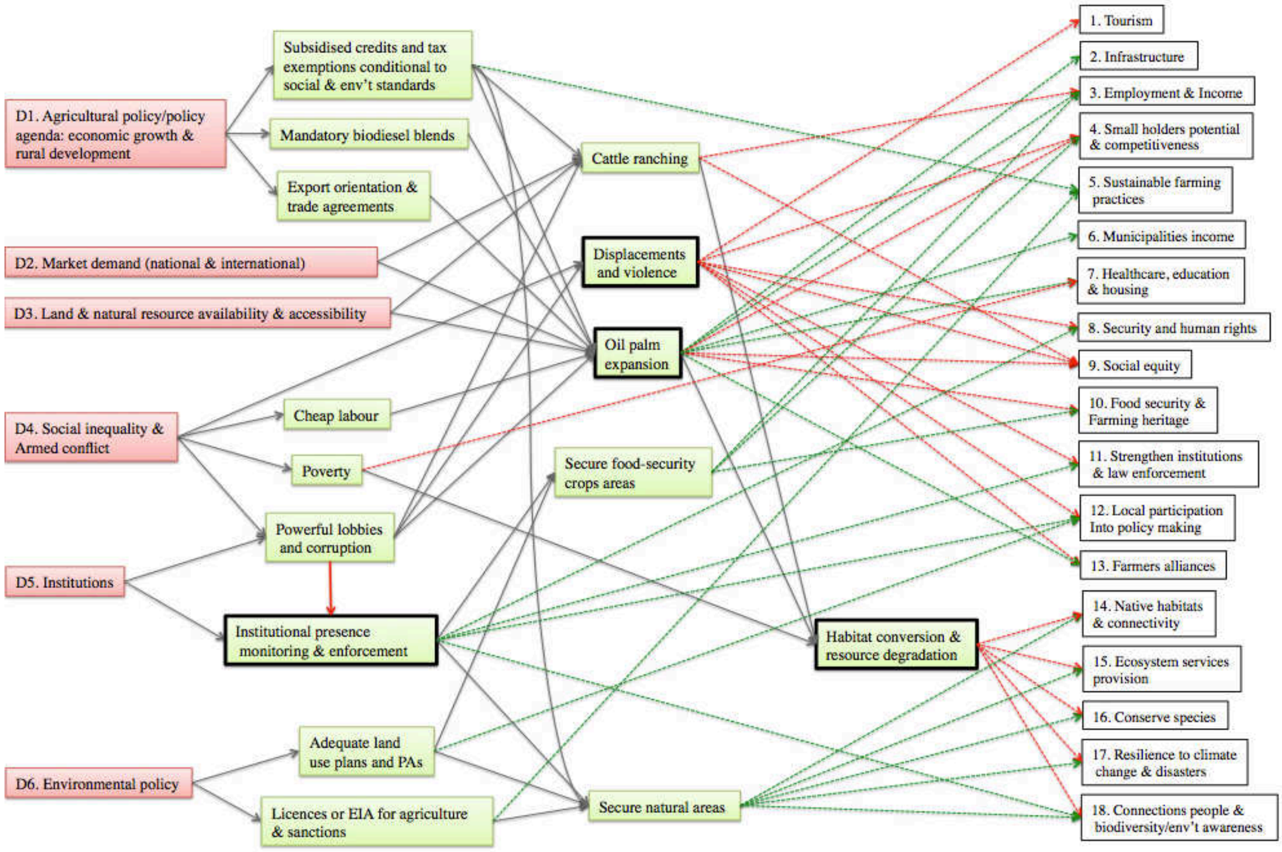
3.2.1 Stakeholders' views

Stakeholders and experts viewed this scenario more positively than the current situation but they felt that even if adequate incentives could achieve some positive and localised changes, without a strong enforcement framework and coordination between different authorities it would be unlikely to achieve long term changes at the scale needed.

3.3 Regulatory based scenario: drivers of change and effects on sustainability

In the REG scenario increased monitoring and enforcement ensures that adequate land use plans are developed and enforced together with environmental law. Also, the agricultural sector is required to perform EIAs, and the current agricultural subsidies become conditional to social and environmental standards. Even with a much stronger regulatory framework in place is unrealistic to think that no habitat conversion and resource use and degradation would occur in the system, hence those entities persist. However because of institutional strengthening and law enforcement and the new conditions on the subsidies to the agricultural sector oil palm plantation should not cause displacements (Fig. 5). Institutional presence, monitoring, and enforcement would also have a positive effect on security and human rights (Obj. 8), while adequate and participatory land use plans would help biodiversity and natural resources conservation (Obj. 14-18), increase participation in policy making (Obj. 12), and improve food security (Obj. 10). Having food security crops areas can also help income generation and small farmers (Obj. 3 and 4). In addition, the introduction of EIAs, adequate sanctions, and new conditions on agricultural subsidies would contribute to secure natural areas. This would have a positive effect on the biodiversity and natural resources sustainability objectives (Obj. 14-18) as well as on achieving sustainable farming practices (Obj. 5). This scenario seems to deliver positive effects on more sustainability objectives than the incentive one (Table 2), however it is highly dependant on institutional presence and high level of enforcement, which are hindered by the powerful lobbies and corruption still present in the system as a consequence of armed conflict and social inequality.

Fig. 5. Network graph representing the causal relationships between the drivers of change (D1-D6), their consequences and their positive (green dotted lines) and negative (red dotted lines) effect on the sustainability objectives (1-18) under the REG scenario. Thicker boxes represent central nodes in the graph.



3.3.1 Stakeholders' views

Stakeholders and experts preferred this scenario to the INC and BAU ones as they considered that a robust regulatory framework is necessary to achieve desired changes. They expressed that empowering institutions and increasing enforcement is key to improve sustainability in the region and also stressed that coordination between authorities and institutions at different levels is imperative.

3.4 Key nodes and identification of management priorities

The sustainability objectives tend to be affected by multiple drivers and their interactions, resulting in a complex network. For example, in the BAU scenario the achievement of species conservation is directly affected by habitat conversion and resource degradation, which in turn are directly and/or indirectly affected by agricultural policy, market demand, institutions, environmental policy, and even the armed conflict. Therefore we used Network analysis to identify the key factors in the achievement of the sustainability objectives under each scenario. The analysis showed that under all scenarios key entities in the system are *oil palm plantation expansion* and *displacements and violence*, followed by the *lack of institutional presence and enforcement*, and *habitat conversion and resource degradation*. This suggests that to achieve a sustainable development of the area we should focus on policies applying to the oil palm sector, improving both its environmental and social standards, as well as addressing violence and displacements or their consequences. Also, halting resource degradation and habitat conversion is key since it underpins the achievement of all sustainability objectives related to biodiversity conservation and natural resources (Obj. 14-18). Finally it is imperative to increase institutional presence, monitoring and enforcement because it directly and/or indirectly affects many sustainability objectives. Changes in different drivers (e.g. agricultural policy, market demand, environmental policy) may not improve significantly the sustainable development of the area unless institutions and monitoring improve.

4. Discussion

Given an increasing human population and per capita consumption, reconciling agricultural expansion with biodiversity conservation and overall sustainable development is a challenging but crucial priority, especially in biodiversity-rich tropical countries such as Colombia. Our analysis showed that agricultural expansion is indeed a complex land use change phenomenon and it does have direct and/or indirect impacts on all aspects of sustainability: environmental, social, and economic. It is therefore important to focus on the agricultural sector to achieve a sustainable development in the region. To understand such complex land use problems it is crucial to understand the system in which they occur, integrating different disciplines and scales (Grau et al., 2013; Nesheim et al., 2014) while unravelling the causal relationships between drivers and impacts; and our methodology enabled us to do so. The exploration of the BAU scenario showed that most sustainability aspects are impacted negatively. Current national policy agendas, trade agreements, and agricultural subsidies are only beneficial to certain land uses (such as oil palm cultivation) and to large holders preferentially thus failing to achieve significant socio-economic development and securing a more sustainable future, as also described by the World Bank (2008) .

Cattle ranching and the expansion of oil palm plantations in the region are damaging ecosystems, biodiversity and natural resources as found elsewhere (Danielsen et al., 2009; Fitzherbert et al., 2008; Koh and Wilcove, 2009; McAlpine et al., 2009) and are not improving social inequality issues. Land and income concentration in turn exacerbate corruption, weaken already frail institutions, and slow long term socio-economic development (Castiblanco et al., 2015; Molano, 2009). The impacts of oil palm cultivation on rural development described in our study region are aligned to the national level and to other regions, i.e. Indonesia (McCarthy, 2010), Brazil (Martinelli et al., 2010), and Africa (Vermeulen and Cotula, 2010). On the contrary, oil palm plantations can benefit small holders but authorities, farmers' alliances, and clear land rights played a key role for this to happen in Colombia and elsewhere (Molano, 2009; Rist et al., 2010).

The analysis of the two alternative scenarios show that both a stronger regulatory framework or different incentives within the agricultural policy could improve sustainable development in the region and are preferable to the current situation. Adopting the regulatory scenario would deliver more objectives but it is also more vulnerable to existing corruption. Both regulatory and incentive based approaches to conservation of biodiversity in agricultural landscapes have been explored in other countries by previous literature, which confirms that the former are generally more effective and bring greater additionality but are also more costly and more prone to leakage and weak governance (Harvey et al., 2008; Lambin et al., 2014; Phalan et al., 2013). On the other hand, voluntary approaches do not necessarily deliver sustainable land use at the scale needed since they are not adopted by all producers within a region or country and can have negative consequences if dropped by future governments or policy changes (Lambin et al., 2014; Phalan et al., 2013).

In order to provide policy recommendations, informed by network and scenario analysis, it is key to focus on the central entities identified by the network analysis and on the administrative levels of the various drivers of change. The national agricultural policy and policy agenda (D1) is an exogenous driver controlled both by the national government and international trends such as globalisation of markets (Hazell and Wood, 2008). Similarly market demand (D2) is both an exogenous and endogenous driver as the demand is local, national and international. The same also applies for social inequality and armed conflict (D4), institutions (D5), and environmental policy (D6) since they are not confined to the study area and may be partially or totally governed at higher administrative levels. Therefore to address the key entities in the graph (i.e. oil palm plantation expansion, displacements and violence, lack of institutional presence and monitoring, habitat conversion and resource degradation) it is key to coordinate policy and decision making at different levels.

Habitat conversion and resource degradation were identified as important entities because they underpin all environmental sustainability objectives. However, providing policy recommendations exclusively aimed at reducing habitat and resource loss might not be highly effective because it would not address the drivers behind them. Therefore the focus of policy recommendations is on the other key entities emerged.

At the *international level* in the developed world reducing consumption, waste, and requiring certified products may help reducing oil palm expansion or making it more sustainable (Koh and Lee, 2012). At the *national level*, as shown by the scenario analysis a stronger regulatory framework is needed. Strict environmental and social criteria should be put in place to gain access to the current subsidies within the agricultural sector, as well as requiring EIAs and increasing sanctions. Stronger regulatory framework have been suggested as successful for biodiversity conservation in productive landscapes elsewhere (Arima et al., 2014; Lambin et al., 2014; Verburg et al., 2014). At the same time new incentives and subsidies to other land uses that are not oil palm should be adopted, and the government could request that all palm oil used in biodiesel blends in the country is certified. Certification and traceability should become prerequisite for the Colombian oil palm industry to keep a share of the international markets while continuing to increase its importance in national ones. However the level at which certification would be promoted has to be determined carefully (Tscharntke et al., 2015) and a strong national and international consumer demand for Certified Sustainable Palm Oil must be created first, as it can be key driver of increased sustainability in agricultural production systems (Ruviaro et al., 2014).

At the *regional* and *local* levels good land use plan should be developed though a participatory approach, integrated at the different scales, and enforced; while oil palm expansion should be directed on already modified pasture lands as identified by Garcia-Ulloa et al. (2012). This would minimise its environmental impact and would ensure that remaining natural habitats in the region and important wetlands are conserved and can serve as refuges for biodiversity, including threatened and iconic species such as jaguars (*Panthera onca*) and West Indian manatees *(Trichecus manatus manatus)*. In addition, to address the consequences of past displacements and violence in the region and of low institutional presence, local and regional authorities, including environmental ones, should be strengthened and restructured to decrease corruption levels.

Stronger institutions, enforcement and coordination at *all administrative levels* are crucial to achieve a more sustainable development (Nesheim et al., 2014). Also, more participatory approaches to decision making and more engagement and knowledge exchange between the different sectors and stakeholders would be highly beneficial, as highlighted by previous research (Pretty, 2008; Reed, 2008; Tzanopoulos et al., 2011). Finally, governments at the national and local level should promote further agricultural (including oil palm) development via individual smallholdings rather than large agribusiness. Policies should focus on small farmer development, competitiveness and access to markets. The need to re-orient rural policies in favour of small farmers to achieve sustainable agricultural landscapes has been highlighted before since it would decrease poverty, increase well-being and social equity, safeguard food security, maintain higher levels of biodiversity, and even improve resilience to climate change (Pokorny et al., 2013; Pretty, 2008; Tscharntke et al., 2012).

5. Conclusions

To achieve biodiversity conservation and sustainable development in the area and similar rural areas in the tropics it is imperative to coordinate policy and decision making at different administrative levels. It is optimal to adopt a mixed policy approach encompassing both a stronger regulatory and enforcement framework as well as incentive schemes. It is also key to advance and enforce good land use planning if we are to conserve remaining habitats, biodiversity and ecosystem services. While to maintain food security and achieve social equity and long term growth policies should be re-oriented to favour small farmers. Lastly institutions at all administrative levels need be strengthened and restructured to decrease corruption. Our analysis has also shown that history cannot be ignored when thinking about the future, especially in areas of armed conflicts that have lead to strong inequalities. Changes in agricultural policies alone are not enough to achieve sustainable development if the deep social and economic impacts of such conflicts (and resulting social structures) are not addressed by other social restructuring policies.

Finally, combining scenario analysis, network analysis and sustainability assessment can provide a useful methodological tool to study complex land use change issues holistically and integrate knowledge from different disciplines, enabling to explore systems with different drivers and desired outcomes from different perspectives (environmental, social and economic) and at different scales. It also allows formulating management and policy recommendations that are locally relevant thanks to stakeholders and experts consultations, ultimately enabling science to be proactive.

Funding disclosure

This study was supported by: 1. The Rufford Foundation, Rufford Small Grant #14968-1. The funder had no role in study design, in the collection, analysis and interpretation of data, in writing the report, and in the decision to submit the article for publication. 2. The Explorers Club, Exploration Fund grant. The funder had no role in study design, in the collection, analysis and interpretation of data, in writing the report, and in the decision to submit the article for publication.

Acknowledgements

We would like to thank J. Murillo, C. Oviedo, Cabildo Verde, and Casa de la Cultura in Sabana de Torres for their local support. Thanks also to Panthera Colombia office staff in Bogota for their logistical help. Finally, we are deeply grateful to all stakeholders who contributed their knowledge during the interviews, and to the experts who helped review the causal diagrams.

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