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Prospective analysis of deforestation determinants in the Amazonian landscapes

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ABSTRACT

Amazonian landscapes are socio-ecological systems that provide fundamental ecosystem services for the maintenance of landscape regulation, biodiversity, and climate regulation. The increasing pressure of population density, productive activities over natural resources, infrastructure development, timber exploitation, and illicit crops among other determinants have put Amazonian landscapes at risk due to deforestation. This research work aims to understand the possible interactions of the determinants of Amazonian deforestation and to describe its complex behavior with the socio-ecological systems with a supporting vision for future studies. Initially, a rigorous analysis the of literature review on the determinants of deforestation in the Amazon was made to be carried out a systemic representation based on the dynamics of systems methodology on the behavioral interactions between these different determinants. The determinants of deforestation can be classified into determinants by activity, by support, by social dynamism, and by political pressure, which converge in these natural areas of the Amazonian landscape and transform into an urban-agricultural area, this change in the coverage of Amazonian land use generating rate environmental problems both locally and globally. By analyzing the causal relationships of the determinants of Amazon deforestation in the different scenarios, the proposed hypothesis is that with the large-scale increase of productive activities on natural resources, the Amazonian landscapes will not be sustainable in urban-agricultural environments. Finally, this research found that Amazon can confront different scenarios with diverse futures subject to the socio-ecological actions generated for the conservation and relevance of its ecosystem services.

1. Introduction

Amazonian landscapes are socioecological systems that provide ecosystem services [1] for the sustenance and regulation of the region [2,3]. It contains the most extensive tracts of intact forest in the world with unique biodiversity but is at risk of deforestation [4] and forest fires that represent up to 48% of total CO_2 emissions into the atmosphere [5]. In addition, the absence of the State in this area causes few improvements in the living conditions of the population, and its inhabitants have limited opportunities to guarantee their fundamental subsistence conditions, so little by little forest, its biodiversity, cultural wealth, the abundance of water and natural resources will be falling and losing [6].

Economic activity has a significant impact on the degradation of Amazonian ecosystems due to the increase of one inhabitant per square kilometer can generate the loss of more than 7% of natural ecosystems, becoming a significant concern for climate systems, economies, local societies, the sustainability of ecosystems and human well-being [4]. Consequently, it is necessary to analyze in detail the variables involved that are part of this problem to provide an adequate description of the interactions and their behavior that clarifies and supports future studies regarding the population and migratory dynamics of deforestation in some states of the basin, as well as the drivers of deforestation that may interact differently according to the context of each country that integrates the Amazon rainforest [7]. Deforestation occurs due to different determinants that could categorize as (1) determinants of anthropic activity, where, for example, the extension of legal and illegal agricultural activities [3], the exploitation of hydrocarbons and minerals [8], and selective logging [9]; (2) determinants for the support of anthropic activities, such as the expansion of national interconnected systems for electricity supply [10], and the expansion of road infrastructure [11]; (3) determinants of social dynamism, derived from population growth [12], and land colonization [13,14]; and, finally, (4) determinants of state policies, which correspond to the guidelines of local public institutions and government public policies [15], such as, for example, the privatization of land by government subsidies [16] or the change of protection borders.

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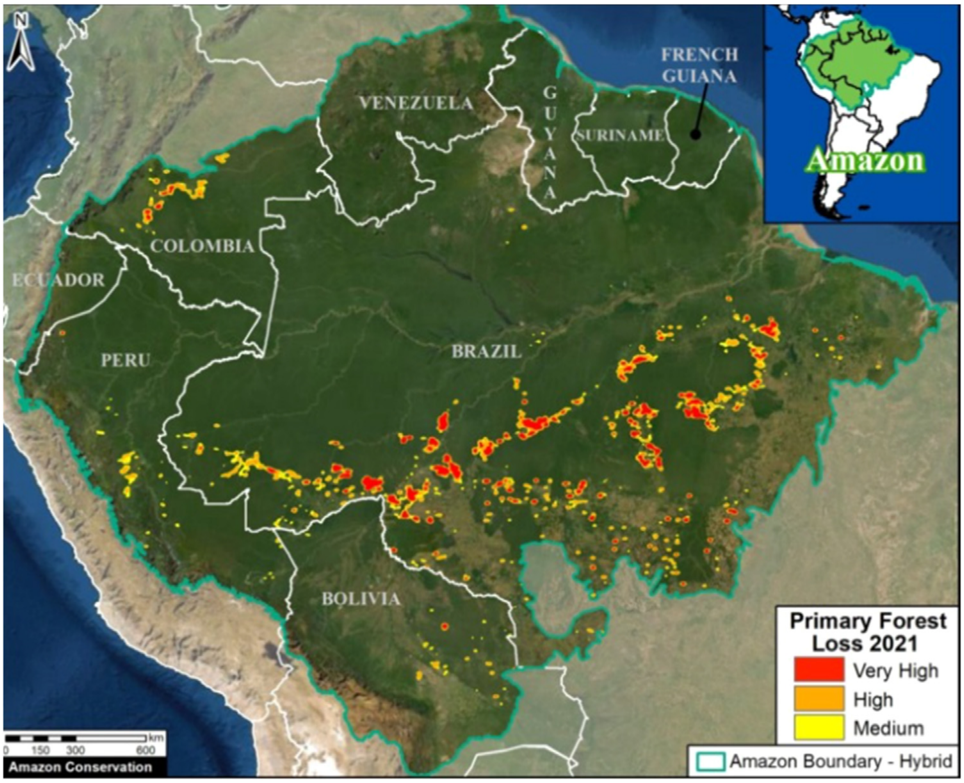

Image 1. Positive and negative causal relationships, respectively.

The purpose of this article is to analyze the interactions between the determinants of Amazon deforestation and describe the complexity of the prospective behavior of these socio-ecological systems with a focus to promote future research under three simulation scenarios: Amazonian landscape, agricultural landscape, and landscape of licit and illicit crops.

The hypothesis is that the Amazonian landscapes are not sustainable if they are part of the urban-agricultural system environments amid an increase in large-scale production seeking to increase and enhance profitability, food security, and growing connections to global commodity markets.

Systemically represented the determinants of Amazonian deforestation through 5 interconnected feedback loops: loss of the natural engine, feeding dynamics, fragmentation dynamics, agricultural profitability, and productivity. This representation allowed us to obtain a mathematical model built with the system dynamics methodology, from which was evaluated the prospective behavior of the Amazon Forest. In this way, it has given us arguments reported in this publication.

Section 2 presents the explanation of the methodology based on system dynamics, together with the causal and Forrester diagrams, which gave rise to the system's equations of motion. Section 3 describes the assessment results of three simulation scenarios for prospective analysis. Finally, Section 4 presents the discussion of the results, and Section 5 the conclusions.

2. Methodology

This section presents the system dynamics-based methodology that was developed to systematically articulate the different determinants of deforestation in the Amazon rainforest and prospectively analyze three different transformation scenarios: Amazon landscape (null transformation), agricultural landscape, and crop landscape legal and illegal.

For the mathematical modeling of the problem presented in this article, a systemic, deterministic, aggregated, and dynamic representation has been considered, which is derived from the systems thinking methodology known as system dynamics and leads to a system of time-dependent nonlinear ordinary differential equations called the mathematical model. The preference for this selection considers the following points: (1) the dynamics of a system's behavior are given by its structure [17], which is a systemic representation, (2) the references to make a probabilistic representation between attributes were not available, while cause and effect relationships were at hand, (3) a disaggregated representation would have led to a very large set of elements that could have enriched the discussion for a much smaller scale than the one selected in this work, but this is not the case, (4) the system represented is not static and it is its trend behavior that is of particular interest for this work, which is why the dynamic perspective was selected.

In this order of ideas, a brief introduction to the methodology of system dynamics is presented below, which will facilitate the reading of the rest of the paper.

Let us assume a system (X, R), in which X represents a set of elements that interact causally with each other through the relation R. Let A and B be elements in X. A is said to be a cause of B, if a variation ∂ of A generates a change ∂ on B, that is:

$$\frac{\partial B}{\partial A} \neq 0$$

This inequality can be interpreted through the relation $\partial B/\partial A>0$, which expresses that the positive variation of A generates an increase in B, or the relation $\partial B/\partial A<0$, which expresses that the positive variation of A generates a decrease in B. The first case is called a positive causal relation, while the second is called a negative causal relation. How these relationships are expressed in this paper is shown in Image *1*: Positive and negative causal relationships, respectively, Image 1:

The cause-and-effect relationship between two variables can be expressed mathematically through the formulation of their functional dependence. Again, let A and B be attributes of a system. If A is the cause of B, then, B=f(A), where f is a function that, for modeling purposes, must be piecewise smooth.

Methodologically, the first step for the construction of a mathematical systemic model with which it is intended to study a specific issue from the dynamics of systems is the identification of all the attributes of the system, along with the cause-and-effect relationships that exist between them, thus constituting a representation called causal di-

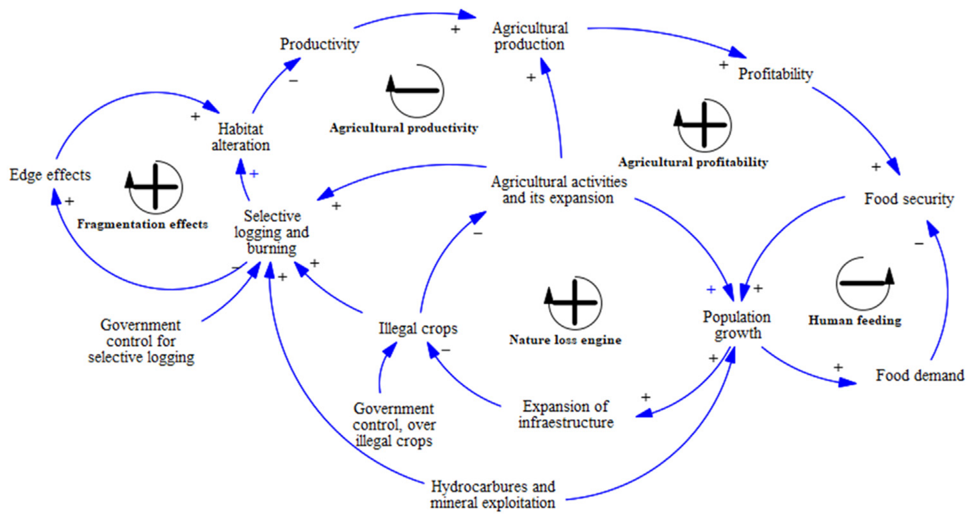

Image 2. Nomenclature for the interpretation of the level-flow diagram. Note that for the parameters only the text is incorporated.

agram. From this diagram, the attributes are interpreted as levels (state variables), flows (reasons for change), auxiliary variables, and parameters, in another representation known as levels and flows diagram. The nomenclature of the attributes in the level-flow diagram is shown in Image 2:

The logic for interpreting an attribute as a level, flow, auxiliary variable, or parameter is very simple. Attributes that accumulate from an initial value and represent the state of the system can be interpreted as levels. Attributes that cause levels are interpreted as flows, input if the causalities are positive, or output if the causalities are negative. The attributes that are not interpreted as levels or flows open two possibilities: if the attributes have causes, they are considered auxiliary variables, but if the attributes only have effects, they are considered parameters.

Finally, the levels and flows diagram are a very important construct because it facilitates the definition of the equations of motion of the represented system, expressed as differential equations. The equations are constructed under the logic of the following integral equation:

$$Nivel(t) = Nivel(0) + \int_0^t \left(\sum_{i=1}^{m} Flujo_i \right) dt$$

The System Dynamics methodology is summarized in the formulation of a dynamic hypothesis, the formulation of a simulation model, testing, and policy-making [17]. This is how the organization of this work was carried out, Fig. 2 shows the causal diagram proposed, and Fig. 3 shows the five loops of this diagram. Fig. 4 represents the Forrester diagram of the drivers of deforestation in the Sustainability of Amazonian landscapes and in Figs. 5–7 the three simulation scenarios proposed to prospectively evaluate and analyze the behavior of the coverage of the Amazonian natural area. regarding edge effects, agricultural production, food demand, and selective slash-and-burn.

2.1. Study area

The study area is the Amazon forest with an approximate extension of 7,989,004 Km^2, made up of nine South American countries, which in order of surface of the Amazon forest are Brazil with 5,144,000 Km^2 (64.4%); Peru 774,000 Km^2 (9.7%); Bolivia with 558,000 Km^2 (7%); Colombia with 531,000 Km^2 (6.6%); Venezuela with 473,307 Km^2 (5.9%); Guyana with 164,997 Km^2 (2.1%); Suriname with 150,000 Km^2 (1.9%) and French Guyana with an area of 63,700 Km^2 (0.8%) [1] (See Fig. 1).

Over the last quarter-century, global rates of tropical deforestation have averaged between 10 and 15 million hectares per year, which has impacted vast expanses of the fragmented forest [9]. Its most extensive use has been livestock regardless of illicit crops that cover a smaller area but have increased their economic importance since the early 1980s have also had an influence [15].

2.2. Causal diagram

Fig. 2, presents the causal relationships between the determinants of Amazonian deforestation, forming the causal diagram through five loops related to the actions of the human population, the central loop presents the main deforestation actions (expansion of agriculture, infrastructure, and illegal crops as the driver of natural loss, generating strong changes in the land, and driving the complete loss of tropical forest [13]. The loops were named as follows and in the following order: natural loss driver, feeding dynamics, fragmentation dynamics, agricultural productivity, and profitability.

2.2.1. Natural loss motor

The first loop was called the "natural loss motor" with positive feedback (see Fig. 3a). This loop shows how the increase in population and landowner colonization in a rural area requires an increase in road infrastructure and transport networks services to ensure the well-being of the new settlers, connecting communities, increasing land value and access to the forest and markets, making commercial activities on these lands more profitable [18], which in turn exposes illegal activities and forces them to decrease while encouraging the growth of agricultural activities, and their expansion.

Economic activity has a significant impact on the degradation of natural ecosystems in these areas initially, due to population growth [8]. However, a close relationship has been found between land use and deforestation, suggesting that land use is linked to demographic dynamics [7]. The course that population development has projected the advancement of roads at 55 km/year so if this dynamic continues, extensive areas of the Amazon will be subject to considerable anthropogenic changes [19]. Road networks are expanding in tropical countries, increasing human access to remote forests that are havens for biodiversity and provide globally important ecosystem services [20].

Likewise, it also found that the transmission lines are next to the road network, so it was estimated total length of the power line network within the legal Amazon is 39,625 km, concentrated mainly in the Southeastern Amazon wherever is found the highest population density and the greatest number of existing water dams [21].

In the case of the Colombian Amazon, it has been seen that livestock is the most extensive use of the land besides illicit crops occupying a smaller area but has reached economic importance. As a result, the growth of deforestation with high guerrilla activity and under government control of forbidden crops and selective logging. However, where there is high road accessibility, there are fewer illegal crops since it

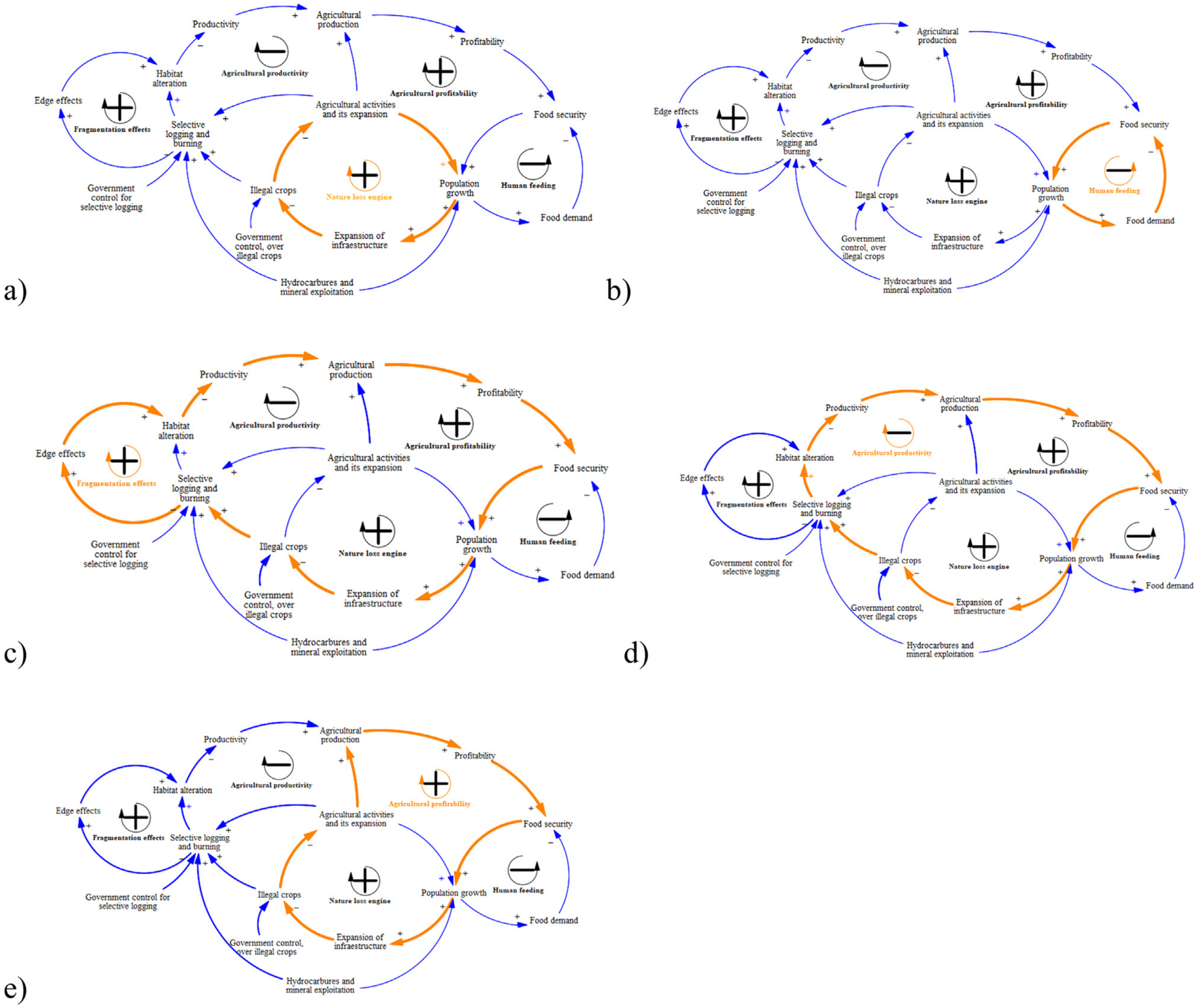

Fig. 1. Deforestation map in the Amazon 2020 [2].

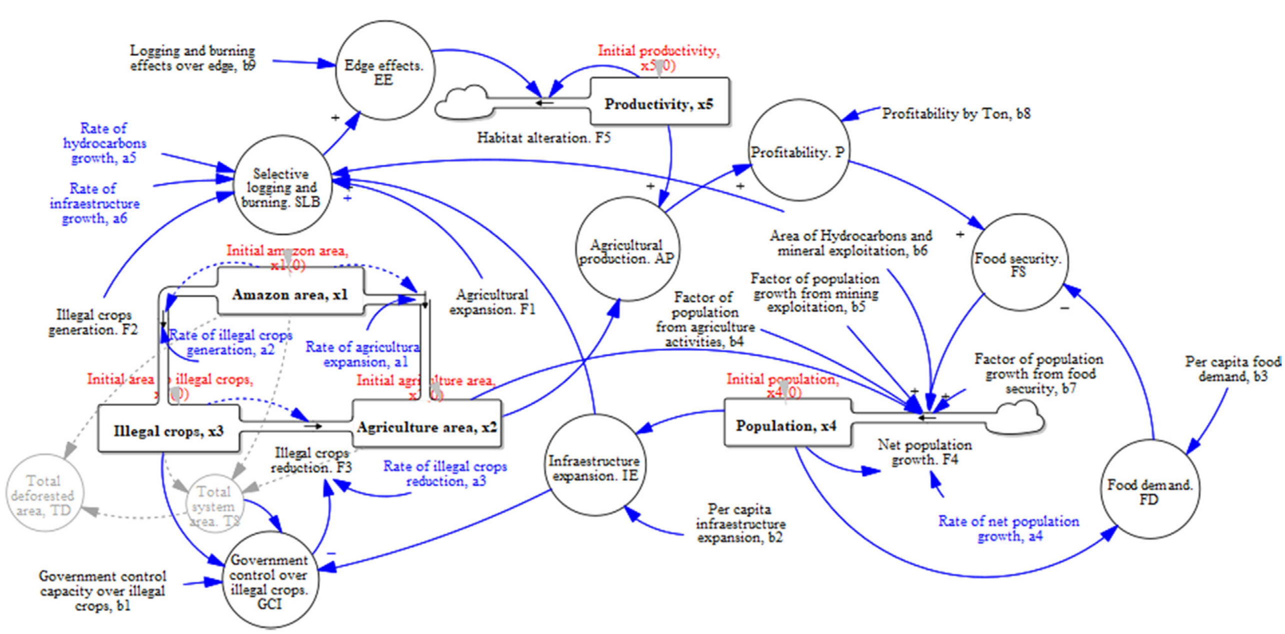

Fig. 2. Causal diagram of the deforestation drivers on the Sustainability of Amazonian landscapes.

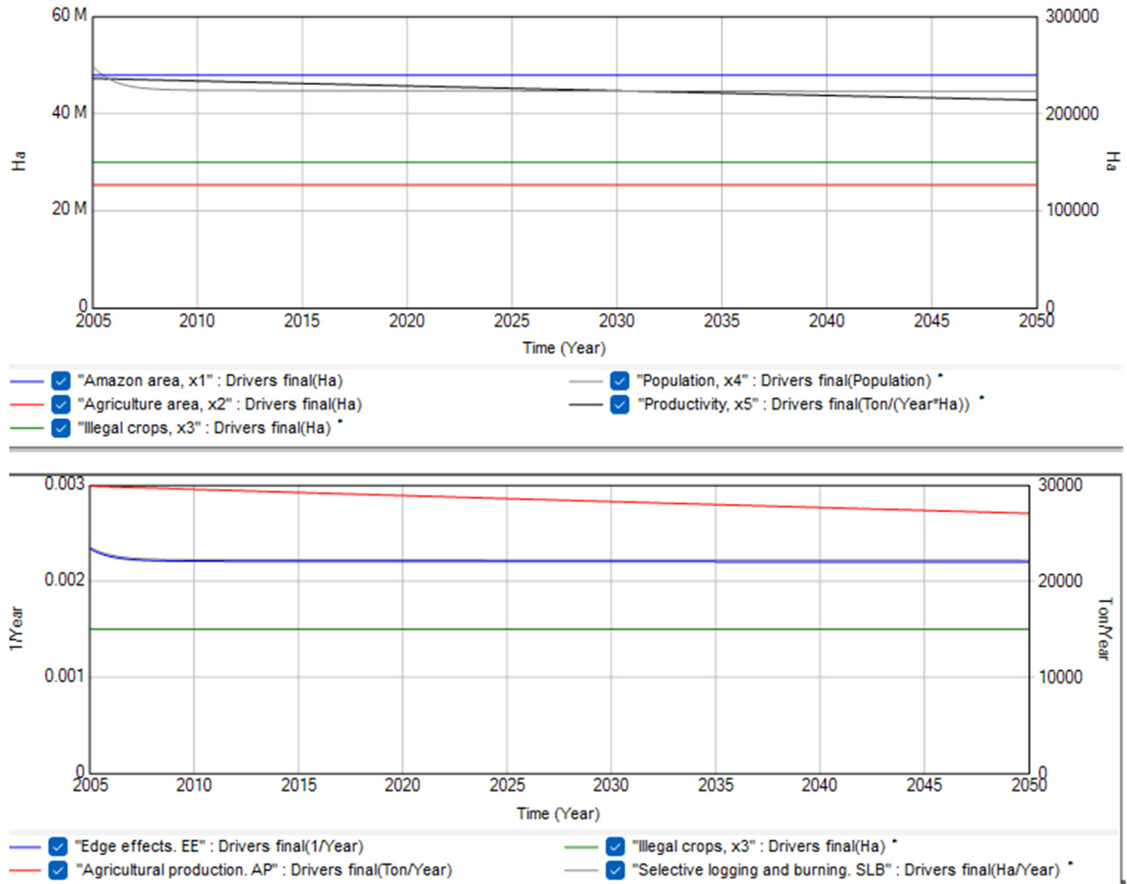

Fig. 3. Loops analyzed in the causal diagram (Causal relationships between the determinants of Amazonian deforestation).

does not expand in this area but rather in municipalities with a high percentage of natural cover. It represents another obstacle to reducing deforestation and the creation of conservation strategies [6].

In this sense, for decades, it has been visible through satellite images that pastures have eliminated Amazonian forests due to the excessive requirements demanded by agricultural activities, forming a triangle of deforestation associated with the increase in population as well as with crossroads and main roads [14], putting the sustainability of this socio-ecological system at risk.

2.2.2. Food dynamics

The second loop shows the "food dynamics" as negative feedback (Fig. 3b). In this loop, you can see how the population increase in this Amazonian area increases the demand for food a fact that can decrease food security while the population continues to grow. While population and migration are a key part of the demographic dimension of deforestation in the Amazon, land use variables, as well as contextual factors such as development policies in the area or the border area, also influence land cover change [7,22].

The agricultural landscapes in this Amazonian area change markedly with their land transformation impacts due to the high food demand generated by the intensity of land use [23]. However, these expanding market pressures through damaging impacts on agriculture could extend beyond the tropics [24].

As evidence, empirical model studies have indicated that tropical deforestation influences on many scales at the local, regional, and even global climate levels, with consequences reflected in the food security through water availability, climate scarcity such as temperatures high and low, extreme rainfall that could have grave implications for agricultural production systems in the implicated and nearby region [24].

There is an expanded zone of protected areas in the Amazon to prevent up to a third of the projected forest loss. However, this is not enough because the conservation of private land is essential to reinforce food security in the Amazon region, which has resulted in high urbanization [10].

2.2.3. Fragmentation dynamics

The third loop, fragmentation dynamics, was represented with positive feedback, see Fig. 3c. In this loop, the increase in population is visible, demanding an increase in road infrastructure and service networks for access to these areas, forcing a decrease in illegal crops because this activity takes place far from populated areas. These activities encourage an increase in the areas affected by logging and selective burning, causing an increase in the edge effects that disrupt the habitat and increase the impact on biodiversity, and afterward, the decrease in productivity.

The conservation of the Amazon and its wildlife communities are challenged by human-dominated landscapes, as depicted in Fig. 3c. Through population growth (locals, colonizers or landowners), infrastructure expansion has been generated, and different activities that promote selective logging and burning cause more and more deforestation and fragmentation of the Amazonian habitat of many living beings [25].

The expansion of infrastructure facilitates the colonization and change in land use toward urbanization. In addition, the economic activities in the region, and the illicit crops are far from the roads of urbanized areas causing deforestation in remote areas. This rapid degradation wears down ecosystem functions, increasing their vulnerability to edge effects, aggravating habitat loss, fragmentation, and alteration impacting biodiversity [6].

Likewise, if future agricultural production in the tropics continues increasing due to the search for high profitability in this area there will be a risk of causing an increase in average temperature induced by deforestation, impacting extreme heat associated with the rainfall from the frequency of rains [24].

2.2.4. Agriculture productivity

The fourth loop represents “agricultural productivity” with negative feedback (Fig. 3d). The third loop, begins with population growth (locals, colonizers, or landowners), showing an increase in road infrastructure and service networks in that area, as mentioned, has an impact on reducing the productivity of illegal crops. However, these activities increase selective logging and burning that impacts habitat conservation, and it also causes a decrease in productivity because ecosystem services are also altered during high agricultural production, affecting its profitability and the food security of the population.

Current production trends and increasing habitat settlements are subject to agricultural expansion, which is estimated to eliminate about 40% of Amazonian forests by encouraging slash-and-burn, releasing 3268 Pg of carbon into the atmosphere. As a result, productivity, profitability, and food security will decrease prospectively [10]. An example has been the case of agriculture in the Brazilian Amazon, where mechanized monoculture has been widely used, especially for soybean production, which has been responsible for almost 70% of the total deforested area in this region [26]. Increasing connections with global commodity markets [27].

2.2.5. Agricultural profitability

In the fifth loop, find the representation of the "profitability of agriculture" with positive feedback (Fig. 3e). Amid the quest to increase profitability through growth in agricultural production and increased food security, there is research reporting the use of macro-level processes that more directly influence land use and land cover change. This can drive population or landowner growth in the area, increasing road infrastructure and service networks, and exerting a decrease in illegal crop activity, which in turn could increase agricultural production [7]. The widespread socioeconomic stratification of the rural Amazonian population is compounded by subdivision and consolidation of ownership, both complicated by the emergence of a second generation of rural residents despite predictions that these settler agricultural systems would be unsustainable from the point of view of an ecological and financial point of view [27].

Policy interventions that highlight the genuine value of standing forests are needed to curb deforestation and fragmentation in this rapidly changing ecosystem landscape to protect the Amazon and its biodiversity [6]. As seen in the fifth loop of Fig. 3e, the profitability of livestock and agriculture is focused on its expansion to generate high agricultural production, promoting the infrastructure expansion in the Amazon rainforest [5]. In this way, they increase their yields and favor the establishment of population settlements, attracting migrants and thus facilitating other activities that determine deforestation, such as the exploitation of mineral hydrocarbons, which, although it generates a socioeconomic stimulus, unleashes effects that can further deteriorate the socio-ecological system and expose their ecosystem services to risk [28].

2.3. Forrester diagram

From the causal diagram, the levels and flows diagram were created, also known as the Forrester diagram presented in Fig. 4.

The levels (state variables) were the five areas of interest: the Amazon area, an agricultural area, illicit crop coverage, population, and productivity. The flows (reasons of change) were agricultural expansion, illegal crop generation, illegal crop reduction, net population increase, logging, and burning.

Within the model evaluation tests were considered for this type of model: (1) empirical tests of confirmation of structure and empirical confirmation of parameters; (2) theoretical tests for confirmation of structure and theoretical confirmation of parameters; (3) dimensional consistency test; (4) extreme value tests; (5) sensitivity analysis of the system to the variation of parameters; and (6) tests of the relationship between phases [29].

Comparison tests with time series did not carry out due to the data being insufficient for most of the indicators, and state variables were contemplated in this modeling and simulation work.

3. Results

In this section, we find the results obtained from the diagrams made by applying them to a simulation set of different scenarios to analyze its behavior over time. The outlines considered were the landscape of the Amazon area, agricultural landscape, and landscape of licit and illicit crops with their variables involved.

3.1. Scenario 1: landscape of the Amazon area

This first scenario represented the absence of agricultural systems. This simulation considers the values of the expansion of the agrarian sector at zero. As a result, the natural area of the Amazon remains constant, the population initially tends to descend but then remains constant, and productivity decreases in the absence of these farming systems.

Simulations of this scenario showed a constant amount of Amazonian natural area, with no activity, remaining intact (see Fig. 5). Whereas concerning edge effects and selective logging showed a representative drop initially and then remained constant. Agricultural production presented a continuous fall, and illicit crops were absent.

3.2. Scenario 2: agricultural landscape

This scenario represented a landscape with natural areas and socioeconomic dynamics rotating around agricultural production, but without the existence of illicit crops, so its coverage values for this type of crop were simulated as zero.

If there is no generation of illicit crops, there is an expansion in the agricultural area, while the coverage of the Amazon area decreases markedly. The effect on agricultural production has an impact of rapid growth and then falls until it disappears since it is an area not suitable for these activities, the same thing happens for logging and selective burning, which according to the intensity of each action, will eventually tend to fall, as they will do not find a more natural area to cut down (See Fig. 6).

In addition to generating conversion in agricultural and urban areas, there is a change in coverage with other activities such as the expansion of infrastructure, selective logging and burning, and the exploitation of hydrocarbons, among others, causing the loss of natural areas due to their time causing an impact on reducing biodiversity and agricultural productivity over time, thus showing a dynamic due to this socioeconomic situation of the inhabitant population.

The social situation in this scenario shows, when there is an increase in agricultural production depending on the amount of capital involved in search of better profitability, initially tends to increase quickly but then falls and disappears, indicating that the Amazon area is not sustainable in the future in an urban-agricultural environment [22] (Fig. 6).

3.3. Scenario 3: landscape of licit and illicit crops

In this scenario, a landscape has been described with natural areas whose dynamics and socioeconomic context depend on agricultural production and illicit crops. It is noted that, although illegal crops can exceed agricultural activity during a given period with the increase in population, the agricultural activity becomes the main activity, so the expansion of infrastructure grows and, on the contrary, coverage of illicit crops tends to disappear or instead move to remote but conserved locations causing further deforestation [30].

Although illegal crops that arise from the armed conflict are not the main determinant of deforestation, the relationship exists and may vary

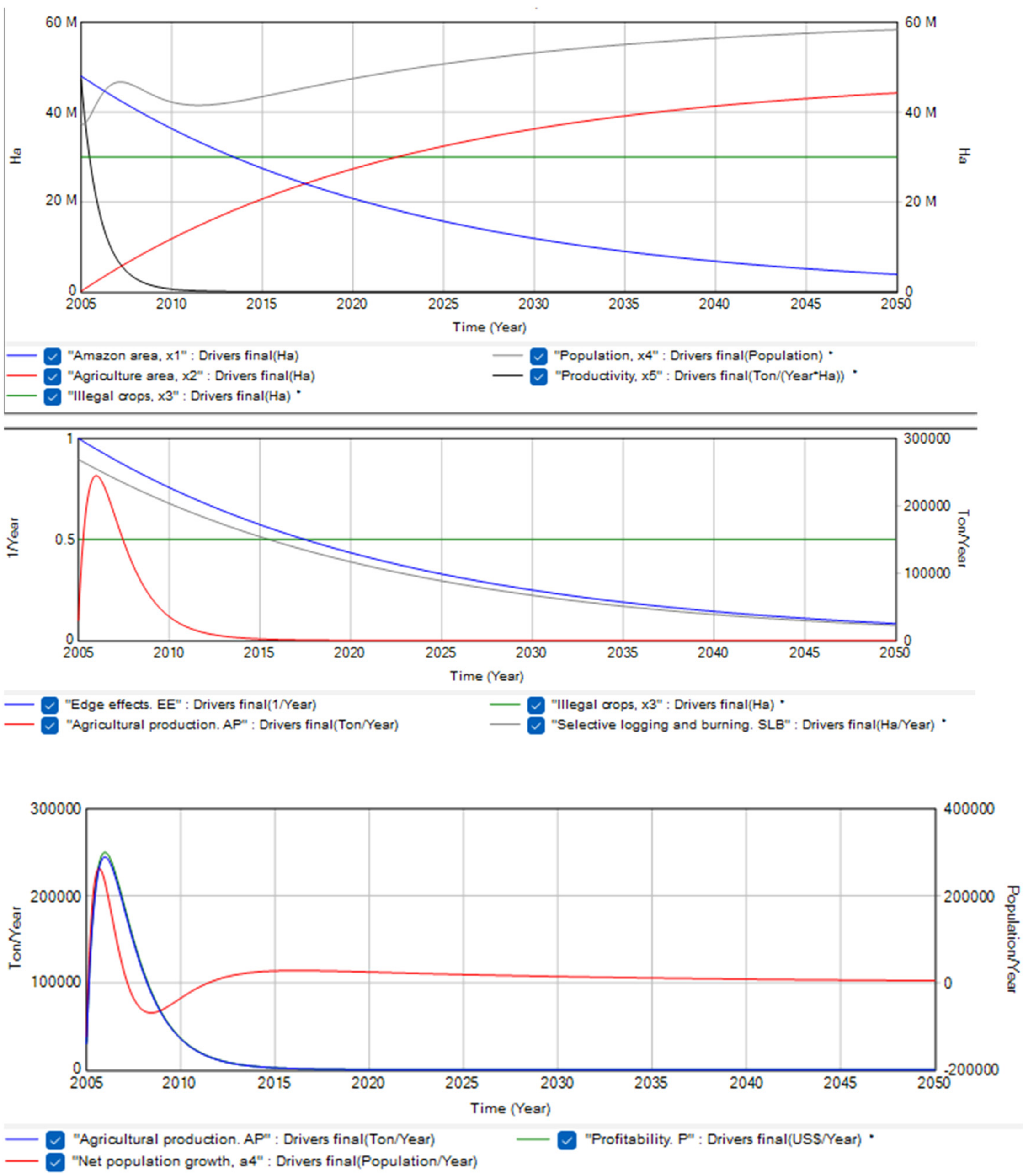

Fig. 4. Forrester diagram to study the deforestation drivers and sustainability in the Amazonian landscapes.

over time, it is noteworthy in this scenario that the presence of crops from illicit activities in the Amazonian landscape increases the population in these areas in a significant way where there has been controlled by different armed groups for decades. This has caused potential impacts not only at the social and economic level due to the phenomena of violence but also for the conservation of the Amazon, as in the case of Colombia, which has had incalculable impacts related to irreversible alterations of the natural environment, due to the agrochemicals used for the maintenance, extraction, and refinement of this type of crop [31]. As a result, the natural areas are transformed into an Amazonian landscape transformed into an urban-agricultural pasture area (Fig. 7).

4. Discussion of results

According to the results obtained through the System dynamics methodology, with the simulation of the three scenarios, the proposed hypothesis was corroborated, Amazonian landscapes will not be sustainable if it forms part of the urban-agricultural system environments amid an increase in large-scale production [22] seeking increase and improve its profitability and food security, growing connections to global commodity markets without compensating for the value of ecosystem services with a prospective analysis of the behavior of the different driving variables of deforestation in the Amazon rainforest showing variations in the behavior and interaction of these agents involved to support future research and actions for the conservation of the Amazon.

Finally, scenario 3, was represented a landscape with natural areas with socioeconomic dynamics depending on agricultural production and illicit crops where there is a temporal relationship, observing that although illicit crops can surpass agricultural activity during a certain period, with the increase in population, the agricultural activity becomes the main activity, which encourages the expansion of infrastructure, causing illicit crops to disappear in this sector or instead move to remote but conserved locations causing further deforestation (Fig. 7).The present research analyzed the interaction of the behavior of different

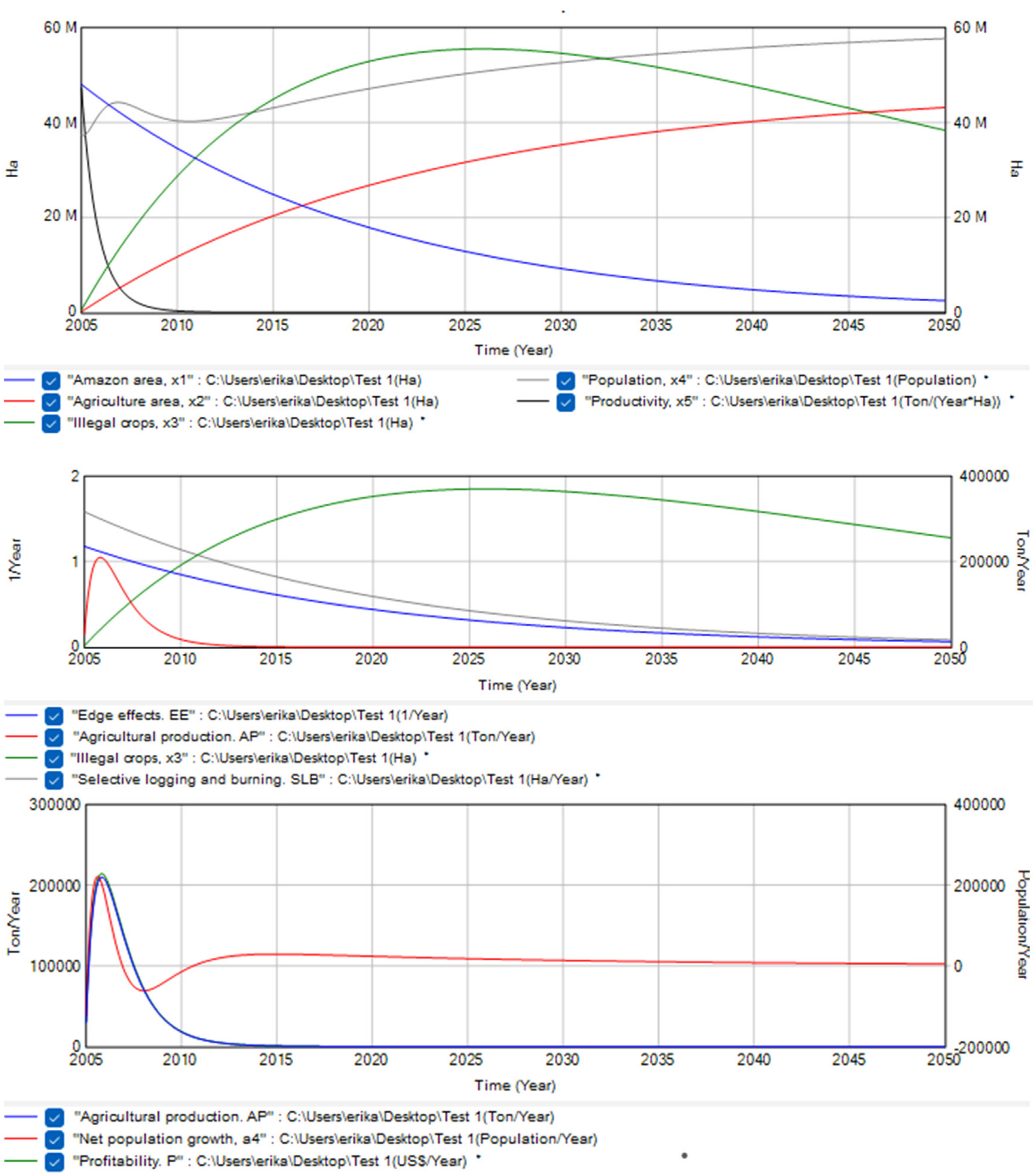

Fig. 5. Landscape scenario of the Amazonian area and its behavior of the coverage of the Amazonian natural area concerning edge effects, agricultural production, food demand, and selective logging and burning.

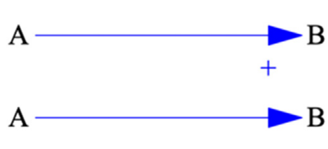

Fig. 6. Agricultural landscape and its behavior in the coverage of the Amazonian natural area about edge effects, agricultural production, food demand, and selective logging and burning.

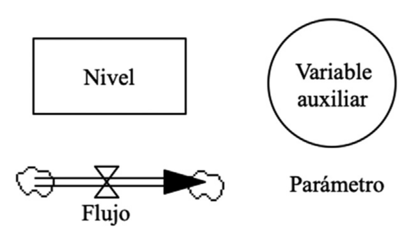

Fig. 7. Landscape of licit and illicit crops and its behavior in the coverage of the Amazonian natural area about edge effects, agricultural production, food demand, and selective logging and burning.

drivers of deforestation in the Amazon supported by previous research, which has also emphasized the direct impacts of human interventions on natural forests and their ecosystem services, highlighting the economic interests caused by a constantly growing extractive industry, the expansion of the agricultural frontier, timber extraction and road construction, among others. According to scenarios 2 and 3, if deforestation continues in this manner, it will leave little or no habitat available for the existence of life [25,32].

From the literature review, it was possible to see that the Amazon has already undergone a considerable transformation to urbanization. Now, it must be recognized for its ecosystem services, and its importance for climate change, so its conservation can be studied through the analysis of the drivers of deforestation. The researchers reviewed did not analyze the perspective of the behavioral interactions of these determinants for future studies and decision-making in the conservation of the Amazon rainforest [3].

The findings of this research reinforce previous studies that have reported the determinants of Amazon deforestation, such as population growth, which is represented in one inhabitant per kilometer, which can generate the loss of more than 7% of natural ecosystems [4]. Through the proposed scenarios, it was analyzed that when there is an increase in population, the effect on agricultural productivity has a rapid growth impact, as well as its profitability, to become the main activity that then encourages the expansion of infrastructure. Population identification of land cover change in the Amazon can vary by country, each with its own historical and political economic variables [7].

However, just as in some research, population growth is the main determinant of deforestation in the Amazon [33], in other studies, the driver of population density did not play a significant role in explaining deforestation which may be a result of rural to urban migrations observed in recent decades [18,34], other studies have linked forest clearing and the establishment of agricultural activities by specific groups or colonizers and not by the migrant or growing population [6]. Deforestation in the Amazon reflects many processes that occur, such as domestic land use, local population changes, regional economic change, national development policies, and responding to national and external political and economic circumstances, resulting in a high scale of land change that varies depending on the amount of capital involved by landlords, settlers or companies [7,22]. The changing conditions of an Amazonian resource base are depleting. An alternative scenario is the continued attrition of the rural population and accelerating concentration of land ownership, posing a future of increased rural poverty and urban growth [27].

To conclude, supporting that the most influential variables are those related to forest access [18]. In the present study, these variables were focused on the first loop called natural loss driver, which was also related to the five loops represented and in the three proposed scenarios. With this loop it is possible to analyze the main dynamics drivers of Amazon deforestation as a central element of this study since it has the following deforestation drivers: Population growth, Infrastructure expansion, Agricultural activities and their expansion, and Illegal crops.

5. Conclusions

The modeling approach presented in this identified study based on system dynamics systematically articulated the different determinants of deforestation in the Amazon rainforest to analyze its behavior prospectively under three different transformation scenarios: Amazon landscape (no transformation); agricultural landscape; and, a landscape of legal and illegal crops (complete transformation) with which it could be finally found, that the Amazon can face different scenarios with diverse futures subject to the socio-ecological actions generated for the conservation and relevance of its ecosystem services by being part of the urban-agricultural system environments, and the socio-political and economic context of each country that forms the Amazon, and the socio-political and economic context of each country that makes up the Amazon. No single and unified theory of the expansion of borders adequately explains the various nuances of reality that are observed in countries developing.

The risks of deforestation and its drivers are documented through different research in different periods, registering an alarming increase in recent decades, urgently requiring key local and global actions for its conservation and to curb climate change. To this end, Amazon deforestation can be analyzed through the behavior of the interaction of its drivers, such as the use of the land that, according to the capital involved, generates large-scale agricultural expansion and contextual factors such as border development policies [27].

This study helps to clarify and contribute to new related studies such as the analysis of variables with access to the forest because they are among those that can most influence deforestation, i.e., those that fall into the category of determinants for the support of anthropogenic activities, which although not directly related to population growth, can make commercial activities on these lands more profitable and increase the value of the land. Similarly, the expansion of interconnected national systems for the supply of electricity requires both the growth of road infrastructure and transportation network services to ensure the welfare of new settlers and connecting communities.

Finally, the results of this research indicate that the drivers of deforestation are dynamic in time and space as well as their influence and intensity may vary from region and country, so it is advisable to analyze future studies of this dynamism in terms of location, intensity and historical records to support not only future studies but also to support the implementation of impact actions on the territory and rural communities that currently inhabit areas with higher rates of deforestation.

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Declaration of Competing Interest

This research "Prospective analysis of deforestation determinants in the Amazonian landscapes” did not receive specific funding from funding agencies in the public, commercial, or nonprofit sectors.

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