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

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## 38 **Abstract**

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

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

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## 64 **Highlights**

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

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## 74 **1. Introduction**

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76 With an increasing human population and consumption reconciling agricultural expansion with  
77 biodiversity conservation and sustainable development is an ever increasing challenge, especially in the  
78 tropics where most of this expansion is occurring (Foley et al., 2005; Gibbs et al., 2010; Tschardt et al.,  
79 2012). Increasing agriculture is a complex land use change phenomenon, being a key driver of both  
80 environmental and socio-economic change: it increases food production and stimulates economic  
81 development, but it comes at a high environmental cost, particularly in areas with weak and dysfunctional  
82 governance such as the tropics (Foley et al., 2011, 2005; Gibbs et al., 2010). Agricultural expansion leads to  
83 habitat loss and fragmentation, which in turn are the main causes of biodiversity decline worldwide (Fahrig,  
84 2003; Green et al., 2005). It also accounts for one-third of global greenhouse gas emissions, thus contributing  
85 to climate change and is the largest user of fresh water (Foley et al., 2005; Rockström et al., 2009); while its  
86 intensive use of oil synthesised fertilizers (+700% in the last 40 years) has altered global nutrients cycles and  
87 impacted water quality, ecosystems, and fisheries (Rockström et al., 2009; Tilman et al., 2001). Since  
88 agriculture is expanding, both biodiversity conservation and sustainable development will ultimately depend  
89 on understanding the different forces (socio-political and economic) acting in these systems and on strategies  
90 to achieve integrated landscape management where environmental and socio-economic objectives can be met  
91 in the same region (Gardner et al., 2009; Grau et al., 2013; Harvey et al., 2008; Perfecto and Vandermeer,  
92 2008).

93 Historically traditional shifting agriculture, illegal crops, and extensive cattle ranching, have been the  
94 main drivers of deforestation and habitat conversion in South America, including Colombia (Etter et al.  
95 2006; Grau & Aide 2008). However new land uses are now causing landscape conversion, driven by export-  
96 oriented industrial agricultural policies and strong market conditions (Grau & Aide 2008, Pacheco 2012).  
97 This is primarily related to the expansion of soybean cultivation in Brazil, Argentina, Paraguay and Bolivia,  
98 as well as the expansion of oil palm in Colombia, and to lesser extent, in Ecuador and Peru (Pacheco, 2012).  
99 The expansion of oil palm has led to the conversion of natural ecosystems, landscape homogenisation,  
100 pollution, biodiversity loss, and carbon emissions both across the tropics and in Colombia (Castiblanco et al.,  
101 2013; Danielsen et al., 2009; Fitzherbert et al., 2008; Pacheco, 2012; Savilaakso et al., 2014; Turner et al.,  
102 2011; Wicke et al., 2011). While the sector can contribute to countries' economic growth and income  
103 generation, it can also exacerbate problems associated with social inequalities and concentrate land  
104 ownership by favouring industry owners (Castiblanco et al., 2015; McCarthy, 2010; Mingorance, 2006;  
105 Vermeulen and Cotula, 2010).

106 In Colombia extensive cattle ranches still occupy as much as 70% of the agricultural land (Etter et al.  
107 2006a; McAlpine et al. 2009). However oil palm cultivation has been expanding since the 1970s supported  
108 by the National government with tax exemptions, subsidised credits, and mandatory consumption through  
109 biodiesel blends (Castiblanco et al., 2013), turning the country in the 4<sup>th</sup> largest oil palm producer worldwide.  
110 Such land use changes can impact sustainability in multiple ways; hence it is challenging to design strategies

111 to ensure both biodiversity conservation and socio-economic development across regions where complex  
112 land use transitions are occurring.

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

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

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145 **2. Material and methods**

146 **2.1 Study site**

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

154

155 **Fig. 1.** Map of the study region.



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158 However, the majority of its natural ecosystem has been converted into cattle ranches and oil palm  
159 plantations while the remaining natural habitats are threatened by further agricultural conversion  
160 (Castiblanco et al., 2013; Etter et al., 2006). Extensive and low productivity cattle ranching and increasing  
161 oil palm plantations are the dominant land uses in the region, which has the second largest amount of  
162 suitable land for oil-palm conversion in the country (Etter et al. 2006a; Molano 2009; Castiblanco et al.  
163 2013). Other economic activities are gold mining and oil extraction (Molano, 2009).

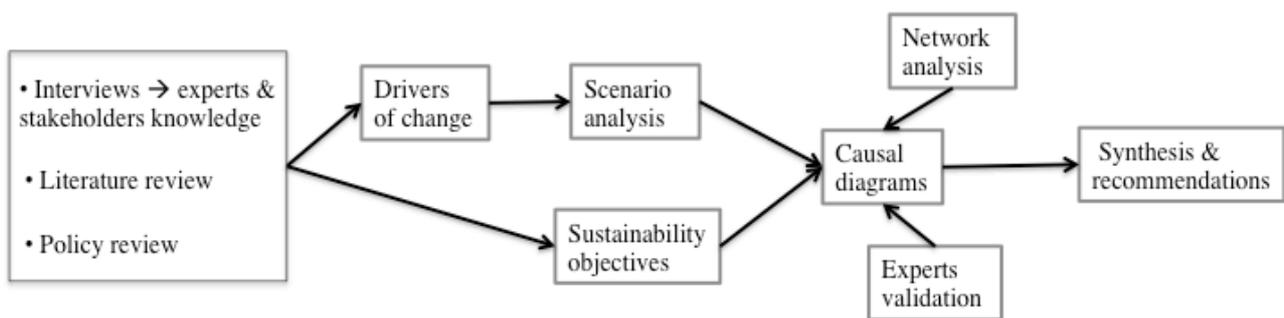
164 The economic and social context has been characterised by violence, uneven development, and lack of  
165 government presence and institutions, which led to a coercive context of powerful elites, unofficial  
166 authorities, and poor participation (Molano, 2009). Poverty is still widespread with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

## 170 2.2 Data collection and analysis

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

181

182 **Fig. 2.** Diagram of the methodological framework employed.



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184 We further integrated network analysis to understand the relationships between drivers, impacts, and  
185 sustainability, and to inform management and policy recommendations to reconcile agricultural expansion  
186 and rural development with biodiversity conservation in the region. Network analysis is based on graph  
187 theory and focuses on the causal relationships (links) among different entities (nodes) (Wasserman and Faust,  
188 1994). It is particularly helpful to explore real world systems in which drivers do not act in isolation and may  
189 have multiple consequences, and to identify which entities are key within such systems (de Nooy and Mrvar,  
190 2005).

191 The research involved a number of stages. First, we conducted a literature review on the region and on  
192 Colombian agricultural policy to understand the changes that have occurred in the area and its social,  
193 economic, and environmental issues. We then interviewed experts and stakeholders (N=42) to understand  
194 further the drivers of change acting in the area and their impact on sustainability, to explore potential future  
195 scenarios and interviewees' views on them, and to identify important sustainability objectives. Through the  
196 interviews we also wanted to incorporate local knowledge, explore trade-offs, and consider different  
197 perspectives of landscape change and views for the future, as recommended by previous studies (Mitchley et  
198 al., 2006; Sheate et al., 2008). In order to achieve a comprehensive portrait of the region we ensured that

199 different administrative levels and stakeholders groups were represented in the interviewees sample  
200 including: farmers and landowners (N=10), of which three were large holders (>1000ha), and seven were  
201 medium and small holders (<1000ha); researchers/experts within ecology, agriculture, and social sciences  
202 (N=13); conservation practitioners/NGOs representatives (N=12); politicians and/or authorities (N=11). The  
203 interviews were semi-structured and the questions dealt with the main drivers of landscape change in the  
204 region in the last 40 years and their impact; objectives that would be important to achieve in the area; visions  
205 of the future; and potential solutions to reconcile agricultural expansion and rural development with  
206 biodiversity conservation. Through both processes (interviews and literature review) we identified the main  
207 drivers of change acting in the system at different scales and their consequences. We then developed a list of  
208 sustainability objectives under which the different scenarios would be assessed, incorporating the following  
209 aspects: biodiversity conservation, natural resource management, and socio-economic development. The  
210 objectives were informed by a review of policy documents, including the National Development Plan for  
211 Colombia (DNP, 2014), and by the interviews to ensure their relevance at the local level.

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

232 Following this, we produced network diagrams depicting the causal relationships between drivers of  
233 change and their impacts on the previously identified objectives under the three scenarios. We then explored  
234 the scenarios, the sustainability objectives, and the diagrams with experts (an ecologist, two social scientists,  
235 a land-use planning researcher, and two conservation practitioners), five of which were part of the 42  
236 interviewees at the initial stage. In these network graphs the drivers of change, their consequences, and the

237 sustainability objectives are the nodes, while the causal relationships between them are represented with  
238 arrows. The assessment of stakeholders/experts views on each scenario was carried out through discussion  
239 on potential scenarios and ways forward during the initial stage interviews and at a later stage through the  
240 experts input on the conceptualised scenarios and network graphs. We further investigated these graphs with  
241 network analysis and the Pajek software (de Nooy and Mrvar, 2005). This enabled us to identify the central  
242 nodes in the graphs, which correspond to the entities that have a primary effect on the system and therefore  
243 on the sustainability objectives. We treated the network as an undirected one and used degree centrality. The  
244 latter consists in assigning to each node/entity a value that corresponds to the number of lines that are  
245 connected to it. We then define as key entities the four nodes with the highest degree centrality (de Nooy and  
246 Mrvar, 2005). Finally, we developed a comparison matrix from the network graphs validated by the experts  
247 to summarize the positive or negative effects of the three scenarios on each sustainability objective, reporting  
248 the driver(s) directly responsible for those effects. Both understanding what entities have a central role in this  
249 system and the comparison matrix particularly informed on which measures/strategies should be adopted to  
250 achieve the sustainability objectives.

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275 **3. Results**

276 **3.1 Business as Usual Scenario: drivers of change and effects on sustainability**

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

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283 **Table 1.** Sustainability objectives for the study area.

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<b>Study Area Objectives</b>	
<b>Rural-economic development</b>	
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
<b>Social development</b>	
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
<b>Institutional capacity</b>	
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
<b>Biodiversity and natural resources</b>	
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

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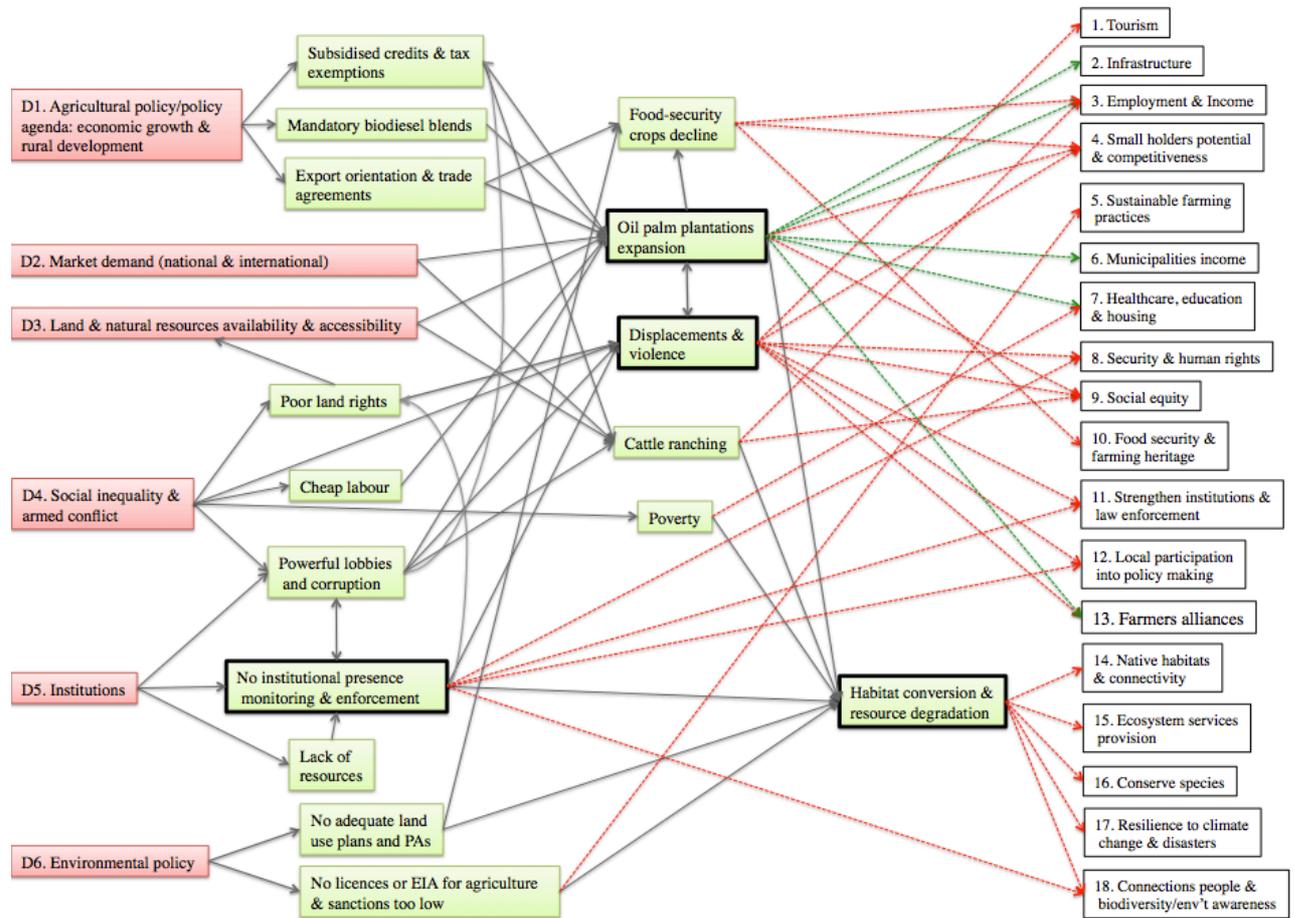
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**Fig. 3.** Network graph representing the causal relationships between the drivers of change (D1-D6), their consequences and their positive (green dotted lines) and negative (red dotted lines) effect on the sustainability objectives (1-18) under the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



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**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
<b>Rural-economic development</b>			
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
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
<b>Social development</b>			
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
Obj. 10	(-) Oil palm expansion	(-) Oil palm expansion	(+) Small holders credit access
	(-) Food security crops decline	(+) Food security crops areas	(-) Oil palm expansion
	(-) No land use plans		(+) Food security crops areas
<b>Institutional capacity</b>			
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
<b>Biodiversity &amp; natural resources</b>			
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

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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.

334 Cattle ranching negatively affects the environmental sustainability objectives (Obj. 14-18), social equity  
335 (Obj. 3), and does not generate employment (Obj. 9) because of its high inefficiency and its low labour force  
336 requirements (Vergara, 2010). Rates of natural habitat conversion for cattle ranching are estimated at  
337 150,000-250,000 ha/year for forest and 50,000 ha/year for savannahs at the national level (Etter et al. 2006).  
338 The sector has played an important role in the Colombian society and in shaping the country landscapes  
339 since the 1500s, when it was used to gradually gain control over indigenous land during the colonisation  
340 (McAlpine et al., 2009). Nowadays the industry is still responsible of land appropriation through habitat  
341 clearing later secured by the planting of introduced grasses and used as pasture (Etter et al. 2006).

342 Oil palm cultivation has been expanding in the area favoured by national policy (D1) through subsidized  
343 credit, mandatory biodiesel blends (20% by 2020), and tax exemptions such as the biodiesel sale tax or  
344 producers income tax (Law 939 of 2004 and 1970 of 2005) and there are no signs of policy shifting.  
345 Although at the national level the oil palm industry only represents 2.6% of the agricultural GDP (MADR,  
346 2013) when it is present in an area, such as our study region, it has important effects. Oil palm plantations  
347 cause habitat and biodiversity loss and affect soil quality and water resources through the use pesticides,  
348 fertilisers and the draining of water bodies (Obj. 14-18). They also cause forced displacements, violation of  
349 human rights, loss of traditional farming practices and local food security, thus negatively affecting Obj. 4, 9,  
350 and 10. All these effects are expected to continue into the future. Although not all palm plantations  
351 establishment happened through violence and forced displacement, different authors documented the  
352 connections between oil palm plantations, armed groups, and violence (Mingorance 2006; Ocampo-Valencia  
353 2009; Segura 2008; Castiblanco et al. 2015). A decrease in food security in the region happened as a  
354 consequence of both oil palm expansion, which increase land prices and displaces subsistence crops to more  
355 marginal lands, and trade agreements affecting the small farm economy (Salamanca et al. 2009; Infante &  
356 Tobón 2010).

357 On the development side, oil palm plantations increase infrastructure (Obj. 2), employment (Obj. 3) and  
358 can achieve lower rates of unmet basic needs and higher municipalities income (Obj. 6 and 7), as also  
359 reported by Castiblanco et al. (2015). However, interviewees' views on the quality of employment provided  
360 by the sector were not always positive: because of the lack of labour unions as a consequence of violence in  
361 the region (Molano, 2009) contracts are often temporary, with few workers' benefits and rights. Oil palm  
362 plantations also have a positive effect on the establishment of farmers "productive alliances" (Obj. 13) where  
363 the company owning the plantation outsources the production to local farmers, but there is scepticism of how  
364 beneficial they really are for farmers because companies retain control over the fruit price (Ocampo-Valencia,  
365 2009). Overall the oil palm sector tends to negatively affect social equity (Obj. 9) because of the differences  
366 between farmers earnings and the income generated at the industrialization and commercialization stage  
367 (Castiblanco et al., 2015) and it is generally a mean of land concentration because large holders are more  
368 likely to access credits and can afford the 4-year wait until the first yield. There seem to be no signs of  
369 changes in these trends in the future.

370 Social inequality and the resulting armed conflict (D4) have long been part of Colombian history with  
371 over 60% of land owned by 0.4% of landowners (Albertus and Kaplan, 2012). Land grabbing and forced

372 displacement are also severe issues and affected almost 5 million people in the country from 1985 to 2008  
373 (Fensuagro, 2012). Even if violence and displacement ceased in the region in the last 10 years their  
374 numerous consequences are still present. They foster powerful lobbies and corruption and negatively affect  
375 tourism (Obj. 1), security and human rights (Obj. 8), social equity (Obj. 9), institutions and law enforcement  
376 (Obj. 11), local participation into policy making (Obj. 12), and farmers' alliances (Obj. 13). Displacements  
377 can also have positive and negative effects on natural habitat cover (Sánchez-Cuervo and Aide, 2013).

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

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

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

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### 394 *3.1.1 Stakeholders' views*

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

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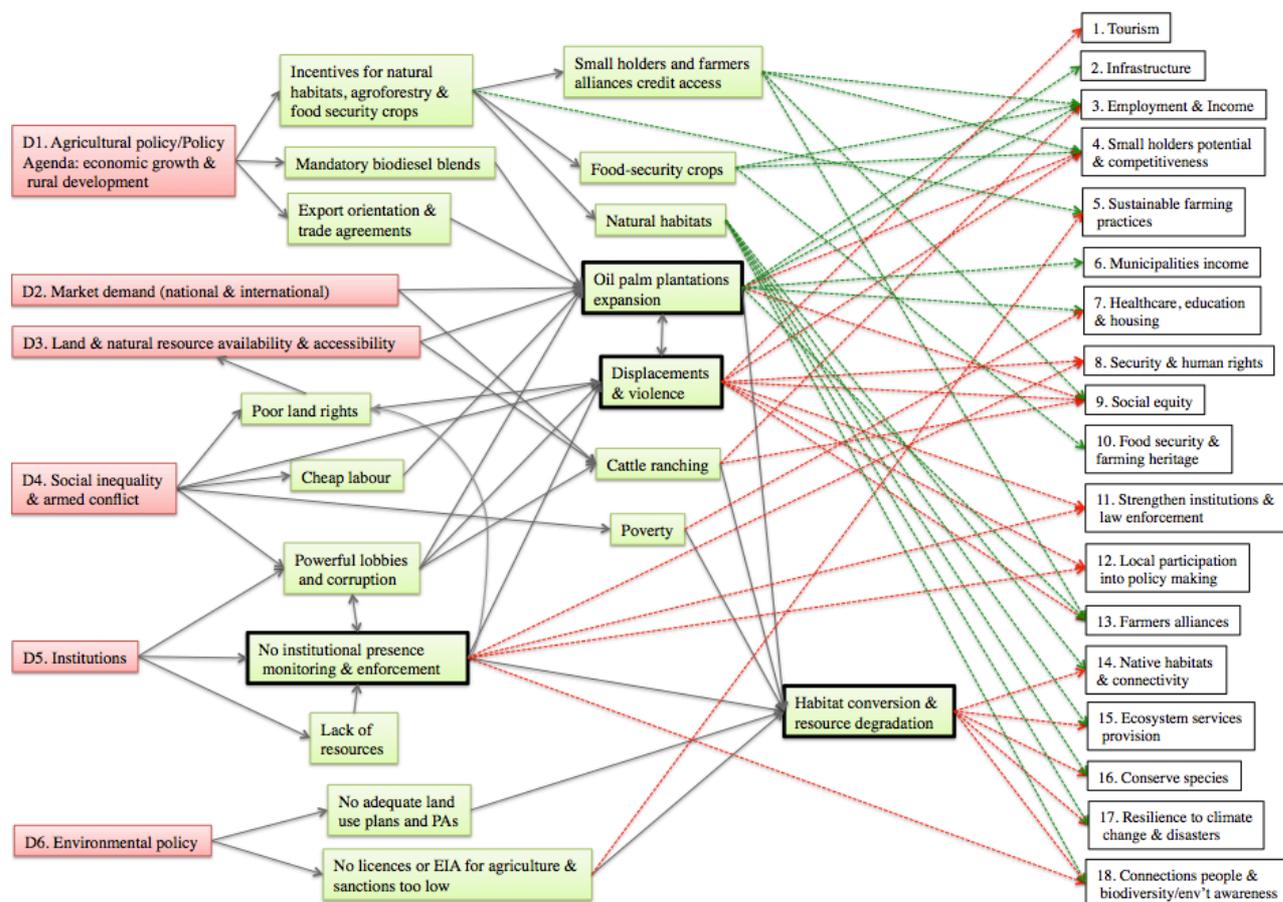
## 403 **3.2 Incentives based scenario: drivers of change and effects on sustainability**

404 In the INC scenario, the national government increases its spending on the environment and provides  
405 incentives to landowners to maintain natural habitats and establishing food security crops areas with a focus  
406 on small farmers alliances/cooperatives. Under this scenario many of the causal links remain the same but  
407 we would expect an increase in food security crops production, persistence of some natural habitats in the  
408 landscape, and increased credit accessibility for small holders and farmers alliances (Fig. 4). This in turn

409 would impact positively several sustainability objectives: employment and income (Obj. 3), small holder  
 410 potential and competitiveness (Obj. 4), social equity (Obj. 9), food security and farming heritage (Obj. 10),  
 411 the establishment of farmers alliances (Obj. 13), and the environmental ones (Obj. 14-18) (Fig. 4). Overall  
 412 this scenario would represent an improvement to the BAU since more sustainability objectives are positively  
 413 affected (Table 2).

414

415 **Fig. 4.** Network graph representing the causal relationships between the drivers of change (D1-D6), their  
 416 consequences and their positive (green dotted lines) and negative (red dotted lines) effect on the  
 417 sustainability objectives (1-18) under the INC scenario. Thicker boxes represent central nodes in the graph.  
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### 421 3.2.1 Stakeholders' views

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

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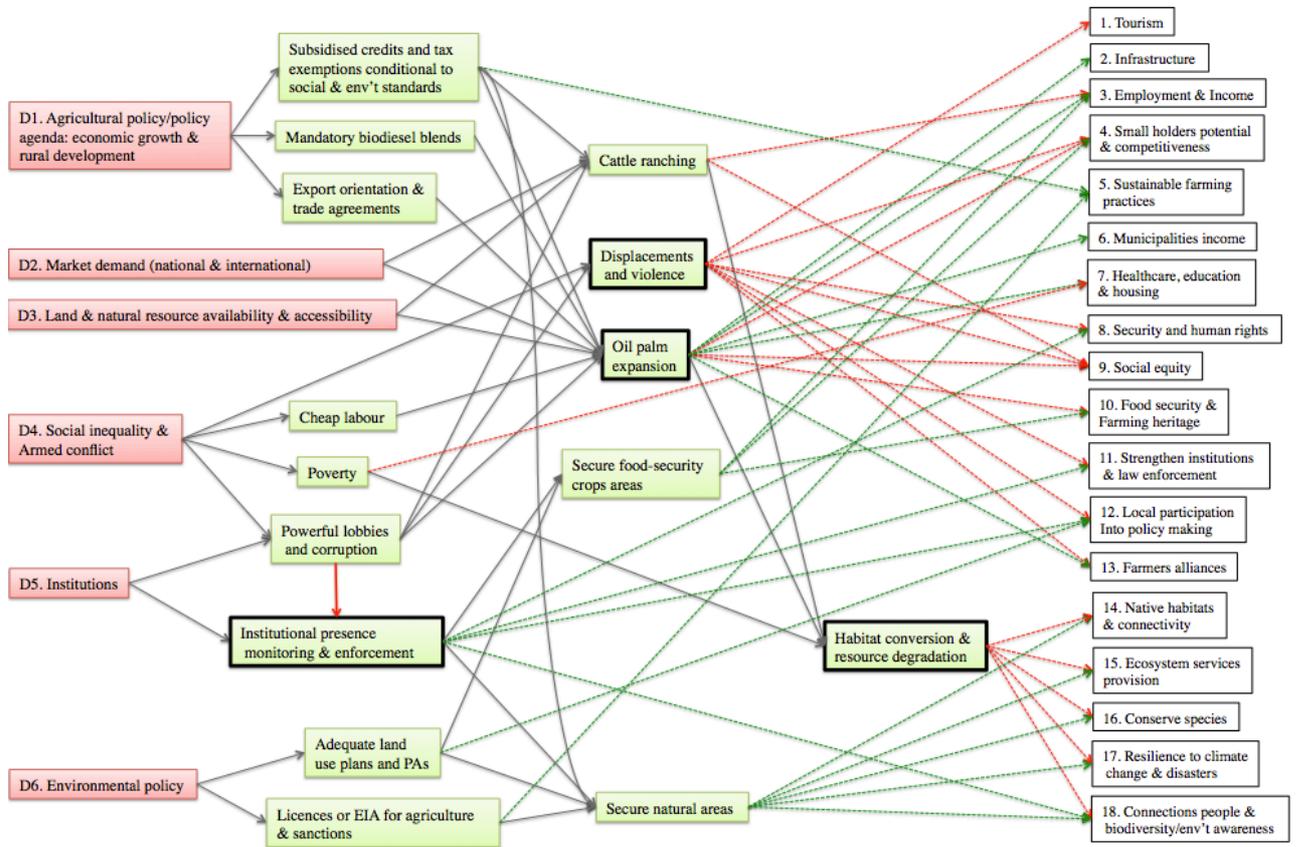
430 **3.3 Regulatory based scenario: drivers of change and effects on sustainability**

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

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**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.



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### 3.3.1 Stakeholders' views

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

479

### 3.4 Key nodes and identification of management priorities

481 The sustainability objectives tend to be affected by multiple drivers and their interactions, resulting in a  
482 complex network. For example, in the BAU scenario the achievement of species conservation is directly  
483 affected by habitat conversion and resource degradation, which in turn are directly and/or indirectly affected  
484 by agricultural policy, market demand, institutions, environmental policy, and even the armed conflict.  
485 Therefore we used Network analysis to identify the key factors in the achievement of the sustainability  
486 objectives under each scenario. The analysis showed that under all scenarios key entities in the system are *oil*  
487 *palm plantation expansion* and *displacements and violence*, followed by the *lack of institutional presence*  
488 *and enforcement*, and *habitat conversion and resource degradation*. This suggests that to achieve a  
489 sustainable development of the area we should focus on policies applying to the oil palm sector, improving

490 both its environmental and social standards, as well as addressing violence and displacements or their  
491 consequences. Also, halting resource degradation and habitat conversion is key since it underpins the  
492 achievement of all sustainability objectives related to biodiversity conservation and natural resources (Obj.  
493 14-18). Finally it is imperative to increase institutional presence, monitoring and enforcement because it  
494 directly and/or indirectly affects many sustainability objectives. Changes in different drivers (e.g.  
495 agricultural policy, market demand, environmental policy) may not improve significantly the sustainable  
496 development of the area unless institutions and monitoring improve.

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## 521 **4. Discussion**

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

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

544        The analysis of the two alternative scenarios show that both a stronger regulatory framework or different  
545 incentives within the agricultural policy could improve sustainable development in the region and are  
546 preferable to the current situation. Adopting the regulatory scenario would deliver more objectives but it is  
547 also more vulnerable to existing corruption. Both regulatory and incentive based approaches to conservation  
548 of biodiversity in agricultural landscapes have been explored in other countries by previous literature, which  
549 confirms that the former are generally more effective and bring greater additionality but are also more costly  
550 and more prone to leakage and weak governance (Harvey et al., 2008; Lambin et al., 2014; Phalan et al.,  
551 2013). On the other hand, voluntary approaches do not necessarily deliver sustainable land use at the scale  
552 needed since they are not adopted by all producers within a region or country and can have negative  
553 consequences if dropped by future governments or policy changes (Lambin et al., 2014; Phalan et al., 2013).

554        In order to provide policy recommendations, informed by network and scenario analysis, it is key to  
555 focus on the central entities identified by the network analysis and on the administrative levels of the various  
556 drivers of change. The national agricultural policy and policy agenda (D1) is an exogenous driver controlled  
557 both by the national government and international trends such as globalisation of markets (Hazell and Wood,

558 2008). Similarly market demand (D2) is both an exogenous and endogenous driver as the demand is local,  
559 national and international. The same also applies for social inequality and armed conflict (D4), institutions  
560 (D5), and environmental policy (D6) since they are not confined to the study area and may be partially or  
561 totally governed at higher administrative levels. Therefore to address the key entities in the graph (i.e. oil  
562 palm plantation expansion, displacements and violence, lack of institutional presence and monitoring, habitat  
563 conversion and resource degradation) it is key to coordinate policy and decision making at different levels.

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

568 At the *international level* in the developed world reducing consumption, waste, and requiring certified  
569 products may help reducing oil palm expansion or making it more sustainable (Koh and Lee, 2012). At the  
570 *national level*, as shown by the scenario analysis a stronger regulatory framework is needed. Strict  
571 environmental and social criteria should be put in place to gain access to the current subsidies within the  
572 agricultural sector, as well as requiring EIAs and increasing sanctions. Stronger regulatory framework have  
573 been suggested as successful for biodiversity conservation in productive landscapes elsewhere (Arima et al.,  
574 2014; Lambin et al., 2014; Verburg et al., 2014). At the same time new incentives and subsidies to other land  
575 uses that are not oil palm should be adopted, and the government could request that all palm oil used in  
576 biodiesel blends in the country is certified. Certification and traceability should become prerequisite for the  
577 Colombian oil palm industry to keep a share of the international markets while continuing to increase its  
578 importance in national ones. However the level at which certification would be promoted has to be  
579 determined carefully (Tscharntke et al., 2015) and a strong national and international consumer demand for  
580 Certified Sustainable Palm Oil must be created first, as it can be key driver of increased sustainability in  
581 agricultural production systems (Ruviaro et al., 2014).

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

590 Stronger institutions, enforcement and coordination at *all administrative levels* are crucial to achieve a  
591 more sustainable development (Nesheim et al., 2014). Also, more participatory approaches to decision  
592 making and more engagement and knowledge exchange between the different sectors and stakeholders  
593 would be highly beneficial, as highlighted by previous research (Pretty, 2008; Reed, 2008; Tzanopoulos et  
594 al., 2011). Finally, governments at the national and local level should promote further agricultural (including  
595 oil palm) development via individual smallholdings rather than large agribusiness. Policies should focus on

596 small farmer development, competitiveness and access to markets. The need to re-orient rural policies in  
597 favour of small farmers to achieve sustainable agricultural landscapes has been highlighted before since it  
598 would decrease poverty, increase well-being and social equity, safeguard food security, maintain higher  
599 levels of biodiversity, and even improve resilience to climate change (Pokorny et al., 2013; Pretty, 2008;  
600 Tscharrntke et al., 2012).

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## 603 **5. Conclusions**

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

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

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