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Scenarios and story lines: drivers of land use change in southern Mexico

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Abstract The study presents three scenarios of land use and cover change (LUCC), the most important factor for environmental degradation in southern Mexico. We developed story lines and quantitative projections for regional scenarios based on historic LUCC processes, environmental policies, socioeconomic drivers, stakeholder consultations and official planning documents to gain a better understanding of drivers of LUCC, and quantitative scenarios were modeled with DINAMICA-EGO. Regionally specific interactions between social and natural systems are recognized, and detrimental policies and policy options for landscape conservation and management for sustainability are acknowledged in a base line, variant and alternative scenario. Incongruent policies and ineffective ground implementation of conservation actions were identified as the critical underlying drivers of deforestation and forest degradation that could lead to a severe reduction in natural forests, while the local socioeconomic situation stays precarious. The baseline scenario parts from an analysis of historic LUCC processes and shows the consequences of LUCC tendencies: 73% of temperate forests and 50% of tropical forests would get deforested until 2030. In the variant scenario, these tendencies are adjusted to planning goals extracted from official documents and recent changes in public policies. The alternative scenario further addresses policy options for fostering conservation and sustainable development, but because of the time lag of implementation, still 59% of temperate forests and 36% of tropical forest would get lost until 2030. Nevertheless, this represents a reduction of 13% of forest loss and 11% less pastureland due to the proposed measures of conservation, and sustainable management, including strategies for reforming agricultural systems, agricultural and forestry policies and trade, land tenure and livelihood risk management.

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1 Introduction

Deforestation and land use and cover change (LUCC) are processes through which global change affects the dynamics of the earth system and its ecosystems (Roebeling and Hendrix 2010). LUCC is a long-term, broadscale disturbance related to public politics that determines the regional landscape dynamics and biodiversity conservation. Causes of LUCC are heterogeneous and change over time and from region to region (Qasim et al. 2014). At local scale, deforestation relates to changes in demography and livelihood conditions, while at regional scale deforestation is related to land tenure and agricultural development policies (Tadesse et al. 2014). Lambin et al. (2001) suggest that the driving forces for LUCC in general, and deforestation in particular, can be divided into proximate and underlying causes: The proximate causes act directly on the vegetation cover at local scale, for example, the introduction of urbanization, forestry, agriculture and pastures (Roebeling and Hendrix 2010), while underlying causes are related to demographic, consumption patterns and technological changes, individual and social responses to changing economic conditions, mediated by institutional or political factors (Lambin et al. 2001; Geist and Lambin 2002; MA 2005; Roebeling and Hendrix 2010; Qasim et al. 2014). Particularly, the formulation of policies that promote extensive livestock farming and generate pressure for more forest products and agricultural land is among the principal drivers of tropical deforestation (Schmook and Vance 2009; Tadesse et al. 2014). Underlying drivers usually emerge from the broader context, operate in a diffuse manner and thus are not easily detectable, making it very hard to consider them in spatially explicit analysis. Besides, the complexity of underlying and direct drivers of LUCC hampers a thorough understanding of specific causal factors, making it difficult to generate alternative policy options that promote the conservation of biodiversity and socioeconomic development (Chowdhury 2006).

Scenarios and storylines have been proposed as a tool to research this complexity, because they are based on understanding recent changes in order to explore probable futures of land use and related biophysical and socioeconomic drivers (Rounsevell et al. 2006; Daconto and Norbu Sherpa 2010). Qualitative scenarios in the form of narratives, or so-called story lines, describe plausible drivers of change and explain the complex interplay of drivers and their influence on more than one proximate cause; this way it is possible to give an insight on causal connections between human pressures and the changes in land use on a landscape level (Dockerty et al. 2006; Westhoek et al. 2006). Scenarios are applied in a wide range of disciplines for estimating the probable effect of one or more factors based on a hypothetical sequence of assumptions, which creates an internally consistent picture of a phenomenon with a focus on causal processes and decisions points (Houet et al. 2010). Scenario development is a relatively new method in land use science (Kok et al. 2007), but the need for advanced forecasting, scenario-based studies has been recognized, because prospective analyses are efficient tools for synthesizing and communicating complex information beyond business as usual to decision makers (UNEP 2002; Verburg et al. 2006).

In southeastern Mexico, LUCC is a complex process in which deforestation is usually the last step in a cascade of land use (LU) intensification, beginning with forest degradation by unsustainable extractive and agroforest activities before degraded forests get deforested (Kolb and Galicia 2012). Particularly, the combination of extremely high biodiversity and LUCC calls for a better understanding of the factors related to the widespread habitat destruction and disruption of biotic–environmental relationships caused by LUCC. However, studies of proximate and underlying drivers of LUCC and prospective modeling exercises in Mexico are scarce and until now did not use an explicit scenario approach, but rather extrapolate historic LUCC dynamics with a LUCC model (Mas et al. 2004; Chowdhury 2006; Flamenco-Sandoval et al. 2007). Even though some federal government entities have published strategic outlines in form of story lines and quantitative goals for 2025 (CONAFOR 2001) and 2030 (Presidencia de la República 2007), explicit studies about the possible effects and impacts of governmental policies on LUCC and regional development are lacking.

We present three LUCC scenarios for 2030 that explore the effect of different policy options related to the most important proximate factors of LUCC, including official governmental planning. The scenarios represent an explicit political framework for agricultural production systems and conservation actions, in order to provide inputs to the discussion of key questions for decision making for more sustainable land use in SE Mexico. The scenarios are constructed in the framework of anticipatory history which draws on the combination of history and future scenarios to make decision makers visualize and imagine dynamic and nonlinear human–nature interactions in a socioeconomic precarious setting. To illustrate the narratives, modeled quantitative land use and cover (LUC) tendencies are provided.

2 Methods

2.1 Study area

The Grijalva–Usumacinta watershed in southeast Mexico, 18.71°–15.22°N and −94.25° to 90.38°W, served as a natural boundary for the study area (Fig. 1). It covers 87,686 km^2 and is one of the most important watersheds in Mexico and North America. By volume the Usumacinta River is the most important stream flow in the Gulf of Mexico after the Mississippi (the 7th worldwide) and contains 30% of Mexico's superficial freshwater. The basin is characterized by an extremely irregular relief, reaching altitudes up to 3050 masl, resulting in different climates and vegetation types. Tropical rainforests can be found in the humid coastal plain and the eastern lowland areas, whereas the Central Depression, owing to a double rain shadow, is dominated by tropical dry forests. On the mountain ranges, like the Northern Mountains of Chiapas (1400–1800 masl), the central plateau or Altos de Chiapas (1200–2800 masl) and the Sierra Madre de Chiapas (1500–3050 masl) different types of temperate and cloud forests can be found. The huge amounts of surface water feed a high number of inland and coastal water bodies, flood plains and wetlands in the coastal plain covering an area of more than 400,000 ha (Sánchez and Barba 2005). Chiapas, part of the Mesoamerican hot spot of biodiversity, alone is home to more than 10,000 species of vascular plants, almost 10% of global plant diversity. This immense diversity forms the habitat for a great number of fauna, like the 659 bird and 205 mammal species registered, corresponding to 50% of all Mexican species described for these groups (González-Espinosa et al. 2005).

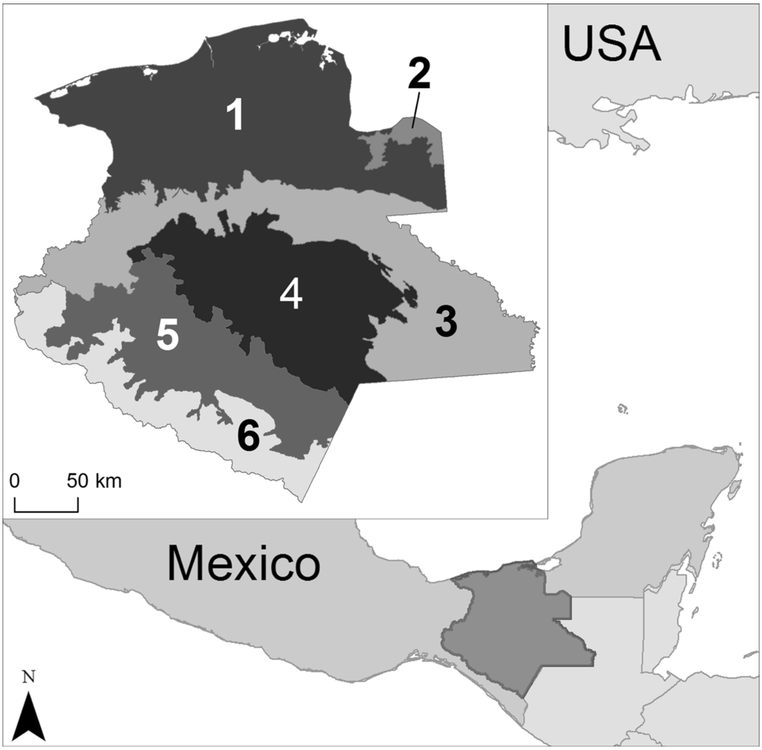

Fig. 1 The Grijalva–Usumacinta watershed and its ecoregions with the main vegetation types. (*1*) Gulf of Mexico coastal plain with wetlands and high tropical rain forest, (*2*) hills with high and medium semi-evergreen tropical forest, (*3*) Northern Mountains of Chiapas with medium and high evergreen tropical forest, (*4*) Altos de Chiapas with conifer, oak and mixed forest, (*5*) Central Depression with low deciduous and medium semi-deciduous tropical forest, (6) Sierra Madre de Chiapas with conifer, oak and mixed forests

2.2 Data collection

Since future LUCC will depend in large part on historic and present actions, such as investments in agricultural production (Westhoek et al. 2006), the quantitative LUCC models illustrating the narratives are based on historic LUCC dynamics. The LUCC analysis was based on three official 1:250,000 LUC maps from the National Institute of Geography and Statistics (INEGI) in Mexico and comprised the change periods 1993–2002 and 2002–2007 (INEGI 2001, 2005, 2008, for technical details see Kolb and Galicia 2012).

Workshops with key actors constitute a strategy to assess social perception of current and future probability of LUCC. The most relevant direct and underlying drivers of LUCC were identified with academic and governmental sector stakeholders and later incorporated in the storylines. A workshop was held in Mexico City in August 2008 and included focal group discussions and key informant interviews (mainly governmental dependency of agriculture and forestry). The workshop was attended by 30 participants that represent stakeholders directly involved in the environmental governmental sector, like delegates from the Federal Ministry of the Environment (SEMARNAT), the National Commission of Forestry (CONAFOR), the National Commission for the Knowledge and Use of Biodiversity (CONABIO), as well as from academic institutions including the National

Autonomous University of Mexico (UNAM), the Institute of Ecology (INECOL) and the College of the Southern Frontier (ECOSUR). The large spectra of participants opened the possibility of contrasting official and non-official perspectives on drivers, and to maintain discussions, through which consensus was reached.

After the workshop, official data were reviewed on short- and medium-term planning goals for different political sectors in Mexico like agriculture, forestry and conservation. This information was used to establish underlying drivers related to planning for the use of natural resources and agricultural policies (SAGARPA 2007a, b, 2009), forestry (CONAFOR 2001, 2007) and livestock (FAPRI 2008), but also census data and demographic estimations (CONAPO 2008), as well as international or global studies with data for Mexico and estimates for the regional context (FAO 2001, 2005, 2006; OECD 2008; UNEP 2001, 2002, 2004) (Table 1).

2.3 LUCC modeling

For the quantitative models, the originally very detailed classes were aggregated into broader classes, so that besides temperate and tropical forests, primary and secondary states of each forest type were considered, in order to distinguish between deforestation and forests degradation (for technical details see Kolb and Galicia 2012). The modeled change rates were based on change probabilities from 1993 to 2007, generated with the software DINAMICA-EGO (Soares-Filho et al. 2002), and areas for each class were extrapolated to 2030 with Markov Chains using the following formula:

$$\mathrm{Pt} = M \times V1\ t \times M - 1$$

where P is the annualized probability of change, M the eigenvalues of the matrix, V the associated eigenvectors and t the number of time steps within a time period.

2.4 Story lines and scenarios

We present a mix of the policy optimization and vision building scenarios, combining a baseline scenario with a variant and an alternative scenario. A medium-term time horizon seemed appropriate due to the importance of agricultural policies in LUCC and because recent historic tendency of deforestation can be assumed to be ongoing until 2030, which is the estimated date when population in Mexico could stop to show a net increase (CONAPO 2008). In order to make the scenarios explicit for drivers in the regional context, the key driving forces are exposed in the form of narratives which are structured along two axes that constitute the two most critically relevant dimensions as identified in the expert workshop: (1) the political and institutional framework, ranging from contradicting and not consistent policies to coherent regulations; (2) the implementation of conservation and management of biodiversity, ranging from non-effective short-term conservation and management to varied and well-regulated conservation tools put in place (Fig. 2). This assures that scenarios are logically different considering drivers like demographic trends, agriculture, livestock farming, forestry and conservation tools, socioeconomic status, education, environmental legislation, the interrelation of primary sector and policies, regional economic integration and regional planning (Westhoek et al. 2006).

For each scenario, first, a general outline is presented regarding current directions and trends of policies and economic value of different resources within Mexico based on the stakeholder workshop (see "Data Collection" section). The main sections consist of the

Table 1 Documents used for scenario construction

Institution	Topic/title	Scale	Time horizon
CONAPO (2008)	Population growth	Settlements	2005–2030
	Economically active population	State	2005–2030
	Economically active population	State	2005–2030
INEGI (1995, 2000, 2005)	Economically active population	State	1995, 2000, 2005
SAGARPA (2007a, b, 2009)	Programa Sectorial de desarrollo agropecuario y pesquero	National	2007–2012
	Plan National pecuario	National	2007–2012
	Expectativas de producción y demanda de granos forrajeros	National	2006–2008
	Programa de producción sustentable de insumo para bioenergéticos y de desarrollo científico y tecnológico	National	2009–2012
	Normateca de distritos de riego	National	
	Programa para el uso sustentable del agua en el campo	National	2007–2012
FAPRI (2008)	Agricultura	National/ Global	1997–2017
	Ganadería	National/ Global	1997–2017
CONAFOR (2001, 2007), Chagoya and Iglesias (2009)	Programa institucional	National	2007–2012
	Programa estratégico forestal	National	2025
	Esquema de pago por servicios ambientales de la CONAFOR	National	
CONANP (2009)	Prioridades de nuevas AP	National	2008
Presidencia de la República (2007)	Visión México 2030	National	2030
	Plan National de desarrollo	National	2007–2012
FAO (2001, 2005, 2006), Torres Rojo (2004)	Primera revisión del programa estratégico forestal 2025 y del programa National forestal 2001-2006	National	2005–2025
	Estudio de tendencias y perspectivas del sector forestal en América Latina al año 2020 Informe National México	National	2020
	Global forest resources assessment 2005	National	1990–2005
	Future production from forest plantations		2050
OECD (2008, Bakkes et al. (2008)	Tendencies of land use and cover	National	2030
	Background report to the OECD Environmental Outlook to 2030	Global	2030
	OECD Environmental Outlook to 2030	Global	2030
UNEP (2001, 2002, 2004)	Global Environmental Outlook 3	Global	
	Global Environment Outlook Scenario Framework (GEO-3)	Global	2050
	An assessment of the status of the world's remaining closed forests	Global	1997

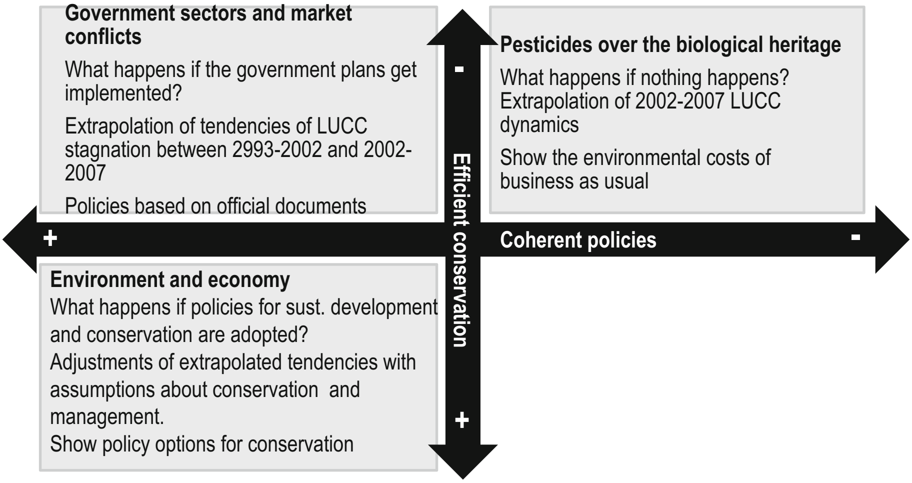

Fig. 2 Structure of scenarios around the two most critically relevant dimensions of underlying drivers: the political and institutional framework and the implementation of conservation and management of biodiversity

narratives that include the quantitative results for the different LUC classes based on the LUCC model. In the story lines, the data sources are referenced where possible, but in many cases, the information was obtained in the stakeholder consultations. Besides the citations in the narratives, Table 2 shows a summary of the scenario assumptions integrated from the multiple data sources.

1. "Pesticides over the biological heritage" represents the base line or business as usual scenario. It is an extrapolation for 2007–2021 of the historic tendencies of land use change, in which deforestation is usually the last step in a cascade of LU intensification, beginning with forest degradation of primary forests by unsustainable extractive and agroforest activities before degraded forests get deforested (Kolb and Galicia 2012) (change probabilities 1993–2007), followed by a 9-year period until 2030 in which the scarcity of primary temperate forests and certain types of tropical

Table 2 Periods and the corresponding change rates applied in the quantitative model for each scenario

	Pesticides	Conflicts	Conservation
Period 1	2007–2021	2007–2016	2007–2016
Change rates	1993–2007	1993–2007	1993–2007
Period 2	2021–2030	2016–2023	2016–2023
Change rates	2002–2007	2002–2007	2002–2007
Period 3		2023–2030	2023–2030
Change rates		Extrapolated tendency of decrease in deforestation and forest degradation from 1993 to 2002 versus 2002 to 2007	Same as in conflicts, but to obtain smaller rates, further time steps were extrapolated and then taken for the modeled period

forests, together with the stabilization of human population, lead to a saturation effect and LUCC is slowing down (change probabilities 2002–2007, Table 3).

2. “Government sectors and market conflicts” is a variant scenario, building on the base line scenarios, but showing tendencies related to recent changes in policies and statements in the agricultural and conservation sectors and other official documents, in order to show the effect of governmental policies on LUCC in a neoliberal economic setting. This scenario extrapolates the tendencies of decreasing LUCC dynamics observed between 1993–2002 and 2002–2007. Change probabilities were calculated based on the decline of change probabilities from 1993–2007 (applied for 2007–2016) to 2002–2007 (applied for 2017–2023) and the extrapolation of the trend to obtain change probabilities for 2024–2030 (Table 3).
3. “Environment and economy” is the alternative scenario in which measures of efficient resource use and appropriate food production systems give impulses to socioeconomic development, and natural capital conservation through the decoupling of economic growth from natural resource use. The LUCC trends are based on the assumptions of the variant scenario coupled with a rapid change toward more sustainable development and conservation from 2017 onward. The change probabilities for 2017–2023 and 2024–2030 were extrapolated in the same fashion as for scenario 2, but to obtain smaller rates, further time steps were extrapolated and then taken for the modeled period (Table 3).

3 Results

3.1 Pesticides over the biological heritage (baseline scenario)

This baseline scenario shows LUCC due to the maintenance of the unsustainable use of natural resources without improving substantially the precarious socioeconomic situation of most of the population. Even though LUCC decreases slightly with time because of a saturation effect related to small forest remnants in inaccessible and little productive areas, strong processes of forest degradation and deforestation deplete natural temperate and tropical forests; 73% (3270 km^2) of temperate forests will be lost by 2030 and tropical forests will be reduced to 50% (3730 km^2) of their extent in 2007 (Fig. 3). The use of temperate forests as rangelands leads to the deterioration of ecosystems through habitat destruction and the depletion of natural resources (CBD 2010). Forest degradation is so widespread that disturbed temperate forests show an increase of 12% until 2030. But first (after 2013) the lack of well-preserved forests leads to an increase in deforestation of disturbed temperate forests, and only after 2021, as a result of the saturation effect, the area of temperate disturbed forests starts to increase. Disturbed tropical forests decline steadily until 2021 because of the greatly increasing demand of areas for livestock. The slight increase registered after 2021 is due to the lack of remaining primary forest (Fig. 3). Forest degradation and deforestation are related to the small value attributed to forest resources, resulting in their exploitation for small revenues and illegal logging (CONAFOR 2001). In montane cloud forests, firewood and timber extraction are responsible for forest degradation (Ramírez-Marcial et al. 2005; Orantes-García et al. 2013). Even though necessary policies are identified for changing this situation, the strategic plans are not realized because of incongruent implementation and lack of economic incentives for capital investments in the needed timescale (CONAFOR 2001; Ramírez-Marcial et al. 2005).

Table 3 Summary of scenario assumptions

Drivers	Pesticides		Conflicts		Conservation	
	Assumption	Deforestation/degradation	Assumption	Deforestation/degradation	Assumption	Deforestation/degradation
Agricultural subsidies	Foment directly and indirectly deforestation	High	Maintained but volume reduced and coupled with eligibility criteria leading to partial intensification	Slightly reduced	Phased out, intensification of productive areas, organic principles applied where possible, regeneration of unproductive areas/erosion/water	Reduced
			Energy crops allowed	Increased	No energy crops allowed	Reduced
Cattle farming subsidies	Foment directly and indirectly deforestation	High	Partial intensification of cattle production	Slightly reduced	Less productive pastures are converted into forest plantations	Reduced
Little productive areas	Subsidies apply	High	No intensive agriculture allowed	Slightly reduced	No subsidies apply	Reduced
Trade and commerce	Free trade acts are fully implemented	High	Free trade acts are fully implemented	High	Free trade acts are modified to halt expansion of ineffective cattle farming (non-tariff barriers)	Reduced
Economic sectors	Industry and services do only exist in few urban centers	High	Industry and services need more space in secondary urban areas	Increased	Industry and services need more space in secondary urban areas	Reduced
	Industry: small and medium scale (highly contaminating)	High	Industry: small and medium scale (highly contaminating)	high	Industry: small and medium scale (clean)	Reduced
	Service-sector: traditional financial services	High	Service-sector: traditional financial services	High	Service-sector: ICT and ecotechnology	Reduced

Table 3 continued

Drivers	Pesticides		Conflicts		Conservation	
	Assumption	Deforestation/ degradation	Assumption	Deforestation/ degradation	Assumption	Deforestation/ degradation
	Agriculture: traditional and industrialized farming	High	Agriculture: traditional and industrialized farming	High	Agriculture: traditional and biological farming, eco-recreation	Reduced
Urban development	No restrictions	High	No restrictions	High	Restrictions on urban sprawl	Reduced
Education and health	Not sufficient	High	Education levels are rising	Slightly reduced	Education levels are rising and include effective environmental education	Reduced
Government intervention	Maximum freedom	High	Weakly implemented regional planning	Slightly reduced	(Spatial) policies determines land use	Reduced
Environmental legislation	Loose	High	Intermediate	Slightly reduced	Strong	Reduced
REDD	Not existent	High	Partially implemented	Slightly reduced	Implemented	Reduced
Biodiversity conservation	Isolated efforts	High	Concentrated in PA, some PSA programs with time restrictions	Slightly reduced	System of PA, corridors and managed sites effectively implemented, reconversion into forest plantations, UMA, etc. agri-environment payments, PSA, guaranteed areas, no time restrictions	Reduced

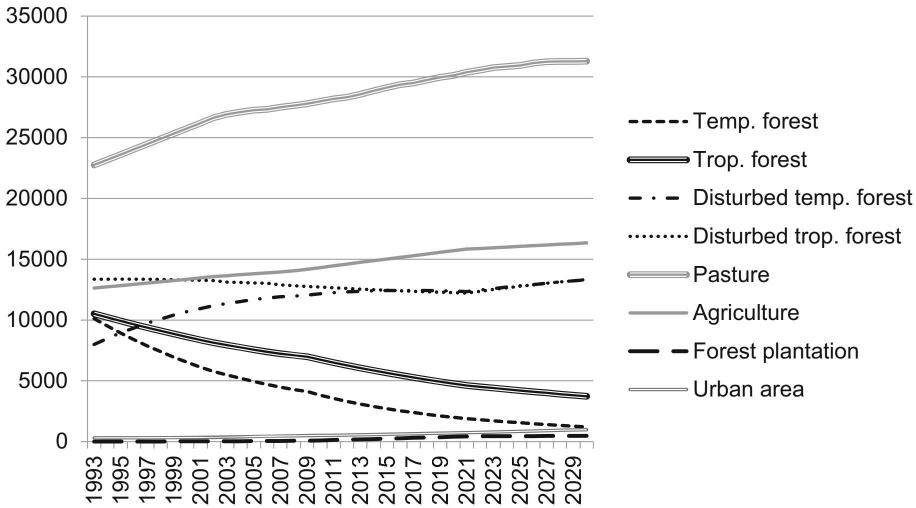

Fig. 3 Tendencies of land use and cover for the baseline scenario (“Pesticides over the biological heritage”)

Agriculture increases over the whole period (2383 km^2, 17%), as do urban zones (518 km^2, 112%) and forest plantations (426 km^2, Fig. 3). Maize is mostly a subsistence crop grown on small plots with yields under 1500 kg/ha (Aguilar-Jiménez et al. 2013). Maize contributes to the livelihood of millions of farmers in Mexico; particularly in highland Chiapas maize agriculture (shifting cultivation) is a major direct driver of LUCC (Ochoa-Gaona and González-Espinosa 2000). The underlying cause of agricultural expansion is to supply society with sufficient goods and to obtain income in the case of the *campesinos*. To compensate farmers for the negative impacts of the North American Free Trade Agreement (NAFTA), the government implemented the *Programa de Apoyos Directos al Campo* (PROCAMPO), which transfers to producers of basic staple crops (including maize) on a per hectare basis, with the intent that this support should help them become more efficient (Sadoulet 2001). All remaining agricultural trade restrictions were lifted in 2008, but PROCAMPO has been extended through 2012.

Pastures for livestock farming sustain their growth before they start stagnating in 2025 because of demographic stabilization and LU saturation; the increase of 3797 km^2 until 2030 represents 14% in relation to the 2007 extent. Conventional cattle ranching typically employs extensive grazing and annual pasture burns (Ferguson et al. 2013). In the lowlands of Chiapas, grazing by sheep and cows is also common in abandoned fields, which interferes with the recruitment of seedlings and saplings of trees and shrubs, and may lead to the establishment of permanent grasslands (Nahed-Toral 1989; González-Espinosa et al. 2005). The area of pastures increases rapidly because of the increase in demand for cattle products and specific subsidies and credits (Vaca et al. 2012). Another contributing factor is that they are a cost-effective activity which requires little labor and is compatible with the cycles of emigration of the head of the household for capital supply. Furthermore, cattle farming constitutes a strategy of income diversification and risk management, since livestock is considered as an ambulant bank that is a buffer against poverty and minimizes the risk of food insecurity (Schmook and Vance 2009). In remote zones, the agricultural frontier is moving on, even after specific advocating policies are not in place anymore, driven by impoverished settlers searching for land and subsistence.

Natural forest regeneration is low because of the growing food demand and the change from traditional shifting cultivation toward field–pasture systems, both of which contribute to the need for more agricultural land. Afforestation is not effective because it is not a profitable investment; efforts are neither systematic, nor articulated with other government programs. A lack of incentives and support on the long term and a lax implementation of forest plans are also responsible for lack of conversion of little productive pastures into forest plantations (CONAFOR 2001). Conservation has little success because protected areas (PA) and biological corridors are not effectively implemented and because of unsolved conflicts between local communities themselves and with the different levels of government. Interest in conservation is low because high poverty does not allow to recognize the natural capital as such and subsidies and revenues from conservation programs are too small and of short-term character. Technological capacity building and education is rudimentary. A large part of the local population continues to be excluded from social and economic development and from political participation. Land use planning and other regulations of LUCC are not enforced.

3.2 Government sectors and market conflicts (variant scenario)

"Conflicts between governmental sectors" represents a variant of the baseline scenario in which the neoliberal economic model, based on development through market forces continues and progress in income, health and education stays inaccessible for the marginalized population in remote areas. Together with a slow demographic transition, this situation causes an increase in the demand for ecosystem services. These conflicts get reflected in the political agenda, propitiating the continuity of inconsistent policy targets between the different sectors. The cover of undisturbed forests declines 64% for temperate forests (2944 km^2) and 39% for tropical forests (2848 km^2) (Fig. 4). Even though deforestation is beginning to decrease over time (FAO 2005; Kolb and Galicia 2012), persistent forest degradation, caused by unsustainable forestry practices and overexploitation of non-timber forest products, leads to a continuous increase in disturbed vegetation (32% for temperate forests and 15% for tropical forests). The long time span needed to make certain decisions for adaptation and from there to implementation, together with a persistent lack of incorporating the sustainable principle in all sectors, lowers the success in reducing deforestation rates and forest degradation until 2030 (UNEP 2004). Despite the goal of increasing the area under forestry use (20 M ha in 2025 on a national level, CONAFOR 2001), not only the area, but also the intensity and productivity of the forestry sector are decreasing (FAO 2005). This reduction in timber activity and a growing scarcity of natural resources for forestry production is due to too little investments attracted by the forestry sector (FAO 2005). Community forest plans are supported but the established goals are not met, because they are general, diverse, not prioritized and not synergistic (FAO 2005).

However, ecological restoration could be used to recover certain sites, with benefits for rural communities by providing many useful and commercial forest products (Román-Dañobeytia et al. 2012). Actually, small-scale reforestation projects supported by government agencies and non-governmental organizations are becoming increasingly common in recent years. However, as in many other tropical regions, incipient financial markets and a lack of basic silvicultural data of useful/commercial native forest trees impede the widespread adoption of tree plantations for ecological restoration, carbon sequestration and timber production (Piotto 2008; Milder et al. 2010).

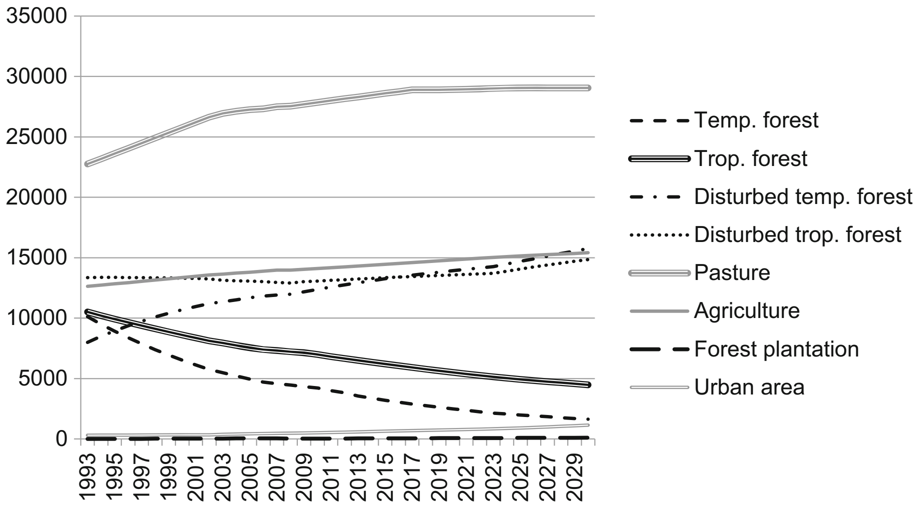

Fig. 4 Tendencies of land use and cover for the variant scenario until 2030 ("Government sectors and market conflicts")

Agricultural areas keep on growing until 2030 (10%, 1448 km^2), while the total area for pastures stays stable from 2018 onward (6% or 1552 km^2 increase in the years before) (Fig. 4). The policies for intensifying agricultural production lead to a stagnation of growth rates for agriculture and pastures. Traditional agroecosystem (slash, fell and burn) could be adjusted by modifying the sowing density and crop rotation and using green manure to increase yields and financial returns. Even though agricultural subsidies are adjusted to reduce deforestation (FAO 2005), intensification through technological changes in agricultural, fisheries and energy production is slow, based on conventional techniques, and is focused on converting subsistence into commercial agriculture under the assumption that *campesino* agriculture is not profitable. The use of fires as an agricultural practice is reduced, especially in the Mesoamerican Biological Corridor (SEMARNAT 2009). On the other hand, silvopastoral systems are a prototype of agroforestry with a livestock component, which provide a variety of goods and services to society, including adaptation and mitigation of climate change (Aguilar-Jiménez et al. 2013). Programs for increasing the productivity of livestock production by genetic and forage improvements (SEMARNAT 2009) cannot reduce the absolute area of pasture because the demand for cattle is growing more rapidly. Incipient regional planning permits small advances in reducing the use of forests as rangeland, but regulations are not respected because of weak implementation of penalties. The lack of technical and economic support for converting unproductive pastures into forest plantations (only 50% of costs in the first year and 30% in the third year; FAO 2005) is so prominent that even the conversion of pastures with a high risk of being affected by natural disasters (e.g., hurricanes) does not pay off (SEMARNAT 2009). The discrepancy between established goals of forest plantations (10 M ha in 2030 on a national level, SEMARNAT 2009) and reality is growing over time (FAO 2005). Intents of redirecting commercial activities to other sectors (SEMARNAT 2009) are failing because no alternative industries and income opportunities are created and the pressure over the natural resources cannot be reduced significantly.

Natural regeneration stays low until 2021 because of the abandonment of traditional agriculture in favor of livestock farming. But the ongoing demographic transition, more efficient conservation and the conversion of unproductive agricultural land into forests lead to a balance between deforestation and regeneration in 2030 (Presidencia de la República 2007). This forest process provides opportunities to restore forest cover through actively stimulating afforestation and technological change toward more sustainable land use practices (García-Barrios et al. 2009; Vaca et al. 2012). Partly because of international conventions, the value of the natural capital of Mexico is being recognized and attempts to incorporate it into the market and to achieve a more sustainable use are undertaken.

The implementation of conservation tools expands, like PA and biological corridors, based on a focus of sustainability in policies, but their effectiveness is still mainly a result of inaccessibility and the isolated efforts for restoration have almost no positive effect (FAO 2005). Options for conservation are decreasing and the few isolated advances are at risk of being lost by insufficient financing of conservation in the face of better financed incentives from the agricultural sector. Other conservation tools, like the payment for ecosystem services (PES), are consolidating, but the market segment is still very small and develops slowly (FAO 2005). Units for the conservation of wildlife (UMA for its acronym in Spanish) are of growing importance for maintaining natural vegetation and generating income from native biodiversity.

3.3 Environment and economy (alternative scenario)

The sustainable development scenario shows the outcome of consistent changes in the development scheme and politics, which makes it possible to agree upon environmental and social goals. Clear and congruent policies based on prevention and adaptation of environmental and social problems, together with a strong implementation and control of corruption, will lead to a rational and more efficient administration. Deforestation starts to decline, but the time needed for planning, implementation and conceivable results in the landscape of the link of production and conservation still leads to a reduction of 59% of temperate forests and 36% of tropical forests until 2030 (Fig. 5). Disturbed forests will increase, first because of high rates of forest degradation; after 2021, this increase is boosted by better forestry management and more effective conservation (48% or 5674 km^2 and 26% or 3324 km^2 for temperate and tropical forests, respectively) (Fig. 5). The revalorization of forest resources and the employment opportunities generated in this sector can help to stop agricultural expansion, especially in areas with less potential for agricultural use. For example, the state plan for sustainable forestry development in Chiapas (2001–2006) seeks to implement the productive restoration through re-establishment of forest mass and the development of forest plantations. Regional planning promotes a rational land use and thus regulates and strengthens forestry; forest plantations are established in unproductive agricultural areas to supply sufficient input for industrial processes (CONAFOR 2008).

Despite the intensification of agricultural production in highly productive areas with environmental friendly high tech methods, the strong future demand for agricultural products and the alternative production systems (e.g., agroforestry) in other already existing agricultural areas account for a 10% increase in agriculture until 2030. Agricultural and energy production are reorganized and policies are synergistic for multiple targets like energy supply, biodiversity use and conservation, as well as human well-being. Subsidies and other economic incentives are redesigned in order to avoid further environmental degradation, to strengthen and to train *campesinos*, so their production can be adapted to cover their basic needs under local circumstances (SEMARNAT 2009, 2011). Agronomic research and capacity building incorporates traditional and innovative

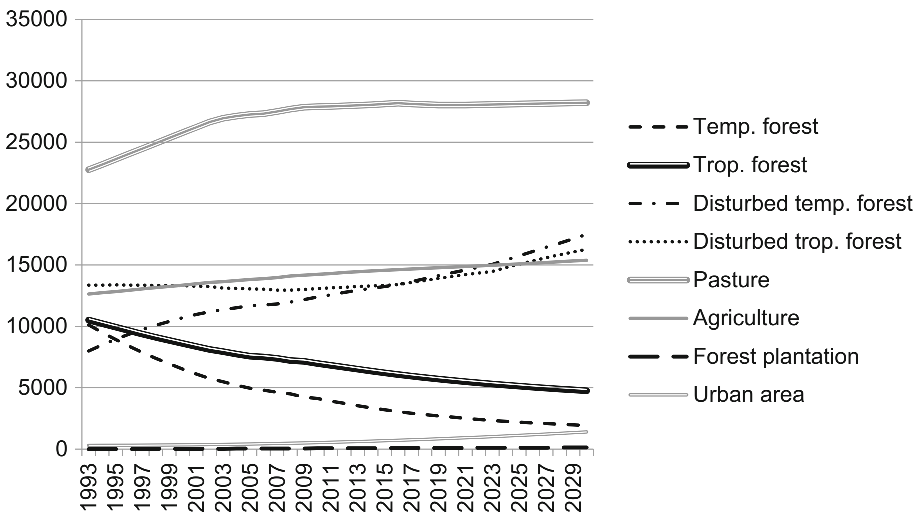

Fig. 5 Tendencies of land use and cover for the alternative scenario until 2030 ("Environment and economy")

techniques allowing for a reduction in the dependence on pesticides, synthetic fertilizers and contamination, while increasing productivity. Laws and other regulations strengthen the incorporation of the principles of environmental sound production systems, sustainable management of natural resources and restoring environmental integrity in the agricultural sector. The use of traditional varieties and their further development are enforced, because of their potential of adaptation to changing climatic and soil characteristics. Principles of organic agriculture and permaculture are applied where possible and diversification of crops is a possibility to increase income and nutritional status (SEMARNAT 2011). Livestock farming is based on more productive systems, better integrated with other agricultural production systems (e.g., alternative sources of forage and input of feces as fertilizer), so that the area at 2030 is not growing from 2016 onward (less than 3% increase in total). The use of natural vegetation as rangelands is drastically reduced and degraded pastures are converted into agroforestry landscapes and forest plantations (CONAFOR 2001). Especially in indigenous regions, policies for integrating an industrialized production chain take effect and the processing of forestry products represents an alternative income that helps to reduce agricultural expansion (SEMARNAT 2009).

Classic conservation tools like PA and biological corridors are effectively implemented and measures of sustainable management of natural resources and agricultural production are widely applied in priority sites for conservation. The challenge is to identify management opportunities that maintain ecological function while minimizing restrictions on human land use, as land use change isolates PA from their surrounding landscapes (Cortina-Villar et al. 2012). Important income-producing activities such as coffee plantation contribute to the maintenance of large areas with forest cover. Many communities in montane areas that derive income from logging and forest management have maintained forest cover and restored density and commercial productivity in previously mismanaged forests. Together with the sprawl of UMA, this is an important step toward the expansion of conservation from isolated PA into the landscape matrix.

Other conservation tools, like the PES, are consolidating (up to 2175 Mha in 2030) and are converted into permanent programs (CONAFOR 2001; SEMARNAT 2009). Compensatory actions for emissions and pollution from industry and trade are used for environmental restoration of degraded and eroded lands. A strong emphasis of avoiding deforestation in regulations and implementation of alternative income possibilities like PES and Reducing Emissions from Deforestation and Forest Degradation (REDD +) for livestock farming leads to a stabilization of areas for cattle ranching. The feasibility study for the REDD + mechanism in Chiapas seeks to contribute to the development of REDD + strategy in the state, contributing elements, proposing schemes, identifying opportunities and gaps, quantifying the potential of REDD + and posing a "road map" for successful implementation mechanisms of this type in the state. Conservation is no longer seen as a restriction for development but as a viable alternative to traditional land use systems with sustainable social benefits and citizen participation is growing.

4 Discussion

Story lines in combination with quantitative projections were used in this study to show the implications of the interplay of various factors, politics and key sectors and to improve the conceptual framework of LUCC processes and their specific drivers. "Pesticides over the biological heritage" (base line scenario) describes how LUCC is related to the economic, demographic, social and natural settings of the Grijalva–Usumacinta watershed. "Government sectors and market conflicts" (variant scenario) and "Environment and economy" (alternative scenario) show how policy drivers of LUCC can be turned into policy drivers of conservation; the former shows some of the caveats in this process for a third world country with high corruption levels and low efficiency in policy implementation. The proposed measures in the alternative scenario could lead to a reduction of 13% of forest loss (equivalent to 8843 km2 more forest) and to 11% less pastureland (equivalent to 3085 km2 less pasture). One of the major shortcomings in all of these scenarios is the lack of quantitative regional specific planning that could be used for scenario analysis. The few available "hard" goals from the governmental sector are for all of Mexico, illustrating the lack of acknowledgement of the immense differences in natural and social settings. OECD (2006) data are too general to be evaluated in absolute numbers, but the tendencies of an increase in agricultural areas like fields for annual crops and grasslands for cattle production were used as a general validation of the model results. The same applies for data from FAO (2005) which show a sharp decrease in forest area.

4.1 Policy drivers of land use and cover change

Disarticulated institutions and political sectors in developing countries have favored biodiversity loss and deforestation (Geist and Lambin 2002; Schmook and Vance 2009). Particularly, in Mexico, sectorial policies implemented in the 1950 had a strong influence on enhancing or reducing certain drivers (Durand and Lazos 2004; Bray and Klepeis 2005). Territorial planning, management and policies were based on sectorial analysis that did not take into account other effects than their focal goals, leading to undesirable social or environmental impacts. The consequences are inconsistent regulations and stimulations of contrary goals by different policy sectors.

Especially, agricultural policies and related subsidies, together with the historic influence of laws of deforestation and colonization (until 1992), have been found to be strong incentives for deforestation (Klepeis and Vance 2003; Manjarrez-Muñoz et al. 2007; Schmook and Vance 2009). Between 1981 and 2002, the real income from agricultural products decreased 50%, a development related to trade liberalization (North American Free Trade Agreement, NAFTA) and resulting federal policies implemented through governmental support programs like PROCAMPO and PROGAN (Cámara de Diputados 2002). The impoverishment of rural lively hoods in turn increases the dependence on those programs, and cultivated areas are increased and fallow times shortened, leading to further ecological degradation (Cámara de Diputados 2002; Carr et al. 2009).

This compound of policies turned livestock into one of the few profitable agricultural activities under NAFTA leading to a strong expansion of pastures for extensive cattle ranching (Barbier and Burgess 2001; Klepeis and Vance 2003; Zahniser and Coyle 2004; Manjarrez-Muñoz et al. 2007). The low requirements of material and labor, little dependence on climate, a lack of alternatives for risk management and education together with specific policies made pastures the largest land use in the study area (Manjarrez-Muñoz et al. 2007). Other drivers for agricultural expansion and deforestation include an increasing demand for staple foods because of demographic growth, the available initial large forest areas (Carr et al. 2009) and little access to technology for intensification, because of the precarious socioeconomic situation and a lack of sufficient and specific subsidies (Schmook and Vance 2009; Manjarrez-Muñoz et al. 2007).

4.2 Policy drivers of conservation

Equilibrium between deforestation and regeneration in this region can only be obtained through land use planning that eliminates contradictory policies and favors sustainable forest management, in combination with an efficient conservation program that exploits the synergies between biodiversity, climate change and human well-being. Ordering land use is a prerequisite for integrating different land uses, enhancing agricultural production and for effective implementation of policies. Mismatching spatial and temporal scales of regional planning and ecological processes need to be considered to achieve an effective implementation of conservation and restoration measures (Theobald et al. 2005).

Conservation strategies need to consider multiple tools in order to not just conserve natural islands in a transformed matrix. PA are the central column of conservation but only when combined with a diverse and sustainable use of biodiversity in biological corridors, priority sites for conservation and UMA, biodiversity loss can be reduced (CONABIO et al. 2007). Conservation goals may not be compatible with the local human populations as a result of conflicting local perceptions and the need for subsistence activities (Nygren 2004; Sarukhán 2009). Additionally, managed natural forests have to play a leading role in reducing deforestation and forest degradation, but management plans alone can hardly be effective. Good practices, less bureaucracy, capacity building and follow-up, in combination with systematic reforestation and erosion control, are crucial. The creation of community forest enterprises has shown to be a promising solution in Mexico, but existing investments are not sufficient (Bray et al. 2007). The extensive problem of forest degradation demands special attention regarding rural energy supply. The demand needs to be reduced through more efficient energy use and provide simple alternative energy sources so that forests do not need to provide fuel wood that could be provided by specific reforestation and agroforestry practices. Green subsidies need to be so competitive that support programs like payment for ecosystem services can be a viable option for local stakeholders (Sarukhán 2009).

Income sources need to be diversified as an answer to the steady decrease in real income and economic crises in the neoliberal context (Reardon et al. 2006) with a special emphasis to non-farm employment like small- and medium-scale industries and integrated production chains on a subregional scale (de Janvry and Sadoulet 2001; Schmook and Vance 2009). Strategies need to consider regional specific settings and identify synergies between ecosystem services (e.g., REDD+), conservation, production and commercialization (Sarukhán 2009). The reorganization of agricultural activities and related policies is extremely challenging but necessary for intensifying production (Tilman et al. 2002). Just as for conservation strategies, production incentives should be adjusted to social, cultural, natural and technological settings for specific regions to control unintended deforestation, pollution and erosion (de Janvry and Sadoulet 2001; Klepeis and Vance 2003). Subsidies need to be redesigned so that they stop being welfare payments and start to promote intensification and sustainability through adequate technical assistance (Sadoulet 2001). Productivity in suitable areas has to be a primary goal and, in the case of livestock farming, can only be achieved with a radical regulation of activities. Unproductive lands in turn should be used for sustainable agroforestry activities or converted into secondary forests, to maintain seminatural habitat in production areas to assure the persistence of multi-functional landscapes in the study area.

4.3 Possibilities and limits of scenarios and story lines

There is no unique or best method for constructing scenarios, but the most common are a descriptive narrative (qualitative scenario) and tables and figures based on quantitative data (UNEP 2004; MA 2005; Bakkes et al. 2008; CBD 2010). Qualitative scenarios are helpful in giving a general framework including relationships and trends for which few or no data are available, while for modeling purposes, quantitative data not only complement and illustrate certain key points of the scenario story line, but are essential for model parameterization (UNEP 2004; MA 2005; Bakkes et al. 2008; Rounsevell and Metzger 2010). The scenarios presented here are not intended to represent an unbiased exact prognosis, but a tool to explore possible alternatives. The uncertainty among alternatives is taken into account implicitly by showing clearly the differences between the assumptions (story lines) and the quantitative estimates of land cover and use (models) of each scenario. In general, three main challenges for scenarios are recognized: their credibility, saliency and legitimacy (Rounsevell and Metzger 2010). A validation as such for explorative scenarios is impossible, but considering that the presented alternatives are based primarily on medium to high-level well-informed stakeholders, it could be assumed that scenarios give a general idea of possible future situations under possible future policies. This fact not only covers aspects of credibility, but at the same time indicates a high level of legitimacy. Even though our analyses do address several of the main of drivers of LUCC in our study area, there are additional aspects of these relationships that our scenarios do not address. We identify as drivers of LUCC in southern Mexico a synergistic combination of resource scarcity and the subsequent increase in pressure on resources, market opportunities and policy interventions and changes in social organization. Although population pressure and economic factors are an important part of the explanation of deforestation in southern Mexico, other social and political processes (such as land tenure and the existence of institutions stimulating forest protection and technological change toward more sustainable land use practices) constrain forest cover trends (Vaca et al. 2012; García-Barrios et al. 2009). This leads to the situation that forest transition has been extremely localized and incipient and has been the result of passive processes associated with reductions in the intensity of land use (García-Barrios et al. 2009). It could be speculated that this fact could be based on the same processes that lead to a lack of correlation of local positive changes in socioeconomic status vs. forest cover, when we consider that there should be a correlation between economic growth and environmental degradation, as demonstrated on a macrolevel for GDP and forest cover and pollution (Alvarado and Toledo 2016). Moreover, there are many additional factors and drivers, like wildfires, economic recession, drastic price level changes and climate change that could severely affect the hydrological system, etc. that are not considered in the scenarios, but could have potentially a high impact on LUCC and proposed alternatives. Other sources of constraints are represented by knowledge uncertainties among scenario developers and include issues of the broader social–cultural context. Storylines are especially important to assure the acknowledgement of expressing subjective assumptions.

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