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Dynamic analysis of feasibility in ethanol supply chain for biofuel production in Mexico

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HIGHLIGHTS

- Set of key variables to analyze scenarios related to the feasibility of ethanol and biofuel supply chains in Mexico.
- System Dynamic is a powerful tool to simulate and understand the future conditions for energy sources.
- Availability of area for the sowing of grain sorghum and sugarcane crops to develop an effective ethanol supply chain.

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ABSTRACT

Since ethanol is considered an essential additive for biofuel production, there may be the opportunity to employ it as such in Mexico. However, an analysis of the ethanol supply chain should be performed first. Therefore, in order to analyze the main variables of the ethanol supply chain, as well as the feasibility for its use, the present research developed a System Dynamics model based on an idea suggested by SENER (Secretariat of Energy in Mexico). The model explores five possible scenarios (between 2014 and 2030), and evaluates the availability of area for the sowing of sugarcane and grain sorghum crops, the production capacity for ethanol and fuel, as well as the possible reduction of carbon dioxide emissions. The model considers the trends and parameters of the agricultural and energy industries, and produces valuable information about future conditions of the Mexican biofuel and fossil fuel production and supply. The obtained results predicted two situations. First, Mexico would face a fuel shortage in the future. Second, from the amount of fuel available by that time, the biofuel produced and accumulated would collaborate little to meet the domestic fuel demand. Also, as System Dynamics is concerned, it is demonstrated that it is a powerful methodology to simulate and understand the biofuel supply chains in emerging markets as Mexico.

1. Introduction

Crude oil is considered the main source of energy in Mexico. In fact, according to the U.S. Energy Information Administration, 56% of the Mexican energy consumption in 2010 was produced from oil [1,2]. However, this energy source is suffering depletion within Mexican land, while the need for fuel is paradoxically increasing (see Fig. 1). Also, Mexico is ranked as one of the biggest producers of CO_2 emissions in Latin America, (it produced 450,000 million tonnes in 2011) [3]. This reveals the urgent need to diversify the energy sources of the country by prioritizing the renewable ones in order to ensure oil resource and reduce the negative consequences due to its irrational use [4]. This would eventually save crude oil for the future and strengthen the emerging economy of Mexico, since currently import rates represent 60% of domestic consumption of transport fuels, with an associated cost of 10,000 million USD [5].

Ethanol is an example of renewable energy used as substitute or additive in transportation fuels [6], and it is mainly obtained from the so-called energy crops [7]. Also, based on international experiences, the use of ethanol to produce biofuel represents the beginning of a transition process leading to sustainable transportation systems [8]. However, the use of ethanol does not pretend to replace the entire use of gasoline (refined crude oil), since as Ewing and Msangi explain [9], it is important to carry out an analysis to assure the fulfillment of sustainable criteria for energy crops production. This would permit meeting the demand from ethanol

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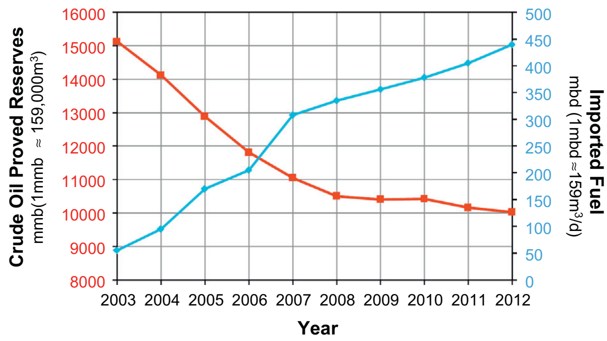

Fig. 1. Crude oil proved reserves and imported fuel in Mexico [1,2].

industries, without affecting the food security and the ecological balance.

A high percentage of the ethanol in the United States comes from corn [10]; however, the use of this feedstock in Mexico for the same purpose implies political, social, and economical issues, since it would increase the price of the corn grain, and would compromise the food security [11]. However, using other varieties of crops has proved to have the same or a better potential to become feedstock in the ethanol production [8]. This is proved by the use of sugarcane in China and Brazil [12,10], cassava in Thailand [13], or jatropha in India and Malaysia [13]. Besides, other materials, such as agricultural residues used in Sweden [14] or waste paper in England [15], can be also used for the ethanol production.

According to SENER, Mexico possesses optimal conditions to produce ethanol targeted to the production of biofuel [16], although the biofuel supply chain structure today is not as defined as the one for fossil fuel [17], which is entirely handled by PEMEX (the sole operator in charge of extraction and refining crude oil in Mexico). Therefore, to demonstrate it is necessary the analysis of this paper to demonstrate what SENER states, and considering the following features:

- PEMEX possesses six oil refineries able to process 1940 mbd of oil [2].
- PEMEX does not have infrastructure for ethanol production; it thus requires an outsourcing service for its procurement.
- According to prior analysis, potential suppliers of ethanol in Mexico [8] can use two main raw materials for their productions: (1) molasses obtained from sugar production – in which Mexico is self-sufficient [18] – and (2) grain sorghum [19].
- The goal for biofuel production defined by SENER [20]; which is the blending of 90% gasoline with 10% of ethanol (as additive) by volume.

The regular Mexican fuel currently uses MTBE (methyl tert-butyl ether) or TAME (tert-amyl methyl ether) as additives in 5% of any production volume [21] to obey the official Mexican normative [22]. Hence, MTBE and/or TAME could be substituted by ethanol to reduce the environmental impact of fossil fuel consumption.

This paper uses the System Dynamics modeling approach to evaluate whether the production of ethanol in Mexico could meet the potential demand of this substance as biofuel additive. For the agricultural industry, the System Dynamics modeling considers the following conditions: (1) continuous production according to the constraints of soil yield and capacity, and (2) trends for demands of different sectors. On the other hand, for the energy industry, the modeling considers: (3) production capacity of ethanol and gasoline according to the current infrastructure and feedstock, and (4) trends for fuel demand. The feasibility is observed in the gaps between the simulated capacity and the forecasted demand according to the trends. Therefore, it is important to highlight that the present study will be useful to define the involved features in the biofuel supply chain and anticipate future needs related to fuel production and supply.

The paper is structured as follows: Section 2 presents a background about biofuel supply chains, Section 3 describes the System Dynamics approach, and Section 4 introduces the results and an analysis of the most relevant scenarios. Finally, the conclusions of this study are presented in Section 5.

2. Background

Nowadays, several studies are being carried out to study different aspects of biofuel. For instance, the use of biofuel in Mexico has been studied in [21,23,24]. These works have analyzed the physico-chemical properties as well as the benefits of biofuel. Also, research carried out in [25–27] have studied the biofuel production from grain sorghum, and they have presented its advantages in terms of the production yield and the economic constraints related to its use. In addition, research in [12,28] have studied the environmental impacts when using molasses for ethanol production, and other works have described the necessary technology to process alternative raw materials, such as cellulosic [29] and switch-grass [30]. Even though the aforementioned works focus on different aspects of the study of biofuel, they all agreed that biofuel production is an efficient option to preserve the crude oil reserves, since ethanol replaces not only traditional additives (MTBE or TAME), but also part of refined oil (gasoline). In addition, biofuel produces fewer emissions of greenhouse gases, which mean a reduction of the environmental impact [31].

However, none of these works has yet managed to define the features and variables of an ethanol supply chain to ensure the feasibility of biofuel production using ethanol. This means that Mexico has not either developed any detailed study to analyze the current situation of biofuel supply chain with the inherent uncertainty for the ethanol production. However, if it were done, the study could also be used as example in other emerging markets.

In fact, studies about Mexican biofuel have merely considered the environmental impacts generated [32]. For instance, as Awudu et al. indicated [33], these studies have proved that biofuel burning results in lower emissions of greenhouse gases, expressed in CO_2 equivalent (CO_2e). Also, according to García et al. [24], Mexican fossil fuel can generate 3,104.64 kg of CO_2 per tonne ($KgCO_2e/t$), while biofuel (gasoline and 10% ethanol by volume) can only generate 2,722.824 $KgCO_2e/t$ as average. These values were obtained by assuming a density of 722.5 tonnes per cubic meter (t/m^3) for biofuel, and a density of 712.85 t/m^3 for fossil fuel [23]. This represents 351,889.68 tonnes of CO_2 per thousand barrels of fossil fuel (tCO_2e/mb) and 312,791.21 tCO_2e/mb for biofuel.

It is worth mentioning that in countries such as the United States and England, the biofuel supply chain has already been defined, and some studies have focused on the optimization of its parameters. For instance, Awudu et al. [34] developed a simulation model to assure the optimal location of a company seeking to produce biofuel in the U.S. In addition, An et al. [35] analyzed the feasibility of producing ethanol from lignocellulosic materials through mathematical algorithms, while Papapostolou et al. [36] presented a study to obtain the major benefits from an energy crop for biofuel production. Moreover, the integration of supply chain processes was addressed in [37–39]. These last three studies specially considered the economic impacts of biofuel, as well as certain factors affecting the biofuel supply chain.

3. System Dynamics approach

System Dynamics (SD) is a powerful methodology that provides a useful perspective for situations of dynamic complexity [40]. SD