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A Conceptual Model for the Design of a Renewable Energy Supply Chain from Biomass

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Abstract. Renewable energy (RE) is one of the areas where major research and development efforts are currently developing. Demand for electrical energy is increasing because of population growth and accelerated industrialization, particularly in developing countries like India and China. Traditional forms of energy generation produce large amounts of CO^2, which adversely affects the environment. Renewable energies include solar, wind, geothermal, hydropower and biomass (BM), the latter being the option with the greatest potential for electricity generation in Mexico [1], which ranks 20th in the world in producing energy from BM. However, identifying regionally important types of BM to evaluate their energy potential, localities of conversion and demand, besides integration of the conventional electrical system, represents technological challenges in administration and control. This generates high logistics costs and the need for good supply chain planning (CS). The efficient management of CS of bioenergy and logistics for key processes (procurement, production and distribution), represents key issues [2]. According to some authors, a new trend has arisen; where it is not enough to compete between organizations; instead, the competition shifts towards the terms of CS of RE and traditional forms of energy generation. This paper presents the conceptual development of a bioenergy supply chain in Mexico, using system dynamics as a methodology for the design and evaluation of the supply chain, since this is a suitable approach to model and study the interaction between variables in a complex system by applying feedback loops [3].

Keywords: system dynamics, renewable energy, biomass, supply chain.

1 Introduction

The fossil energies (FE) are the most commonly used energies worldwide; however, they have two major disadvantages: 1) they use non-renewable sources and, 2) they are aggressive to the environment; because of this, studies for the implementation of renewable energies have increased in the last decades. In addition, many countries are seeking to replace FE with renewable energies (RE). An RE is described as "*Energy derived from a natural process that is constantly replenished*"[4]. One of the leading countries on the subject is Spain, which has evolved as one of the countries with the best generation of electricity in areas where solar and wind energy are most feasible [5]. Conolly et al [6] carried out a study in which they proposed to achieve the generation of electricity through RE to fulfill 100% of energy demnd by the European Union. According to Gold and Seauring [2], within the concept of RE technologies, Bioenergy will play a decisive role in the following decades and under favorable conditions and based on an intelligent design can be applied for electricity generation. Bioenergy is the energy obtained from biomass, which is defined as "*Biodegradable part of products, waste and residues from agriculture, forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste*" [7].

Although the country is highly rich in RE sources, Mexico´s potential for generating this type of energy has not been fully exploited. However, the diversification of primary energies represents an opportunity for the strengthening of national energy security, as the biomass industry has been expanding rapidly in recent years. The Official Gazette of the Federation [8, 9] lists some of the technological challenges faced by efforts to expand the country´s capacity to generate energy by this strategy, including, 1) The viability of its incorporation into the national electricity system, 2) The different scenarios for the participation in generating electricity from (BM), 3) The evaluation of technological options within the production scenarios, 4) The implications of energy efficiency in production, transformation and generation of energy from BM and, 5) The costs of the logistic processes of supply, generation and marketing of bioenergy (supply chain).

The main objective of a bioenergy supply chain is to produce energy in an economically viable way. However, uncertainty propagates in spatial and temporal dimensions through it, which significantly affects the performance of the system [10]. This makes the design and development of the supply chain one of the most critical points. The main contribution of this research is, therefore, a conceptual model for the design of the biomass supply chain for the generation of electricity, considering the key logistics processes (procurement, production and distribution). Similarly, evaluation of the model uses system dynamics (SD) because this is an approach to model and study the interaction between variables in a complex system by applying feedback loops [3].

2 Tools for the Study of Renewable Energies

Although studies on renewable energies have increased in the last couple of decades, they do not yet allow a broad idea of resources to be analyzed but partially.

However, Engelken et al. [11]; Gatzert and Kosub [12]; Yudi and Sofri [13]; Goh et al. [14]; Lund [15]; Hitzeroth and Megerle [3] and Lokey [16] offer a rather detailed analysis of the different risks faced when designing, implementing and managing a renewable energy plant. Aslani and Mohaghar [17] and Andersen et al. [1] propose a

business model for the implementation of some type of renewable energy, such as the installation of stations to recharge electric cars. On the other hand, Loong Lam et al. [18]; López et al. [19]; Mikatia et al. [20]; Rylatt et al. [21], among others, use different techniques, such as P-Graph, Road map, MatLab and agent-based simulation, to solve different aspects of renewable energies, such as the power needed to implement a photovoltaic plant. Renewable energies possess many advantages, but they also present some major challenges to the supply system. One of the most demanding features is the uncontrolable variability of the source, since it is not possible to guarantee environmental conditions in advance and, consequently, neither the supply.
Although there are different tools that handle uncertainty using stochastic programming, optimization, fuzzy programming or some other optimization technique under uncertainty [22], in this project, systems dynamics will be the methodology to use, since it is an approach to model and study the interaction between variables in a complex system by applying feedback loops [23].

2.1 Supply Chains in Renewable Energies and Systems Dynamics

The Supply Chain (SC) is a network of interdependent and connected organizations that work in a coordinated way to control, manage and improve the flow of materials and information from raw material suppliers to customers [24].

Rendon [25] and Ramos [26] have described some of the techniques and tools used in the design and evaluation of SC. Rendón analyzed the SC of biofuel generation through ethanol and Ramos analyzed the SC of the creation of a new product generated from a waste. D 'Amore et al. [27] investigated a supply chain considering cultivation of bio mass, transport, conversion to bio ethanol or bioelectricity, distribution and its final use as bio fuel and electric cars. Azadeh and Vafa [28] presented a hybrid systems dynamics/mathematical programming model to design and plan a bio-diesel supply chain. The performance of the bioenergy supply chain depends highly on good coordination between links. A whole range of strategies can be adopted for the efficient design and evaluation of the SC to ensure that these interrelationships work; the methodology used in this project is outlined below.

3 Methodology to Design a Bioenergy Supply Chain

Figure 2 represents the methodology for setting up the conceptual model of the design and evaluation of a bioenergy supply chain. The methodology consists of 6 main steps: 1) Search of variables; 2) Definition of relations between the variables 3) Implementation of the diagram to blocks; 4) Elaboration of the causal diagram; 5) Evaluation of causal relationships and, 6) Final conceptual model. These steps are described below.

1. ***Variable search***. This is carried out through a systematic research of the state of the art concerning the key words: biomass, renewable energy, supply chain, supply chain design and supply chain evaluation.

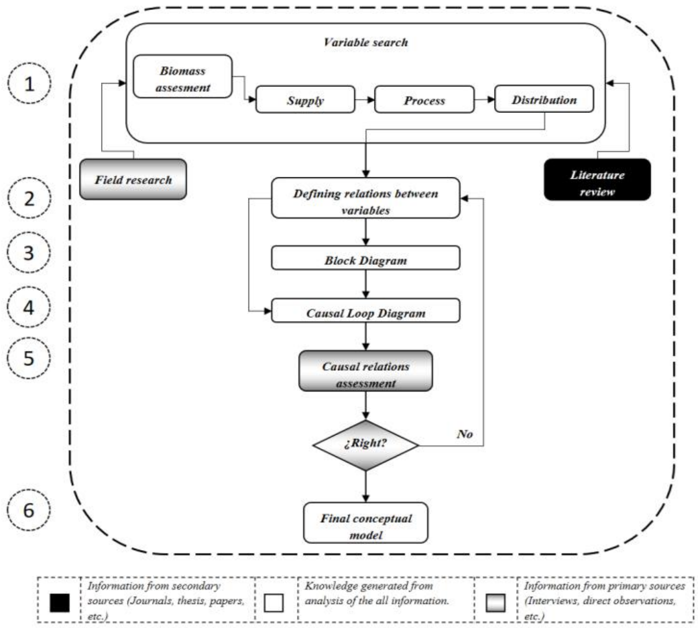


Fig. 1. Methodology for the design and evaluation of a bioenergy supply chain.

2. ***Definition of relations between variables***. Each variable identifies the existing primary relationships with other variables in addition to the link in which they are within the supply chain.
3. ***Block Diagram.*** With the primary relations already identified, the block diagram is elaborated.
4. ***Causal diagram***. Once the main relationships have been identified, the most complex relationships between two or more variables, as well as the manner in which they impact each other (positively or negatively) are set. The feedback loops and the type to which they belong (Balance or Reinforcing), are also indicated.
5. ***Evaluation of causal relationships***. Once the causal diagram is finished, an evaluation of the causal relationships, the type of impact and the interconnected variables are representative of the system to be evaluated.
6. ***Final conceptual model.*** The final conceptual model is the causal diagram with the causal relationships already evaluated. This diagram will be base for the simulation of the supply chain for its evaluation and generation of policies and strategies that allow its development.

This article presents the steps for the development of this methodology, which culminates in the elaboration of the causal diagram that gives rise to the final conceptual model. The steps are described in the next section.

4 Results of the Application of the Methodology for the Design of a Bioenergy Supply Chain

This section presents the steps to follow the methodology for the conceptual model of design and evaluation of a general bioenergy supply chain.

4.1 Steps 1 and 2 - Search for Variables and Definition of Relationships Between Variables

Supply, production and distribution are the three main parts of a supply chain [29], however, for the design of the bio-energy supply chain, it is necessary to add an extra link for the evaluation of biomass potential. The importance of these four parts is described below.

Biomass potential. The estimation of the potential energy of the biomass residue requires an evaluation of these residues. Authors such as Paiano and Lagioia [30] recommend a qualitative evaluation to identify the crop that best adapts to the needs of the study (region, cultivation area and harvesting period, among others).

Procurement. The purpose of procurement is control of supplies in order to meet the needs of operational processes. [31].

Production. The production process converts raw materials into finished products, and in the supply chain of bioenergy generation the process becomes even more complex when using anaerobic digestion, since it must consider variables that are mostly unstable, such as Ph, temperature and bacterial growth, among others [32].

Distribution. It ensures that these final products reach the consumer through a network of distributors; however, the final product being the electrical energy, the considerations to take are more. These considerations depend on the analysis for incorporation into the national electricity system and their respective policies [33].

Due to the importance of the links mentioned above, the variables to be searched are focused on each one of them and in locating which link they are in. Table 1 lists the variables that are in the block diagram and that will later integrate the causal diagram.

4.2 Step 3 - Block Diagram of the Design of a Bioenergy Supply Chain

This section analyzes the interaction between the links in the supply chain and the assessment of the availability of biomass. These elements are part of the conceptual model proposed for the design of the bioenergy supply chain and will be analyzed by means of a diagram of blocks. Figure 1 shows the block diagram of the operation of a general bioenergy supply chain. The interactions work as described below:

Table 1. Variables in the links of a bioenergy supply chain.

Authors	Variables	Authors	Variables	Authors	
11, 12	Crop area	14, 27	Process yield	30,33	Supplier's storage
	Hectare average		Harvest waste		Supplier's storage capacity
14, 27, 33	Raw material		Processing waste		Distance
	Herbaceous		Available waste		Supplier's transport
	Arboreal		Unusable waste		Transport cost
	Forest	32	Initial transport		Supplier's transport capacity
	Growth rate		Storage cost		
	Decreasing rate	30	Biomass as raw material	34	Biomass conversion plant's storage
	Yield per hectare	28	Biomass allocation	3	Conversion process capacity
	Harvest		Type	6,13	Conversion process to electricity
	Process		Master program		
15, 16, 18, 28	Costs	1, 7, 33	Standards	29, 32	Distribution
	Demand		Substrate		Anaerobic reactor

1. A biomass availability assessment is performed, based on the type of raw material (RM), its area of sowing and the average yield considering the growth rates and decrease of the type of crop.
2. The available biomass is transported to a supplying company (Supply), where the reduction obtained in previous steps is converted to RM for power generation plants.
3. The BM received at the electric power plant (Production) must pass through a process of conversion (Biomass to energy).
4. Finally, the energy generated must be distributed through the lines of the national electricity system.

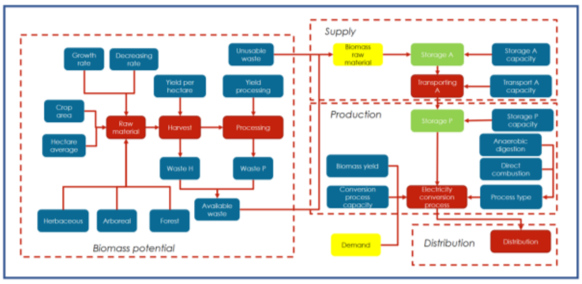


Fig. 2. Block Diagram of the Bioenergy Supply Chain.

4.3 Step 4 and 5 - Causal Diagram and Evaluation of Causal Relationships

Once the block diagram is constructed, these primary relationships are plotted in a causal diagram, which is likewise a graphical representation of the interactions between the variables of a system. However, more complex relationships can be represented between them, as well as how another variable is affected either positively or negatively, in addition to feedback loops.

The result of having captured the primary relationships in a causal diagram, together with the identification of the complex relationships and feedback loops generated is shown in Figure 3. As can be seen, several complex relationships are generated along with 3 balancing loops and 2 of reinforcement, which will be explained later.

The feedback loops generated in the causal diagram are described below.

B1. *Supplier's storage* negatively impacts the *Back orders* since, if there is more biomass in the supplier's warehouse, then the number of pending orders may decrease; on the other hand, if there is not enough biomass, then the number of outstanding orders will continue to grow. *Biomass ordered* is affected by back orders in a positive way.

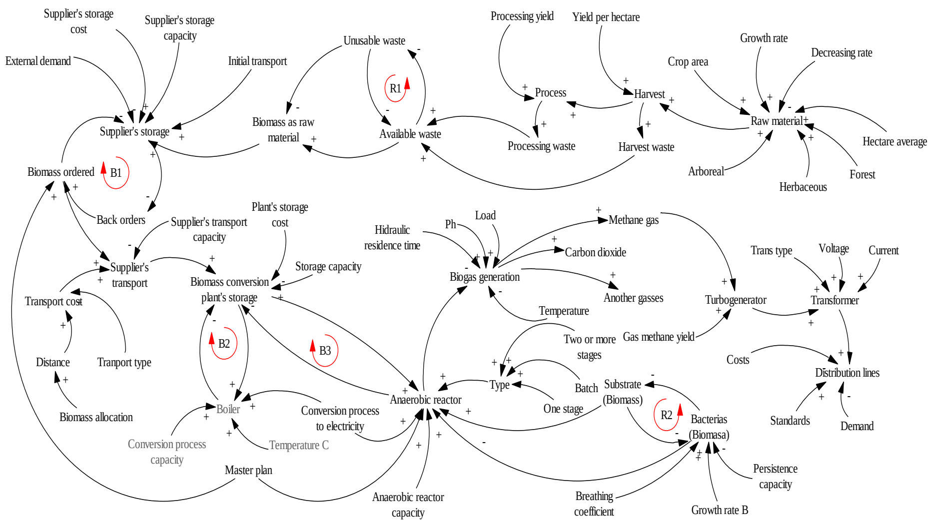


Fig. 3. Causal diagram of a bioenergy supply chain.

B2. *Biomass conversion plant's storage* positively impacts the *Boiler* variable because, if the storage of biomass is at a good level, it will be more feasible to carry out the conversion process through a direct combustion boiler; on the other hand, if there is not have enough of biomass, then the conversion process will be hindered. On the other hand, the variable *Boiler* negatively impacts to the *Biomass conversion plant's storage* if indeed greater production goes together with smaller volume in inventory.

B3. The relationship between the variables *Biomass conversion plant's storage* and *Anaerobic reactor* lies in the inventory levels, since the higher the available biomass, the greater the feasibility of carrying out the conversion process. Similarly, the higher biomass demands for the reactor, the lower amount of biomass available for processing.

R1. The variables Unusable waste and Available waste generate a loop where, the greater the amount of available waste, the smaller the amount of waste that is unusable and vice versa.

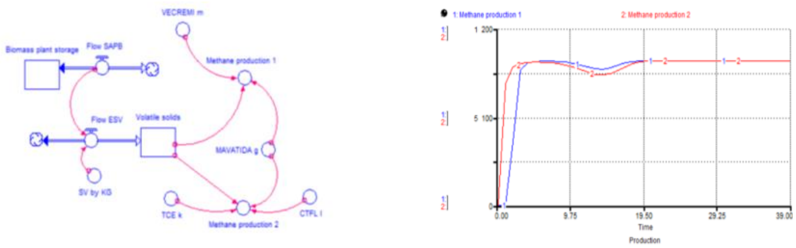
R2. The variables Substrate (Biomass) and Bacteria (Bio-mass) reinforce the idea of having 100% organic matter inside the reactor.

After performing the causal diagram, validation tests of causal relations are performed. From these tests, along with the experts in the matter we conclude that the causal diagram is representative of the system.

4.4 Step 6 of the Methodology Followed - Final Conceptual Model

Once the causal relationships of the causal diagram have been evaluated and its representativity of the system is verified, it is taken as the final conceptual model. This model serves as reference so that the system can be captured in a Forrester diagram and then, simulated. As an example, a fraction of the causal diagram of the SC of bioenergy, which represents the generation of biogas, is presented. Figure 4b represents the Forrester diagram and Figure 4c the results of simulation.

Although this step is terminated in the present methodology, there are still steps to follow within the methodology of system dynamics for the design and evaluation of a SC of bioenergy, as indicated in the section of conclusions and future work.



a. Diagrama de Forrester b .Simulación del comportamiento de biogas

Fig. 4. Generation of biogas in a bioenergy supply chain.

4 Conclusions and Future Work

Using the system dynamics and causal diagram approach, this paper proposes a model for designing and evaluating a biomass power supply chain based on the regional needs and biomass available in the geographic region. We verified that system dynamics is an adequate approach for this type of studies, since it is a tool that allows to integrally model the different interactions between the links of the supply chain and the biomass evaluation link available. Likewise, the model provides the basis for the construction of simulation models for the design and evaluation of supply chains, not only of different types of biomass, but also of different types of renewable energies. As a future work, the proposed conceptual model will be applied in a case study following the steps described in the methodology section, with the aim of validating the model in its field of application and thus obtaining feedback from the system.

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