Model for Assessment Sustainability Indicators in biofuels.

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Abstract- A method for representing systems that allows the study of change and of necessity is required for sustainability assessment. Therefore, in this study a model for dynamic and prospective assessment of the sustainability in biofuels, was developed. The proposal of this work is shown with an example in the bioethanol production from sugarcane in Colombia. First a model of a bioethanol supply chain is developed and it is linked with associated variables which represent sustainability indicators, these indicators were proposed by the Global Bioenergy Partnership- GBEP. Then desired regions of the state of the system and indicators are suggested, which were defined for some Time of Evaluation of sustainability such as: Desired Scenario, Alert Scenario and Non Desired Scenario. This model allowed important findings for monitoring and evaluation of sustainability in biofuels production.

Keywords: Sustainability, Modeling, System Dynamics, Viability Theory, Biofuels.

1. Introduction

Sustainability is currently one of the most important concepts in scientific research and government programs of different countries (Nabavi et al 2017). This applies to all productive sectors that grow in local and global economies. The application of sustainability principles into supply chains is also an evolving research area currently suffering from a scarcity of established theories, models, and frameworks (Ahi & Searcy 2015). One of the most noteworthy sectors for the implementation and assessment of sustainability is the biofuel sector, because in recent years its production specifically bioethanol has increased worldwide, due to the implementation of measures and policies that encourage local production (Scarlat and Dallemand, 2011). Currently, these production policies have focused on the construction of projects and sustainability standards, thus, encouraging many countries to investigate, implement or consider the opportunity to introduce the production of biofuels from different feedstocks in their national energy systems (Pacini, et al 2013). All this is also encouraged because biofuels have been considered as an option for reducing emissions of greenhouse gases, increasing the diversity of the energy mix, creating jobs and promoting rural development (Scarlat and Dallemand, 2011). However concerns remain about the potential direct and indirect impacts with respect to sustainable development, specifically the contribution of greenhouse gases, food safety, environmental effects and economic development, which are still discussed in different contexts (Valencia and Cardona 2014).

Hence the pursuit of sustainable development as an adaptive process of learning-by-doing may benefit from using sustainability indicators, (Pupphachai y Zuidema, 2017). Accordingly, sets of indicators have been developed to approach the assessment of sustainability in biofuels production (Diaz-Chavez, 2011). In this direction, a set of sustainability indicators was proposed by the Global Bioenergy Partnership (GBEP), which consists of 24 indicators for sustainable bioenergy production assessment. This was the first global consensus of governments to assess the sustainability in the use of bioenergy through indicators (GBEP, 2011). These are based on the three pillars of sustainability: economic sustainability, social sustainability and environmental sustainability. GBEP indicators focus on a national and / or regional market level, as well as throughout the life cycle of the biofuel (Hayashi and Ierland Zhu, 2014), i.e. throughout the supply chain. The use of indicators provides a tool for generating and analyzing information. They are useful for sharing and comparing and to facilitate decision-making to the different stakeholders (Diaz Chavez, 2011) in building sustainability policies in different contexts. However the assessment and monitoring of these indicators is made based on historical data and present and past behaviors. Since this is a weakness of current methodologies, as it is necessary to link the structure of the system and to define the rules of evolution in order to visualize the different scenarios of future projection of biofuel production and the behavior of the sustainability indicators in the future, i.e., a prospective evaluation of sustainability is necessary.

In this vein, a method for representing systems that allow the study of change and of necessity is required, and that also shows emergent behaviors that demonstrate the existence of adaptation. Thus, the main goal with this study is to make an original contribution to the biofuel sector, developing a tool that involves the ideas of change, necessity and adaptation, developed in the context of the Methodology of System Dynamics and the Viability Theory to prospectively evaluate the sustainability indicators established by the GBEP.

The proposal of this work for the evaluation of sustainability in biofuels is shown with a specific example in the production of bioethanol from sugarcane in Colombia.

2. Bioethanol production in Colombia

Colombia is the tenth producer country of bioethanol in the world, and the third in Latin America. In Colombia, bioethanol production comes from sugarcane and the installed production capacity increased from 1,250,000 liters / day in 2013 (CUE, 2012) to 1,650,000 liters / day at present (Fedebiocombustibles, 2016).

In 2014 406.5 million liters of bioethanol were produced and in 2015 almost 450 million of liters (See Figure 1.), intended for mixing with gasoline at an E8 ratio, 8% ethanol and

92% gasoline (Fedebiocombustibles, 2015). The growth of this industry in the country has had both positive and negative impacts on the economic, environmental and social fields since these production systems are quite complex and have many factors influencing the sustainability of their production (Janssen and Rutz, 2011). Biofuels are expected to account for a substantial part of the diversification of energy sources, but it is necessary to assess the sustainability of its market to explore its effects on the economic, social, political and environmental dimensions (Espinoza et al, 2017).

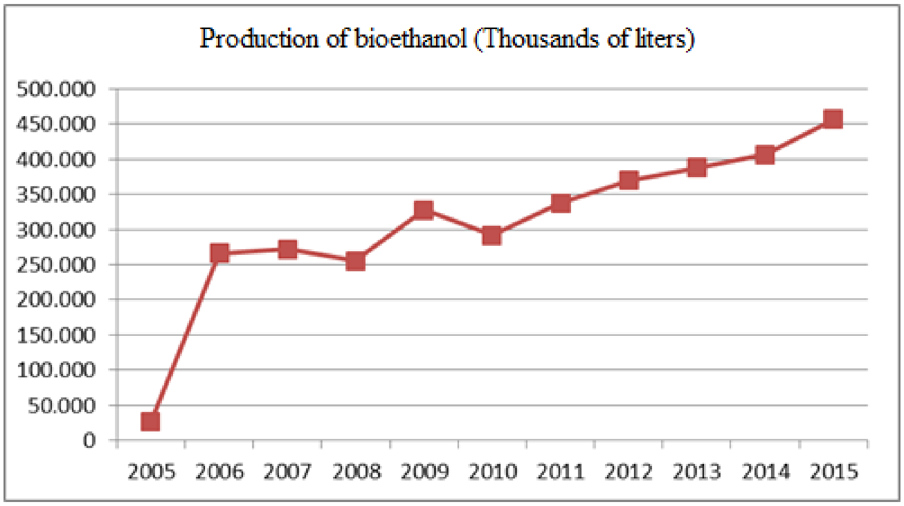

Figure (1). Bioethanol production in Colombia. Modified from: (Asocaña – Balance azucarero 2012 y 2016)

2.1 Sustainability of bioethanol in Colombia

Colombia has made significant progress in the production of bioethanol from sugar cane, being the best ranked biofuel in the national market. Currently, the production of bioethanol is located in three departments of Colombia: Risaralda, Cauca and Valle del Cauca. Significantly, the supply chain of the sugar industry was adapted for the production of bioethanol and the sugar that was destined for export, is now used to produce ethanol (Valencia, 2012).

Although the directive of the national government is to continue increasing this production capacity, there is uncertainty about the true environmental, social and economic impacts that this increase could bring. These impacts generated in the production of bioethanol, are associated with different stages of the supply chain.

The commitment of the government is to increase production in the short term, but considering the sustainability guidelines that were established in the CONPES 3510 (2008), which wants the country to achieve an efficient and sustainable production in the economic, social and environmental fields. Therefore, it is necessary to develop rigorous tools to link the environmental aspects and impacts related to the production process of bioethanol along the supply chain.

In the Colombian context, the most important study that had been conducted to evaluate the environmental impacts of biofuels was made as a requirement of the private sector and the national government, see (CUE, 2012), where the authors used the Life Cycle Analysis to conclude that biofuels are environmentally friendly in Colombia. However, this study does not allow to see future scenarios that consider increasing production.

In this paper, we seek to link and model proposed social and environmental indicators to assess the sustainability in different contexts. The complete set of indicators that are required for the evaluation and monitoring of sustainability are presented in the following section.

3. Methodology for Assessment Sustainability Indicators

Due to the dynamic nature of supply chains and the complexity of the the production process of biofuels and specifically sugarcane bioethanol, the modeling is perceived as a natural and important tool for analysis and design of supply chains and chain management (Tako, A. and Robinson, S. 2012). System Dynamics is among the modeling and simulation methodologies. How is widely known SD is a methodology for analysis and problem solving, which attempts to simulate the behavior of systems over time. In System Dynamics, any aspect of the world is conceived as the causal interaction between attributes that describe it. Thus, systemic representations are built with arrows and nodes, called causal diagrams that capture all scenarios proposed by the modeler, from those which you can learn from the system to act upon it in the exercise of decision (Ibarra and Redondo, 2015). With System Dynamics several researches have been conducted for the assessment of sustainability in different sectors (Nabavi, et al 2017, Zhang, et al 2017, Dacea, et al 2015 Banos-Gonzalez, 2016). This methodology has also been used for evaluating sustainability in the biofuels sector (Musango, et al 2012, Robalino, et al 2014, Demczuk & Padula, 2017).

After developing the model, it is necessary to know if the system evolves through desired states that correspond with the objectives of sustainability of the sector or to understand the behavior of to understand the behavior of sustainability indicators, for this, some concepts of Viability Theory have been linked.

The Viability Theory designs and develops mathematical and algorithmic methods to investigate the adaptation of the states of complex systems to their viable evolution sets. It involves interdisciplinary research covering fields that have traditionally been developed in isolation. The aim of the theory of viability is to provide "control maps" associating any state of the complex system, with the subset of controls or regulations governing viable evolutions, possibly empty (Aubin, 1992). For the assessment of sustainability in the biofuels, we have defined the scenarios that are shown in Figure (2).

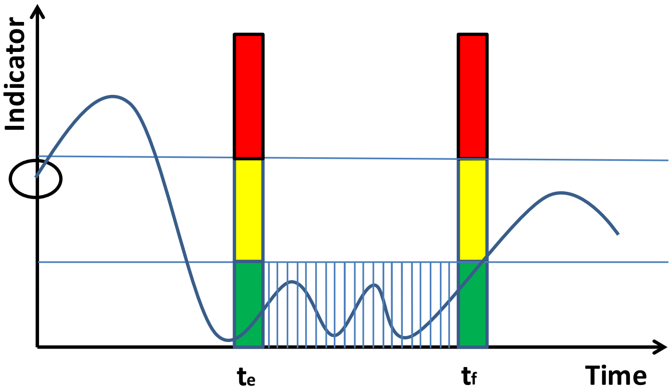

Figure (2): Prospective evaluation of sustainability indicators. The figure shows three scenarios: desired scenario in green, alert scenario in yellow and non-desired scenario in red. We also see the evolution of an indicator of sustainability, from a certain initial condition in alert scenario. Note that from some evaluation time t_e, to a final time t_f, the indicator is in the desired scenario (hatched area).

We will say that the system has the desired values $\mathrm{t_e}$for the time of evaluation $\mathrm{t_e}$, when for the time of evaluation and any future value after it in a well-defined time interval, we have the system state in the desired scenario ($\forall \mathrm{t} \in [\mathrm{t_e}, \mathrm{t_f}]\ \mathrm{x(t)} \in \mathrm{A_D}$)

4. Description and modeling of the System

Bioethanol is a type of biofuel produced from the fermentation of sugars from agricultural crops or crop residues. This is by far the most technologically mature biofuel derived from microorganisms and a good candidate to replace fossil fuels (Zerva A. et al 2014). In Colombia it is produced from sugar cane, because the production of this type of plant is consolidated in the country and has higher energy efficiency compared to other raw materials from which bioethanol is produced. Its production in Colombia takes place mainly in the Cauca River Valley, in the departments of Cauca, Valle, Risaralda and Caldas, covering 47 municipalities (CUE 2012). For this article we took as base a supply chain of sugarcane bioethanol generally presented in (CUE, 2012 and Valencia and Cardona, 2014) The main links in the chain of bioethanol are producing sugar cane (Hectares of sugarcane), processing of raw materials, production and transportation (Ibarra 2016).

Below are shown and defined the key attributes that were identified to build and define the system to be studied, which describe the parts of the supply chain of bioethanol.

- Hectares of Sugarcane: The amount of hectares of sugarcane planted for the production of bioethanol.

- Net Increase: Increase rate of hectares for sugarcane production.
- Harvested: Number of Hectares harvested and destined for the production of bioethanol.
- Enlistment of sugar cane: Cleaning and grinding process of harvested sugarcane
- Installed Capacity: Production potential or maximum production volume of bioethanol in the country.
- Sugarcane juice: Amount of sugarcane juice intended for fermentation.
- Bioethanol Production: Production process in function of production rate of fermentable juice and installed capacity
- Produced bioethanol: The accumulation of liters of produced bioethanol.
- Distribution: Amount of bioethanol for blending with gasoline.
- Productivity: An economic indicator that shows the amount of volume produced per hectare of sugarcane.
- Impact on social indicator: Positive repercussions on social indicators
- Environmental Impact indicator: Negative repercussions on environmental indicators

From the identification of the system attributes, we proceed to the construction of the basic causal diagram of a simple supply chain:

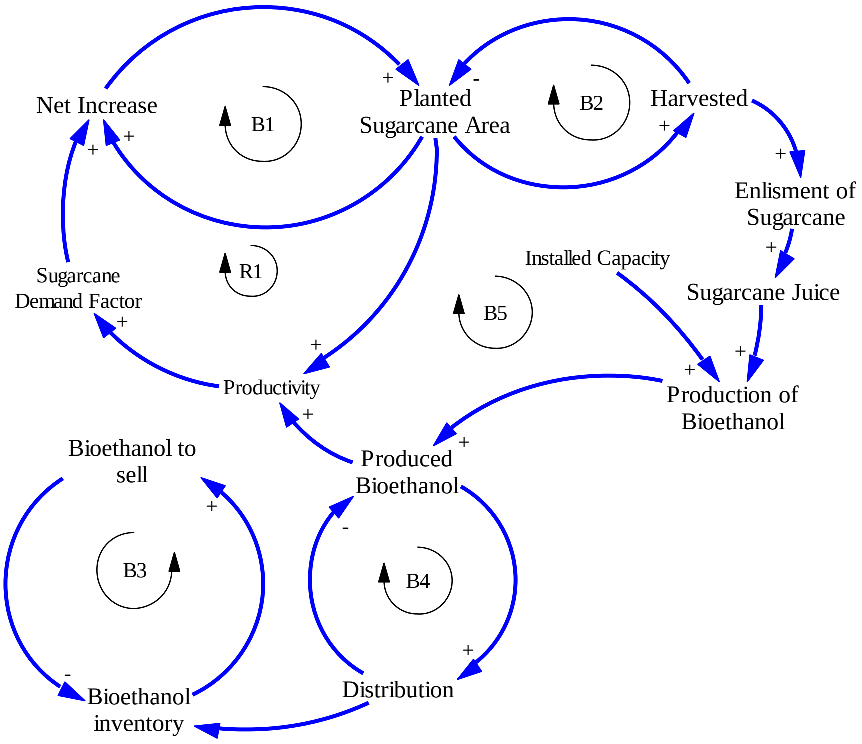

Figure (3) Causal loop diagram of the supply chain of bioethanol.

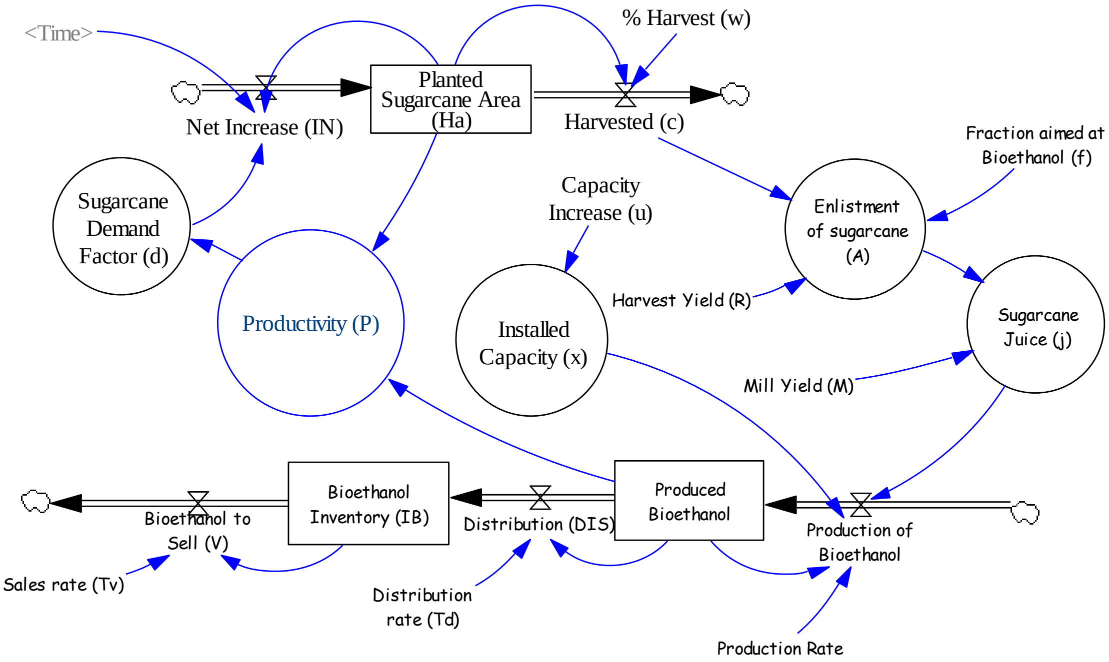

Figure (4) Stocks and Flows Diagram of the supply chain of bioethanol.

From the diagram of Stocks and flows, we make equations representing the evolution in time of the state variables of the system. Thus we can say that the hectares of planted sugarcane are given by:

$$\frac{dHa}{dt} = IN - C, \tag{1}$$

where IN is the net increase given by changing a demand factor, in relation to the time and hectares of planted sugarcane and it is defined by a piecewise function:

$$IN = \begin{cases} Ha + (Ha.k) & Si \;\; t < ti \\ Ha + (Ha.k1).d & Si \; t \geq tj \end{cases} \tag{2}$$

The harvested flow variable C is the number of hectares of sugar cane that are harvested per a fraction of hectares w. This is given by:

$$C = Ha.w \tag{3}$$

Flow variables IN and C are measured in hectares of sugarcane Ha.

Bioethanol production is estimated annually, it accumulates in the level of bioethanol produced variable, B which is given by:

$$\frac{dB}{dt} = Production\ of\ B - DIS, \tag{4}$$

The production rate parameter *p* Rate is a percentage production parameter and goes from 0 to 1. It allows calibration of the model.

In turn the sugarcane juice j is defined by the product between performance R and the auxiliary variable Sugarcane Enlistment A, which is a function of crop yield Rc, the milling rate TM and the fraction for Bioetanol f, expressed as folows:

$$j = A.R\ ,\ \text{where}\quad A = \ (R.C).f. \tag{5}$$

The installed capacity in this model is represented by an auxiliary variable with an annual increase u as follows:

$$X = X_0 + \quad X.u \tag{6}$$

The variable flow Distribution *DIS,* is given by:

$$DIS = B.Td \tag{7}$$

The amount of inventory of Bioetanol *Ib* is represented by the difference between what is distributed *DIS* to stock and what is sold *V*:

$$\frac{dIb}{dt} = DIS - V. \tag{8}$$

Sales relate to a constant sale rate *Tv*:

$$V = IB.Tv \tag{9}$$

To estimate the net increase, it is associated to a demand factor *d*, which is based on the *Productivity.* This is defined by the amount of Bioethanol produced *B* on the number of hectares of sugarcane aimed at production Ha:

$$Productivity = \frac{\mathrm{B}}{\mathrm{Ha}} \tag{10}$$

$$Demand\ factor = \begin{cases} d1 \quad si\ \ P \geq \ n \\ \\ d2 \quad si\ \ P < \ n \end{cases} \tag{11}$$

The general initial conditions for the simulation of the model and the water consumption indicator are presented in the following table:

Table 1.
Initial conditions. Modified from: (Ibarra, 2016, CUE 2012).

Variables	Values
Hectares	14000 Ha
Harvest Yield	118 Ton/Ha
Fraction aimed at bioethanol	62%
Installed Capacity	100.000 L/day

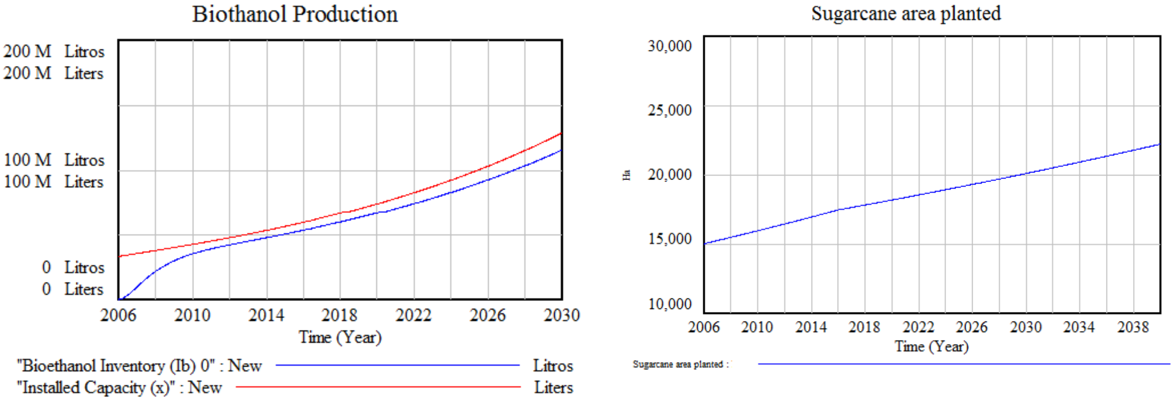

Figure (5) Simulation of bioethanol production and sugarcane hectares.

4.1 Sustainability Indicators.

The Global Bioenergy Partnership (GBEP) developed a set of twenty-four indicators for the assessment and monitoring of sustainability of bioenergy at national levels.

The GBEP indicators are intended to inform policymakers in countries on environmental, social and economic aspects of bioenergy industry in their countries and guide them towards policies that promote sustainable development, see Table (1). These are presented in detail in Hayashi et al. (2014) and GBEP (2011).

Table 1.
List of GBEP indicators.

Environmental Indicators	Social Indicators	Economic Indicators
1. Lifecycle GHG emissions	2. Allocation and tenure of land for new production	3. Productivity
4. Soil quality	5. Price and supply of a national food basket	6. Net energy balance Ratio
7. Harvest levels of wood resources	8. Change in income Local currency	9. Gross value added
10. Emission of non-GHG air pollutants	11. Jobs in the bioenergy sector	12. Change in consumption of fossil fuel and traditional biomass

13. Water use and efficiency	14. Change in unpaid time spent by women and children collecting biomass	15. Training and re-qualification of the workforce
16. Water quality	17. Bioenergy used to expand access to modern energy services	18. Energy diversity
19. Biological diversity and landscape	20. Change in mortality and burden of disease attributable to indoor smoke	21. Infrastructure and logistics for distribution of bioenergy

For this study, the environmental indicator water use and social indicator employment was modeled and evaluated, as are explained below:

- **Use and water efficiency Indicator**

This indicator defined by the GBEP as the volume of water extracted from certain watersheds nationwide, used for production and processing of raw materials for bioenergy per unit of bioenergy produced, in this way for this case we modeled the indicator, considering the estimated water consumption for growing sugar cane intended to produce bioethanol, this is a function of the hectares of sugarcane. The causal diagram that complements the one presented in Figure (3), and that shows the link of the water usage indicator is shown in Figure (6a). In turn the Levels and Flows diagram that complements the one presented in Figure (4) and that models the indicator, is shown in Figure (6b).

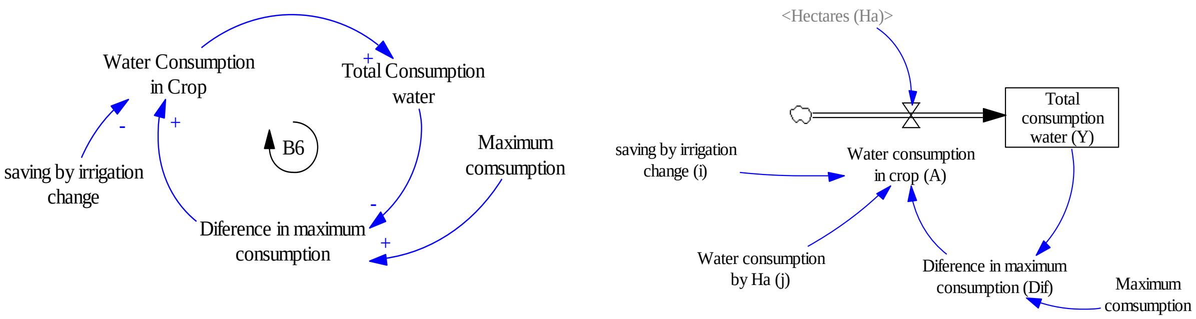

Figure 6a) Causal Diagram of water consumption Indicator. 6b) Stocks and Flows Diagram of water consumption Indicator.

The general initial conditions for the simulation of the model and the water consumption indicator are presented in the following table:

Table 2.

Initial conditions . Source: (Ibarra, 2016, CUE 2012).

Variables	**Values**
Hectares	14000 Ha
Harvest Yield	118 Ton/Ha
Fraction aimed at bioethanol	62%
Water consumption in crop	7,2 m3/Ha-year

As a result of the simulation model it is evidenced that the evolution in time of the annual water consumption variable without any intervention for a first evaluation time $t_{e} =$ 2035 is within the Non-Desired scenario (Red color), as the amount of water consumed is not within the range defined as desired (≤ 100,000 Green color). Thus it is necessary to implement a strategy or policy that allows moving the indicator state to the desired region. So we implemented the saving strategies for water consumption in which is considered the greater consumption activity, sugarcane cultivation. These strategies seek savings in water consumption by 20%, 30% and 60%, with the combination of improved irrigation techniques of cultivation (see Table 3).

Table 3. Information about water-saving techniques. Source CUE (2012)

Saving strategy	**Technical description of savings**	**4 irrigation / year**	**% Savings**
NA	BAU-Business As Usual	7200 m^3	NA
Savings 1	CAR (administrative control of irrigation)	6000 m^3	20
Savings 2	CAR and alternate groove	5000 m^3	30
Savings 3	CAR, alternating groove and pipe with gate	3000 m^3	60

The results of the evaluation of the annual water consumption indicator show that the intervention of the system by implementing saving strategies, would improve the outlook and would lead the system within the desired region, but only for the system that includes savings strategies 2 and 3. (See Figure 7) For its temporal evolution it is in the Desired scenario in $t_{e} =$ 2035 and for $t_{e} = \geq t_{e.}$ Fulfilling the proposal in section 4.2 of this paper.

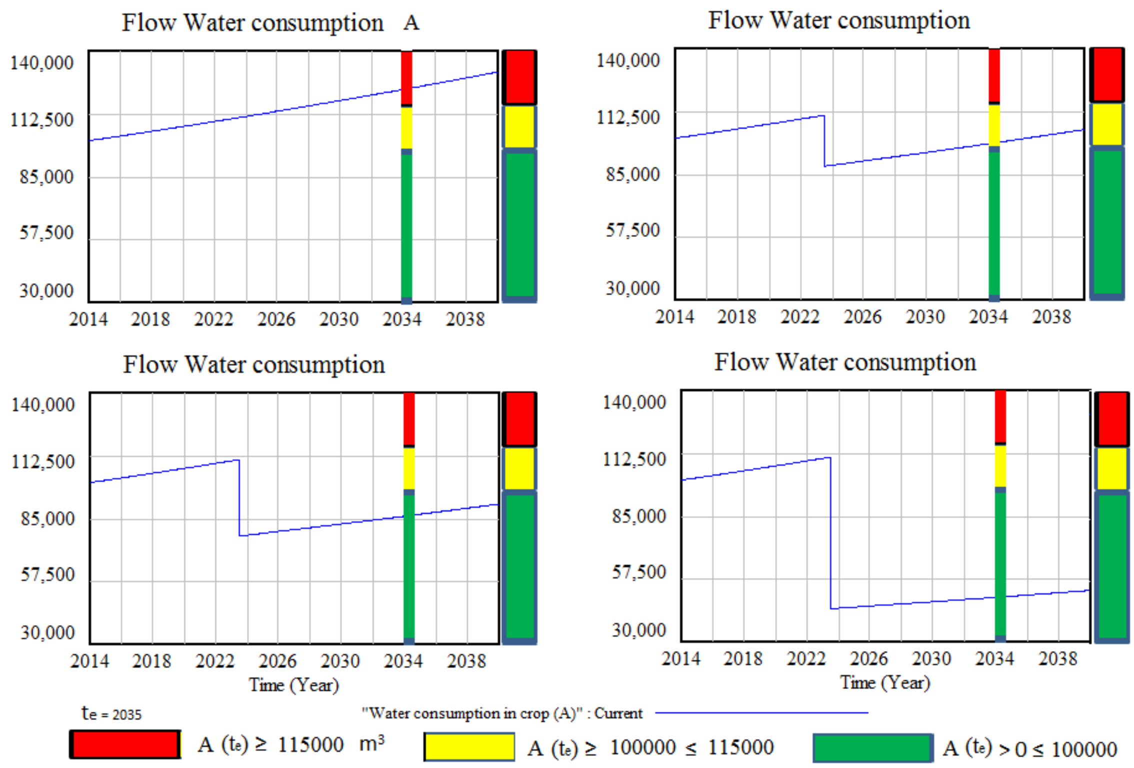

Figure 7 Prospective evaluation of indicators. Water consumption.

- **Employment Generation Indicator**

This indicator defined by the GBEP as net job creation as a result of the production and use of bioenergy. For this article, we used the employment indicator, measuring it as the number of jobs generated throughout the production chain of bioethanol presented in Figure (3, 4).

The causal diagram that complements the one presented in Figure (3), and that shows the link of the number of jobs indicator is shown in Figure (8a). In turn the Levels and Flows diagram that complements the one presented in Figure (4) and that models the indicator, is shown in Figure (8b).

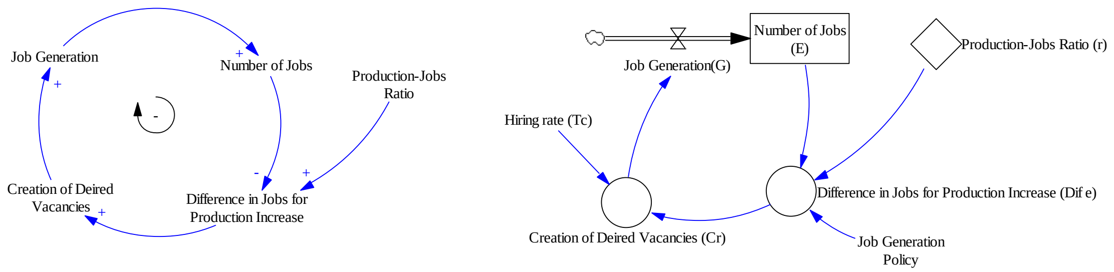

Figure 8a) Causal Diagram of Jobs Indicator. 8b) Stocks and Flows Diagram of the Jobs Indicator.

The initial conditions for the simulation of the model are the same as those presented in Table 2. With an employment relationship of 10,000 existing jobs for every 33 million bioethanol liters produced annually.

The results of the evaluation of the indicator, without any intervention of government policies, show that with the initial conditions suggested and with the increased production of bioethanol with economies of scale the number of jobs would be reduced, leading the time evolution to a Non-desired region (Red) on it $t_e = 2025$. Thus, the implementation of sectoral policies by the government is needed to increase the number of jobs in the production of bioethanol and to monitor the existing relationship between the amount of ethanol produced or increased production and the generation of new job opportunities. With the aim to discuss social benefits.

Thus, the results of the Jobs indicator evaluation, show an improvement in the time evolution of the indicator, since we implemented in the model a policy that seeks to increase 10%, 50% and 80% of jobs for $t_e= 2025$. Defining as the Desired Scenario an amount of more than 15,000 jobs.

Figure 9 shows the evaluation with the three policies. It is concluded that the implementation of policies to increase employment by 80% would improve the outlook and lead the system within the desired region, because its evolution is in the Desired scenario in $t_e = 2025$ and for $t_e = \geq t_e$.

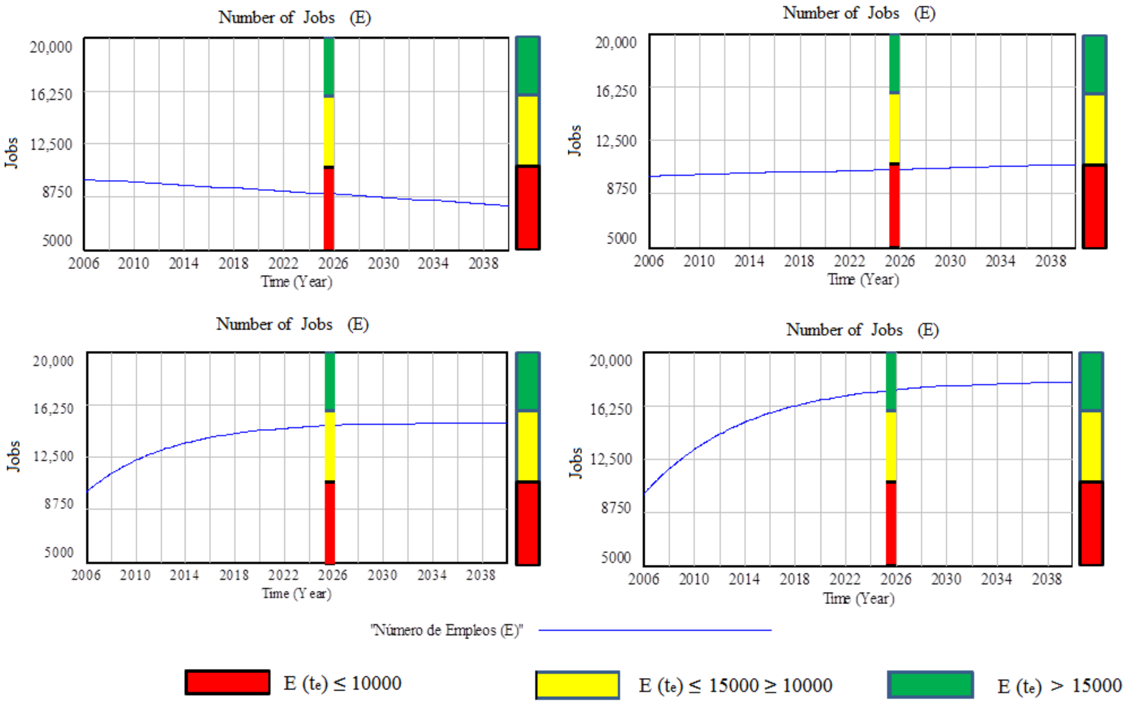

Figure (9). Prospective evaluation of Water Consumption Indicators.

After of the simulations and de indicators assessment. We present de the causal diagram that complements the one presented in Figure (3). This new causal diagram, represents the whole supply chain and the way for integrate the sustainability indicators. See Figure (10).

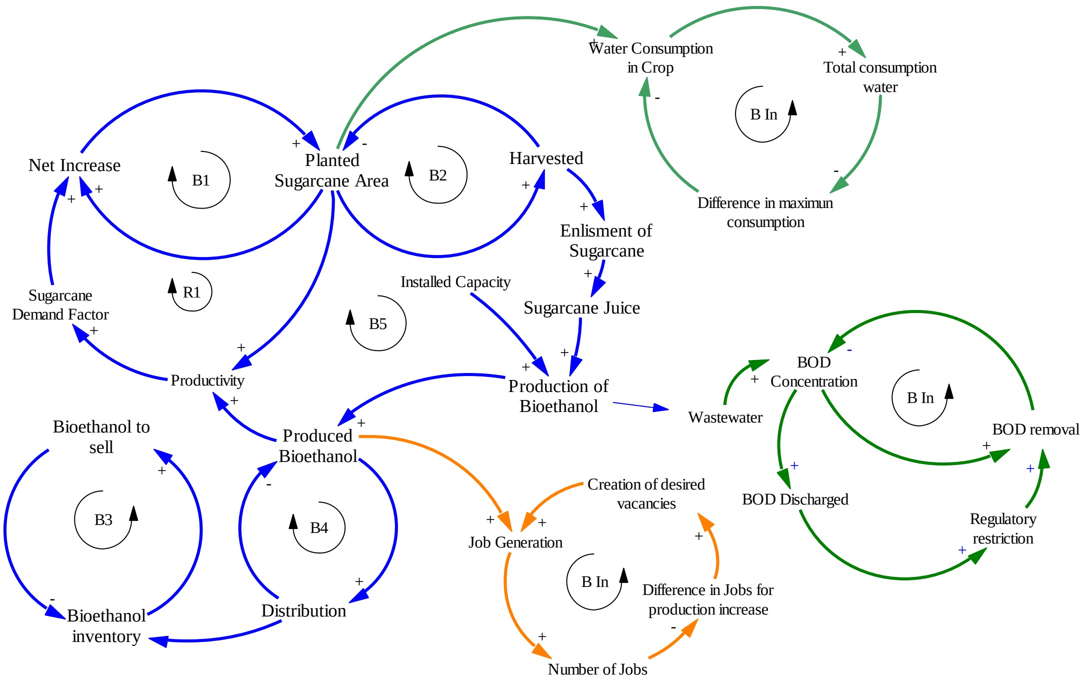

Figure (10) Causal loop diagram of the supply chain of bioethanol with sustainability indicators.

5. Conclusions

In this paper a model was developed, with the purpose of evaluating sustainability indicators in the biofuels sector, the methodological proposal, involves the ideas of change, necessity and adaptation, developed in the context of Viability Theory , These ideas were represented within a theoretical supply chain of bioethanol of sugar cane, for an installed capacity of 100,000 liters / day, starting from the Methodology of Systems Dynamics and defining desired regions for some evaluation times.

Although the model constructed using Systems Dynamics methodology is based on first-order ordinary differential equations, it can represent very closely the sustainability indicators (Water use and Jobs) required for the prospective assessment of sustainability in the production of biofuels.

The model proposed in this study, tested with the sugarcane bioethanol in Colombia, shows that the methodology can be used for the prospective evaluation successfully. For this it is necessary to model the production chain to be evaluated defining the raw material, the installed production capacity, the annual increase in biofuel production, also we choose and model the sustainability indicators that we want to evaluate, later and after developing the model, it is required to know if the system evolves through the desired regions, raising evaluation times and interval values where we want the state of the indicator to evolve, according to the policies and interests of the context in which it is developed.

Modeling with system dynamics allows the intervention of the system with strategies that the decision makers can implement, in order to be able to lead the state of the indicators to desired regions or sustainability goals.

5.1 Future results

Future work should link the sustainability indicators that apply to each production context. As an example, the modeling and simulation of the water quality indicator, described in the amount of BOD discharged to surface water, from the waste water of the production is presented below.

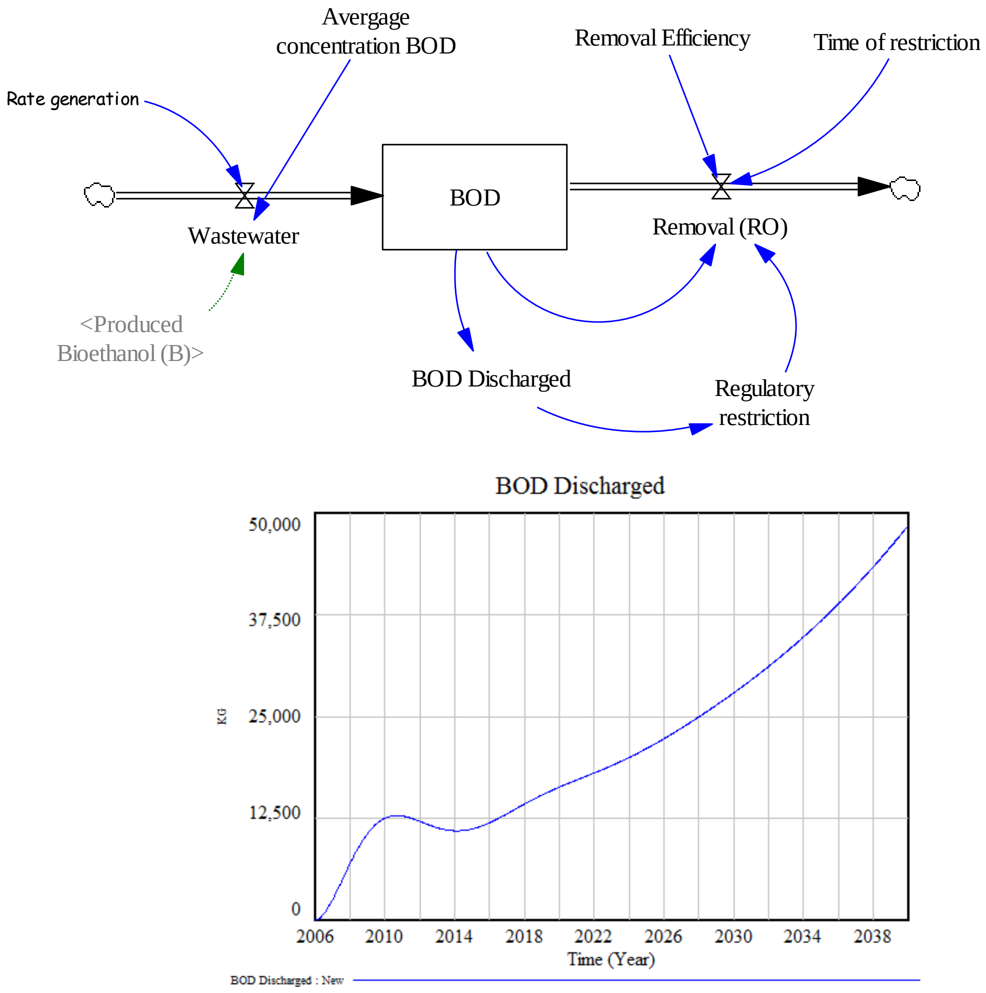

Figure (11a) Stock and flow diagram of the water quality indicator. (11b) Initial simulation of the indicator

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