AMAZALERT PROJECT

Deliverable 4.2

Set of land-use scenarios for Brazil, linked to implications for policies:

Final Report

Elaborated by:

Ana Paula Aguiar, Graciela Tejada, Talita Assis and Eloi Dalla-Nora (INPE)

November 2014

To complete by the Coordinator

Approved by the Coordinator	YES
Date of approval by the Coordinator	30/11/2014

TABLE OF CONTENTS

1 INTRODUCTION

This report summarizes the AMAZALERT land use qualitative and quantitative scenario results, corresponding to Deliverable 4.2: **Set of land-use scenarios for Brazil, linked to implications for policies: Final Report.** The description of D4.2 according to the project DoW is:

> *"To develop a set of long term qualitative scenarios for the future of land-use and land cover in the Amazon and translated into parameters for quantitative modelling. Scenarios will primarily be developed for Brazil, with a second focus on Peru and Bolivia. To identify the means of increase policy instrument effectiveness such as: - qualitative scenario implications - model results implications - implications for mitigation and adaptation instruments."*[1]

In order to respond to these items, this document is organized as follows:

> **Section 2:** Qualitative scenarios: summarizes the qualitative scenarios for the future of land-use and land-cover in the Amazon built with stakeholder participation (as described in Deliverable D1.2).
>
> **Section 3:** Quantitative land use change modeling: describes how the qualitative premises in the scenarios were translated into quantitative parameters for the Amazon Basin.
>
> **Section 4:** Policy implications of the qualitative and quantitative scenarios, including: qualitative scenario implications - model results implications - implications for mitigation and adaptation instruments.

2 QUALITATIVE SCENARIOS

The approach adopted for the construction of scenarios of land use in AMAZALERT was the use of participatory methods, combining qualitative and quantitative elements. Qualitative stories about the future were discussed with representatives from different sectors of society during two workshops held in Brazil. A complete description of the qualitative scenario process involving stakeholders is presented in Deliverable 1.2.1. The qualitative scenarios were then translated into computational models capable of

---

[1] In AMAZALERT, qualitative scenarios were developed for Brazil, and adapted for Bolivia. Quantitative spatially-explicitly land use projections were then generated by INPE for Brazil and Bolivia. These results were combined to spatial projections generated at the University of Wageningen for the other countries intercepting the Amazon River Basin (including Peru), in a joint effort with the EU-funded ROBIN project. (https://www.wageningenur.nl/en/project/ROBIN-Role-Of-Biodiversity-In-climate-change-mitigatioN.htm). The combined results (Section 3.4 Results) were then used by WP2 and WP3 model runs.

generating alternative spatially explicit representations of land use in the region in the coming decades. In this Section 2 we summarize the main aspects of the qualitative scenarios, as a basis to explain their quantification process in Section 3.

Why new scenarios for the Amazon?

Several modelling exercises (Laurance et al., 2001; Soares-Filho et al., 2006, Aguiar, 2006; Lapola et al., 2011) have attempted to project deforestation rates for the Brazilian Amazon, all of them highly overestimating the deforestation after 2004 (Dalla_Nora et al., 2014). Until the beginning of the last decade, the aggressive deforestation and illegal land appropriation processes in the region seemed to be uncontrollable, peaking at 27,772 km2yr-1 in 2004 (INPE, 2014). Clear-cut deforestation rates have been decreasing since then, falling to 4,571km2yr-1 in 2012. Although some recent analyses have discussed the role of commodity prices and other economic factors in the slowdown of deforestation rates, most have unveiled the integrated set of actions taken by the Brazilian Federal Government to curb deforestation as a decisive factor (Assunção et al., 2012; Arima et al., 2014; Dalla-Nora et al., 2014). These measures included the creation of protected areas, the use of effective monitoring and control systems, and rural credit restriction mechanisms. In 2010, the Brazilian government committed to an 80% reduction in clear-cut deforestation in the Brazilian Amazon by 2020 compared with the 1996-2005 average annual rates (Federal Decree 7390 of 9 Dec. 2009).

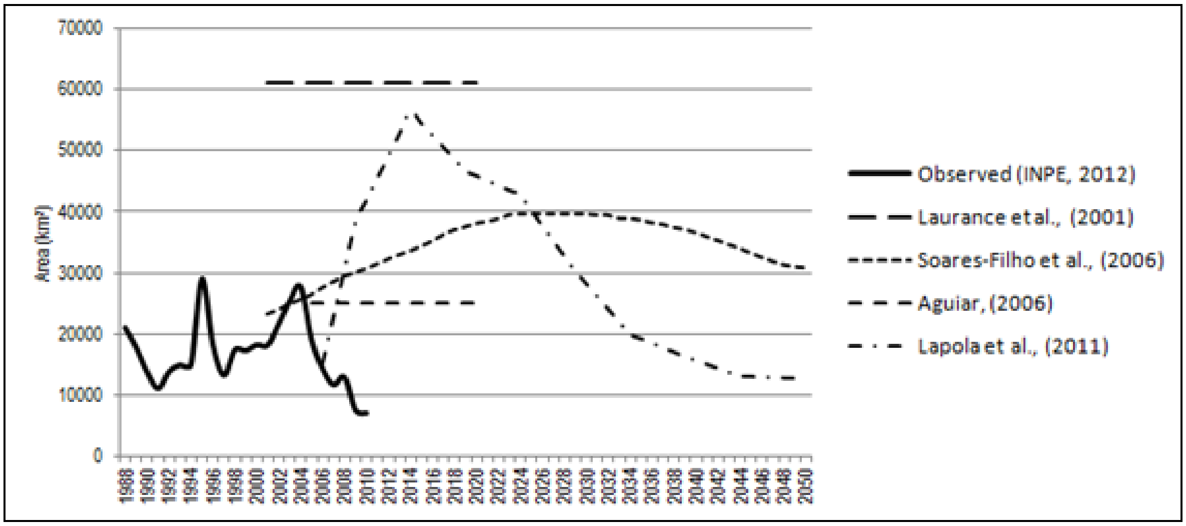


Figure 1 –Comparison of previous scenarios for the Brazilian Amazon, overestimating deforestation rates after 2004 (source: Dalla-Nora et al., 2014)

However, multiple other forces can potentially contribute to the return of high deforestation rates in the next decades. Among them the rapidly expanding global markets for agricultural commodities fuelled by the increasing world´s population and consumption, large-scale transportation and energy infrastructure projects, and - no less important - weak institutions. Besides, the threats to the forest are becoming more scattered and difficult to control. Recent remote sensing assessments (INPE´s DEGRAD system) have identified approximately 16,000 km^{2}yr-^{1} of degraded forests due to illegal logging and fire activities from 2007 to 2012.

In such context of high level of uncertainty about the future, we developed three contrasting futures for the Brazilian Amazon until 2050, which capture some aspects of the land use dynamic trends discussed above. Our approach combined exploratory *("where plausibly are we heading to?*") and normative/anticipatory ("*what do we want and how do we get there?*") scenario approaches. The scenarios vary from *Low to High Social Development* and *High to Low Environmental Development*, as illustrated in Figure 1. In brief, we define high environmental development as the responsible management of natural resources (or more broadly, environmental stewardship). By High Social Development we mean high quality and equal access to services, opportunities and resources, supported by strong institutions. These two axes were already being used in a scenario project being developed at INPE before AMAZALERT started. As Figure 1 also illustrates, the stories have a good match to the IPCC AR5 global SSPs (Socioeconomic pathways). As proposed in the new IPCC scenario process (Arnell et al., 2011), the different socioeconomic context provided by the SSP can be combined to alternative climate change scenarios. The possible combinations act as a placeholder to analyze the effects of adaptation and mitigation policies/actions. Thus, the IAV (Impacts, Adaptation and Vulnerability) community can also benefit from our nested approach for Brazil and Amazonia using different combinations of climate change and the regional socioeconomic context our storylines will provide.

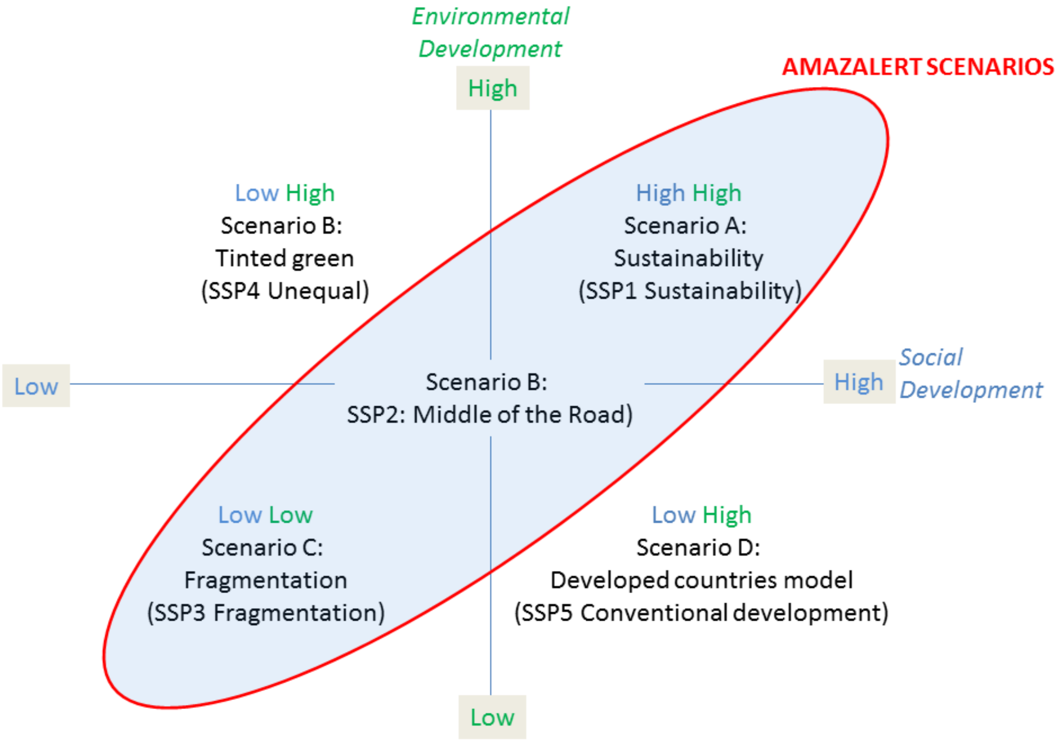


Figure 2: Representation of AMAZALERT scenarios of land use in the context of the Environmental and Social Development axes (also aligned to the IPCC AR5 Socioeconomic pathways).

In AMAZALERT, we developed three of the scenarios shown in Figure 2. We included an ideal "*Sustainability*" scenario (Scenario A) in which we envision major achievements in the socioeconomic, institutional and environmental dimensions. Scenario B stays in the "*Middle of the road*", maintaining some of the positive trends of the last decade, but not reaching a full potential from an integrated socioeconomic, institutional and environmental perspective. Finally, Scenario C is a very pessimistic scenario, named "*Fragmentation*". In this scenario we envision a weakening of the efforts of the recent years, mainly in the socio-environmental dimension. The envisioned scenarios are schematic and contrasting, as Table 1 illustrates. The rationale behind such normative/exploratory approach is to support discussion about how to build a trajectory towards Scenario A rather than towards Scenario C.

Table 1: Brief storylines describing the socioeconomic and institutional contexts

Scenario A: Sustainability	**Scenario B: Middle of Road**	**Scenario C: Fragmentation**
"Relying on strong institutions, the Amazon rural landscapes become mosaics of sustainable territories. Economy and society are well organized around mid-sized urban centers, relying on a diversified economy based on the industrial, forest and agricultural sectors. The strong agricultural sector uses intensive and environmentally safe methods".	"There is some environmental and socioeconomic development, continuing the trend after 2004. Mining and cattle ranching are the dominant sectors in the economy. Forest economy and industrialization are insipient, except in few centers".	"Due to political and institutional changes in Brazil, allied to a global pressure for food, environmental protection loses space to the agricultural expansion. As a result, until 2050, around 35% of the forest is converted to agricultural use".

For each scenario we defined a coherent set of premises about the land use dynamics, which were in turn later transformed into model parameters, as Section 3 details. The quantitative results were then used to run AMAZALERT WP2 and WP3 (climate, vegetation and hydrology) models. Therefore, the construction of qualitative land use scenarios in AMAZALERT had a dual role: (a) to subside WP2 and WP3 model runs using updated scenarios for the region; (b) to subside a discussion about the future with stakeholders, in which the quantitative results to illustrate the impacts of alternative scenarios, extracting inputs for WP4 policy analysis and WP5 Early Warning System.

3 QUANTITATIVE LAND USE CHANGE MODELING

Based on key aspects of each scenario, we generated deforestation, secondary vegetation and agricultural annual maps from 2010-2100 (Brazilian and Bolivian Amazonia), using a 25 x 25 km^2 grid cell. The first step in the process of quantification was the definition of key elements of the land use dynamics which would be represented in the quantitative/spatially-explicit models. Figure 3 synthesizes the selected elements: (a) law enforcement rules representing the institutional context; (b) changes in the major spatiotemporal deforestation drivers (protected areas, paved and unpaved roads, and connection to national markets); (c) annual deforestation rates, spatially distributed by the models according to the spatiotemporal drivers and law enforcement rules; (d) and rules regarding the secondary vegetation parameters. The second step was the definition of a coherent set of premises about these factors for Brazil and for Bolivia in each scenario. Although the qualitative scenarios were only detailed for Brazil during the workshops, we adapted similar assumptions for Bolivia, and were able to quantify the three scenarios there too.

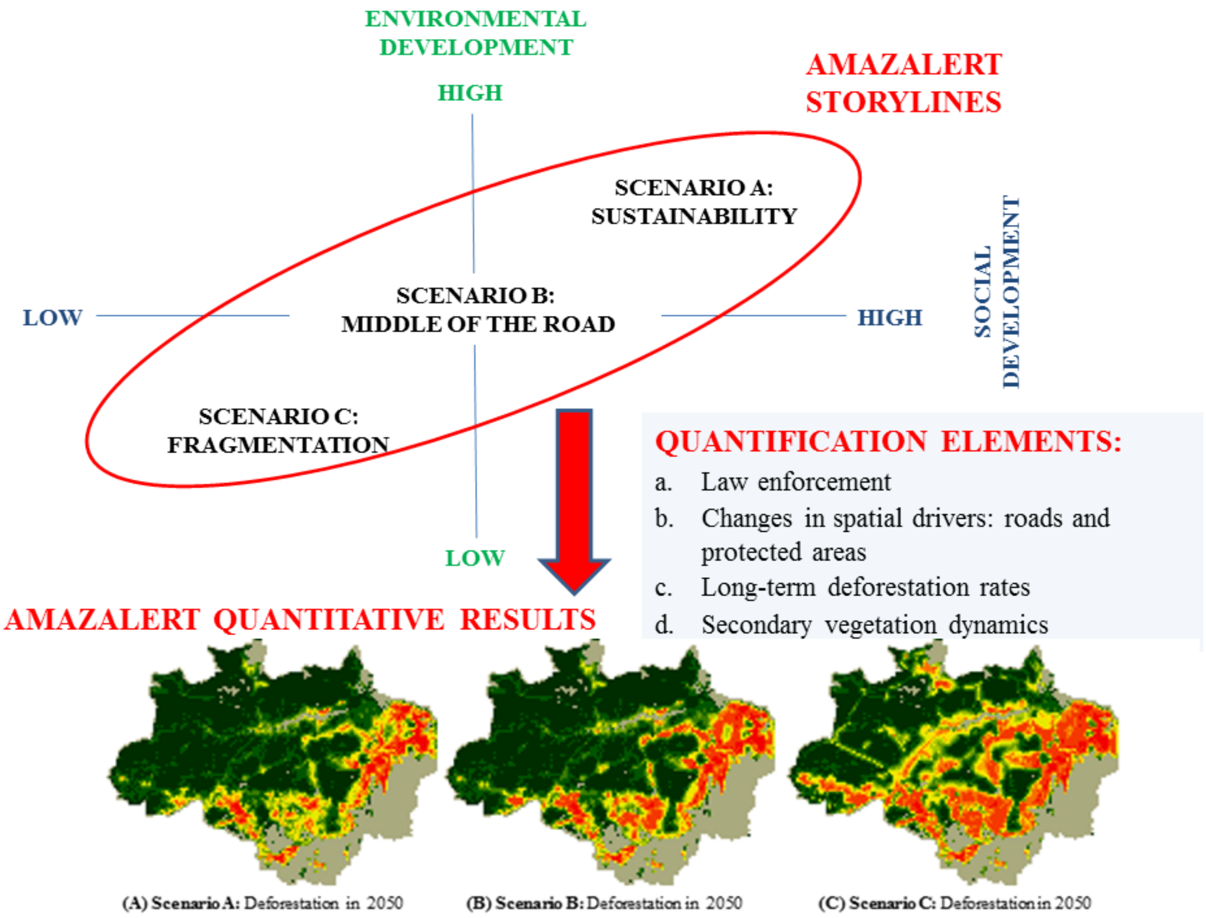


Figure 3: Selected elements to quantify AMAZALERT land use scenarios.

Our land use spatially explicit modelling approach combines a new version of the CLUE model (Verburg et al., 1999) implemented in the LuccME Modelling Framework, and the INPE-EM emission modelling framework (51). We use LuccME to generate annual deforestation maps, and INPE-EM to represent the subsequent secondary vegetation dynamics in the deforested areas. This section describes the methods and results we generated, as follows.

Section 3.1 Modelling tools: LuccME and INPE-EM overview

Section 3.2 Scenario quantification for the Brazilian Amazonia: parameters and results

Section 3.3 Scenario quantification for the Bolivian Amazonia: parameters and results

Section 3.4 Basin-wide results

3.1 MODELING TOOLS

3.1.1 LuccME

LuccME is an open-source framework for the development of spatially explicit land use and cover change models developed at INPE, built as an extension to the TerraME programming environment (Carneiro, 2006). LuccME facilitates the creation of deforestation, agricultural expansion, urban sprawl and other land change process models at different scales by combining basic components or developing new ones. The goals are to provide a collaborative platform for scientific advances in the field, and to disseminate the use of dynamic models beyond the academic world. LuccME can be freely downloaded from http://www.terrame.org/luccme.

A wide variety of approaches and concepts underlie existing LUCC models. In spite of this diversity, a common structure can be identified in several spatially explicit models (Verburg et al., 2006), addressing the following two questions separately (Veldkamp and Lambin, 2001): where land-use changes are likely to take place (location of change) and at what rates changes are likely to progress (quantity of change). Figure 4 schematically represents this common structure, in which three major components can be identified: Potential, Demand and Allocation. Land change decisions are controlled by an allocation mechanism which uses the suitability of each cell for a given land change transition (potential of change) to distribute a given amount (demand) of change in space. The cell potential for change is computed according driving factors of location of change, using empirical evidence and/or expert knowledge.

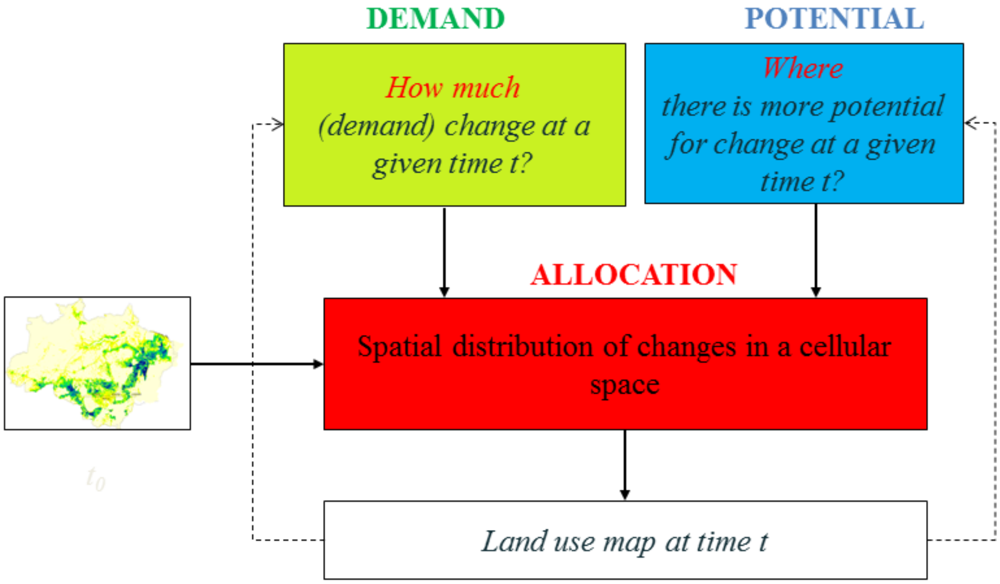


Figure 4 - Generalized structure of LUCC spatially-explicit models (adapted from Verburg et al., 2006).

LuccME allows the construction of LUCC models combining existing Demand, Potential and Allocation components according to the needs of a given application and scale of analysis. The framework provides an initial suit of components for discrete and continuous land use variables, based on well-known LUCC models, such as CLUE (Veldkamp and Fresco, 1996; Verburg et al., 2002) and DINAMICA (Soares-Filho et al. 2002). The framework is open-source, thus it is easy to modify existing components or to create new ones using alternative methods (Eastman et al., 2005; Lesschen et al., 2007). Table 2 summarizes the LuccME 2.0 components.

Table 2 – Demand, Potential and Allocation components available in LuccME 2.0.

	Demand	Potential	Allocation
Discrete (land use variable: categorical)	PreComputedValues	NeighSimpleRule	AllocationByOrdering
	ComputeInputTwoDateMaps	InverseDistanceRule	AllocationClueSLike
	ComputeInputTreeDateMaps	NeighInverseDistanceRule	
	ReceiveDynamicValues	LogisticRegression	
		NeighAttractionLogisticRegression	
Continuos (land use variable: percentage in each cell)	PreComputedValues	LinearRegression	AllocationClueLike
	ComputeInputTwoDateMaps	SpatialLagRegression	AllocationClueLikeSaturation
	ComputeInputTreeDateMaps		
	ReceiveDynamicValues		

In the scope of AMAZALERT, we used the LuccME *AllocationClueLike* component derived from the CLUE model for continuous land use variables (Verburg et al., 1999) to generate annual deforestation maps. In the case of deforestation, cells with a positive change potential received a percentage of the annual change that must be allocated to the whole area, proportionally to their potential. The INPE version differs from the original CLUE model as it was adapted for the Brazilian context (Aguiar, 2006). For instance, there are parameters to control the amount and speed of change that can happen in each cell. In the current application, to control the speed of change we use a dynamic spatiotemporal variable, dynamically updated every year, which indicates if the cell is in a more consolidated or in a frontier area. The amount of change allowed is Scenario dependent, used to represent the Forest Act limits in each Scenario (Table 1). In terms of potential, the original CLUE model relied on Linear Regression to estimate the cell potential for change. We created an alternative method based on the Spatial Lag Regression method (Anselin, 1988; Aguiar et al., 2007) accounting for spatial auto-correlation (*SpatialLagRegression* component). Using this component, we were able to dynamically update the potential of change at each time step considering not only the temporal changes in the spatial drivers (according to the scenario premises), but also the distance to previously opened areas. Finally, the amount of deforestation is prescribed according to each scenario premises (*PreComputedValues* Demand component)

3.1.2 INPE-EM

INPE-EM (Aguiar et. al., 2012) is a deforestation-driven carbon emission modelling framework based on the book-keeping model proposed by earlier work (Houghton et al., 2000), also developed in the TerraME modelling environment. The framework allows the representation of the spatiotemporal dynamics of the deforestation process of the primary forest (old growth) and secondary vegetation dynamics in the opened areas. These processes area represented by two different framework components, as described in Aguiar et al. (2012). In the scope of AMAZALERT, we used the Secondary Vegetation component INPE-EM to represent the secondary vegetation dynamics in the deforested areas for the alternative scenarios, and to generate annual maps of agricultural and secondary vegetation classes from 2010-2100. INPE-EM is available for download at: www.inpe-em.ccst.inpe.br

The framework allows the representation of different pathways in the dynamics of secondary vegetation using spatially distributed parameters, depending on land use practices (Ramankutty et al., 2007). The main parameters we use to represent these processes are the following: the percentage of the deforested area in a given cell that will be abandoned after some years of agricultural use (*AgriculturalUseCycle*) and become secondary vegetation (*AreaPercVegSec*) according to the dominant land use practice in that cell; and the number of years, on average, it will take for that growing vegetation to be removed again. We use the parameter *HalfLife*, based on the ideas of Almeida (2009), to estimate the secondary vegetation removal rate in each cell. The *HalfLife* parameter indicates the number of years to remove 50% of the secondary vegetation (identified using remote sensing images), following an exponential curve. The model estimates the secondary vegetation removal rate for the following years using this exponential curve. Although the main goal of this INPE-EM component is to estimate net CO_2 emissions associated with the regrowth and removal of the secondary vegetation in a spatially explicit manner, the framework also generates as a product the annual maps of the resulting secondary vegetation spatial distribution. Thus, in the scope of AMAZALERT, we used this functionality to decompose the deforested areas into agriculture and secondary vegetation land use classes. In the following sections we present the specific parameters adopted to run LuccME and INPE-EM for the Brazilian and Bolivian Amazonia in each scenario.

3.2 SCENARIO QUANTIFICATION FOR THE BRAZILIAN AMAZONIA[2]

Table 3 synthesizes the elements from each Scenario used for quantification, considering law enforcement rules representing the institutional context, changes in the major spatiotemporal deforestation drivers, annual deforestation rates and secondary vegetation dynamics.

Table 3 – Elements of quantification of each Scenario for the Brazilian Amazon until 2050

Quantification element		**Scenario A: Sustainability**	**Scenario B: Middle of Road**	**Scenario C: Fragmentation**
Law enforcement		Restoration of LRs and PPAs are enforced and incentivized. Amazon deforestation follows the current slowdown trend and achieve the deforestation target set to 2020 (3900 km^2)	LRs and PPAs are satisfied by compensation mechanisms, such as remote forest quotas, instead of local restoration. The deforestation target set to 2020 is achieved	LRs and PPAs requirements are neither met by restoration nor compensation mechanisms throughout the Amazon. Also, the deforestation target set to 2020 is not achieved
Long-term deforestation rates		Follow the lower deforestation trend up to the target 2020 (3900 km^2/yr), and then a new "Zero" (residual < 1000 km^2/yr) deforestation target after 2025	Follow the lower deforestation trend up to the target 2020 (3900 km^2/yr) , but stabilize after that at this level (around 4000 km^2/yr)	Deforestation rates start to rise from 2014 to 2020 and continue uncontrolled until 2050, at historical levels prior to 2004.
Secondary vegetation dynamics		Percentage of secondary vegetation in relation to the deforested area in every cell increase to 35% from 2015-2030. Existing areas of secondary vegetation are not perturbed after 2015	Percentage of secondary vegetation and half-life in each cell follows the current dynamic (less secondary vegetation in more densely occupied areas, ~5 years half-life).	Percentage of secondary vegetation is reduced in the 2015-2050 period in relation to present. Densely occupied areas reduce secondary vegetation to zero.
Changes in spatial drivers	***Roads network***	On-going paving concluded in 2017 (BR-163, BR-319 and BR-230). No new federal or State roads built after 2017.	Same as Scenario C.	All paving and planned roads (Federal and State) built, distributed in 2017, 2025, 2030 and 2042.
	Protected areas-PAs	Maintenance of the 2010 protected areas network.	Same as Scenario A.	Decrease in the extension and level of protection of the PAs, gradually returning to the 2002 extension in 2022 (2018=2006; 2020=2004; 2022=2002).

---

[2] If any part of section 3.2 is used, please cite: Aguiar, A. P. D., Vieira, I.C.G., Assis, T.O., Toledo, P.M., Dalla-Nora, E.L, Araujo, R., Nobre, C.A., Ometto, J.P.H. (submitted) Deforestation emission scenarios: forest transition in the Brazilian Amazon?

3.2.1 Model parameterization

In summary, Scenario A assumes old growth forest deforestation rates will continue to decrease until 2020, achieving a broader "zero deforestation" target. The percentage of secondary vegetation increases from 22% to 35% from 2015 to 2030. Scenario A considers the regeneration of all illegally deforested areas inside private properties (LR and PPA) as measured by Soares-Filho et al., 2014 according to the Brazilian Forest Act (Brasil, 2012). In Scenario B, we assume deforestation rates will continue to decrease reaching 3,900 km^2yr^{-1} in 2020 (according to the voluntary emission reduction national targets), and stabilize at this level up to 2100. But, differently from Scenario A, in Scenario B we assume the secondary vegetation will follow the current dynamics, maintaining a relatively low percentage and life span in more densely occupied areas (30, 31). On the other hand, Scenario C assumes a recrudescence of the deforestation rates in the following years, returning to historic levels prior to 2004. We created two versions of Scenario C for Amazalert in relation to the long term deforestation rates until 2100. One of them uses the average 1996-2005 deforestation rate (19500km2/yr) from 2020-2100. The 1996-2005 average was used to estimate the voluntary emission reduction target by the Brazilian government as this period represents an uncontrolled and aggressive deforestation process. The second version assumes an average of 15000 km2/yr based on a recent modelling result. Dalla-Nora et al. (submitted) and Dalla-Nora (2014) modified a Global General Equilibrium Model (GGEM) to estimate deforestation rates for the Brazilian Amazonia and Cerrado, combining the effect of intra-regional policies applied after 2004 (such as the credit restriction and the creation of Protect areas) and the global demand for commodities (based on population and GDP growth projections until 2050). In their worst scenario, without control, they estimated an average rate of 15000km2/yr for the Amazonia. We used this value as a basis for Scenario C1, extending the projection until 2100. Figure 5 illustrates the deforestation rates in the different scenarios, comparing them to the previous modelling exercises and also to the IPCC AR5 rates based on the RCPs. It is interesting to notice how the recent modelling results reinforce the perception of the stakeholders about importance of the intra-regional action as a balance to the demand for commodities. Scenario C also assumes the creation and paving of several Federal and State planned roads and a decrease in the protected areas network, consistent with the increase of deforestation rates and a lower level of law enforcement. Annex A illustrates the assumptions regarding the temporal evolution of the spatial drivers changes in each scenario. Finally, in Scenario C we assume the secondary vegetation area will be halved, as secondary forests would be substituted by other agricultural uses, and land price and concentration process reduce the abandonment of degraded pasture and fallow agricultural practices.

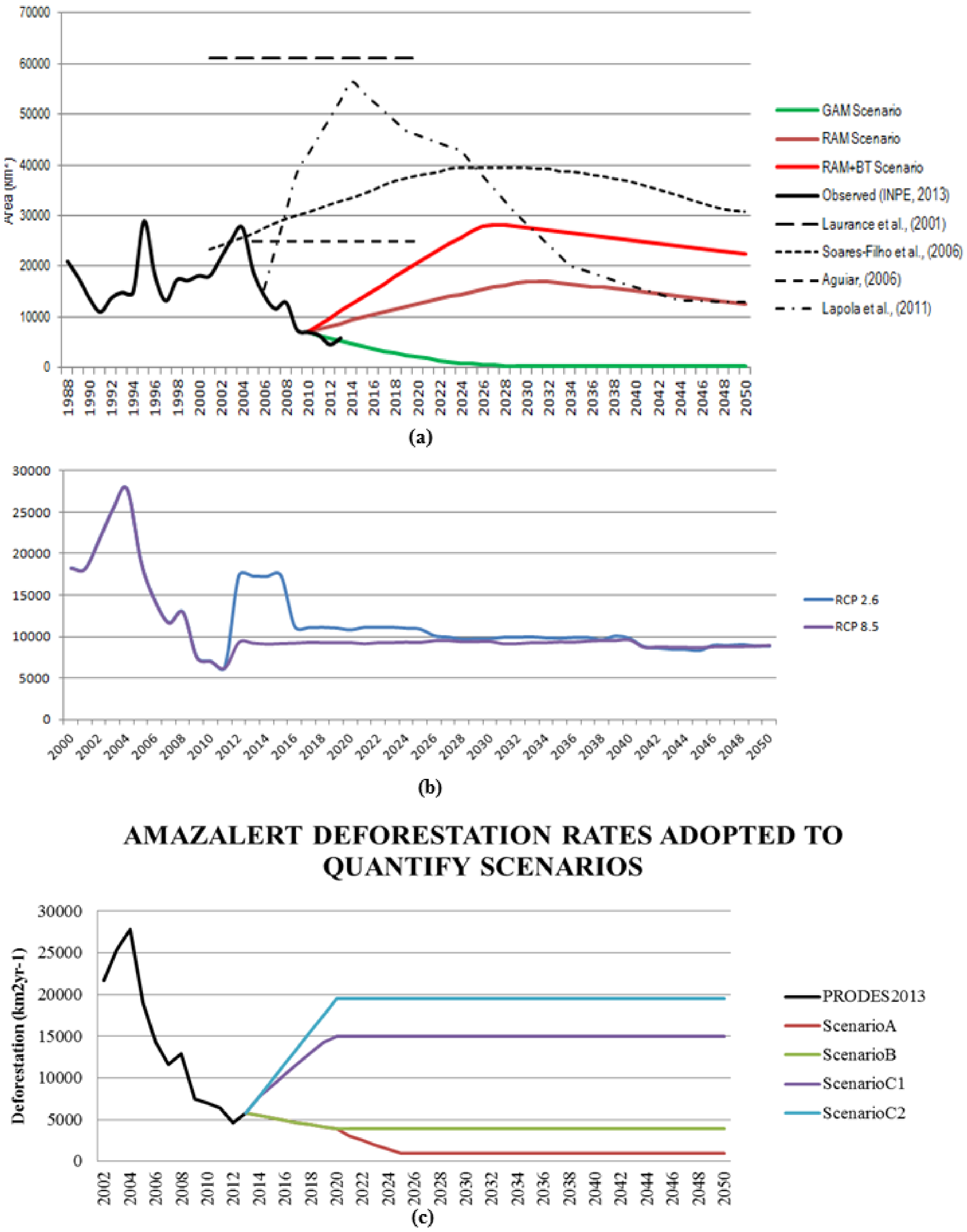
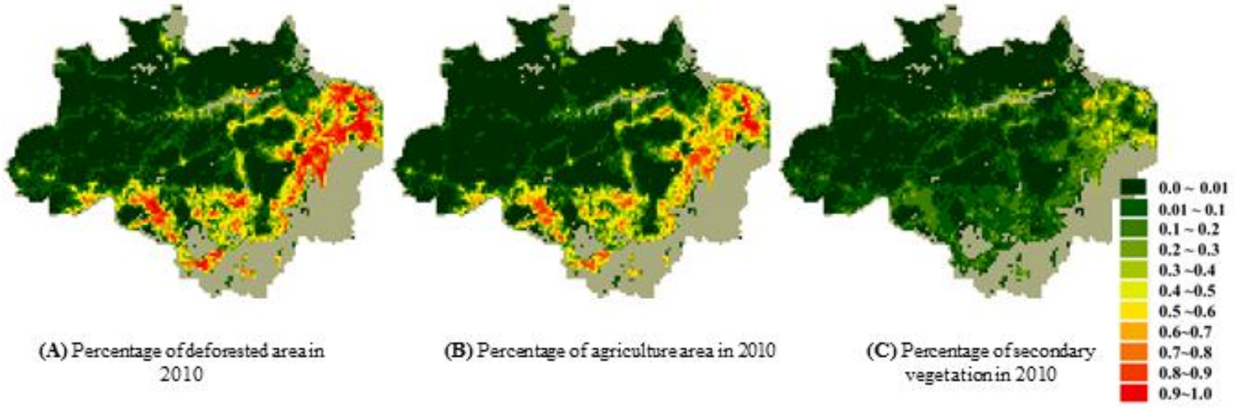


Figure 5 – Future deforestation rates: (a) previous modelling exercises; (b) IPCC AR5 RCPs; (c) adopted to represent the AMAZALERT Scenarios.

Given these premises, we calibrated LuccME and INPE-EM models (Section 3.1) using observed deforestation data from 2002-2010 (Figure 6), and run the different scenarios from 2010-2050. Initially we quantified the scenarios until 2050. Later in the project, it was required by WP2 and WP3 to extend the temporal scale until 2100. We basically maintained the same parameters and premises until 2100, but not changing the spatial drivers after 2050. Table 4 details the final LuccME Potential (*SpatialLagRegression*), Allocation (*ClueLikeAllocation*) and Demand components (*PreComputedValues*). Table 5 presents the *SecondaryVegetation* INPE-EM component parameters.



(A) Percentage of deforested area in 2010

(B) Percentage of agriculture area in 2010

(C) Percentage of secondary vegetation in 2010

Figure 6 – Observed 2010 information (source: PRODES/TerraClass INPE) used for model validation and as the first year of scenario model runs.

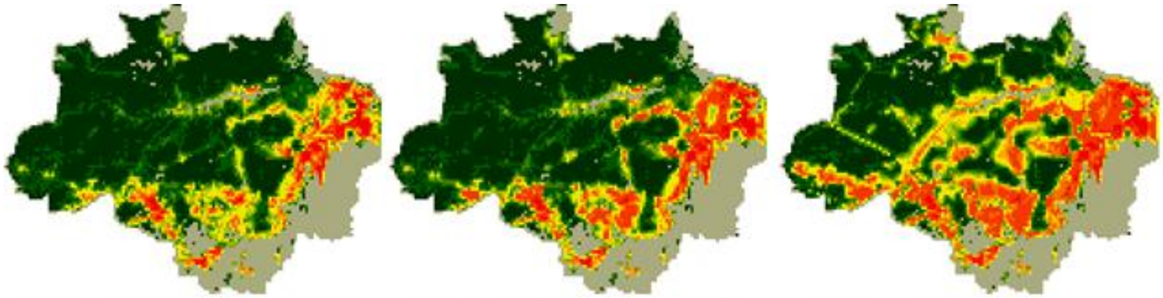
Table 5 – Brazilian Amazonia INPE-EM (*SecondaryVegetation* component) parameters

***SecondaryVegetation* parameter**	**Average value**	**Source**
AreaPercVegSec	0.21*	TerraClass
AgriculturalUseCycle	2 anos	Aguiar et al. (2012)
RecoveryPeriod1Perc	70%	Houghton et al. (2000), Aguiar et al. (2012)
RecoveryPeriod1	25 anos	Houghton et al. (2000), Aguiar et al. (2012)
RecoveryPeriod2Perc	30%	Houghton et al. (2000), Aguiar et al. (2012)
RecoveryPeriod2	50 anos	Houghton et al. (2000), Aguiar et al. (2012)
HalfLife	5**	Almeida (2009), Aguiar et al. (2012)
InitialAbandonmentCycle	3	Almeida (2009), Aguiar et al. (2012)

Table 4 –Brazilian Amazon LuccME Parameters

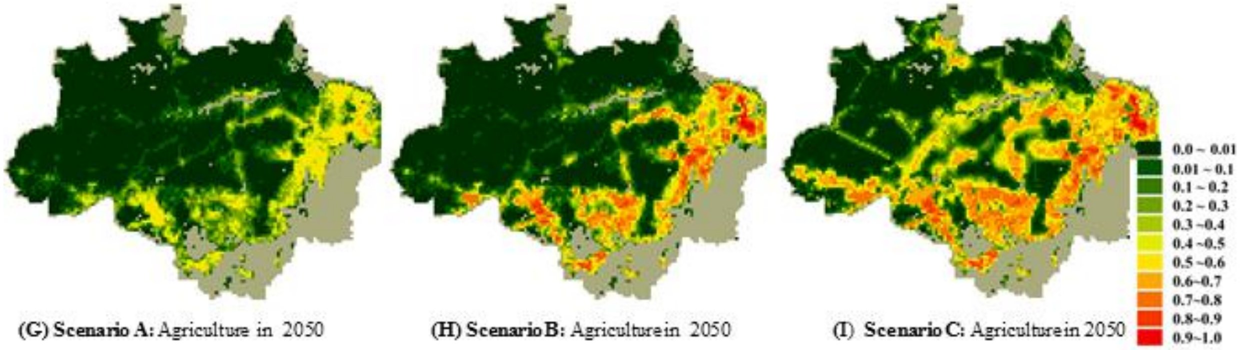
Spatial scale	Extent	Brazilian Amazon Rain Forest area (according to PRODES mask)				
	Resolution	Regular cells of 25 x 25 km2				
Temporal scale	Extent	2010-2050-2100	*initially run until 2050, then scenario C was expanded to 2100			
	Resolution	yearly				
	Calibration	2002-2006 (PRODES)				
	Validation	2006-2010 (PRODES)				
Land use/cover classes	Percentage of forest, deforest, no-data (cerrado, clouds, water) in the cell					
	Selected deforestation spatial determinants (submodel PS31)		*Regression Coefficient*	*Std B*	*Significance*	*Scenario dependent*
W_log_def	Spatial autoregressive coefficient		0.76664980	0.769	0.000	
constant	Regression constant		2.24971000	-0.012	0.000	
connMkt_SPNE	Connectivity index via the road network to São Paulo or Recife, proxies of major national markets for Amazonia (source roads network: DNIT and PAC)		-0.00000019	-0.046	0.000	Y
log_distRoads_PAVED	Euclidean distance to the closest paved road (log10 transformed) (source: DNIT)		-0.10011870	-0.039	0.000	Y
log_distRoads_UNPAVED	Euclidean distance to the closest unpaved road (log10 transformed) (source: DNIT)		-0.08295176	-0.029	0.000	Y
log_distWoodProdPoles	Euclidean distance to the closest timber extraction and processing center (log10		-0.30504930	-0.084	0.000	
settlProject_AGR	Percentage of cell area covered by official agrarian projects for agricultural use (PA) (source: INCRA)		0.40322090	0.048	0.007	
landFertility_HIGH	Percentage of cell area covered by soils of high fertility (source: EMBRAPA/IBGE)		0.20855270	0.044	0.000	
protPublicForests_ALL	Percentage of cell area covered by Indigenous Lands, Conservation Units, Sustainable settlement projects and Military areas. (source: MMA, INCRA and FUNAI)		-0.40388840	-0.103	0.000	Y
	Deforestation allocation parameters - submodel A20		*Scenario A*	*Scenario B*	*Scenario C*	
maxError	Maximum allocation error allowed for each land use		1000 km2	1000 km^2	1000 km2	
minValue	Minimum value (percentage) allowed for that land use as a result of new changes		0%	0%	0%	
maxValue	Maximum value (percentage) allowed for that land use as a result of new changes		50%	80%	80%**	
changeThresholdValue	Threshold applied to the level of saturation in each cell. The saturation level is		40%	40%	40%	
maxChange	Maximum change in a given land use allowed in a cell in a time step until (saturation)		3%	6%	6%**	
maxChangeAbovethreshold	Maximum change in a given land use allowed in a cell in a time step after (saturation)		3%	3%	3%	
	Deforestation rates (km2/ano)		*Scenario A*	*Scenario B*	*Scenario C1*	*Scenario C1*
			Decreasing to 3900 (2020) to 1000 (2025) and stabilizing until 2050	Decreasing to 3900 (2020) and stabilizing until 2050	Incresing to 15000 (2020) and stabilizing until 2050 (2100)	Incresing to 19500 (2020) and stabilizing until 2050 (2100)

3.2.2 Model results



(A) **Scenario A:** Deforestation in 2050 (B) **Scenario B:** Deforestation in 2050 (C) **Scenario C:** Deforestation in 2050

(D) **Scenario A:** Secondary Vegetation in 2050 (E) **Scenario B:** Secondary Vegetation in 205 (F) **Scenario C:** Secondary Vegetation in 2050



(G) **Scenario A:** Agriculture in 2050 (H) **Scenario B:** Agriculture in 2050 (I) **Scenario C:** Agriculture in 2050

Figure 7 – Examples of LuccME results for Brazil

As figures 7 illustrates, Scenario A and Scenario B are similar in relation to the resulting deforestation patterns around the current existing frontiers (Figure 6). Major difference lays in the level of deforestation of some specific cells in the frontier areas (for instance, in central Amazon), due the Law Enforcement model parameter restricting the maximum amount and speed of change in Scenario A (Table 5). However, underneath the similar deforestation patterns in Scenario A and B, lays the difference in the area of secondary forests allowed to regenerate (Table 3), and consequently in the net CO2 emission estimates. In Scenario A, Aguiar *et al.* (submitted) estimate that the region could become a carbon sink after 2020, with a negative net emission of -3±0.3 PgC from 2011 to 2050, reversing the historical deforestation-driven carbon emissions in the region.

In relation to the resulting spatial patterns, Scenario C also shows a gradual concentration of the deforested areas around previously opened and more connected areas, but also the emergence of new frontiers around some planned roads (for instance, in the Amazonas State). The heterogeneous spatial patterns emerge from the spatial drivers' interactions and law enforcement restrictions built-in in the model.

3.3 SCENARIO QUANTIFICATION FOR THE BOLIVIAN AMAZONIA[3]

As some groups in AMAZALERT were focusing their hydrological studies in the Madeira River Basin, we also generated spatially-explicitly projections for the eastern lowland Bolivia, based on Killen et al. (2012) land use and cover change data below the natural montane tree line (~3000 m) that includes the Madeira and the Amazon Basin limit.

In Bolivia, tropical forests cover more than 50% of the country (FAO-FRA, 2010), playing a key role in the provision of ecosystem services such as carbon sink and biodiversity conservation (between others). Nevertheless, from 2000-2012 Bolivia is in the 12th countries with the highest deforestation rate (Hansen et al. 2013). The political decisions pretend to increase the agricultural frontier from 3 to 13 million ha in the next ten years (IBCE, 2013). In addition, oil and mining exploration together with road constructions will expand to intact forest including protected areas and indigenous territories violating the environmental law (Jiménez, 2013). In Bolivia, few studies address future deforestation and its impacts on ecosystem services provision. Thus, due to deforestation rate will increase because of the policies that will incentive to expand of the agricultural frontier and the low governance to control illegal deforestation is relevant to simulate the future deforestation under different scenarios.

3.3.1 Model parameters

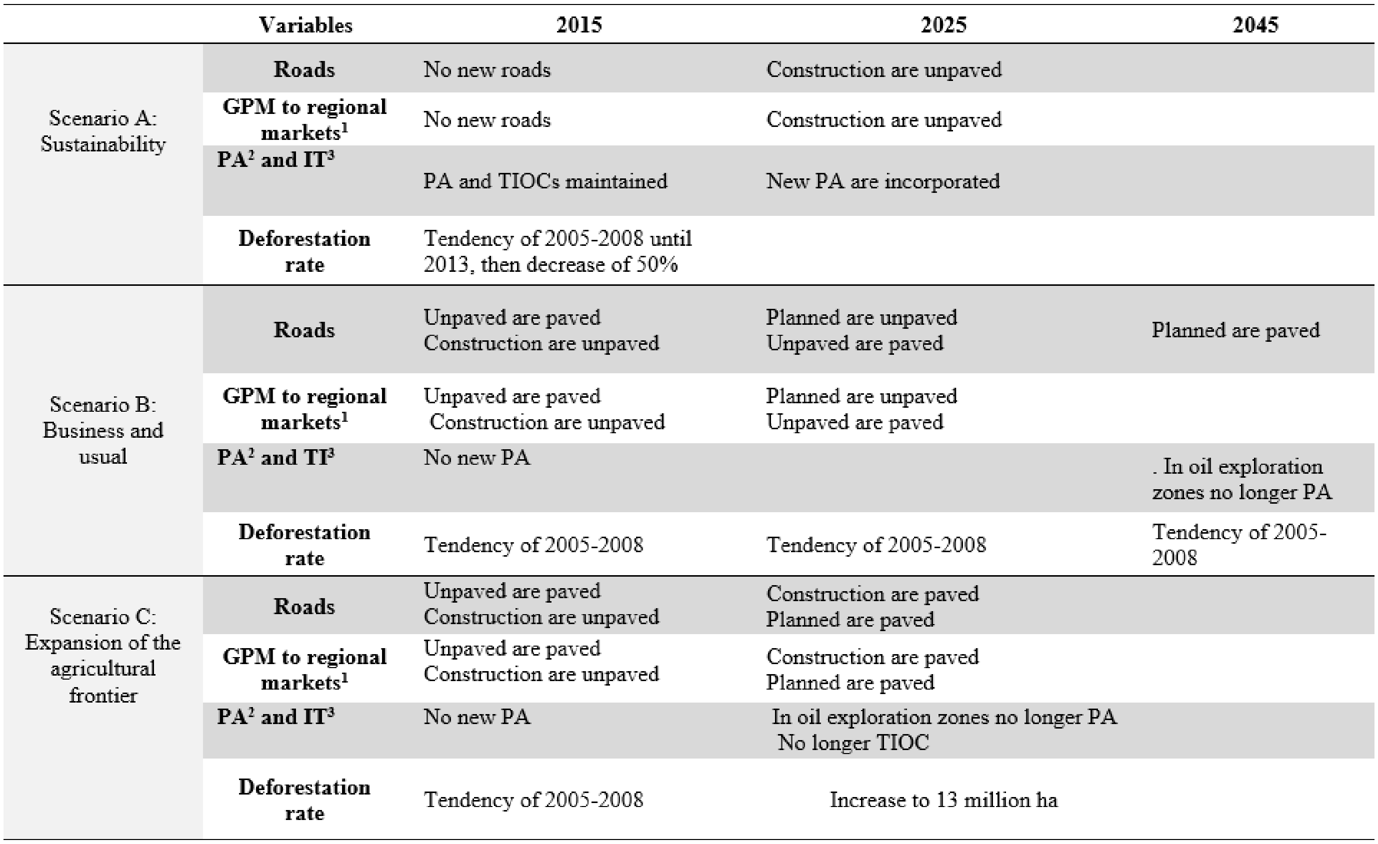
Table 3 synthesize the main assumptions for the quantification of scenarios A, B and C in Bolivia, adapting the same axis presented in Figure 2 to the specific socioeconomic and political context of Bolivia, so that results could be combined for the two countries.

In terms of deforestation rates, Scenario A represent most optimistic situation (*Sustainability*, where all the environmental laws are enforced). Scenario B considers the current deforestation trends (named "*Business as usual Scenario" in Bolivia*), and Scenario C the worst situation (named the "*Expansion of the Agricultural Frontier Scenario"* in Bolivia). Table 6 details LuccME parameters used to run the scenarios. Figure 7 illustrates the spatial drivers of change selected to parameterize the LuccME Potential component. In relation to secondary vegetation, we assumed there is no abandonment of agricultural area, and thus no secondary vegetation in the deforested areas (*AreaPercVegSec* INPE-EM parameter equals zero*)*.

---

[3] If any part of Section 3.3 is used, please cite: Tejada, G et al. (submitted). Land Use and Land Cover Change Scenarios for the Bolivian Amazon.

Table 3 - Scenario quantification assumptions for the Bolivian Amazon (including the Madeira River Basin)



	Variables	2015	2025	2045
Scenario A: Sustainability	**Roads**	No new roads	Construction are unpaved	
	GPM to regional markets[1]	No new roads	Construction are unpaved	
	PA[2] and IT[3]	PA and TIOCs maintained	New PA are incorporated	
	Deforestation rate	Tendency of 2005-2008 until 2013, then decrease of 50%		
Scenario B: Business and usual	**Roads**	Unpaved are paved Construction are unpaved	Planned are unpaved Unpaved are paved	Planned are paved
	GPM to regional markets[1]	Unpaved are paved Construction are unpaved	Planned are unpaved Unpaved are paved	
	PA[2] and TI[3]	No new PA		. In oil exploration zones no longer PA
	Deforestation rate	Tendency of 2005-2008	Tendency of 2005-2008	Tendency of 2005-2008
Scenario C: Expansion of the agricultural frontier	**Roads**	Unpaved are paved Construction are unpaved	Construction are paved Planned are paved	
	GPM to regional markets[1]	Unpaved are paved Construction are unpaved	Construction are paved Planned are paved	
	PA[2] and IT[3]	No new PA	In oil exploration zones no longer PA No longer TIOC	
	Deforestation rate	Tendency of 2005-2008	Increase to 13 million ha	

[1] Connectivity index via the road network to regional markets (cities>70,000 people).
[2] PA: Protected areas.
[3] IT: Indigenous lands

Table 6 –Bolivian Amazon (Madeira River) LuccME Parameters

Spatial scale:	
Area:	*Bolivian Amazon*
Resolution:	*(25km x 25km) 625 km*^{2}
Temporal Scale:	
Period:	*2001-2008*
Resolution:	*annual*
Data for statistical analysis :	*2001*
Data for calibration/validation:	*LU data 2005 and 2008*
Period of scenarios analysis:	*2050*
Land use and cover change data:	
Classes:	*(1) Natural vegetation (Forest, Chaco, Cerrado; Savannah/Wetlands; Puna/Andean scrublands); (2) Others; (3) Deforestation*
Source:	*Museo de Historia Natural Noel Kempff Mercado (Killen et al. 2012)*
Kind of model:	*Continuous*
Relationship between use and location factors:	
Methods to quantify the relationship between land use and location factors:	*Spatial lag regression*
Quantification of land use change:	
Period of observed data:	*2001-2008*
Scenarios	*Scenario A: Sustainability* *Scenario B: Business and usual* *Scenario C: Expansion of the agricultural frontier*

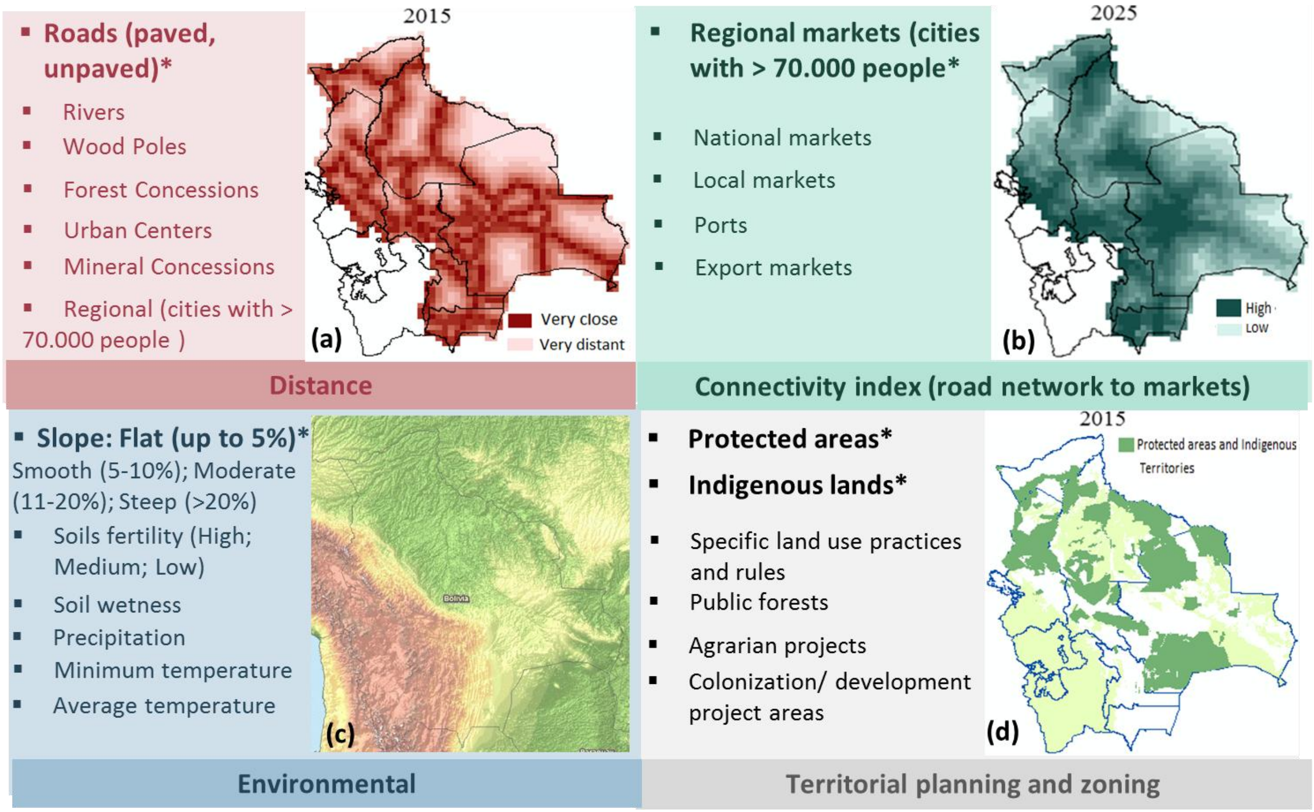


Figure 6 - Independent variables analyzed, determinant variables after the statistical analysis are with *. (a) Distance to the logarithm of closest paved or unpaved road; (b) Connectivity index via the road network to regional markets (cities with > 70,000 people); (c) Slope; (d) Protected areas and indigenous territories.

3.3.1 Model results

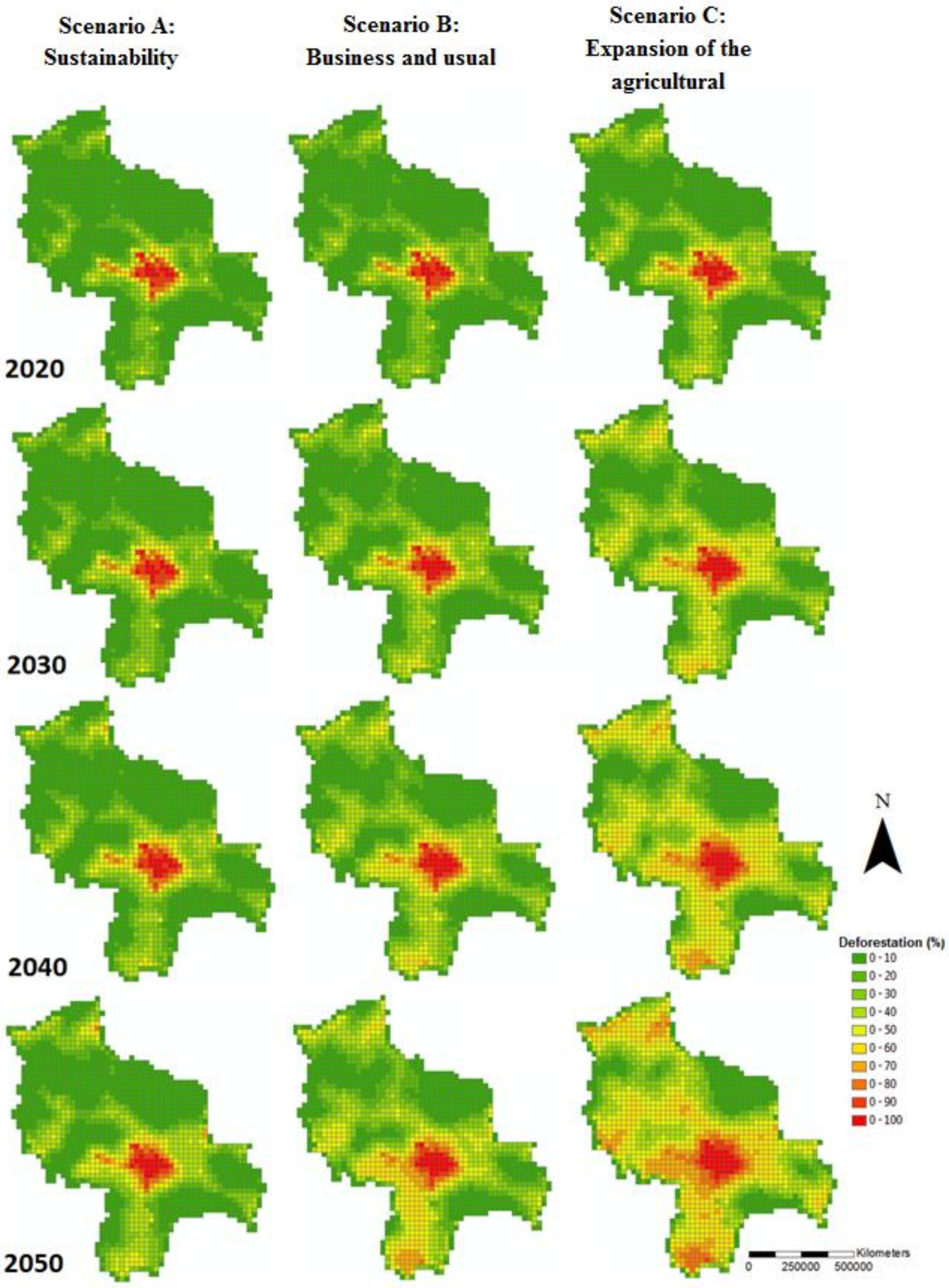


Figure 7 – LuccME Results for Bolivia

3.4 BASIN WIDE RESULTS

The annual spatially explicitly results for Brazil and Bolivia were combined to existing projections for the other countries in the Amazon Basin (Figure 8). The projections for the other countries were generated at the University of Wageningen, in a joint effort with the EU-funded ROBIN project. (https://www.wageningenur.nl/en/project/ROBIN-Role-Of-Biodiversity-In-climate-change-mitigatioN.htm). The combined results (annual maps) were then used by WP2 and WP3 model runs.

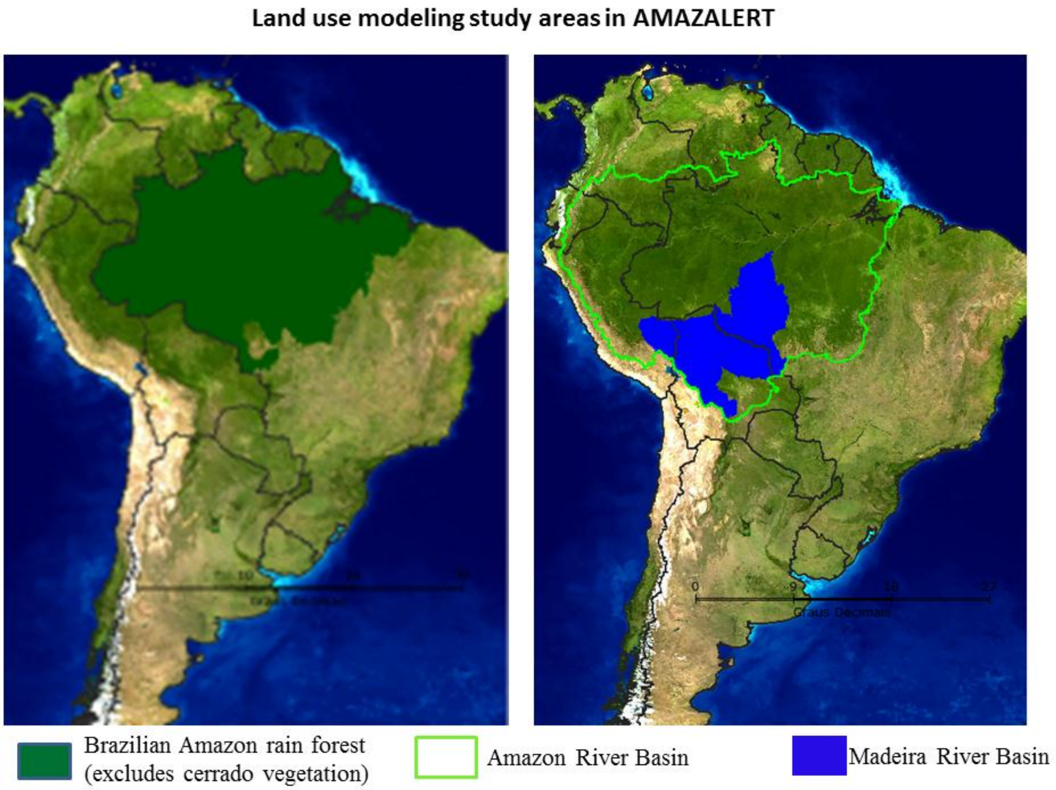


Figure 8 – Amazon River Basin

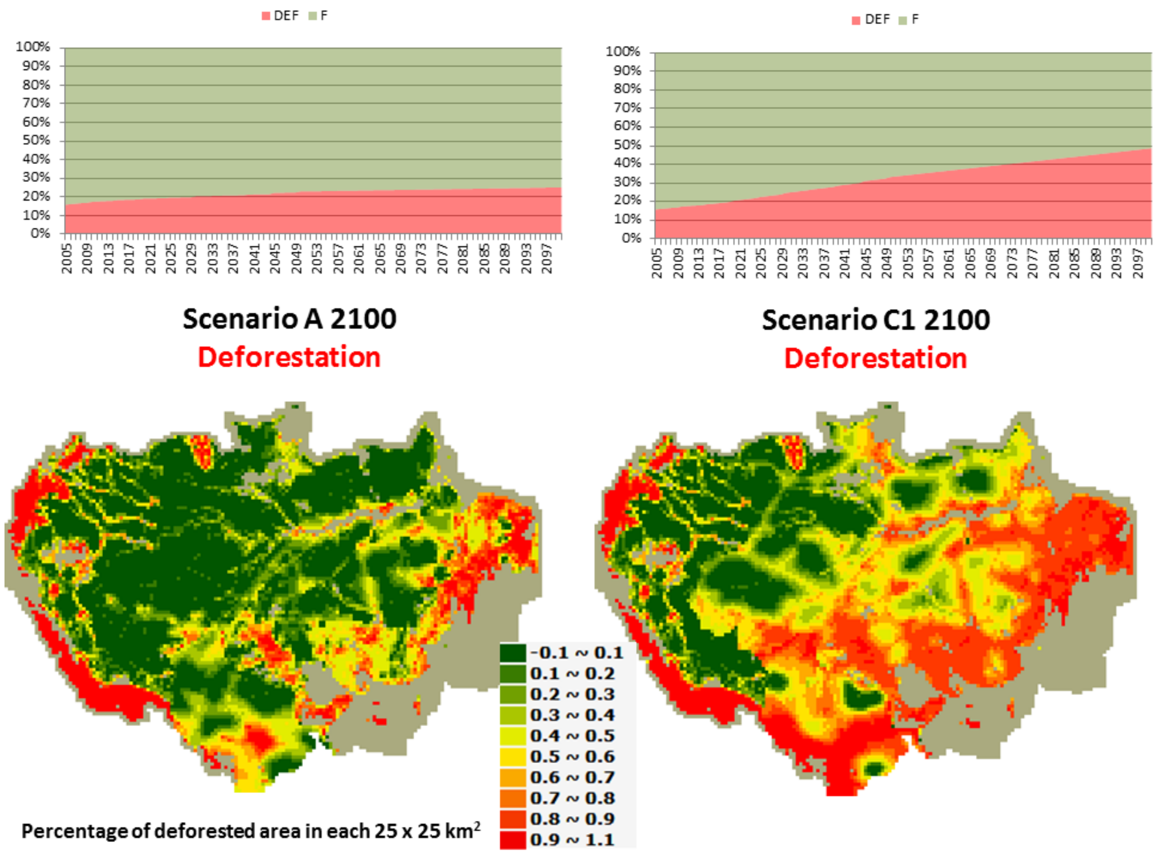


Figure 9 – Examples of AMAZALERT/ROBIN integrated basin-wide results

4 POLICY IMPLICATIONS OF THE QUALITATIVE AND QUANTITATIVE SCENARIOS

The large differences between Scenarios A, B and C developed at AMAZALERT reflects the current level of uncertainty about the future of the region. In the case of Brazil, until the beginning of the last decade, the aggressive deforestation and illegal land appropriation processes in the region seemed to be uncontrollable, peaking at 27,772 km^2yr^{-1} in 2004. Clear-cut deforestation rates have been decreasing since then, establishing at approximately 6000km^2yr^{-1} in the last three years. Although some recent analyses have discussed the role of commodity prices and other economic factors in the slowdown of deforestation rates, most have unveiled the integrated set of actions taken by the Brazilian Federal Government to curb deforestation as a decisive factor. These measures included the creation of protected areas, the use of effective monitoring and control systems, and credit restriction mechanisms. In 2010, the Brazilian government committed to an 80% reduction in clear-cut deforestation in the Brazilian Amazon by 2020 compared with the 1996-2005 average annual rates (Federal Decree 7390 of 9 Dec. 2010). However, multiple other forces can potentially contribute to the return of high deforestation rates in the next decades. Among them the rapidly expanding global markets for agricultural commodities fuelled by the increasing world´s population and consumption, large-scale transportation and energy infrastructure projects, and - no less important - weak institutions.

In this context, AMAZALERT developed new and contrasting scenarios for the land use in the region. For the Brazilian Amazonia they were constructed using participatory, qualitative/quantitative, normative/exploratory approaches (Aguiar et al. 2014; Aguiar et al. submitted). Representatives of diverse sectors of the society contributed to the construction of the qualitative storylines for the two most opposite scenarios. Scenario A ("*Sustainability*") is an ideal/desired normative scenario, in which stakeholders envisioned and detailed major achievements in the socioeconomic, institutional and environmental dimensions - that would constitute a common sustainable future for the region. The opposite Scenario - Scenario C, named "*Fragmentation*" - is a very pessimistic scenario, in which they envisioned a weakening of the efforts of the recent years, mainly in the socio-environmental dimension and a chaotic urbanized Amazonia.

For each scenario, stakeholders also defined a comprehensive list of actions which would lead to such the opposite futures. From that list (presented in Deliverable D1.3), we extracted five key points proposed to achieve Scenario A and avoid Scenario C, summarized in the Table below. As the selected items cover short to long term actions, the existing initiatives are mentioned as examples, which should be enhanced, integrated - or even avoided in some cases – according to the proposed actions.

Table 7 – Policy recommendation derived from the qualitative scenarios results

ACTION TOWARDS A SUSTAINABLE FUTURE	**EXAMPLES (positive and negative)**
(a) MONITORING SYSTEMS: continuation and enhancement of the satellite based monitoring systems initiated at PPCDAM, considered as the key aspect to control deforestation. This includes the development of new systems (based on new sensors, for instance), and expansion to other biomes, to avoid leakages.	*Examples of current initiatives to be enhanced and expanded: PRODES, DETER, DEGRAD (INPE/MMA), TERRACLASS (INPE/EMBRAPA).*
(b) INTEGRATED TERRITORIAL PLANNING: consolidation and enhancement of multiple instruments for territorial and land use planning, in order to concomitantly regulate pressure for land, create sustainable economic alternatives and integrate social programs at a territorial basis. This includes private and public lands (such as conservation units, indigenous lands, settlements), rural and urban areas.	*Several of the on-going public and private initiatives were mentioned as positive examples, although they need to be consolidated and integrated, some effectively implemented (for instance, the SNUC (National System of Conservation Units, ZEE (Ecological Economic Zoning), Land Titling Program, ABC Program (Low Carbon Agriculture), Soy/Beef Moratorium, Certification, Poverty eradication programs, Food Purchase program[4]). Other aspects of the current were mentioned as really negative, such as the lack of economic opportunities and infrastructure in settlements and many protected areas (for instance, extractive reserves).*
(c) CITIES RESTRUCTURING: Strengthening of cities to create an interconnected network of medium-sized cities, with infrastructure, proper network of services and education to meet the demands of sustainability.	*One of the points most emphasized by the participants during the stakeholder workshops was the process by which the medium and large cities in the Amazon have been through: attracting large populations coming from migration and rural exodus to their peri-urban areas, in spite of the poor services offered, increasing even further the levels of violence and poverty existing in these cities.*
(d) LARGE INVESTMENTS PLANNING: Planning for the implementation of large projects (including infrastructure and mining) combined to the integrated territorial planning (item B), avoiding the boom-bust economies of the cities. In the case of infrastructure, planning geared both to the needs of the local population (river transport, for example), as well as market demands (commodities production flow through hydroways).	*The city of Altamira, which suffers from the changes caused by the implementation of AHE Belo Monte is an emblematic example (also for item c).*
(e) LEGAL FRAMEWORK PROTECTION: enforcement and enhancement of the legislation governing the access to natural resources and land use, creating mechanisms to balance the influence of macroeconomic interests in modifying legal marks at the expense of regional, social and environmental aspects.	*The modification of the legal framework aiming solely at specific sectors interests was another item of concern during the workshops, exemplified by the pressure on indigenous lands, including data showing soy plantations on indigenous lands over lease, and possible revision of their boundaries due to the mining code[5].*

---

[4] See AMAZALERT Deliverable 4.1 for a description of the current policies in place in the Amazon. See AMAZALERT Deliverable D1.2 for the context in which they were mentioned by stakeholders.

[5] As recently documented in Ferreira et al. (2014)

It is interesting to notice how these actions consider the environmental and economic dimensions in an integrated way, while aiming at reducing inequality in access to services and opportunities, as a result of the project choice of initial axis (Figure 10). Scenario B (*Middle of the Road*) was not detailed in the workshops, but is considered a more likely scenario combining elements of social development and environmental heterogeneously. If Scenario B will be more similar to A or C will depend on the actions society takes in coming decades as much to solve structural social problems of the region - as well as for dealing with the internal and external demand for agricultural and mining commodities. The option for the extremes occurred precisely to provide discussion about such *actions* toward (pathways) to future of Sustainability - with emphasis on the power of intervention of local actors, without disregarding the global context.

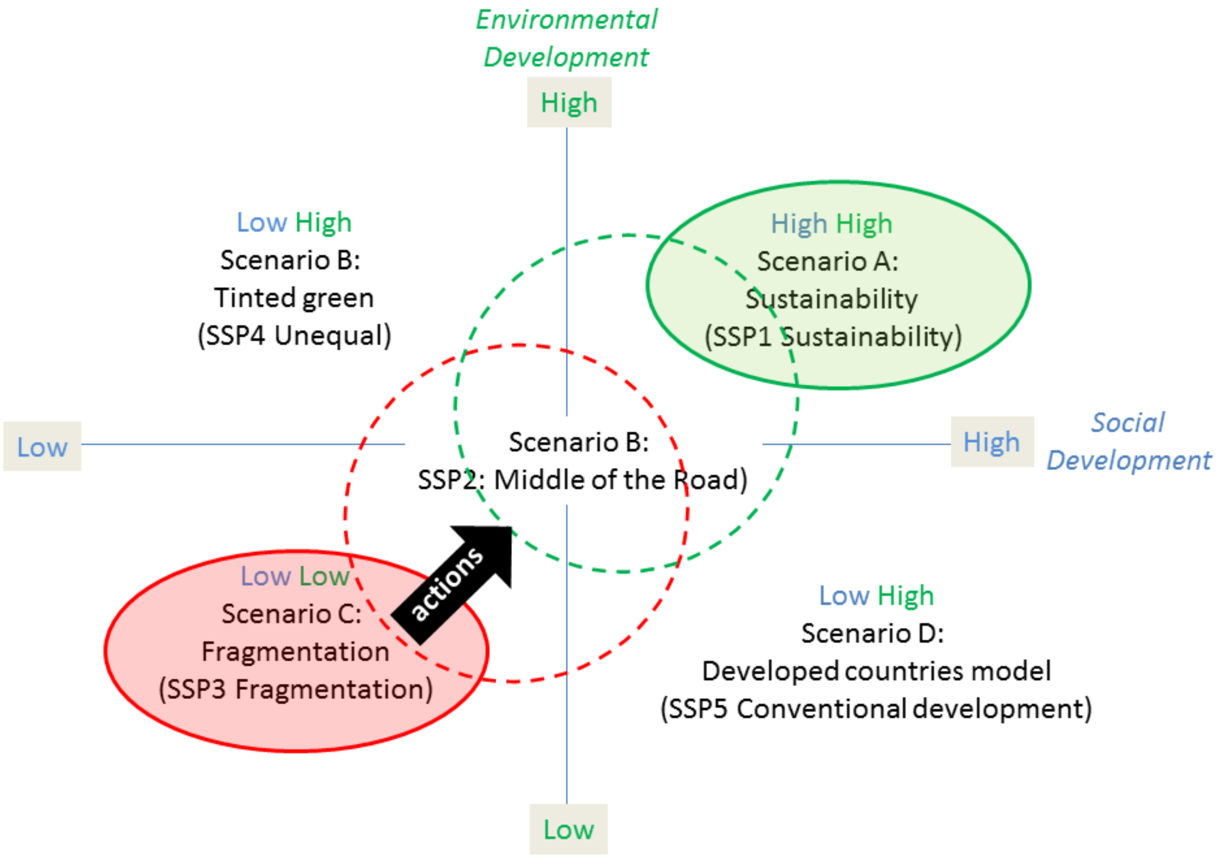
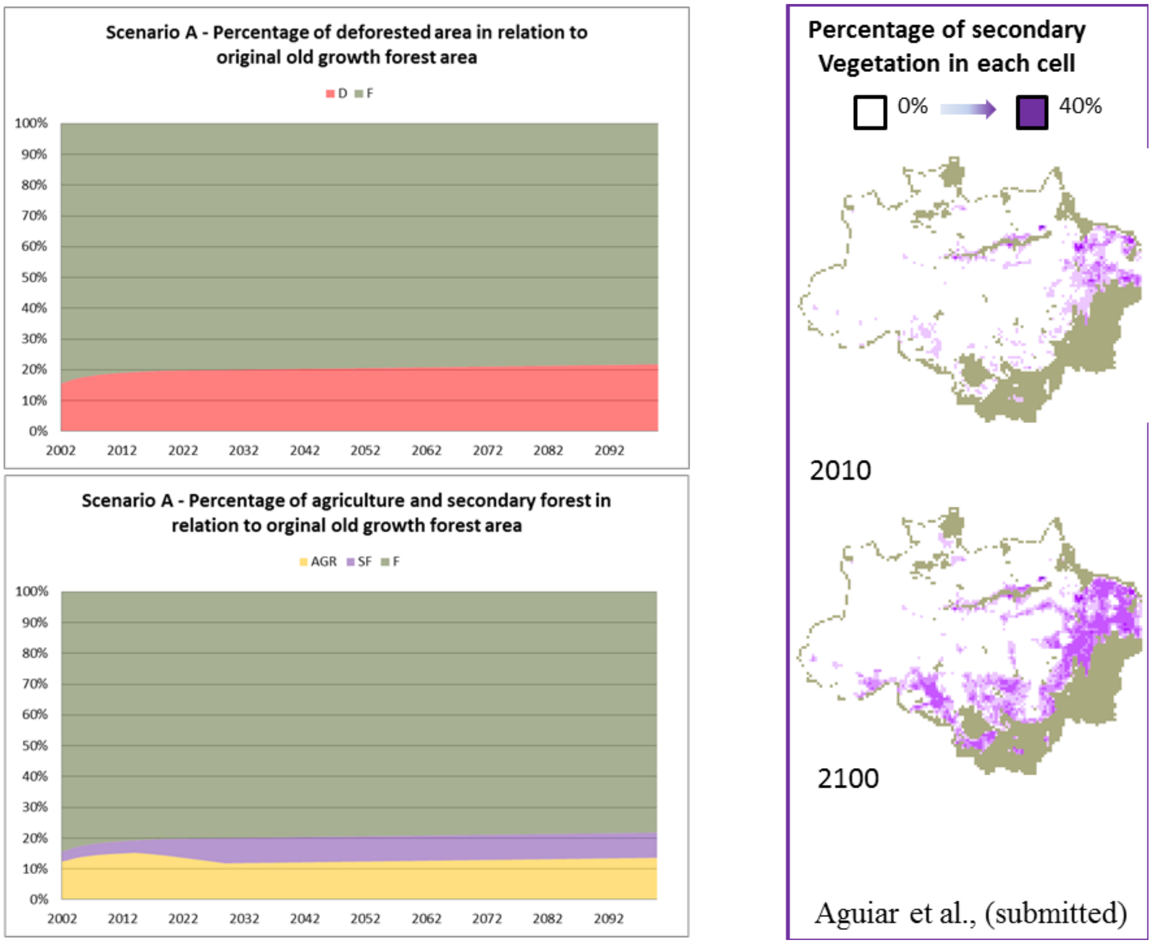


Figure 10 - Representation of AMAZALERT scenarios of land use in the context of the Environmental and Social Development axes

To build a trajectory in the direction of Scenario A, in which natural vegetation areas (primary and secondary) are maintained or even expanded, forests need to be seen as valuable assets by the different actors in the region through their provision of ecosystem services (e.g., biodiversity, carbon, hydrological cycle, bio-products) by the development of a solid forest-based economy, balancing the benefits from forests and agricultural lands to the society as a whole. However, as made clear by stakeholders during the workshops, decreasing deforestation rates or growing secondary forests does not automatically bring socioeconomic development. There is a concern in the region about the deteriorating quality of life in the mid and large-sized cities, due to the lack of economic options both in rural and urban areas. Finally, the stakeholders also stressed a discussion about a Sustainability Scenario for the Brazilian Amazon cannot be restricted to the Brazilian Amazon. Avoiding deforestation only in the Brazilian Amazon can induce leakages of natural resources degradation in the neighbour countries and in regions of Brazil (especially the Cerrado), as recent studies point out (Dalla-Nora et al. 2014).

Some considerations about the quantitative results and mitigation implications

Underneath the similar deforestation patterns in Scenario A and B, lays the difference in the area of secondary forests allowed to regenerate in Scenario A, and consequently in the net CO_2 emission estimates. Aguiar et al. (submitted) estimated that the region could become a carbon sink after 2020 considering Scenario A premises results, with a negative net emission of -3±0.3 PgC from 2011 to 2050. Scenario A in fact represents a Forest Transition scenario for the Amazon (Figure 11). Thus future mitigation options should include incentives to preservation of existing secondary forests and incentive to the regeneration of LR (Legal Reserves) and PPA (Permanent Protection Areas), even above the new Forest Code demands (Soares-Filho et al., 2014).


Scenario A - Percentage of deforested area in relation to original old growth forest area

Scenario A - Percentage of agriculture and secondary forest in relation to orginal old growth forest area

Percentage of secondary Vegetation in each cell

Aguiar et al., (submitted)

Figure 11 – Forest transition scenario in the Brazilian Amazon

6 REFERENCES

Aguiar, A. P. D., Vieira, I.C.G., Assis, T.O., Toledo, P.M., Dalla-Nora, E.L, Araujo, R., Nobre, C.A., Ometto, J.P.H. (submitted) Deforestation emission scenarios: forest transition in the Brazilian Amazon?

Aguiar, A. P. D. 2006. Modeling of land use change in the Amazon: Exploring intra-regional heterogeneity. PhD thesis in Remote Sensing, National Institute for Space Research (São José dos Campos: INPE) pp 25-85.

Aguiar, A. P. D., Carneiro, T., Andrade, P. R., & Assis, T. O. LuccME-TerraME: an open-source framework for spatially explicit land use change modelling. GPL News, 8, 21- 23. Retrieved from http://www.globallandproject.org/arquivos/GLP_news_march_2012.pdf

Aguiar, A. P. D., Ometto, J. P., Nobre, C., Lapola, D. M., Almeida, C., Vieira, I. C., Soares, J. V., Alvala, R., Saatchi, S., Valeriano, D. & Castilla-Rubio, J. C. (2012) Modeling the spatial and temporal heterogeneity of deforestation-driven carbon emissions: the INPE-EM framework applied to the Brazilian Amazon Global Change Biology 18(11), 3346-3366.

Aguiar, A. P. D., Câmara, G. & Escada, M. I. S. Spatial statistical analysis of land-use determinants in the Brazilian Amazonia: Exploring intra-regional heterogeneity. Ecol. Model. 209, 169–188 (2007).

Almeida C (2009) Estimativa da área e do tempo de permanência da vegetação secundária na Amazônia legal por meio de imagens Landsat/TM .INPE, 2009. 130p.; (INPE-15651-TDI/1429).

Anselin, L. & Smirnov, O. Efficient algorithms for constructing proper higher order spatial lag operators. J. Regional Sci. 36, 67–89 (1996).

Arima, E. Y., Barreto, P., Araújo, E., & Soares-Filho, B. Public policies can reduce tropical deforestation: Lessons and challenges from Brazil. Land Use Policy, 41, 465-473 (2014).

Arnell, N., Kram, T., Carter, T., Ebi, K., Edmonds, J., Hallegatte, S., Kriegler, E., Mathur, R., O'Neill, B.C., Riahi, K., Winkler, H., van Vuuren, D., Zwickel, T. 2011. A framework for a new generation of socioeconomic scenarios for climate change impact, adaptation, vulnerability and mitigation research. Available at http://www.isp.ucar.edu/sites/default/files/Scenario_FrameworkPaper_15aug11_0.pdf.

Assunção, J. A., Gandour, C. C. & Rocha, R. Deforestation slowdown in the Legal Amazon: prices or policies? (Climate Policy Initiative, Rio de Janeiro, 2012).

Brazil. Law 12.187/2009. (DOU, Brasilia, 2009).

Brazil. 2012. Law 12.651. Diário Oficial da União, Brasília, p 01.

Dalla-Nora, E. L., Aguiar, A. P. D., Lapola, D. M. & Woltjer, G. Why have land use change models for the Amazon failed to capture the amount of deforestation over the last decade? Land use policy. 39, 403–411 (2014).

Dalla-Nora, E. L. Modeling the interplay between global and regional drivers on Amazon deforestation. PhD Thesis. INPE, April 2014.

Eastman, J. R., L. A. Solórzano and M. E. V. Fossen (2005). Transition Potential Modeling for Land-Cover Change. In: GIS, Spatial Analysis and Modeling. D. Maguire, M. Batty and M. Goodchild. California, ESRI Press: 357-385.

FAN-Fundación Amigos de la Naturaleza. 2012. Mapa de Deforestación de las Tierras Bajas y Yungas de Bolivia 2000-2005-2010.

J. Ferreira, L. E. O. C. Aragão, J. Barlow, P. Barreto, E. Berenguer, M. Bustamante, T. A. Gardner, A. C. Lees, A. Lima, J. Louzada, R. Pardini, L. Parry, C. A. Peres, P. S. Pompeu, M. Tabarelli, and J. Zuanon. Brazil's environmental leadership at risk. *Science* 7 November 2014: 346 (6210), 706-707. [DOI:10.1126/science.1260194]

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342:850-853.

INE. INSTITUTO NACIONAL ESTATÍSTICO DA BOLIVIA. CENSO 2001. Disponível em: http://www.ine.gob.bo/comunitaria/comunitaria.aspx

INPE. Annual deforestation rates recorded in the Brazilian Amazon since 1988. Brazilian National Institute for Space Research (2014).
Jiménez, G. 2013. Territorios Indígenas y Áreas Protegidas en la mira: La ampliación de la frontera de industrias extractivas. PetroPress. CEDIB. Available at: http://www.cedib.org/wp-content/uploads/2013/08/territorios_indigenas-y-areas-protegidas-en-la-mira.pdf

La Razon. 2013a. Agro proyecta ampliar frontera agrícola hasta 15 millones de ha. Diario de circulación nacional. http://www.la-razon.com/economia/Agro-proyecta-frontera-agricola-millones_0_1759624072.html

La Razon. 2013b. YPFB explotará petróleo y gas natural en las áreas protegidas. Diario de circulación nacional. http://www.la-razon.com/economia/YPFB-explotara-petroleo-natural-protegidas_0_1838816152.html

Lapola, D. M., Schaldach, R., Alcamo, J. 2011. Impacts of climate change and the end of deforestation on land use in the Brazilian Legal Amazon. Earth Interactions. 01, 02-29.

Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamônica, P., Barber, C., D'Angelo, S., Fernandes, T. 2001. The future of the Brazilian Amazon. Science. 291, 01-05.

Lesschen, J.P.; Verburg, P.H.; Staal, S.J. (2005), Statistical methods for analysing the spatial dimension of changes in land use and farming systems. Kenya: LUCC Focus 3 Office and ILRI, (LUCC Report Series 7).

Muller et. al. 2011. Proximate causes of deforestation in the Bolivian lowlands: an analysis of spatial dynamics. Springerlink. DOI 10.1007/s10113-011-0259-0, 2011.

RAISG-Amazonian Network of Georeferenced Socio-environmental Information. 2012. Amazonia under Pressure. www.raisg.socioambiental.org. Available at: http://raisg.socioambiental.org/system/files/Amazonia%20under%20pressure16_05_2013.pdf

Rodriguez, A. 2012. Cartografía multitemporal de quemas e incendios forestales en Bolivia: Detección y validación post-incendio Multitemporal mapping forest fires and burn in Bolivia: detection and post-fire validation. Ecología en Bolivia 04/2012; 47(1):53-71.

Soares-Filho, B.; Cerqueira, G.; Pennachin, C. Dinâmica – a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. Ecological Modeling, v. 154, n. 3, p. 217-235, 2002.

Soares-Filho, B. S., Nepstad, D. C., Curran, L. M., Cerqueira, G. C., Garcia, R. A., Ramos, C. A., Voll, E., McDonald, A., Lefebvre, P., Schlesinger, P. 2006. Modelling conservation in the Amazon basin. Nature. 440, 520-523.

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H., Alencar, A. Cracking Brazil’s Forest Code. Science, 344, 363-364 (2014).

Timothy, J.K.; Soria, L.; Quezada B.; Guerra, A.; Calderón, V.; Clazadilla, Steininger M. 2012. Mapa de Cobertura de la Tierra y Deforestación hasta 2008. Museo de Historia Natural Noel Kempff Mercado (MHNNKM), Área de Geografía e Informática.

Veldkamp, A.; Fresco, L. CLUE-CR: an integrated multi-scale model to simulate land use change scenarios in Costa Rica. Ecological Modeling, v. 91, p. 231-248, 1996.

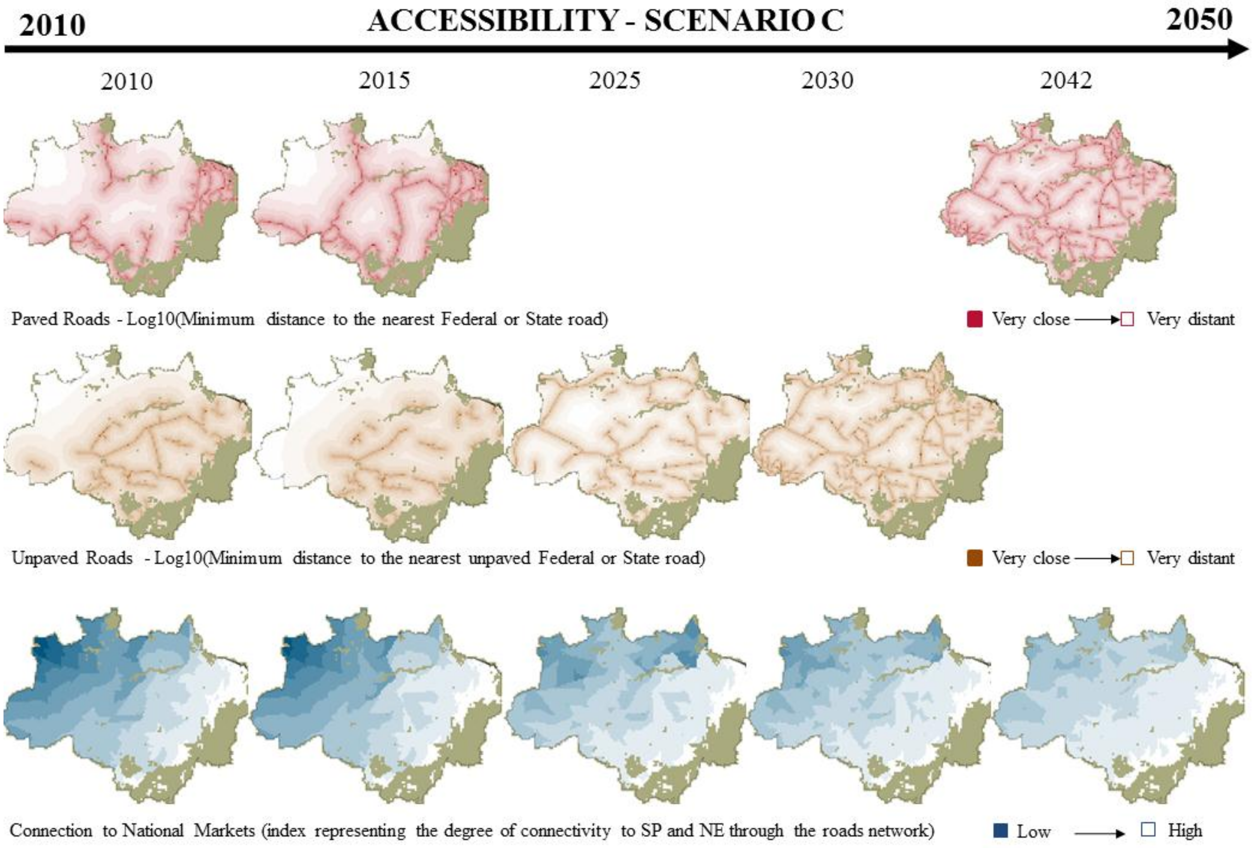
Veldkamp, A.; Lambin, E. Predicting land-use change. Agriculture, Ecosystems and Environment, 85: 1-6, 2001.

Verburg, P. H.; Koning, G. H. J.; Kok, K.; Veldkamp, A.; Bouma, J. A spatial explicit allocation procedure for modelling the pattern of land use change based upon actual land use. Ecological Modelling, v. 116, n. 1, p. 45-61, 1999.

Verburg, P.H., Soepboer, W., Limpiada, R., Espaldon, M.V.O., Sharifa, M.A., Veldkamp, A. (2002). Modelling the spatial dynamics of regional land use: The CLUE-S model. Environmental Management, 30, 391-405.

ANNEX I

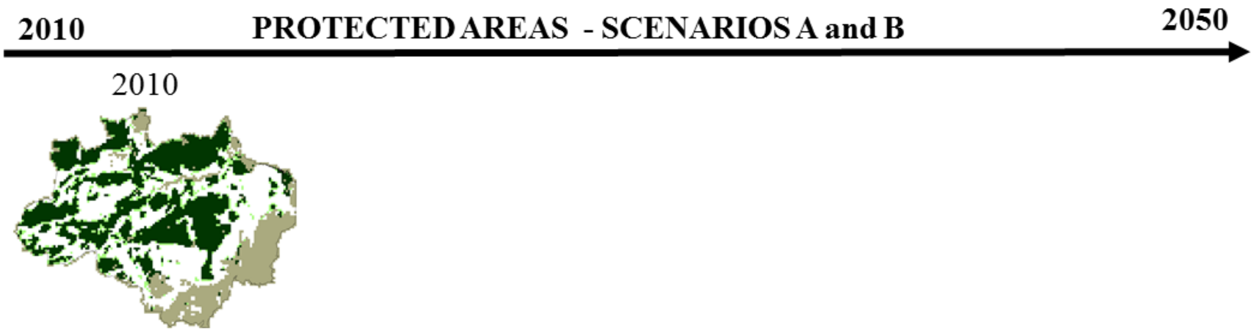
CHANGES IN THE SPATIAL DRIVERS IN THE BRAZILIAN AMAZON



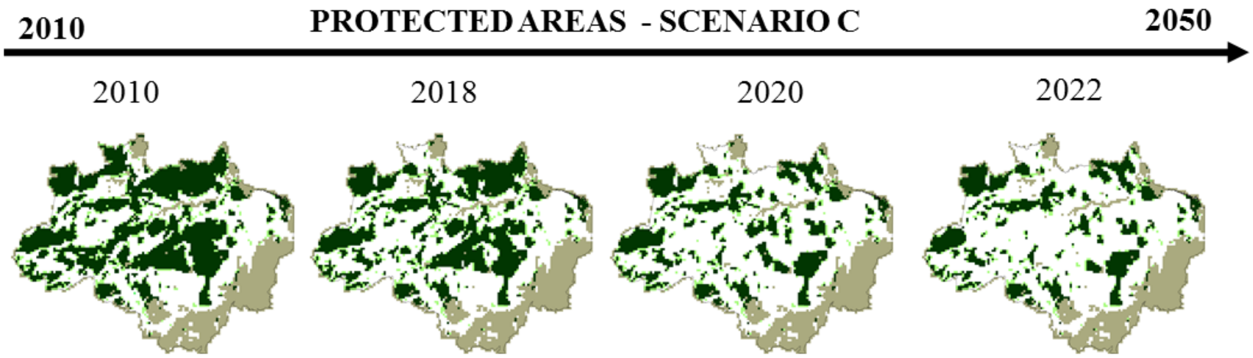
Paved Roads - Log10(Minimum distance to the nearest Federal or State road)

Unpaved Roads - Log10(Minimum distance to the nearest unpaved Federal or State road)

Connection to National Markets (index representing the degree of connectivity to SP and NE through the roads network)



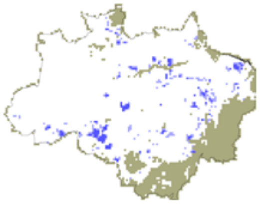
PROTECTED AREAS - SCENARIOS A and B



PROTECTED AREAS - SCENARIO C

2010 **SCENARIO INDEPENDENT FACTORS** **2050**

Fertility - Percentage of cell area covered by fertile soils ☐ 0% → ■ 100%

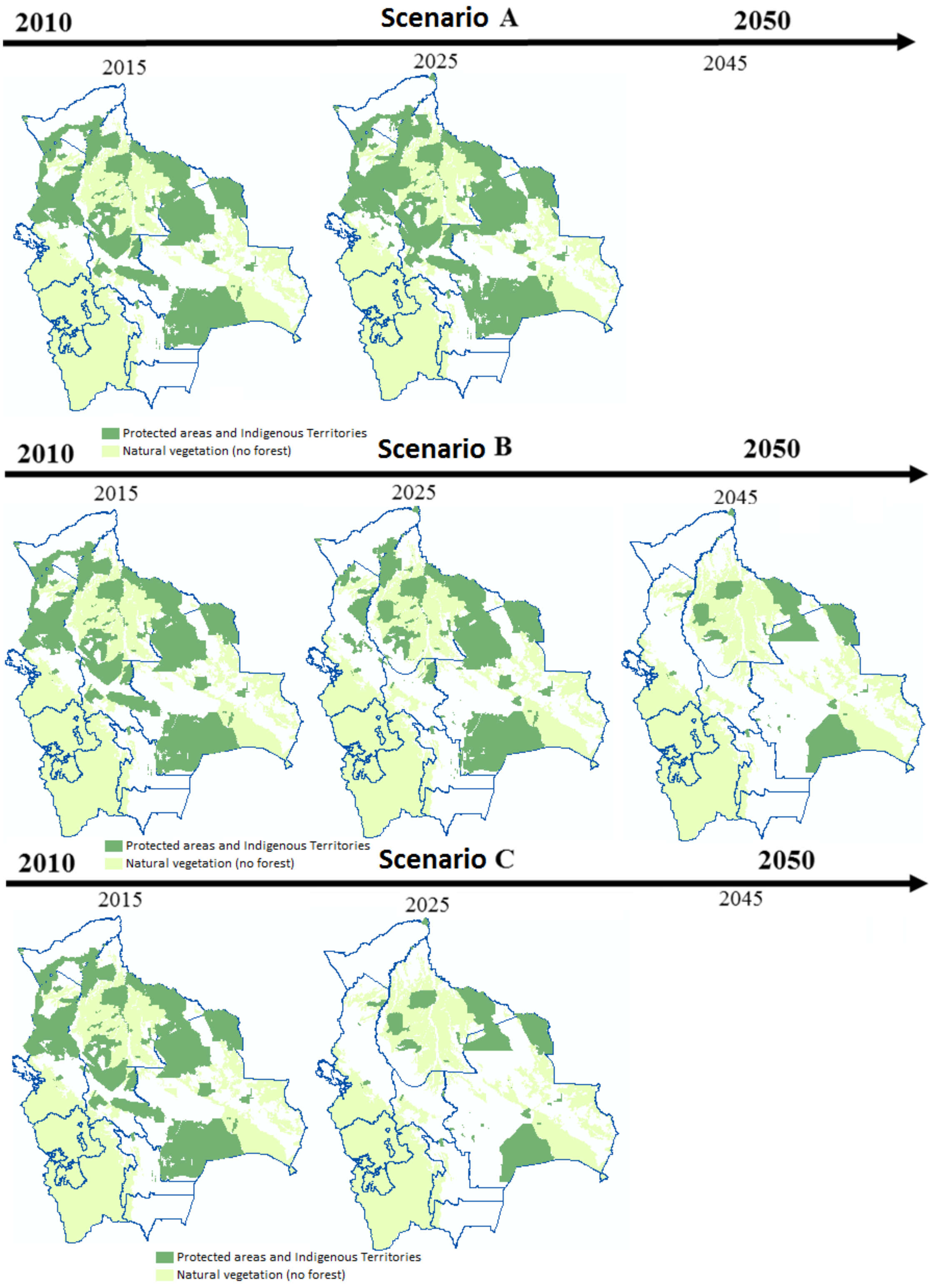


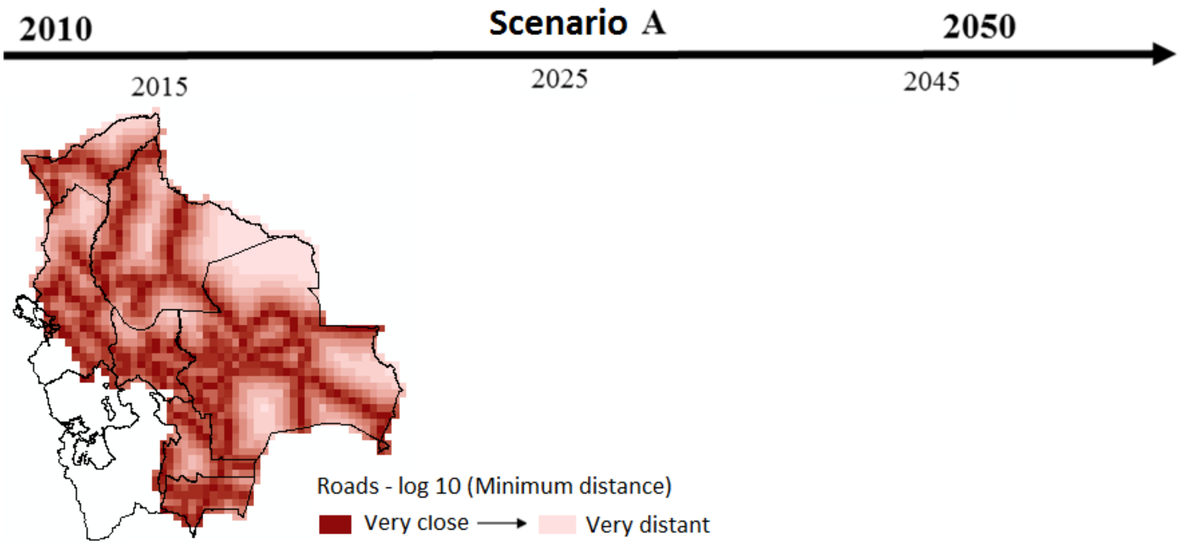
Agricultural settlements- Percentage of cell area covered by official agrarian projects for agricultural use (PA) ☐ 0% → 🟦 100%

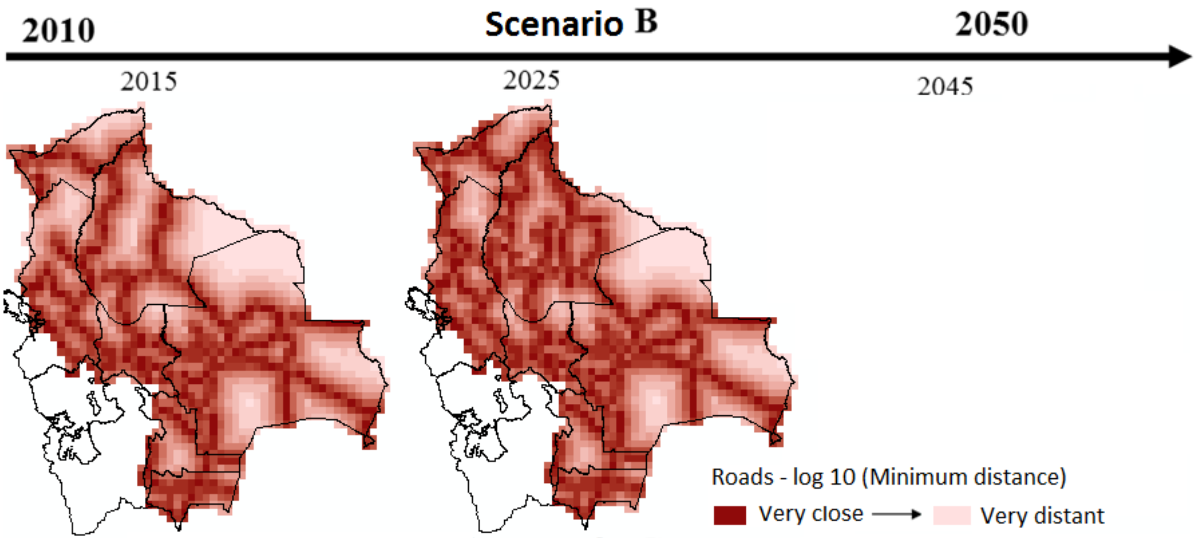
Timber extraction and processing centre - Log10(Minimum distance to the nearest centre) ☐ Very close → ■ Very distant

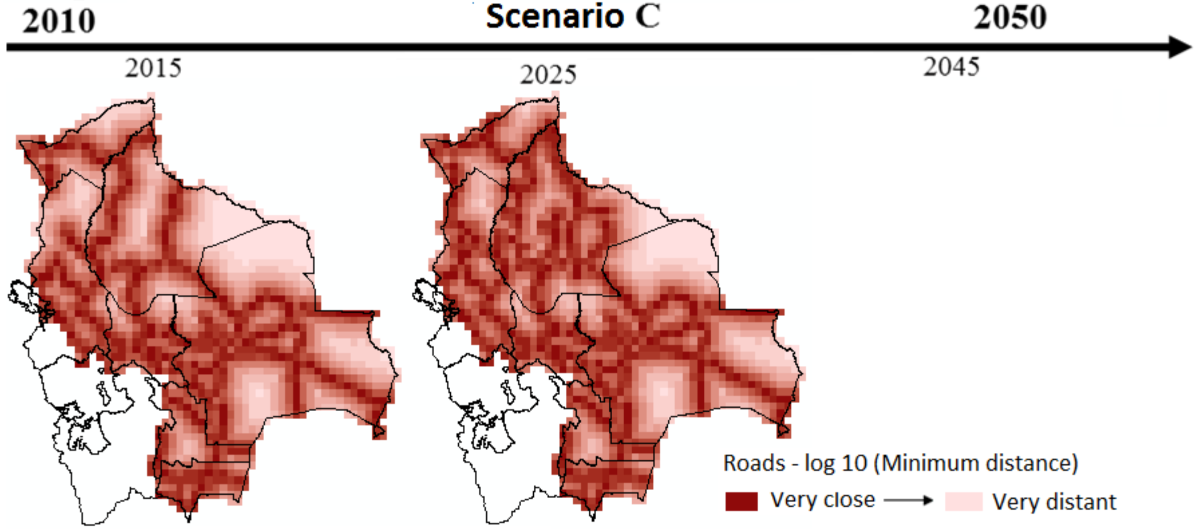
ANNEX II

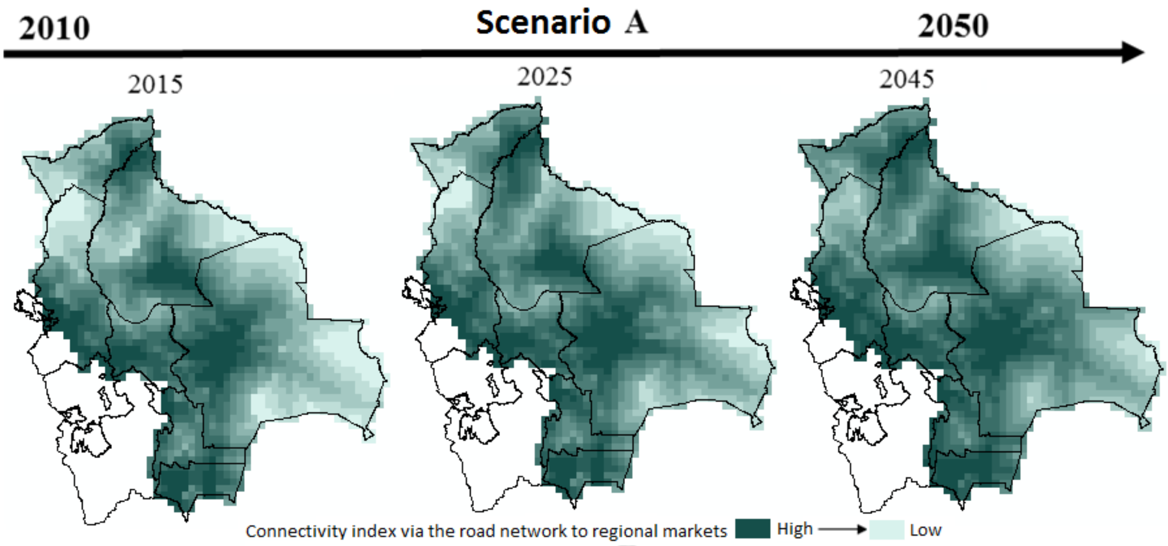
CHANGES IN THE SPATIAL DRIVERS IN THE BOLIVIAN AMAZON

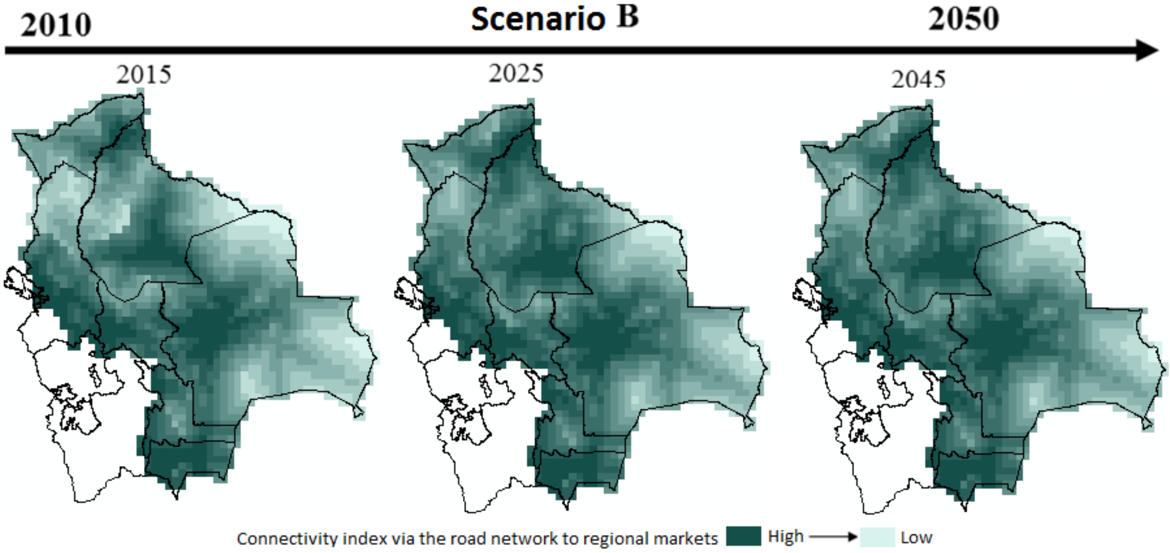


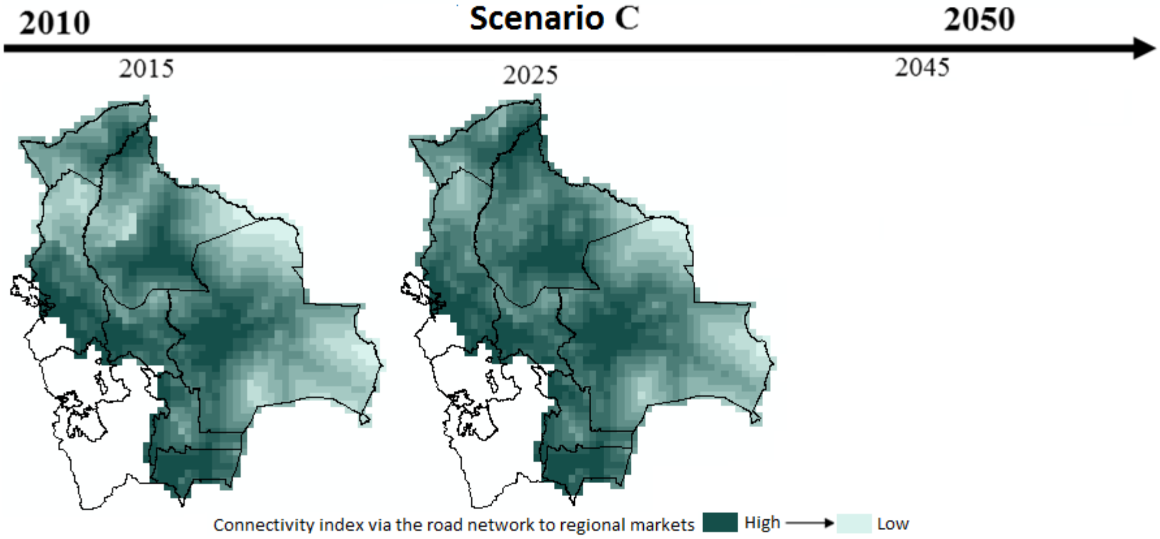

2010
Scenario A
2050
2015
2025
2045
Roads - log 10 (Minimum distance)
Very close → Very distant


2010
Scenario B
2050
2015
2025
2045
Roads - log 10 (Minimum distance)
Very close → Very distant


2010
Scenario C
2050
2015
2025
2045
Roads - log 10 (Minimum distance)
Very close → Very distant


2010
Scenario A
2050
2015
2025
2045
Connectivity index via the road network to regional markets
High
Low


2010
Scenario B
2050
2015
2025
2045
Connectivity index via the road network to regional markets
High
Low


2010
Scenario C
2050
2015
2025
2045
Connectivity index via the road network to regional markets
High
Low