Chapter 1

Modeling Deforestation and CO_2 Emissions in Tropical Forests (Western South Amazon)

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.72806

Abstract

Spatial modeling is a tool to represent deforestation and predict future scenarios according to different landscape change. Establishing 80% Legal Reserve Area (LR) in the Amazon since 90th, the Brazilian forestry code has made clear the biodiversity conservation profile of the largest tropical forest in the world. However, this mechanism did not prevent the advance of deforestation, which in recent years has increased again. This remote tool aims to monitor the deforestation, simulating its possible future trajectories, and thus generate information that can be used to assist in the management of deforestation reduction. The spatial modeling in the prediction of different deforestation scenarios based on public policies and their changes to the state of Acre (north of Brazil). Using the methodological processes of the Dinamica EGO software, three scenarios were projected up to the year 2050: (1) deforestation “Business as usual”, (2) deforestation with 50% LR and (3) deforestation with 80% LR provided by law. Based on these results it was evident that maintaining and respect 80% LR, it’s possible reduce the CO_2 emissions more than 76%, avoiding around 119,534,836 t of CO_2 and influences positively on reducing deforestation. Dinamica EGO proved to be an effective to represent the deforestation.

Keywords: legal reserve area, Dinamica EGO, state of Acre, Brazilian Amazon

1. Introduction

Tropical forests represent the largest terrestrial sink of anthropic emissions of carbon dioxide (CO_2) and are globally responsible for significant carbon stocks (C). The path for the global reduction of terrestrial CO_2 is controlled by the equilibrium between C fixation via accumulation of plant biomass and emission by burning [1, 2].

Modeling deforestation represents a powerful tool in different type of natural forest worldwide. The magnitude of the impact is been attested by predict changes in futures scenarios. In Brazil, modeling mechanisms is use to gauge the efficiency of the environmental policy established in Brazilian forestry code. Brazilian Amazon, since 1996 each property located in the must maintain a Legal Reserve Area (LR) of 80% where the vegetation cover consists of forest phytophysiognomies.

After more than 20 years and recent amnesty for properties the change landscape until July 22nd 2008, recently, in 2016 Legal Amazon lost 786,900 km^2, corresponding to 15.7% of the entire region in 2016 [3]. Precisely, the most common illegal practice is deforestation beyond the limit defined by law of LR [4].

Many landowners in the Amazon region claim to be unable to comply with the Forestry Code. Thus, the dominant debate in the region has always been favorable to noncompliance with legislation and not to its improvement [5]. Such positions may contribute to the loss of forest cover and may also cause direct environmental impacts, such as increased CO_2 emissions into the atmosphere.

The ways to understand the impacts of different methods of using land can be better understood from the construction of scenarios, which may represent the spatial design of future deforestation and its effects on global CO_2 emissions. In view of this, tools for remote deforestation monitoring, spatial dynamics modeling and assessments of the use and occupation of deforested areas can be used to increase the effectiveness of the implementation of environmental policies. The Satellite Monitoring Project of the Amazon Forest (PRODES) and the Amazon Near Real Time Deforestation Detection System (DETER) developed by the National Institute of Space Research (INPE) are good examples of the use of these tools.

PRODES is a project that has been monitoring deforestation in the Amazônia Legal since 1988, estimating annual deforestation areas and rates [3]. DETER is a warning system of changes in forest cover, which has the capacity to detect altered areas larger than 25 ha, thus making public policies to combat and control deforestation more effective [6]. The modeling of landscape dynamics allows the prediction of disturbances and monitoring the dynamics of vegetation, as these have the capacity to explore the role of deforestation, fire, climate, and weather [7].

The modeling process is a useful and multi-application tool. The results of modeling facilitate the study and understanding of deforestation and CO_2 emission issues, allowing simple representation of the complex deforestation processes by simulating the possible future trajectories according to the scenarios to be elaborated.

Thus, for the present case study, a model of landscape simulation based on cellular automata was developed and applied to the state of Acre, located in the Western South Amazon, northern region of Brazil, using the software platform Dinamica EGO [8]. Scenarios were projected for the entire territory of the state of Acre, represented by analysis applied to the simulation process, in order to assess the impacts of deforestation and CO_2 emission, in space and time.

2. Overview of spatial and temporal modeling for environmental services

In order to carry out effective measures of forest management and protection, a basic demand is the construction of methods for the collection, processing, analysis and publishing of spatial data regarding vegetation cover of these areas [9]. It is also important to evaluate the use of soil and changes in ecosystem dynamics, as well as observe advances in legislation, and other factors assessed by simulation models.

The main programs used for spatial image processing in remote sensing worldwide are QGIS, ArcGIS, Udig and Spring in Brazil. FIA Map Maker is used in the making of tables and maps in the USDA Forest Service's Forest Inventory and Analysis Data Base (FIADB), and the ACORn (A Comprehensive Ozark Regeneration simulator) program is used to predict the number of tree species and their potential individuals [10, 11].

Currently, there are versions of mapping programs in mobile devices, such as ArcGIS mobile, ArcPad and Avenza Maps, which replaces PDF Maps. They have been used successfully in assessing forest inventories, ecology studies, and conifer restoration projects in the United States [12, 13].

Many databases used in these programs may be compatible with statistical programs such as R. In addition, most of these programs have tools and interfaces that can be accessed by a variety of programming languages such as C++, Java, Python, Perl, C# and Ruby.

The Dinamica EGO is a spatial simulator of landscape dynamics widely used in Brazil. This simulator allows the construction of explicit scenarios that simulate the dynamics of an environmental system from transition probabilities, reproducing the way its spatial patterns evolve and allowing the projection of the probable ecological and socioeconomic consequences of the dynamics of the systems [8, 14].

Based on previous linear regression analysis, another model used in South America and that presents satisfactory results is the Land Change Modeler. It was used in a study in Peru with the purpose of simulating the loss of primary forest cover and changes in the characteristics of the landscapes from 2015 to 2025 [15].

MELA is a widely used simulator in Finland developed by the Finnish Forest Research Institute. It aims to model predictions for forest indicators (biomass, C sequestration) and economic indicators (yield and wood supply) [16].

In Africa, the MODIS (Moderate Resolution Imaging Spectroradiometer) platform is used in conjunction with the Land Degradation Surveillance framework (LDSF) and is implemented as part of the Africa Soil Information Service (AfSIS) in a soil-quality monitoring project. It has been employed in several tropical landscapes around the globe and also by NASA observatories [17].

The LDSF model stands out for its ability to perform joint map evaluations of several variables such as soil organic matter (SOM), pH, sand, sum of exchangeable bases, quantitative occurrence and degree of root depth restriction in the first soil layers, water infiltration capacity, soil erosion levels, and vegetation cover data, as well as information on structure, distribution, diversity and even species richness. From the joint analysis of these variables, the identification of soil and ecosystem quality can be improved, as well as the contrasts between land uses over time and also the possibility of verifying management interventions at various scales, helping to identify the adoption of these techniques [18].

The LANDIS-II model has been used to simulate the potential of C sequestration of vegetation under different fire regimes and prediction of biomass. The LANDIS-Pro model performs simulations of biomass, forest succession, seed dispersal, species establishments and disturbances in general. The PHENIPS model can be used in phenological prediction in tropical forests, in addition to the productivity and cycling of C and nitrogen in coniferous forests as a result of multiple validated models [19].

The SIMILE and TROLL models have been used in the simulation of plant succession processes [20]. However, such models have a limitation in the validation of their predictions, since most of the studies were conducted in specific times and areas (short-term predictions), which is not compatible with the simulations carried out in the large temporal space used for the most part of these simulations. Such short-term predictions can be more realistic by calibrating the models employed with the use of field data in time series, such as forest inventory data, on an appropriate timeline scale, providing greater predictability credibility [19].

Finally, the DSS-Wuk model, widely used in Germany, follows the tendency of the models to gather several variables (complex dynamic simulation) [21]. Recently, the model's ability to project forest development in the period from 2011 to 2100, compared to the reference period (1971–2000) [22], was evaluated in the country based on two climatic scenarios.

The DSS-Wuk combines several submodels (regionalization of climate, allometric and phenological, nutrient rates, water in the soil, mortality due to drought stress, wind and insect damage, site index, and others) for the purpose of better describing the impacts of climate change, besides including a sub-model of economic evaluation. It is recognized as a very realistic and very promising approach in the modeling area [23].

In the modeling carried out in Geographic Information System (GIS) programs, the analysis known as Anselin Local Moran's I can also be used, a type of Cluster analysis that verifies outliers and which, combined with geostatistical and remote sensing data, is able to evaluate patterns of environmental variables related to forest ecosystems. This was done recently in the simulation of future C sequestration potential in soils in China from 2000 to 2300 [24], and in the analysis and simulation of forest deforestation in Iran from 1972 to 2010 due to residential growth [25].

According to the rapid changes in the landscape observed globally, it is perceived that the systems of earth science have been improved by the use of remote sensing data and models based on the conversion of land cover, especially in a temporal space resolution, starting from the promising use of several submodels and the union of GIS data with data obtained in the field.

Advances in the field of forest modeling present the capacity to improve the predictive ability of different scenarios and the possibility of understanding ecological processes. The results of these models enable the adoption of better practices for the conservation of natural resources, along with the economic aspects of their exploration, as well as predicting the potential of forests, especially tropical forests, to mitigate GHG emissions.

3. Deforestation scenarios for the western south Amazon (case study)

The state of Acre is located in the northern region of Brazil, in the South Western Amazon, covering an area of 164,215.98 km^2 [26]. It borders Bolivia and Peru, and the states of Rondônia and Amazonas in Brazil. About 50% of its territory is composed of protected areas, distributed and classified according to the Brazilian system named "System of Units of Conservation" (SNUC), Law 9985/2000 in 18 Units of Conservation of Sustainable Use, 3 Integral Protection Units and 36 Indigenous Lands (**Figure 1**).

The natural forest types that occurs in the study area are: Open Broadleaf Forest with Palm trees, Open Broadleaf Forest with Dominant Bamboo, Open Broadleaf Forest with Bamboo, Dense Rainforest, Open Alluvial Rainforest with Palm Tree, Open Alluvial Rainforest with Bamboo, Open Alluvial Rainforest with Palms + Secondary Vegetation, Open Alluvial Forest with Palms + Pioneering vegetation.

3.1. Database

The data sources used for the modeling were: Acre data—Economic Ecological Zoning of the state of Acre [26]; PRODES data—Project of Estimation of Deforestation in the Brazilian Amazon, carried out by the INPE [3]; and the National Water Agency (ANA[1]) data. The software used to manipulate and generate the results were ArcGIS®10.x and Dinamica EGO, version 1.8.9.

3.2. Data processing

The entry maps of the deforestation model were obtained by PRODES (land use and land cover map for the years 2006 and 2009) and converted to the matrix format with spatial resolution of 100 × 100 m. Then, the maps were reclassified to the following classes: forest, non-forest and deforestation, as hydrography was defined as null. The 2006 map represented the initial input landscape of the model and the 2009 map represented the final input landscape model.

The static variables used in the deforestation model are subdivided into categorical, continuous and dynamic. The set of categorical variables is composed of maps of vegetation, soils and protected areas. In the set of continuous variables are the maps of altitude, slope, distance to main rivers, urban attraction distance, distances to population nuclei, distance to all roads, and distance from main roads (**Figure 2**). The deforested area distance was used as a dynamic variable.

[1]*Agência Nacional de Águas.*

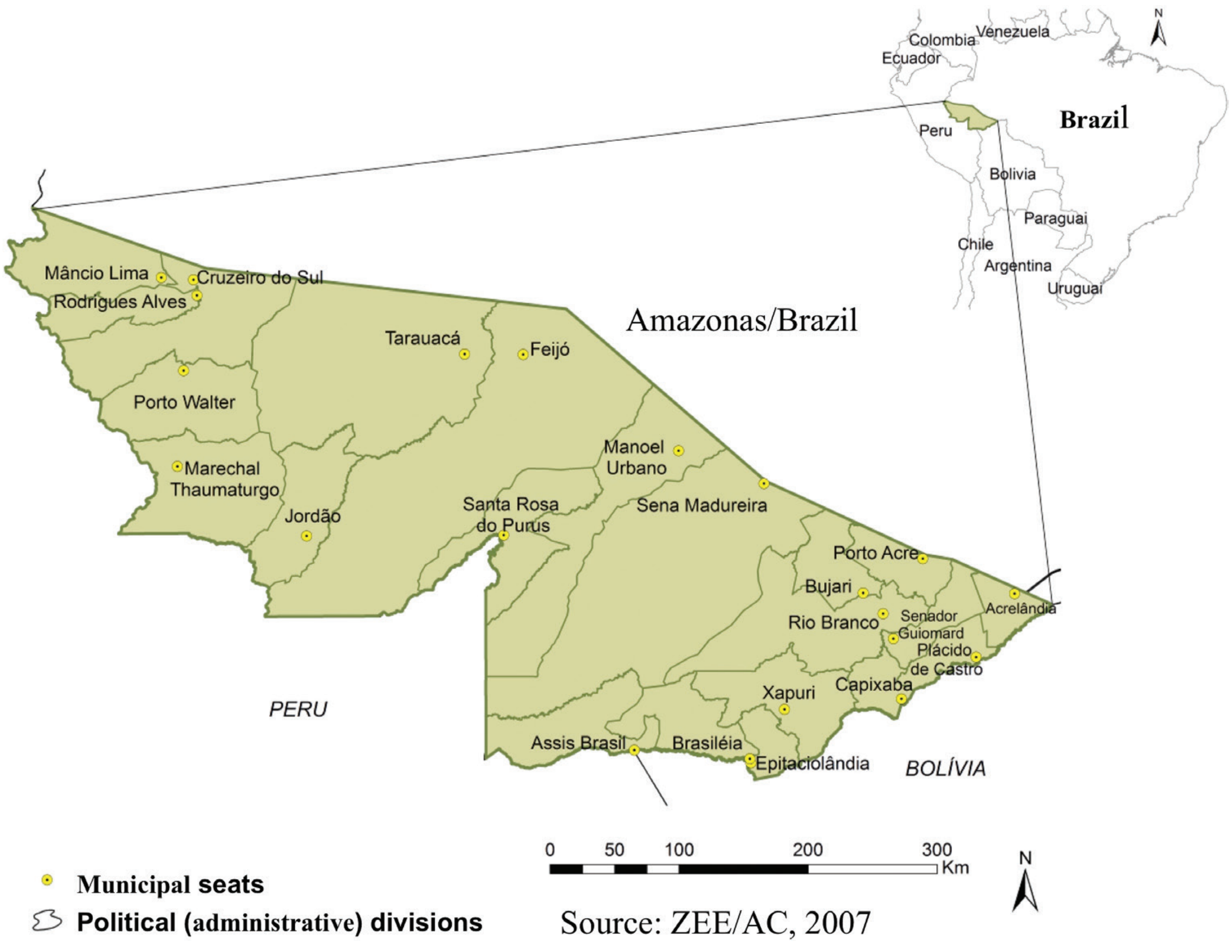

Figure 1. Overview of the study area.

For the analysis of future deforestation, the behavior of subregions was considered, for which a micro-basin map (OTTO basins level 12) was used. The regionalization method allows defining sequences of specific operations for each region (microbasin), modeling as a result the local context influenced by particular phenomena [27].

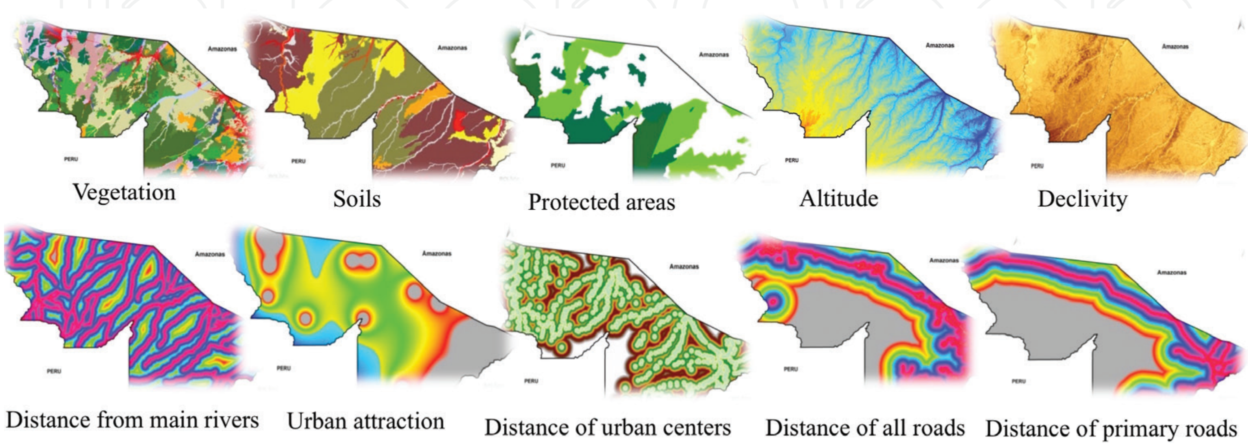

Figure 2. Static variables used to estimate deforestation in different scenarios.

http://dx.doi.org/10.5772/intechopen.72806

With the input data of the model, maps of the initial and final landscape plus the explanatory variables to deforestation, the calibration, validation and future projection of deforestation were carried out. The procedures for developing the model using the software Dinamica EGO can be visualized in **Figure 3**.

Then, the model was performed generating a simulated map for the year 2009 and a probability map (which indicated the areas most susceptible to deforestation) based on the weights of evidence from the variable maps. From the simulated map, the validation process was carried out to verify the similarity between the simulated map and a reference map—land use and land cover map for year 2009 of the PRODES classification. For the validation, the model that

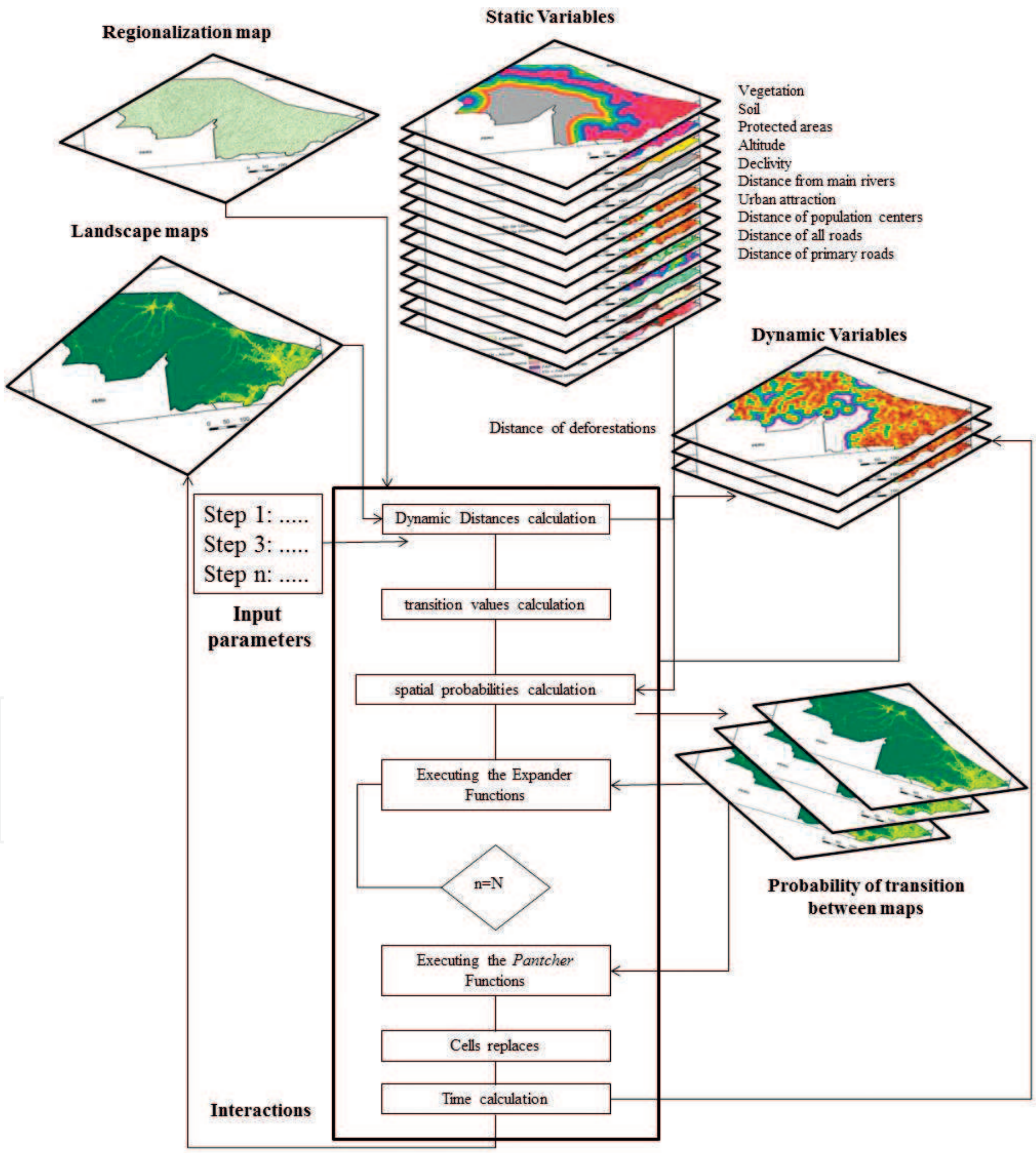

Figure 3. Flow diagram of the Dinamica EGO program. Source: Adapted from Soares-Filho [28].

uses the method of the constant decay function was applied, with windows of variable sizes from 1 × 1 to 13 × 13 pixels. The method is termed as "Fuzzy Similarity" in a familiar local context established by Hagen [29].

3.3. Generation of future scenarios

The study of future deforestation in the state of Acre was evaluated under the following scenarios: Scenario 1—deforestation "Business as usual"; Scenario 2—deforestation with LR of 50%; Scenario 3—deforestation with LR of 80% as provided by law. To evaluate the influence of LR size in scenarios 2 and 3, the useful areas of each basin (OTTO basins level 12) were used, with an average size of 4800 ha. In all scenarios, deforestation was simulated by the year 2050.

For all scenarios, the total deforestation in hectares and the amount of CO_2 emitted in tons were calculated. For scenarios 2 and 3, the amount of deforestation and CO_2 emissions that would be reduced under the following circumstances was calculated: (a) if there was a containment of the increase of liabilities in the micro-watershed already with liabilities up to the year 2010, and (b) if there was no generation of liabilities in micro-basins that, until the year 2010, were with forest assets. Environmental liabilities are deforested Legal Reserve Areas and environmental assets are units of areas that exceed LR size.

3.4. Model for accounting for CO_2 emissions

In order to account for CO_2 emissions, an annual biomass loss map was generated from areas that would be deforested annually, overlapping with a forest biomass map.

The biomass map used in the analysis was made by Saatchi et al. [30], where it was considered that 50% of forest biomass corresponds to C [31]. The CO_2 values resented were obtained by multiplying C by the ratio between the molecular weights of CO_2 and C, which is 44/12 (3.67 t CO_2 equivalent (CO_2 eq)).

4. Future scenarios modeled

In scenario 1, with the "Business as usual" pattern, from 2011 to 2050 more than 550,400 ha will be deforested, representing 42,324,000 t of C originally contained in these deforested forests and released into the atmosphere in the form of CO_2 of 155,329,080 t. The amount deforested by clear-cutting in the Western South Amazon (Acre State) will exceed 20.5% in 2010 [3] to more than 27% in the year 2050.

The areas of liabilities and assets already consolidated up to the year 2010 in the micro-basins and how these areas would remain until the year 2050 are presented in **Table 1**. It also shows the difference of the liabilities that would increase and the assets that would be reduced, based on the scenario of land cover change, considering the "Business as usual" prospects of deforestation with LR of 50 and 80%.

	Forest assets and liabilities (ha)					
	Until 2010		Projection until 2050		Difference 2010–2050	
	Liabilities	Assets	Liabilities	Assets	+ Liabilities	− Assets
LR 80%	988.700	900.100	1.422.200	783.200	433.500	116.900
LR 50%	312.800	2.750.900	545.500	2.433.300	232.800	317.600

Table 1. Table of liabilities and forest assets (LR of 50% and 80%) considering "business as usual" deforestation until 2010 and with the projection of deforestation up to 2050.

Considering the hypothesis that the legislation is not fulfilled, containing deforestation as described in the Law, deforestation trends in hectares and CO_2 emissions in tons would behave as shown in **Figure 4**. Deforestation, maintaining an LR of 80% (Scenario 3), would show a reduction of around 79%, with some 433,500 ha being deforested in relation to "Business as usual" deforestation patterns (Scenario 1). However, if LR changes back to 50% (Scenario 2), there will be an increase in deforestation by more than 170% when compared to an LR of 80%, with about 200,700 hectares being deforested (**Figure 4**).

One of the consequences of deforestation is the emission of CO_2, and the modeling shows that CO_2 emissions, with an LR of 80%, would decrease by more than 76%, avoiding around 119,534,836 t of CO_2 to be released into the atmosphere when compared to "Business as usual" deforestation patterns. However, when considering a LR of 50%, the CO_2 emissions would increase by more than 169% compared to the LR of 80% (**Figure 5**).

In view of the projections made, although the state of Acre (Western South Amazon) presents an even greater part of its territory in forest, it is evident that maintaining and respecting an LR of 80% would be of great importance for maintaining the environmental quality and, consequently, avoiding the reduction of biodiversity.

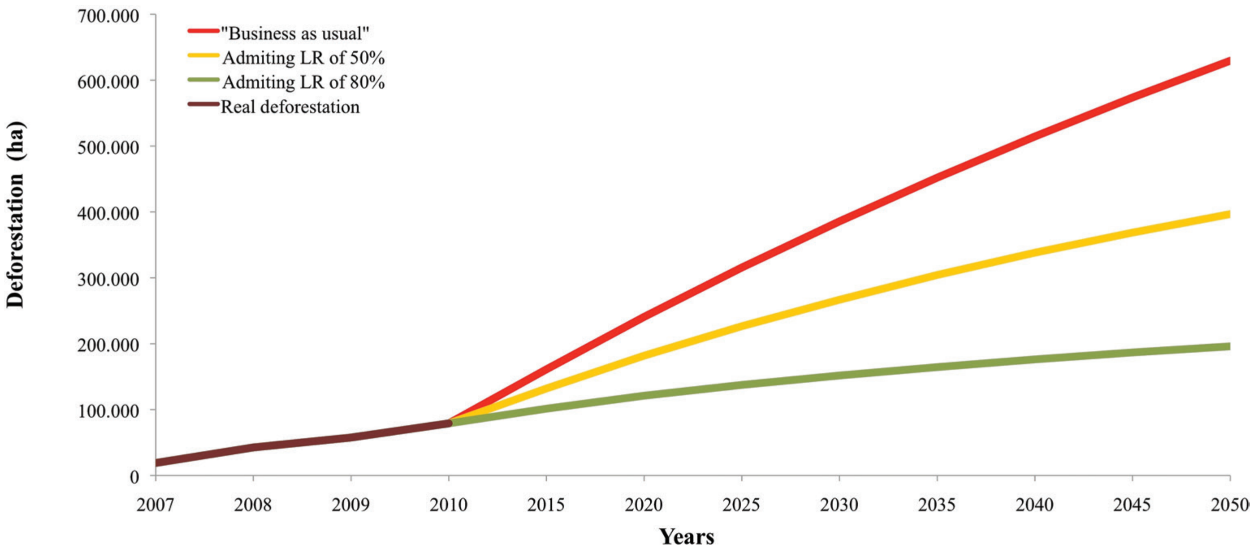

Figure 4. Trend of deforestation under scenario up to the year 2050 in three aspects: "Business as usual", 50% LR and 80% LR.

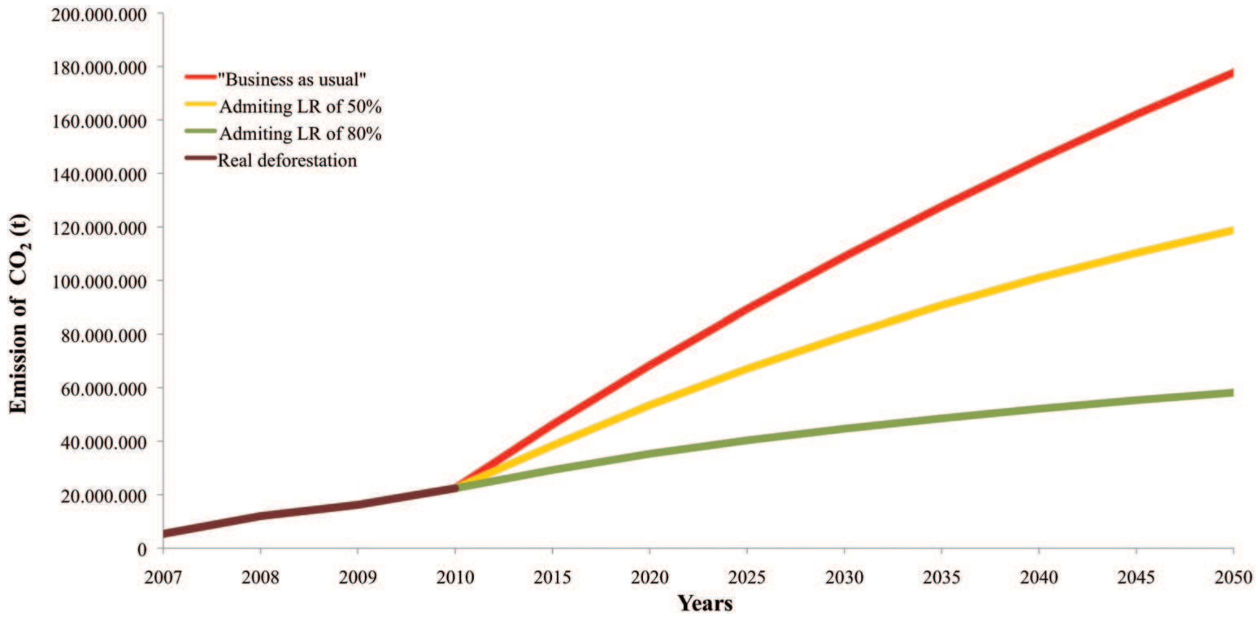

Figure 5. Trend of CO_2 emissions under scenario up to the year 2050 in three aspects: "Business as usual", 50% LR and 80% LR.

The set of variables used in this study presented a peculiar performance in the representation of deforestation, showing that it is mainly concentrated near the areas already deforested and the areas of influence of the current road network of the State. Because it is precisely in areas that are affected by the implantation of agricultural activities and logging, the latter has great importance in the expansion of deforestation in Acre [26]. In this sense, it is worth noting that the scenario presented for the state of Acre may take on another configuration as new roads and branches are deployed in the region. According to Nogueira [32], the influence of static variables on deforestation does not result from the individual action of each one, but from a complex relation of different factors of several causal variables, which has its origin in complex social, political and economic conditions.

The scenario "Business as usual" (Scenario 1) projects the historical evolution of deforestation in the region. The set of policies prohibiting land acquisition and implementation of rural settlement projects in areas of primary forest cover, together with the commitment of land use with adequate techniques and the prevention of clear cutting of vegetation [26] function as a hypothesis that reflects its effects on deforestation rates from 2011 to 2050.

The rates of deforestation on this period are smaller when compared to the deforestation rates of the 1980s, 1990s and the beginning of the twenty-first century when the state's growth rate was still under strong effects of the policy of incentive to occupy and deforest for production. However, deforestation reduction is already a reality throughout Amazonia [3, 26], even if due to the smaller amount of forest available for this activity.

As expected, the 80% LR size positively influenced the decrease in deforestation over a 50% LR, presenting approximately 63% reduction. The difference between the scenarios in maintaining an LR of 80% and reducing it to 50% implies, at the end of 41 years, the emission of around 60,610,417 t of more CO_2 into the atmosphere. This is equal to nearly 7 years of CO_2 emissions from the solid waste and domestic effluent sector in the state of São Paulo in 2008 [33].

http://dx.doi.org/10.5772/intechopen.72806

The commercialization of CO_2 emission certificates avoided by deforestation is still an uncertain market. However, if it was to be regularized and implemented *de facto*, the Clean Development Mechanism (CDM) market, established in Article 12 of the Kyoto Protocol, the emission difference with an LR of 50% in relation to that of 80% may represent a loss of about $606.00 million if we consider an average value of $10.00 a ton of CO_2. And the prospect can be even worse when considering the 80% LR difference with the value obtained from the "Business as usual" scenario, reaching a loss of up to $1.19 billion.

The CO_2 considered in these accounts is only that contained in the C above the ground. Thus, this loss would only be related to the emission of CO_2, without taking into account other benefits offered by forests, such as the conservation of scenic beauty, socio-biodiversity, water and its services, climate regulation and soil conservation.

In the areas of the Brazilian Amazon, one of the elements that facilitate the dynamics of deforestation is the implantation of roads, since this practice allows easy access to forest remnants areas with greater potential for deforestation [34, 35]. In addition to the roads, rivers are also a source of easy access that enables deforestation, without taking into account that their use is often cheaper than transport by road. Ferreira et al. [36] argue that the process of deforestation usually begins with the official or clandestine opening of roads that allow the irregular occupation of land to the predatory exploitation of timber. Normally, after the exploitation of the forest, this area is converted to agriculture or pasture for the extensive creation of livestock, especially in large estates, being responsible for about 80% of deforestation in the legal Amazon.

Some researchers claim that the causes of deforestation in the Amazon are complex and often interrelated. Among them, there is the absent role of states, which in many situations do not restrict illegal deforestation [14, 37]. Added to this, there is still the ambiguity of public policies that stimulate, on one hand, the deforestation by great landowners, who thus assure the land ownership in the face of the "threat" of agrarian reform [37].

The state of Acre follows the model described, especially in the southeast region of the state. In this region, there is the highest concentration of deforestation, as is the case for the municipalities of Senador Guiomar, Acrelândia, Plácido de Castro, Rio Branco, Xapuri, Brasiléia, Epitaciolândia, Bujari and Porto Acre. However, it is in these municipalities that most of the population of Acre is found, along with most of the agricultural activity of the state and the greater demand for water resources. The region has hundreds of properties with 50–100% of its areas deforested [38]. This is a situation that may qualify these properties as illegal when facing the law, regardless of the size of the LR kept inside the property.

The other regions of the state still maintain most of their green areas preserved or, at least, conserved [26, 39]. Law No. 4771 of 1965 which refers to the Forest Code determines, among other obligations, the protection of sensitive areas and that landowners must maintain a portion of the native vegetation inside the rural properties, as is the case of the LR and Permanent Preservation Areas (APPs[2]). In the latter case, in general, forest management is prohibited, except in specific cases. Thus, one of the well-debated points is the size of the portion of the LR area to be maintained within each rural property, since from the implementation of

[2] *Áreas de Preservação Permanente.*

Provisional Measure No. 1511 of 1996 it was determined that the LR in the Amazon region would increase from 50 to 80% of each rural property [5].

The changes in legislation aimed to restrict the rampant devastation that was taking place within the Amazon from 1994 to 1995, time and place in which the highest deforestation rate in history was recorded, with more than 29,000 km^2 of the forest devastated [40]. The size of the LR of a property functioned as a legislative component, which has its direct implications under the prospect of reducing deforestation.

Modification of the property use limit has curtailed deforestation for some years. However, deforestation rates returned to exponential growth starting in 1998 and had its peak in 2004, when, through public policies and more efficient geospatial monitoring, the deforestation scenario in the Amazon was again reduced.

Forests are of fundamental importance for balancing CO_2 emissions globally. When these are suppressed, most of the C stored in them is released into the atmosphere by burning or, more slowly, by decomposition [41].

CO_2 emissions due to changes in soil cover from land use have become a major component in the last decades, already considered as "dangerous interferences" in the global climate system. Approximately 0.8 ± 0.2–2.2 ± 0.8 billion tons of CO_2 from tropical forest deforestation is released annually, accounting for about 10–35% of global CO_2 emissions [5].

Deforestation in Brazil is the process that contributes most to CO_2 emissions, accounting for 70% of national emissions [27]. The stock of C in the state of Acre present in the aerial and underground plant biomass and the C contained in the soil varies from 75 to 270 Mg ha^{-1}, according to data published by the Environment State Secretariat (SEMA[3]) [42].

5. Final considerations

From a modeling point of view, the methodology and concepts used in the Dinamica EGO software were effective in representing deforestation under the three projections for the Western South Amazon. The variables selected and used in the scenarios clearly showed their influences both in the sense of restricting, as well as in potentializing the conversion of forest areas.

About the results of the deforestation of the projected scenario up to the year 2050, and considering the prospects of maintaining the current "business as usual" deforestation patterns, a severe intensification of deforestation is predicted over the years. As a consequence, the South Western Amazon is expected to reach very high levels of degradation, increasing CO_2 emissions to 155 million tons.

In the simulation of scenario 2, a reduction of CO_2 emissions of approximately 59 million tons would occur, when compared to the permanency of the current scenario. In this case, the reduction of the Legal Reserve (LR) to 50% must be considered, as it would lead to a loss, within the legality, of approximately 200,700 ha of native forests in relation to an LR of 80%. In addition, CO_2 emissions would increase by about 609,119,217 t. Based on the results of this

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study, maintaining the size of LR in 80% of rural properties would prevent the emission of millions of tons of CO_2 into the atmosphere.

Thus, modeling tools are important mechanisms for forecasting and decision-making that can be used in order to assist in environmental conservation practices.

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