AN APPROACH TO ESTIMATE THE WATER FOOTPRINT OF THE BIOETHANOL SUPPLY CHAIN AND ITS DYNAMIC SIMULATION

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ABSTRACT
The Supply Chain Management as a source of competitiveness evolves continually. In the last decade, the sustainability of the supply chain represents a key success factor. The energy industry is not an exception. The global pressure to reduce emissions combined with the negative tendency in the world oil reserves is impelling the improvement and development of renewable sources of energy. The bioethanol industry is one of the most active sectors. Under this environment, the market is facing a conflict: to increase productivity (more resources consumed), without compromising the future natural resources. As the bioethanol industry accelerates its productivity and market share, another renewable resource suffers for this expansion: the water reserves. This work proposes to integrate the Bioethanol Supply Chain Analysis with the Water Footprint Assessment. Since water changes in time under the influence of several factors, the System Dynamics approach is very useful to deal with variables that change continually over time. Consequently, a model to evaluate the water footprint of the bioethanol supply chain through the system dynamics approach enables the capacity to simulate the impact of bioethanol production on water resources over time. This work presents a Causal-Loops Diagram useful to observe and analyze the complex relationship that the components of the bioethanol supply chain have.

Keywords: bioethanol supply chain, system dynamics modeling, water footprint assessment, causal loops diagram

1. INTRODUCTION
In recent years, industries have shown a growing interest in managing water consumption effectively. Water availability for domestic, agricultural and industrial use has become an increasingly important topic of international and interdisciplinary research (Susnik et al., 2012). Moreover, there is also a growing awareness on diverse environmental issues such as global warming and climate change that encourage research to explore the best practices for efficient water consumption. Under such restrictive conditions, it is clear that as the population of the world increases and water availability decreases, companies must redesign their supply chains (Carter & Jennings, 2002). Consequently, there are still big opportunities to define the best practices and methodologies to help managers to design policies and strategies to improve the supply chain management. The objective of this effort is to ensure the sustainability of supply chains by reducing the environmental impact that they have. The biofuels supply chain is one of the more dynamic fields looking for better practices for sustainability (Akgul et al., 2012; Bernardi et al., 2012; Dumanli et al., 2007; Eksioglu et al., 2009). It is also crucial to notice that water is not a fundamental element analyzed in the biofuels supply chain. However, local sources supply the water used in biofuel production, a condition that frequently has an impact, not only on domestic sectors but also in the community. In consequence, water plays a vital role in supply chains, especially in biofuels supply chains due to the nature of their raw materials. Therefore, it would be useful in any supply chain, and particularly in the biofuel supply chain, to determine the amount of water consumed in the production of biofuels. The Water Footprint Assessment is a useful approach to reach this objective. However, like any other systems, the bioethanol supply chain is in constant evolution. The System Dynamics Simulation is useful to model and test different scenarios and hypothesis over time. Consequently, this work proposes an integration between the Water Footprint Assessment and the System Dynamics Simulation.

2. SUSTAINABLE SUPPLY CHAINS
In recent years, the supply chain management has gained interest as an essential element to increase the efficiency of the decision-making process in diverse sectors. According to Mentzer et al. (2001), the Supply Chain (SC) is “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services,

finances, and/or information from a source to a customer". Another useful definition for the Supply Chain Management (SCM), is "Supply Chain Management is the systemic and strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain". Mentzer et al. (2001), Gold & Seuring (2011), and Martínez-Jurado & Moyano-Fuentes (2014), offer a more detailed description of the supply chain foundations and the supply chain management. According to Winter & Knemeyer (2013), the field of SCM has an inherent connection to sustainability.

In the past decade, the implementation of several initiatives to improve the environmental performance of firms has been tested. Among these initiatives, which also aim to accelerate the implementation of cleaner production approaches, are environmental clubs, waste exchange programs, eco-industrial parks, and sustainable supply chain initiatives (Hoof & Thiell, 2014). There is an increasing interest in the sustainability of supply chains, essentially motivated for the incorporation of environmental and social issues in the daily work of middle and top managers (Seuring & Müller, 2008).

It is important to mention that most of the articles reviewed do not focus specifically on modeling a sustainable supply chain considering water as a relevant resource for sustainability, nor its required practices.

2.1. Biofuels and the supply chain analysis

The biofuel industry is growing explosively due to environmental regulations, and renewable or sustainable energy needs. Thus, it is imperative to analyze the biofuels supply chain. An et al. (2011) propose a generalized structure based on the agricultural biomass feedstock to examine what currently is known about biofuels supply chains. This structure was developed trying to show, in a general way, how a biofuel supply chain structure is formed. Authors identify various elements such as farms, biomass storage sites, pre-processing facilities, refineries, distribution centers, and service stations that supply customers.

It is important to consider the impact that the analysis of the biofuel supply chain has over the decision-making process, particularly on logistics activities. Dumanli et al (2007) examine the changes that must be planned for transforming the traditional fossil supply chain to a more sustainable chain. The main topic of this article is the production and exploitation of biomass. Authors then analyze the characteristics, logistics and environmental aspects of this supply chain without neglecting the economic, legal and technical issues. Finally, the conclusion shows that it is possible to implement a sustainable and environmentally friendly energy system that creates economic value for a country. Even if the authors explain the basic relations among several important variables in this supply chain, all relationships are evaluated from a static and deterministic point of view.

Eksioglu et al. (2009) carried out a work where they developed a mixed integer programming (MIP) model. The model searches the minimization of the total cost of a biomass supply chain, accounting for deterioration, seasonality and availability of biomass materials. The proposed model identifies the optimal number, size and location of collection facilities, bio-refineries, as well as the amount of biomass shipped, biomass processed and held as inventory. Sustainability is not a central topic in this article.

In the work of Zhang et al. (2013), authors explore this relation through a mixed and integer linear programming (MILP) model. This model minimizes the total annualized costs of switchgrass-based supply chains (SBSC) by optimizing the diverse individual logistic aspects of this SC. However, the study does not consider the dynamic behavior of the supply chain. A dynamic analysis is useful because biofuel supply chains are complex and have a dynamic performance over time (Barisa et al., 2015).

Another approach for sustainability in biofuel supply chains has to do with optimization. Akgul et al. (2012) developed a model that addresses sustainability issues, such as the use of food crops, land use requirements of second-generation crops, and competition for biomass with other sectors. However, issues related to water behavior, their impact, its performance over time on the lands, and the most efficient use for these crops is not considered.

Mafakheri & Nasiri (2014) classify the different models that best deal with decision problems in the various states of a biomass supply chain in five categories, which are the following: i) Biomass harvesting and collection, ii) Biomass pre-treatment, iii) Biomass storage, iv) Biomass transport, and v) Biomass energy conversion. They also identify as the most influencing challenges, diverse issues such as technical and technological, financial, social, environmental, policy/regulatory and institutional/organizational. In this research, it should have been interesting to analyze the relationship between all these issues from the dynamic point of view. In other work, Månsson et al. (2014) use the supply chain approach for analyzing the existing biofuel supply chains in Sweden, in terms of security of supply. Then, authors explain the possibilities to achieve synergies between the implementation of practices to mitigate climate change through an increased production and use of biofuels. None of these works focuses on the analysis of the water consumption in the case of the bioethanol production.

Avinash et al. (2014) describe the biodiesel supply chain. Authors examine the development of biofuel as a substitute for fossil fuels to explore several possible benefits such as: 1) to relieve the world energy and economic crisis; 2) to analyze the environmental impacts that biofuels have on the road transportation and 3) the possible large-scale impacts of biofuel crops on food-based agricultural lands. However, the study

does not take into account the effect that the biofuel production has on water consumption.
Recently, some researchers have recognized that water availability is a severe agriculture constraint to the production of energy crops (Tan et al., 2009). As a partial conclusion, this literature review showed that none of the revised articles analyzes water availability and its impact on supply chains from a dynamic point of view.

3. THE WATER FOOTPRINT IN SUPPLY CHAINS

In general, the renewable forms of energy are considered "green" because they cause little depletion of the Earth's resources (Hall & Scrase, 1998). However, there is still enough effort to specify and analyze in detail, why water plays a crucial role in sustainable biofuels supply chains; mainly to assess the impact that water consumption has in the environment where biofuel is produced. Awareness regarding this issue is growing. According to (Ruini et al., 2013), in the last decade there has been a bigger interest in the evaluation of the water footprint in parallel with the carbon footprint. The Water Footprint Assessment (WFA) opens the door to the analysis of complex water relationships. This analysis also produces vital information for policy actors, business leaders, regulators and managers about their responsibilities on this increasingly scarce resource (Chapagain & Orr, 2009).

3.1. The concept of water footprint

The water footprint of a product is the volume of freshwater used to produce it, measured over the full supply chain (Hoekstra et al., 2011; Kongboon & Sampattagul, 2012). In other words, the water footprint is the water utilized in diverse processes; such as industrial and power generation, as well as the water pollute it through these same processes. The water footprint concept considers the source where the water comes from. The water origin defines its class: blue, green and gray water. According to Hoekstra et al. (2011), blue water refers to the consumption of blue water resources (surface and groundwater such as rivers, lakes, etc.) along the supply chain of a product. Green water is the rainwater stored in soil as moisture, and it refers to the consumption of green water resources (rainwater insofar as it does not become run-off). It concentrates on the use of rainwater, specifically in the flow of soil evapotranspiration used in agriculture and forestry. Finally, gray water refers to the water that has been polluted by a process. It is defined as the volume of freshwater that is required to assimilate a load of pollutants given natural background concentrations and existing ambient water quality standards. The sum of green water, blue water, and gray water that requires a product or service within its whole development process is the water footprint.

3.2. The water footprint assessment methodology

Hoekstra et al. (2011) defined the general methodology as follows: i) Setting goals and scope, ii) Water footprint accounting, iii)Water footprint sustainability assessment, iv)Water footprint response formulation.
Figure 1 shows the minimal phases that every water footprint assessment must have.

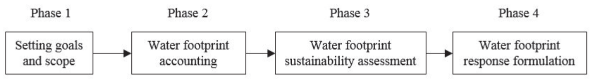

Figure 1. Four distinct phases in water footprint assessment (Hoekstra et al., 2011).

Since the approach of water footprint assessment has been used to evaluate the impacts of specific consumption and production practices on freshwater quality and sustainability, it becomes very important in diverse production processes, particularly for the biofuels process. A more detailed insight about the water footprint components and its assessment, is offered also by Galan-del-Castillo & Velazquez (2010).

3.3. The importance of water footprint assessment in biofuels production process

Until the recent past, there have been few thoughts in the science and practice of water management about water consumption and pollution along the whole production process and supply chains (Hoekstra et al., 2011). As a result, there is not enough awareness regarding the fact that the organizations and characteristics of a production process and supply chain strongly influence the volumes of water consumption that can be associated with a final consumer product. Therefore, it becomes of great importance to be aware of the amount of water used or consumed in any process or supply chains. The water footprint is an indicator of this consumption.
According to Gerbens-Leenes et al. (2009), in the coming decades human beings will face critical challenges, not only to meet the basic needs for water, but also to ensure that the water from rivers, streams, lakes, and aquifers does not affect freshwater ecosystems performing ecological functions. Authors also point out that higher demand for food, in combination with a shift from fossil energy towards bioenergy, puts additional pressure on freshwater resources. This pressure increases the urgency to propose a process of sustainable intensification by increasing the efficiency of water use. Dominguez-Faus, et al. (2009) analyze the management of land and water explaining that as biofuel production increases, a growing need exists to understand and mitigate potential impacts to water resources. Authors discuss that the most significant effects, are related to the agricultural stages of the biofuel life cycle known as the water footprint. Hence, it is necessary to consider that a continuous growth in biofuel production could have far-reaching environmental repercussions.
According to Hoekstra et al. (2011), freshwater is increasingly becoming a global resource, driven by growing international trade in water-intensive commodities. Because of this phenomenon, water resources have become spatially disconnected from the

consumers. One example is the case of cotton. From field to the end product, the cotton passes through diverse production steps with different impacts on water resources. Additionally, these stages of production are often located in different places and final consumption yet in another location. Hence, the impact that a final cotton product has on the globe's water resources can only be estimated through the analysis of its supply chain, and tracing the origins of the product.

The water footprint of biofuel energy depends on the crop being cultivated, the yield selected for this purpose, climatic conditions at the location for production, and agricultural practices (Gerbens-Leenes et al., 2009). Jeswani & Azapagic (2011) review some of the approaches and methodologies for the assessment of the impacts that the consumption of freshwater has in the production of ethanol in 12 different countries but they do not do it dynamically. Thus, only a few studies have examined the relationship between biofuel consumption and pressure on water resources.

4. SYSTEM DYNAMICS ANALYSIS FOR RENEWABLE ENERGY AND BIOFUELS SUPPLY CHAINS

Systems thinking is the process of understanding how things, like parts of a set, influence each other. According to Aslani et al. (2014), System Dynamics (SD) is a methodology based on system thinking to understand and model the behavior and activities of complex systems over time. Therefore, this robust and powerful methodology is used as a decision support tool that helps to identify the interaction of the different components of any complex system (Jimenez et al., 2001). System dynamics models use causal loops diagrams (CLD), which help analyze feedback loops, variables, levels, and delays that can affect the behavior of a system over a specific time. A SD model can depict the interaction and relation that have the different variables of a biofuel supply chain, such as water use and water availability. For a more detailed description about SD, the work of Forrester, (1958), Rehan et al. (2013) and Chen & Wei (2014) is highly recommended.

The research on the application of system dynamics methodology for different aspects of the biofuel supply chain has evolved in the last decade (Barisa et al., 2014). Despite this effort, there are just a few works in the area of biofuels supply chain using the System Dynamics approach. Rendon-Sagardi et al. (2014) carried one of these studies. Authors developed a System Dynamics Model to evaluate whether the production of ethanol in Mexico could meet the potential demand for this substance as a biofuel additive. Even if this work is relevant, water is not analyzed as an important element of the supply chain of ethanol, nor is it evaluated from a dynamic point of view.

Next section explores the relationship between system dynamics and the water footprint.

4.1. System Dynamics modeling for the Water Footprint in biofuels supply chain

Water plays a crucial role in biofuels supply chain, and it is a valuable resource, which has a dynamic behavior. The water consumption and usage also have a potential impact on socio-economics policies; hence diverse research has been supported by system dynamics to visualize the action and effect that hydrologic resources could have in different sectors. Susnik et al. (2012) developed a system dynamics model to analyze the current and future behavior of a catchment to assess water scarcity in Tunisia. The work of Jin et al. (2009) incorporates the system dynamics approach into the ecological footprint for forecasting the ecological footprint. Rehan et al. (2013) developed causal loop diagrams and a system dynamics model to support the financially sustainable management of urban water distribution networks. Thus, it is outlined that the system dynamics is a useful tool to model water management and water security systems. Thus, it becomes very important to develop and apply a methodology that helps to get an insight into the impact that water could have in any region by simulating its dynamic behavior through time.

After a careful analysis of several works, it is possible to propose a general model to integrate system dynamic simulation and water footprint assessment. This basic model contains two stages: (1) theoretical foundations: state-of-the-art and (2) methodological approach. Next section describes both stages.

4.2. Application of the SD-WFA approach

A basic process to deploy the SD-WFA synergy has four stages: 1) Conceptualization: this stage collects basic information about the supply chain under analysis. In this step the construction of the causal loops diagram (CLD) is useful to represent the relationship among variables, 2) Formulation: in this step, it is necessary to define the parameters of the variables influencing the system under study. The model of the system is another product of this stage. 3) Evaluation: in this step, the verification and validation of the simulation model is carried out, and finally, 4) Implementation: in this step the model is able to generate results and works as a support for the decision making process.

It is worth mentioning that in this research, the application of SD modeling remains with the preparation of a causal loops diagram (CLD), which is the final output of the conceptualization stage. Conceptualization is the first stage in the System Dynamics methodology. Figure 2 represents a general scheme for the sugarcane-based ethanol supply chain in the stage of production.

The CLD in Figure 2 is an approximation model that was developed considering the conceptualization for bioethanol production in Mexico. Next points describe the feedback loops defining the dynamics of the system under study.

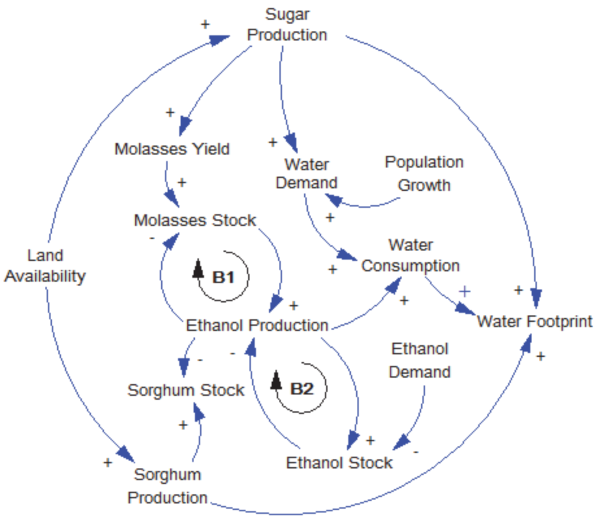

Figure 2. CLD for the analysis of the ethanol production and its water footprint.

- In Loop B1: if the molasses stock increases, the volume of ethanol that can be produced also increases. In the other way, if the production of ethanol increases, the molasses stock decreases.
- Loop B2 represents the ethanol stock in regards to the ethanol production volume. When the production volume of ethanol increases, the ethanol stock also increases. But if the ethanol stock increases, the production volume of ethanol decreases.

The other relations depicted in the CLD can be interpreted as follows. The variable ethanol stock for example, depends on the variable ethanol demand. The variable water consumption depends on the variable ethanol production. This relation is positive because if the ethanol production volume increases, the water consumption also increases. Water consumption in turn, depends on the variable water demand, which has a positive relation with the variable population growth. This is because as population rate increases, the water demand also increases.
Finally, the variable water consumption has a direct impact on the variable water footprint. This is because water footprint is an indicator of the water consumed in the process. The relationship is positive because if the consumption of water increases, the water footprint indicator will be greater.

5. CONCLUSIONS

This work proposes a model able to incorporate the water footprint assessment of ethanol in the production stage of its supply chain. The model has a particularity: it is possible to evaluate the performance dynamically. The System Dynamics approach and its modeling technique could help the ethanol industry to develop policies and strategies that contribute to fulfilling the sustainability requirements of its supply chain. This goal is reachable because the model correlates the water consumption associated with the main crop and production processes from a dynamic point of view.

With this preliminary model is possible to observe the usefulness of the System Dynamics approach to model and integrate both concepts: the supply chain analysis and the water footprint assessment. Integration of System Dynamics Modeling to the Water Footprint Assessment of Bioethanol Supply Chains promises to help managers in the biofuels industry get a more in depth comprehension of consumption of water along the process, and therefore, develop strategies and policies that give better management practices of water resources.
As a future work and improvement of the proposed model, it is necessary to consider the analysis and assessment of the water footprint in all the stages of the supply chain, including the distribution stage of biofuel. More knowledge and insight about the ethanol industry will be available if the oil production system and market fluctuations are take into account in the present analysis. However, the complexity and effort to model this integration will also increase.

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