Biofuel Potential in Mexico: Land Use, Economic and Environmental Effects
(Work-in-Progress)

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Abstract

This paper aims to develop a framework to forecast biofuel policies impacts about fifteen years ahead in Mexico, where there have been several attempts to introduce biofuels into the market but so far no success. Technically, we develop an endogenous-price mathematical programming model emphasizing the Mexican agricultural and fuel sectors, which are embedded in a multi-region, multi-product, spatial partial equilibrium model of the world economy. There is a module for the U.S. and another for Rest of the World. Mexico is disaggregated into 193 crop districts. Production functions are specified for 14 major crops as well as livestock. Biofuel can be produced both from dedicated crops and from agroindustrial residues. We consider three policy alternatives as well as a base case in which, as now, liquid fuels are all derived from fossil sources. The first alternative consists of subsidies to biofuel producers, the second of blending mandates and the third of both combined. Biofuel imports are allowed in all cases. Results show some losses for fuel and agricultural consumers, that are not offset by both ethanol producer and GHG emissions reduction gains. This suggests that some compensating redistribution may be needed if these policies are to be seen as politically sustainable.

Keywords: Mexico, Land Use, Biofuels, Gasoline, Fuel Policies. JEL classifications: C61, Q10, Q42, Q48, Q54

1 Introduction

About 90% of Mexican energy consumption comes from fossil fuels, including that of the whole transportation sector (SENER, 2014). This helps make the country the 14th largest Greenhouse Gas (GHG) emitter in the world, contributing with about 1.5% of the global GHG emissions (World Resources Institute, 2015). The country's environmental goals, in accordance with the Intended Nationally Determined Contribution affirmed at the Paris climate summit, require that 35% of domestic energy comes from renewable sources by 2025. Meeting that goal is likely to require a domestic biofuel industry. The 2014 energy reform, however, was mostly designed to increase fossil fuels production in the transportation sector (Fernandez Madrigal, 2015).

There have been several attempts to introduce biofuels into the market (the current plan is to require gasoline be blended with 5.8% ethanol in most of the country) but so far no success. Anecdotal evidence suggests potential producers are unwilling to bear the fixed costs of setting up production systems because they doubt policies will endure. There has been a surplus of sugarcane in several recent years, but no industrial-scale fermentation or distillation facilities to turn it into ethanol. It is thus paramount that whatever policies the country implements to promote biofuels be seen as sustainable. This paper is aimed directly at that goal, developing a framework to forecast policy impacts about fifteen years ahead so that the probability a policy becomes politically unpopular can be assessed.

Technically, we develop an endogenous-price mathematical programming model emphasizing the Mexican agricultural and fuel sectors, which are embedded in a multi-region, multi-product, spatial partial equilibrium model of the world economy. There is a module for the United States (Mexico's main trade partner) and another for Rest of the World. Mexico is disaggregated into 193 agricultural districts. Production functions are specified for sugarcane, agave and twelve major crops including corn and sorghum as well as livestock (beef, chicken, dairy, hogs and eggs). Biofuel could be produced both from dedicated crops (sugarcane and sorghum) and from agroindustrial residues that result from the processing of spirits, sugar, corn and sorghum for human or animal consumption. In this version of the model, we allow only ethanol production from sugarcane and agave industries. Oil, diesel, gasoline and other oil products production are also modeled in detail, but this version of the model focuses only on gasoline. Other biofuels including Biodiesel and Biogas are leaving for future research.

As usual, we assume all markets are competitive so that the economy maximizes the sum of producer and consumer surplus subject to resource limitations, material balance, technical constraints, foreign offer surfaces and policy restrictions. Consumers' surplus is derived from consumption of agricultural commodities and transportation fuels, the latter measured by vehicle-kilometers-traveled (VKT). The model is calibrated to 2008 market conditions. GHG emissions are calculated based on above ground CO2e emissions factors for each crop, fuel or other products specified.

We consider three policy alternatives as well as a base case in which, as now, no policy is intended to promote biofuels. The first alternative consists of subsidies to ethanol producers, the second of blending mandates and the third of both combined. For the scope of this paper, we consider only two extreme values for the policy variables – i.e., no subsidy rates to one alternative, and no mandate to a 15% biofuel mandate in the blend. Biofuel imports are allowed in all three cases.

Projecting market conditions to 2025, the model results show some losses for fuel and agricultural consumers, that are not offset by both ethanol producer and GHG emissions reduction gains. Most of that benefit will be enjoyed abroad because a subsidy by itself will be transferred abroad in form of ethanol or mandate will require most of the ethanol to be imported. This suggests that some compensating redistribution may be needed if these policies are to be seen as politically sustainable.

The next section provides a brief methodological literature review as well as a revision of the works done for Mexico. Following that we describe the model and the data and assumptions underlying our analysis. A description of the results and policy implications concludes the paper.

2 Literature Review

A rapidly growing literature on the economics of biofuels discusses the scope of land use changes and policy distortions. Rajagopal et al. (2007) provide a review of literature on analysis and modeling aspects of biofuels policy. A more recent review of the literature on modeling aspects can be found in Khanna et al. (2011). The model developed here follows the modeling strategy of a larger and known sectoral partial equilibrium model: FASOM (Forest and Agricultural Sector Optimization Model), which is utilized to evaluate agricultural and environmental impacts of the US Renewable Fuel Standard (RFS) against a scenario with a lower production (Beach et al., 2010). The FASOM is a programming model of endogenous, multisectoral, dynamic, non-linear developed for the US agricultural sector prices. The model uses the approach of maximizing social surplus to determine the simultaneous equilibrium in the markets for agricultural products, disaggregating both the agricultural sector in several major producing regions within the US (McCarl et al., 1980; Norton et al., 1980; Takayama et al., 1971). FASOM covers the main agricultural crops grown in the US, the forestry sector, including biomass wood short, various categories of land rotation, including land conservation, as well as the production of conventional, advanced and cellulosic biomass various raw materials.

Following a similar strategy, Chen et al. (2011) develop BEPAM (Biofuel and Environmental

Policy Analysis Model) to evaluate the change in land use and prices of food and fuel due to US biofuel policies, compared to a stage without any intervention. BEPAM is a endogenous, multisectoral, dynamic, programming model that also uses the approach of welfare maximization. The agricultural supply side of the model is divided into 295 Crop Districts (CRD). Unlike FASOM, this model assumes as endogenous prices of food and fuel. The study results show that the subsidy for the production of second generation ethanol is necessary to fulfill the mandate of cellulosic biofuels.

Regards to partial equilibrium models that consider no high-income economies, most of them has focused on the Brazil market since it is the world largest and oldest biofuel economy. Elobeid et al. (2011) used the FAPRI-CARD models (Farm and Agricultural Policy Research Institute model) to analyze the effects of eliminating distortions in the US ethanol sector, such as tariffs on ethanol imports and domestic subsidies. FAPRI-CARD is a partial equilibrium econometric model that includes the main agricultural products, fuels and crossed between several markets of agricultural products for a variation in a market impact in other effects. The study by Elobeid et al. (2011) argues that the elimination of subsidies and tariffs reduced domestic ethanol production and increased local consumption of ethanol, accompanied by a sharp drop in domestic fuel prices. The liberalization of trade between the US and Brazil would increase ethanol production in Brazil and exports to the US. The authors claim that a biofuels mandate in the US works as a market compensatory payment for cereals (maize and others), which provides the input for biofuels, while internationally the world price increase due to reduced exports. In addition, combining the mandate with a subsidy would increase the total demand for biofuels and, therefore, the crop of basic product, a reduction in domestic consumption and a sharp decline in exports, increasing world prices even more.[1]

More recently, Fabiosa et al. (2010) use the international FAPRI model to quantify the effects of two games in the ethanol market: first, an exogenous increase in US demand for ethanol; and secondly, an exogenous increase in global demand for ethanol. The authors find that increased US demand for biofuels would be mainly supplied by domestic production, which has a considerable effect on grain prices and resulting in a reduction in plantings of wheat and soybeans in the US, leading to an increase of these crops in the world. Elobeid et al. (2011) and Fabiosa et al. (2010) capture only the changes in land use at the aggregate level, but not at the regional level within Brazil and the US. In addition, like other partial equilibrium models, these studies assume the price of gasoline as exogenous. Getting deeper in the Brazilian case, Nuñez et al. (2013) develop a partial equilibrium modeling program to evaluate the alternative to increase

[1]The Environmental Protection Agency (EPA) uses the FAPRI-CARD and FASOM models to assess the economic and environmental impacts of the RFS in relation to a scenario of business-as-usual (EPA, 2010). The EPA based its findings on the most robust results of each of the models. FASOM offers better simulation capability impacts on national agricultural and forestry sectors, while the FAPRI-CARD does better on the effects on international markets.

livestock intensification as a way to release additional land for sugarcane ethanol production under the scenario of a high ethanol demand due to the US RFS. The authors find the alternative viable but most of the benefits would be taken by the fuel and agricultural producers. By using the same model, Nuñez and Önal (2016) assess all the spectrum of policies to modify the ethanol market in Brazil, that is different mandate rates (15% to 30%) as well as different rates of reduction to fuel taxes (from 0% to 100%), aiming to indicate and quantify the implications of alternative choices under different market conditions and the socioeconomic objective(s) of the public policy makers.

According to Rendon-Sagardi et al. (2014) there is an interest by the Mexican government for the development of a domestic biofuel industry, in particular to promote the growth of biofuel production from biomass. However, efforts have not been enough, since currently biofuels could replace only 0.8% of domestic demand for fuel. This low rate of participation can be attributed to the low costs of fossil fuels. Currently, the biofuel is almost three times as expensive than the average cost of gasoline imported by Mexico, which makes unfeasible to develop an economic and sustainable domestic biofuel industry (Sánchez, 2009). But additional analysis to asses the potential of biofuel is required. For the Mexican case, it has not been developed a model as those described above for the US and Brazil. However, some stylized models, descriptive studies and cost-benefit analysis can be found. According to the simulation made by Rendon-Sagardi et al. (2014) is expected fuel demand to increase by almost 60% from 2014 to 2030. The authors point out that this will represent a problem for the expected decline in domestic production oil: today, national proven reserves cannot guarantee self-sufficiency. In this situation, Rendon-Sagardi et al. (2014) found in biofuels a possible exit to this problem. In this sense, the choice of biofuels is potentially important in Mexico since it is the third largest agricultural producer in Latin America, which is reflected in the approximately 75.73 million tons of dry matter generated by 20 major crops in the country. Of these, corn stover, sorghum and wheat straw, as well as leaves of sugarcane represents more than 80% while the rest is mainly bagasse from sugarcane, corn cob and coffee pulp (Valdez-Vazquez et al., 2010). In this context, in recent years they have tried to promote policies that encourage the use and development of renewable energy such as technologies to obtain second-generation biofuels (either through combustion or fermentation).Valdez-Vazquez et al. (2010) explore the location and amounts of crop residues that could be used in the production of second-generation biofuels, and find that there are municipalities that could reach production of 0.3 million liters of bioethanol per year (by anaerobic fermentation).

Sugarcane is the crop that has emerged as the most promising crop in the medium and long term, with regard to the production of ethanol, even above the corn (SENER et al., 2006). [2]

[2] Corn is intended to 20% of the production for ethanol in other countries, but its use is restricted in Mexico.

Sugarcane ethanol, however, could be profitable only under certain economic conditions (SENER et al., 2006), but not a complete study of the sugarcane market has been done to evaluate its viability. A second and relevant source of biomass is the agave, which is primarily used for tequila and mezcal production, and turns out to be less expensive than sugarcane because of its low water demand, less need for fertilizers and their ability to grow in semi-desert areas with lower quality soil. The agave and spirits industry residues have been the subject of significant research and are considered to have high potential as biofuel feedstock (e.g. Munoz et al. (2008); Cáceres-Farfán et al. (2008); Sánchez (2009); Nuñez et al. (2011); Davis et al. (2011)). A study of cost-benefit by Sánchez (2009) find the sugar content of agave to be greater than that of sugarcane or yellow corn from the US. Also, Nuñez et al. (2011) point out that production of biofuels from agave does not compete directly with the distillation of drinks as for the generation of biofuels is to use the waste of agave resulting from the production of tequila and mezcal. Additionally, the authors argue that, with higher conversion efficiency or using sugar that is present in other parts of the plant (reaching up to 212 metric tons per hectare), can reduce the cost to \$0.6 per liter, which would make it competitive with ethanol made from corn or sugarcane.

At this point, the U.S. RFS can play an important role to develop ethanol industry in Mexico. The RFS aims to increase the amount of biofuels blended with conventional fuels to 136 billion liters by 2022. An important component of this target is the 'advanced' biofuel mandate , which is set as 79 billion liters for 2022. According to the RFS provisions, at least 60 billion liters of this amount must be derived from cellulosic biomass while the rest can be met by biodiesel and sugarcane ethanol. Due to the slow progress in advanced biofuel production, part of it could be met by sugarcane and agave ethanol imported from Mexico. If an economically competitive cellulosic biofuel technology is established by 2022 in Mexico and the RFS is maintained as originally designed, Mexico could export part of its production to the US. Therefore, the RFS advanced biofuel mandate may have important implications for the Mexican ethanol industry.

This paper contributes to the related literature by developing a simultaneous framework that incorporates the interactions between food, feed and fuel sectors for analyzing the impacts of policy and technological changes on the biofuel economy and subsequent land use changes in Mexico. This study differs from the previous studies which addressed similar issues in several ways. First, to the best of our knowledge it is the first programming model developed for these sectors in Mexico. In this version of the model, the simulation aims to explore the potential of sugarcane and agave as feedstocks for production of first and second-generation ethanol, respectively, and for the later feedstock biomass would come from agave plant leaves and trash and agave currently not harvested for spirits production. The underlying hypothesis is that Mexico will need high subsidies and mandate blending rates to promote ethanol and consolidate a domestic ethanol market. The advantages of these two crops are that sugarcane will need very few extra land and agave will no require any extra land, so little or none trade-offs in term of land use due to ethanol production. Secondly, this paper includes an explicit fuel transportation component for Mexico that includes fuel trade with the US and the rest of the world. Finally, this research includes a fuel market mechanism that will allow to understand domestic policies and pricing system more accurately, which has not been addressed in the biofuel modeling literature.

3 The Model

The model employs the social surplus maximization approach first introduced by Samuelson (1952) and later fully developed by Takayama et al. (1971, 1964). McCarl et al. (1980) and Martin (1981) provide a rigorous presentation of the methodology and review numerous studies that used this approach. This optimization model simulates the formation of simultaneous equilibrium in multiple markets by maximizing the social-surplus derived from production and consumption of a set of products subject to material balance equations, resource availability, and other constraints related to technical limitations. The social-surplus (quasi-welfare) function includes the the agricultural and fuel markets in Mexico as well as the excesses of supply and demand from U.S. and the rest of the world (ROW). The consumers' surpluses are derived from consumption of agricultural commodities in all these countries, fuel consumption in U.S. and the ROW and Vehicle Kilometers Traveled (VKT) in Mexico. VKT demand are produced from gasoline, diesel, and biofuels, which in this case can be produced from agave and sugarcane.

As in similar models presented in the literature, the supply and demand functions are all assumed to be linear and separable. The supply response in Mexico agricultural sectors is modeled explicitly by using Leontief (fixed input-output) production functions. These assumptions imply an additive quadratic utility function that represents the sum of producers' and consumers' surplus in the three global regions.

The agricultural supply side of the model is regionally disaggregated at agricultural district level in the Mexico component. In this regionally disaggregated component, the model includes major annual crops/commodities produced using commonly practiced intra-year and inter-year crop rotation activities. The comparative advantage between crop and livestock activities in each region is modeled explicitly based on the domestic and world prices, costs of production, processing costs, costs of transportation, and regional yields. The total cost of producing agricultural commodities in the 193 districts is expressed as a linear function of the areas planted assuming fixed production costs for individual crops. In the Leontief production functions used for crop production land is considered as the only primary input and crop yields are assumed as the output. The land allocated to all crops and pastures is constrained by the total agricultural land availability in each district at the base year values, while the availability of all other inputs is assumed to be unlimited at constant prices observed in the base year.

A difficulty that is often encountered when working with programming models in agricultural sector analysis is that optimum solutions generated by the model may involve unrealistic and extreme specialization in crop and livestock production. This difficulty is addressed here by considering the 'crop mix' approach (McCarl and A. (1982); H.Önal and McCarl (1991)) where the land allocation and livestock heads in each region are restricted to a convex combination of the historically observed patterns in that region. To allow some flexibility beyond the historical mixes the model also incorporates 'synthetic crop mixes' which are generated by use of systematic hypothetical variations in crop prices and supply response elasticities (Chen et al., 2012).

The optimal output levels based on the land allocations at district level are aggregated to determine the national supply of agricultural commodities that can be consumed either in the domestic market as food, feed, or exported, all of which are driven by downward-sloping linear demand functions. For the US and the ROW, the model assumes linear excess supply and demand curves based on the quantities traded among the three regions and the international prices. Agave biomass and sugarcane are the biofuel feedstocks considered in the model. In Mexico, the use of agave residues and the use of sugarcane as ethanol feedstock is related to the endogenously determined domestic and export demand for ethanol as well as the domestic and export demands for tequila, mezcal and sugar, respectively. Besides primary commodity demands, the model includes processed commodities from agave, soybean, sugarcane, and livestock in Mexico as well as their processing costs.

In the fuel sector, when projecting market condition to 2025 ethanol and gasoline are assumed to be perfect substitutes within the specified blending regulations to generate VKT and the subsidy to ethanol producers is included in the objective function. The model assumes a perfectly elastic function for oil, gas, and petroleum products (i.e. gasoline, diesel, fuel jet, fuel oil, etc.) in the US and ROW components, since the model works only with the demand and supply excesses. Upward sloping supply functions for oil and gas are assumed in the Mexican component, while the supply of petroleum products are driven by processing costs and the VKT market in the case of gasoline, diesel, and jet fuel and an downward sloping demand curve in the case of gas and the rest of petroleum products. Ethanol trade is also considered based on the total supply and demand from the US and ROW. The model determines the optimal supply chain network simultaneously with the food and fuel market equilibrium.

4 Data and Assumptions

The data inputs include the base year domestic and global commodity prices and quantities demanded, historical crop mixes (areas planted to individual crops), crop yields, costs of production and processing, and cost of transportation. Crop mixes are restricted to the 2000-2013 data. Mexico is disaggregated into 193 districts. The crops sector includes: Agave tequilana Weber variety Blue (hereafter referred to as *A. tequilana*), Agave species for mezcal production (hereafter referred as *A.mezcalero*), alfalfa, barley, beans, yellow corn, white corn, corn silage, grass, green chili pepper, oats, oat silage, orange, sorghum, soybeans, sugarcane, and wheat. In addition to crops, the model includes twelve processed goods: tequila, mezcal and crop residues from Agaves; beef, pork, chicken, milk and eggs from the livestock sector; soybean oil and soybean meal from soybean; sugar from sugarcane; and ethanol from sugarcane and agaves' residues.

Historical land use, crop yields and pasture areas are obtained from Servicio de Información Agroalimentaria y Pesquera (SIAP, 2015). Costs of production of the crops include variable operating costs (seed and treatment, fertilizer, hauling and trucking, drying and storage costs, interest on operating cost, limestone, chemical costs, fuel and oil, and hired labor costs), fixed operating costs (tractor and machinery, crop insurance, marketing and miscellaneous, stock quota lease, irrigation), and capital and overhead costs. For each state, the variable operating costs and interest on investment are assumed to be yield dependent while the remaining costs are fixed. Costs of production are gathered at state level from Sistema Producto (SisProd, 2015).

When specifying the agricultural commodity demands, the model uses 2008 to 2013 average prices, using 2008 as the base year, the prices and quantities as reported in SIAP (2015), CRT (2015), CRM (2015) USDA-FAS (2015) for Mexico, USDA-NASS (2016), USDA-FAS (2015), comtrade (2015) for US and ROW. The price elasticities for Mexico, U.S. and ROW used in the demand functions are obtained from various sources, including USDA-ERS (2016), Database (sf), Meyers et al. (1991), Rowhani et al. (2010), Euromonitor Internacional (2014), Nuñez et al. (2013), Chen et al. (2011) and IndexMundi (2014).

Since agave has not been explored in this type of works, it is useful to deepen on the characteristics and assumptions of the plant used in the model. Agave is one of the most typical and popular crops in Mexico, which has high drought resistance and water-use efficiency and can be grown on marginal lands in arid conditions. There are at least 200 species worldwide; more than 150 can be found in Mexico. The three dominant classes of Agave cultivated in Mexico due to their high sugar and cellulosic content are *A. tequilana*, *A.mezcalero* and henequen. According to the Protected Geographic Status for Tequila (Denominación de Origen Tequila; DOT), tequila '100% Agave' must be produced from *A. tequilana* only in the state of Jalisco and some municipalities in the states of Guanajuato, Nayarit, Michoacan and Tamaulipas (CRT, 2015).The largest acreage of *A. tequilana* in a year was in 2008 with 163,000 Hectares (Ha). In the case of *A.mezcalero*, it reached the largest acreage in 2011 with 26,895 Ha planted. (see Table **??** below). The core of agave (*piña*) is the only part used to produce tequila and mezcal. The *piña* represents 71% of total plant of *A. tequilana* and 50% of *A.mezcalero*. After the original planting, this crop takes at least 6 years before the *piña* can be harvested; during this time it needs periodic maintenance, such as: removal of weeds to avoid competition for nutrients, sunlight and water, loosening of the soil around the plant to facilitate establishment and development of young plants, fertilizer application and additional pests and diseases control.

Respect to agave *piña* yield, *A. tequilana* and *A.mezcalero* report an average yield of 72.66 Mt/Ha and 60.59 Mt/Ha, respectively, while sugarcane is 77.51 Mt/Ha. The state of Jalisco has shown the highest yield with an average of 105 Mt/Ha for *A. tequilana*, while the state of Puebla has reported a yield of 106.7 Mt/Ha for *A.mezcalero.* The tequila and mezcal yields are 133 lt/Mt and 111 lt/Mt, respectively, while sugar yield is 0.12Mt per Mt of sugarcane. In the model we assume that agave residues and agaves not harvested are used for second-generation ethanol production assuming that technology will be available in the next years, and sugarcane for first-generation production using the technology widely developed. Fuel sector in regard to crops transformations from one crop to ethanol are the following: 1 Mt of *A. tequilana* or *A.mezcalero* residues produce 329 lt of ethanol (Davis et al., 2011; Nuñez et al., 2011) and 1 Mt of sugarcane produce 80 lt of ethanol. In the case of the average variable cost of cultivating *A.mezcalero*, *A. tequilana* and sugarcane in Mexico are MXN$ 397.00, MXN$ 1,428.00 and MXN$ 221.00 per Mt for, respectively. The difference between the two types of agaves is because the cost of Hauling and trucking for *A. tequilana* is higher than *A.mezcalero* (SisProd, 2015). The processing cost for tequila is 20.67 MXN$/lt, for mezcal 26.3 MXN$/lt and for sugar 296.1 MXN$/Mt. The cost of producing ethanol from sugarcane is 2MXN$/lt (PECEGE, 2015). While the cost of producing it from agave is 5.28MXN$/. Cost of collecting agave residues are also included. Agave residues come from agave leaves and plants not harvested.

In the fuel sector module, the Mexico components consider the total amount of transportation fuel to generate transportation output (kilometers driven). The price elasticity of kilometers driven is specified as -0.2 following Chen et al. (2011). The price per VKT is obtained by dividing the total cost of fuels consumed by the total kilometers generated. Fuel prices, demand and supply quantities data are obtained from EIA (2016) for the U.S., which includes ethanol, and from Anuario Estadístico for Mexico. For the supply of gasoline, diesel and jet fuel in Mexico, we use a price at the refinery gate of MXN$7.34, $7.72, $7.31 per liter Anuario Estadístico (average 2008-2013), respectively. On top of these, taxes, subsidies, marketing margins and transportation costs are added to build the VKT demand curves.

GHG emissions are calculated for all crops, fuels, and livestock based on the above-ground CO2 equivalent emissions (CO2e). The CO2e emissions are estimated by aggregating the major GHGs emitted, namely carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), using their 100-year global warming potential factors. These are 1 for CO2, 23 for CH4, and 296 for N2O. GHG emissions for crops include CO2e generated from input factors, machinery and transportation. Regards to biofuel crops, sugarcane net emissions are 2,807kg C02e/Mt, while for agaves, we assume a CO2e net absorption of 25,000 kg C02e/Mt.

The entire data set, including the key supply and demand parameters, production costs and yields, and transportation costs between regions can be available from the author upon request.

5 Policy Scenarios and Results

5.1 Model Validation

The table 1 shows only the three most important crops (i.e. white corn, sorghum, and beans) and the three crops of our main interest, namely *A.mezcalero*, *A. tequilana* and sugarcane. This table shows the national distribution of land between model and observed. The biggest difference in the model is the case of *A.mezcalero* and white corn.

The baseline scenario reflects the 2008 policy conditions for the purposes of model validation. Table 2 summarizes the comparative markets in the modeled baseline. In this sense, the Table 2 reports demand, supply and prices of some commodities. The table shows only the three most important crops (i.e. white corn, sorghum, and beans) and the three crops of our main interest, namely *A.mezcalero*, *A. tequilana* and sugarcane. Overall differences between areas observed and simulated are low and total pasture and crop area in the model is 7% lower than that observed. Maps in figures 1 and 2 illustrate the land use modeled and land use observed for *A.mezcalero* and *A. tequilana*, sugarcane and white corn at district level. The maps show a very small deviation in the regional distribution of cropland allocation and highlights the concentration of these crops in the traditional production regions. On the agricultural market side, the model results are usually within acceptable margins of error both in the demand a supply sides such as Table 1 shows. Only the cases of production of sorghum and mezcal demand, validation results report higher differences than the rest of commodities. Table 2 also shows a small difference for the cattle beef heads.

Table 3 reports the demand and supply quantities for the main fossil fuels (petroleum, gasoline, diesel and jet fuel) in Mexico included in the model. The demand and supply determined by the model are again within acceptable ranges, except by diesel supply whose difference is above 15%.

Overall validation results show small deviations and the model therefore appears to reasonably replicate the base-year market equilibrium conditions. The subsequent sections present the empirical results obtained from projecting market conditions to 2025 in the model under different policy scenarios.

Table 1: Model Validation: Land Use

Crops	Observed*	Model**	Difference (%)
	(MMHa)		
A. Mezcalero	0.018	0.013	-26.82
A. Tequilana	0.149	0.163	9.13
Sugarcane	0.738	0.755	2.25
Bean	1.625	1.623	-0.15
Sorghum	1.938	1.956	0.91
White corn	7.519	5.795	-22.94
Total agr. land	45.641	42.135	-7.68

*Average 2008-2013

**Baseline 2008

Table 2: Model Validation: Agricultural Sector

Commodity	Observed*	Model**	Difference (%)
	Demand (MMt)		
Bean	1.086	1.083	-0.28
Sorghum	8.340	9.4	12.71
Sugar	4.605	4.697	2.00
White corn	19.666	19.396	-1.37
Mezcal (MMlt)	1.139	1.179	3.51
Tequila (MMlt)	101.057	101.74	0.67
	Supply (MMt)		
Bean	0.998	0.993	-0.50
Sorghum	6.129	6.709	9.46
Sugar	6.104	6.289	3.03
White corn	20.303	18.842	-7.20
Mezcal (MMlt)	2.315	1.987	-14.17
Tequila (MMlt)	208.74	231.689	10.99
	Heads (Millions)		
Cattle beef	29.35	26.99	-8.20

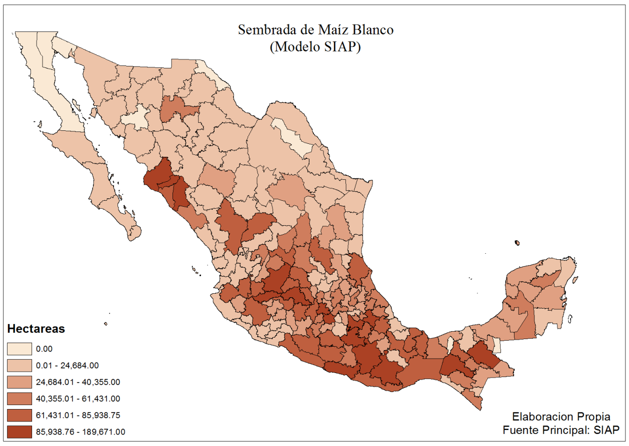
*Average 2008-2013

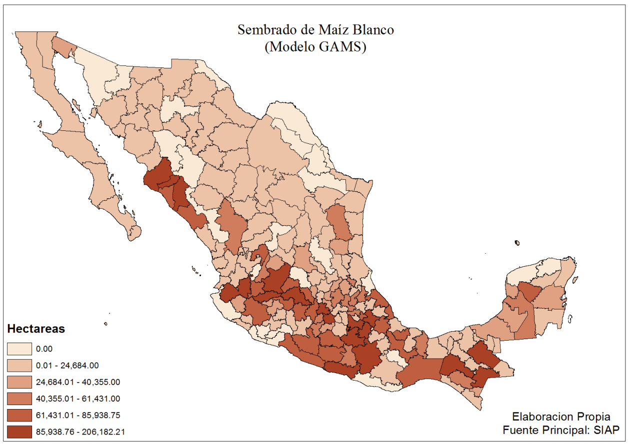
**Baseline 2008

Figure 1: Regional land use validation

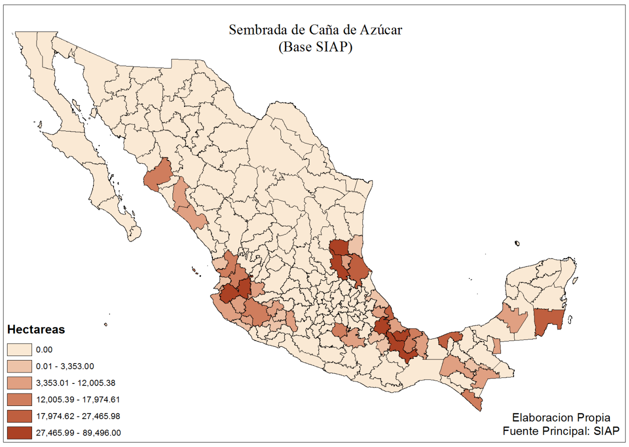
Planted

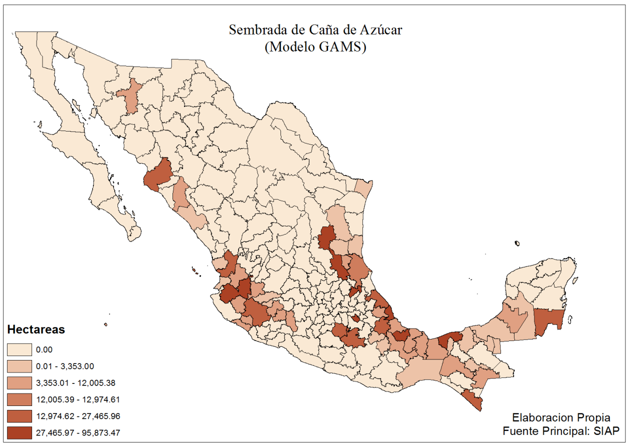
Simulated





White corn





Sugarcane

Figure 2: Regional land use validation (continuation)

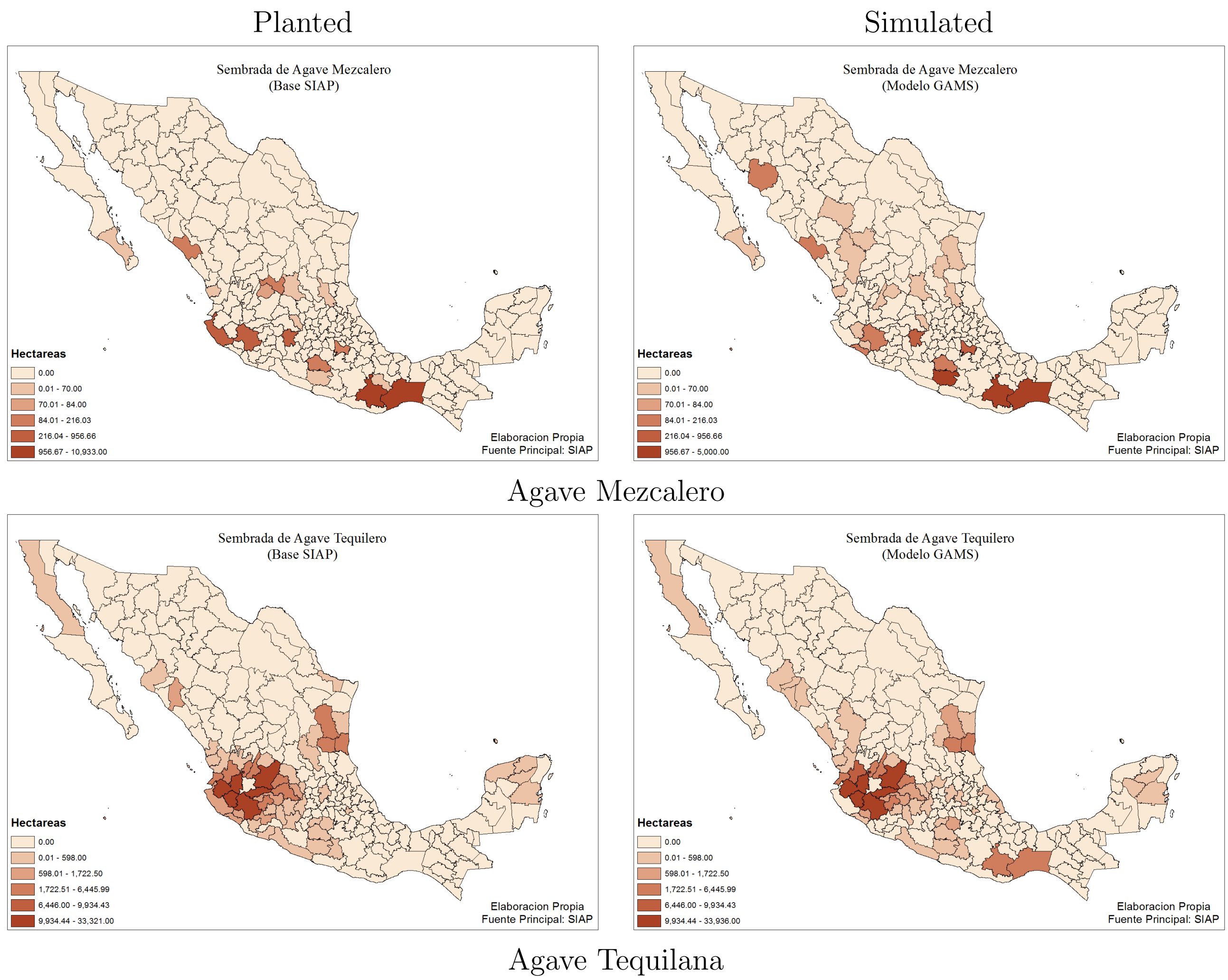


Table 3: Model Validation: Fuel Sector

Fuel	Observed*	Model**	Difference (%)
	Demand (MMBbl)		
Petroleum	437.614	447.758	2.31
Gasoline	290.634	319.623	9.974
Diesel	139.233	134.016	-3.74
Jet Fuel	21.525	21.357	-0.78
	Suppy (MMBbl)		
Petroleum	948.468	875.634	-7.68
Gasoline	168.321	142.886	-15.11
Diesel	97.822	134.016	37.00
Jet Fuel	21.020	21.357	1.60

*Average 2008-2013

**Baseline 2008

5.2 Policy Scenarios and Results

When examining the impacts of alternative biofuel policies under future demand and supply scenarios, we first update the model parameters to reflect the projected domestic demand shifts (both domestic and global) and agricultural productivity improvements over the period 2008-2025. Updating those parameters is based on the historical trends in population growth and income growth (which together affect the food and transportation demands) and crop yield increases. For the scope of this paper, we consider only three policy alternatives as well as a base case in which, as now, no policy is intended to promote biofuels. The first alternative consists of a subsidy to biofuel producers equivalent to a 50% of the gasoline price, the second of a 15% blending mandate and the third of both combined. In all three cases biofuel imports are allowed. Results are reported in tables 6-8. It is worth noting that in a previous step we evaluate different blending and subsidy rates within technical possibilities and we chose those with the highest ethanol production and objective function value to be presented in this paper.

Some general deductions can be made based on the results for the fuel sector displayed in tables 4 and 5. The first and most striking fact is the weak role of a subsidy in the demand supply of all fuels, in particular on the domestic market of ethanol. The third and fourth column corresponds to scenarios without and with mandate, both when subsidy is in place. The results show that ethanol production will be low under both scenarios, but in the former there would not be any ethanol consumption and all the domestic production would be exported to the US. When blending mandate without subsidy is imposed (column 2), producers would make about 500 million liters of ethanol, most of which will come from agave. When mandate is combined with the subsidy (column 4), production would be above 1 billion liters, of which sugarcane and agave would provide one half each. However, under the two later scenarios, Mexico would need to import ethanol from ROW and the US to fulfill the domestic mandate. If international ethanol trade was restricted by Mexico, under the scenario with subsidy and mandate, the country would be able only to provide 0.6% of the total fuel demand (gasoline + ethanol) when subsidy is not allocated and 1.3% when it is. As expected under the mandate, gasoline consumption would be reduced and total VKT too since consumers would have to pay for a more expensive fuel (i.e. ethanol). The results presented in tables 4 and 5 correspond only to the combinations of the extreme changes in the subsidy and ethanol blending rates considered in the analysis. Further analysis must inquire for the entire spectrum of the model results under all combinations of blending and subsidy rates.

Table 4: Effect of alternatives policies on the fuel sector in Mexico 2025

Fuels	Baseline (Gl)	Mandate	Subsidy (% change)	Mand+Subs
		Demand		
Petroleum	74.37	0.00	0.00	0.00
Gasoline	51.16	-22.28	0.00	-22.28
VKT[a] (Billions)	480.53	-0.50	0.00	-0.50
		Supply		
Petroleum	289.07	0.00	0.00	0.00
Gasoline	0.00	0.00	0.00	0.00
		Price MXN$/lt		
Petroleum	6.56	0.00	0.00	0.00
Ethanol	5.67	96.08	-10.2	96.08
Gasoline	8.60	0.00	0.00	0.00
VKT[a]	0.96	5.10	0.00	5.10

[a]Only Vehicle Kilometer Traveled Gasoline

Table 5: Effect of alternatives policies on Ethanol

Ethanol	Baseline	Mandate	Subsidy (Gl)	Mand+Subs
Total Demand	0.00	11.13	0.00	11.13
Total Supply	0.00	0.51	0.28	1.08
Sugarcane Eth	0.00	0.00	0.00	0.56
Agave Eth	0.00	0.51	0.27	0.52

Since not significant domestic ethanol is produced even in the presence of a mandate and a subsidy, no significant amount of land would be required to produce additional ethanol since half of it would come from agave and the second half from sugarcane, which would need only 3%

more land as depicted in table 6. However, area for white corn is reduced significantly respect to the observed acreage, which due to the exponential yield increase rate assumed in the model, of course this issue deserves a revision of this and other figures, but any significant change is unlikely in the main results. Maps in figure 3 display agave and sugarcane allocation across the country under both baseline and the subsidy and mandate scenario. When comparing both scenarios, we can see that landscape picture for these two crops will remain virtually unchanged. Surprisingly, mezcal production increases even when ethanol from agave is produced such as table shows.

Table 6: Effect of alternatives policies on land use in Mexico 2025

Crops	Baseline (MMHa)	Mandate	Subsidy (% change)	Md+Sb
A. Mezcalero	0.011	0.00	0.00	0.00
A. Tequilana	0.166	0.00	0.00	0.00
Bean	1.611	0.06	0.00	0.12
Sorghum	1.958	0.00	0.00	0.20
Sugarcane	0.767	0.00	0.00	2.35
White corn	1.685	0.18	0.06	0.24
Total cropland	36.804	0.01	0.00	0.07

As we can observe in table 8, domestic GHG emissions (in CO2e terms) would decrease only when mandate is in place since ethanol emissions are lower than those from gasoline, when considering all the sectors in the model, CO2e reduction would reach up to 3.4%. This figure belongs to the scenario under mandate alone, in which more ethanol is imported from the ROW and less land is required, therefore there are lower domestic emissions. However, this reduction does not compensate economic surplus losses, which are about -0.1% including the environmental gains and fuel and agricultural consumers losses. [3] As expected, ethanol producers would get most of the gains from the subsidy since ethanol will be sold either domestically or abroad, in the later case Mexican government would make a transfer of the subsidy to foreign countries, which Mexican consumers would have to pay.

6 Concluding Remarks

Mexico has put a good amount of resources on research to develop production of second-generation biofuels, but very little effort in developing a biofuel market for the transportation sector. In this paper we evaluate a subsidy and a blending mandate policy scenarios using an

[3]The carbon price is set at $30 per ton of CO2e based on the estimates from the Mexican government of the marginal external damage from GHG emission in the country. See www.worldbank.org/content/dam/Worldbank/document/SDN/background-note_carbon-tax.pdf

Figure 3: Area Sugarcane and Agave simulated in Mexico 2025 (Ha)

Baseline

Mandate+Subsidy

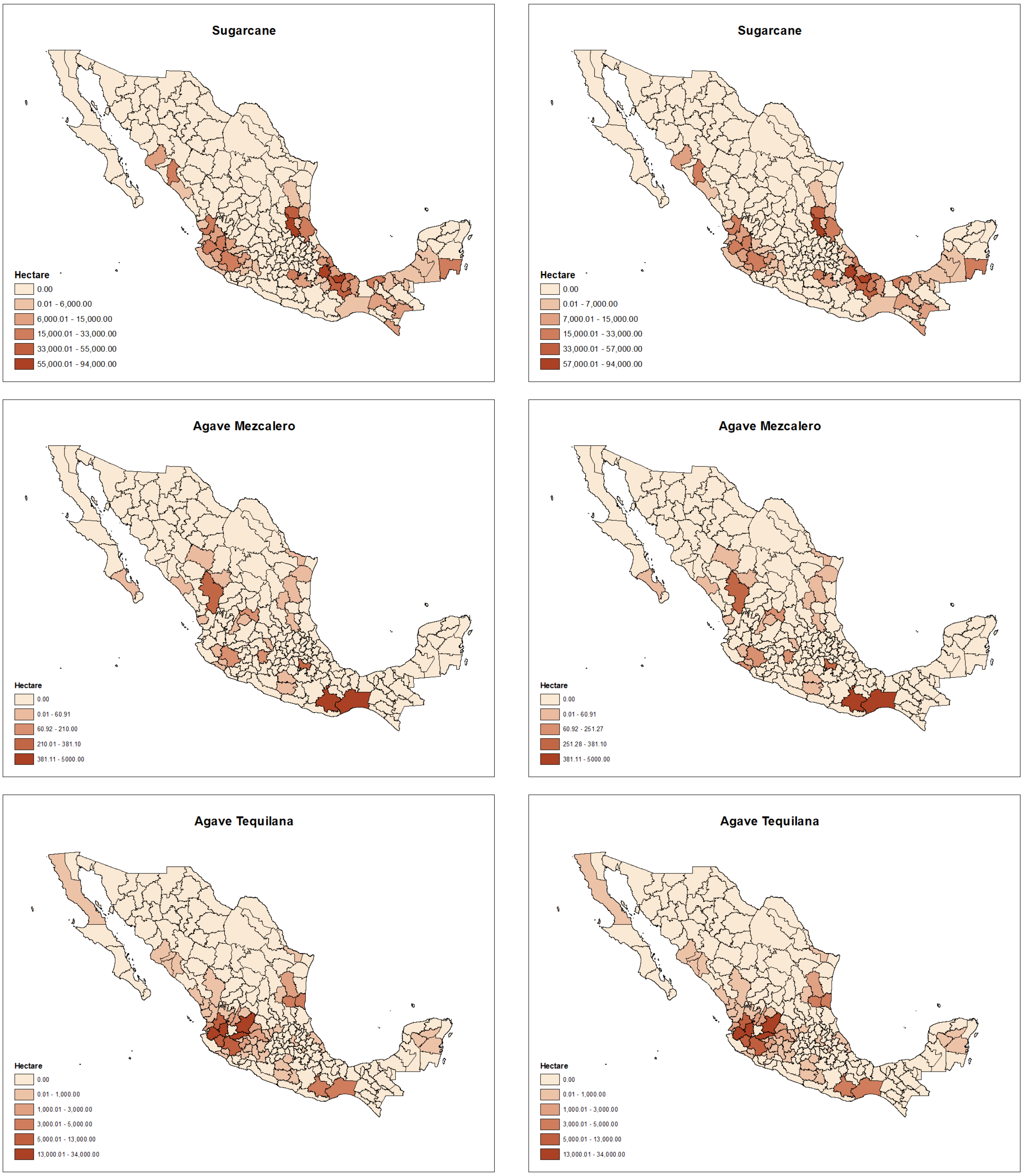


Table 7: Effect of alternatives policies on agro-industrial Sector in Mexico 2025

Commodities	Baseline (MMt)	Mandate	Subsidy (% change)	Mand+Subs
		Demand		
Bean	1.76	-0.06	-0.06	0.00
Sorghum	10.88	0.03	0.04	-0.01
Sugar	4.61	0.02	-0.02	-5.20
White corn	20.13	0.01	-0.01	0.05
Mezcal (MMlt)	1.06	1.78	0.47	2.25
Tequila (MMlt)	111.89	0.02	0.02	-0.05
		Supply		
Bean	1.61	0.06	0.00	0.06
Sorghum	8.42	0.01	0.00	0.02
Sugar	7.46	0.01	0.00	-9.56
White corn	19.94	0.03	0.00	0.10
Mezcal (MMlt)	1.80	1.55	0.17	1.66
Tequila (MMlt)	234.36	0.00	0.00	-0.07
		Price MXN$/ton, MXN$/lt		
Bean	7,122.74	-0.27	-0.04	-0.51
Sorghum	2,882.77	0.00	0.00	-0.07
Sugar	6,418.88	-0.04	0.00	26.23
White corn	765.46	-1.80	-0.02	-7.76
Mezcal	1,429.61	-3.75	-0.41	-4.01
Tequila	768.96	-0.01	0.00	0.24

Table 8: Effect of alternatives policies on social welfare and greenhouse gas emissions in Mexico 2025

Commodities	Baseline (B MXN$)	Mandate	Subsidy (% change)	Mand+Subs
Agr. producers surplus	1,684.45	-0.023	-0.001	0.361
Agr. consumers surplus	4,331.03	0.008	0.000	-0.156
Fuel producers surplus	766.75	0.608	>100	>100
Fuel consumers surplus	6,379.84	-0.289	0.000	-0.289
Eth. Producers surplus	0.00	>100	>100	>100
Government Revenue	10.68	8.041	<100	<100
Total surplus	13,154.99	-0.094	0.001	-0.060
GHG emissions (Mt CO2e)	592.82	-3.393	0.000	-3.386

endogenous-price mathematical programming model. We focus on ethanol made from agave residues, which is the larger crop already established with the potential to generate enough biomass for a significant second-generation ethanol production. However, the model results have shown that maximum production would be about 0.5 billion liters when a 15% blending mandate is in place and producers receive a subsidy equivalent to half of the gasoline price. Under the same policy scenario, sugarcane will be able to provide more ethanol than that from agave. The ethanol production from both groups is expected since they are getting the subsidy and making a significant increase in their economic surplus. However anecdotal evidence suggests sugarcane producers are unwilling to bear the fixed costs of setting up production systems because they doubt policies will endure. There has been a surplus of sugarcane in several recent years, but no industrial-scale fermentation or distillation facilities to turn it into ethanol. According to the model results, losses for fuel and agricultural consumers cannot be offset by both ethanol producer and environmental gains. This suggests that some compensating redistribution may be needed if these policies are to be seen as politically sustainable. Likewise, ethanol will reach a maximum production of 1.1 billion liters by 2025, which is less than 2% of the total projected gasoline demand in the country. Hence it can be concluded that biofuel potential in Mexico is low and a significant change in the fuel transportation matrix will require ethanol imports from the US and the rest of the world, meanwhile environmental gains will be low and are far of compensating economic surplus losses.

Important topics that are left out in the present analysis include relaxing some of competitive markets assumptions, for instance, in Mexico sugar mills owners are better described as a oligopoly. We also need to explore the possibility of livestock intensification as a way to release additional land to energy crops. Likewise, other biofuel feedstocks should be considered such as sorghum, residues of corn and sorghum and organic wastes. Other new energy crops that are not developed yet such as jatropha and some alga species deserve special attention too. In the same way, other biofuels like biodiesel and biogas have to be included in the model. Regards to biogas, although the gas sector is already included in the model as aggregate supply and demand curves, it will require to model the electricity generation sector in more detail. All this would require some critical data, in particular costs and yields, which are still subject to high uncertainty. It is worth noticing that most of these biomass and biofuels report substantially lower GHG emission factor. This makes them advanced biofuels and to have a great export potential to the US since second-generation (cellulosic) biofuels constitute an important component of the RFS mandates.

The purpose of this study is not to send a pessimistic prospective against the development of a domestic ethanol market and it is not either to prescribe a single best choice for the policy instruments considered here. Rather, our analysis aims to call the attention of the industry (e.g. agave, sugarcane, automotive) and the government to start providing incentives and commands to both the demand and the supply sides since now. The empirical results presented here can provide useful guidance for the government and the industry. The model can become a useful tool to assess future policies that aims to develop a domestic biofuel market.

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Appendix

Algebraic Equations of the Model

A simplified version of the algebraic representation of the model is given below together with the description of notation used. The lower case symbols denote exogenous parameters while the upper case symbols represent endogenously determined variables. The subscripts indicate crop/fuel/commodity while superscripts are used for the type of countries and district.

The objective function represents the sum of producers' and consumers' surpluses expressed as follows:

Maximize

$$\begin{aligned}
&\sum_{VKT}\int D_{VTK}^{mx}(\cdot)\,\mathrm{d}(\cdot)+\sum_{RF}\int D_{RF}^{mx}(\cdot)\,\mathrm{d}(\cdot)+\sum_{\substack{FL,\\row}}\int D_{FL}^{row}(\cdot)\,\mathrm{d}(\cdot)+\sum_{\substack{Com,\\cou}}\int D_{com}^{cou}(\cdot)\,\mathrm{d}(\cdot)\\
&-\sum_{\substack{FL,\\row}}(S_{FL}^{row}(\cdot)\cdot price_{FL}^{row})-\sum_{PG}\int S_{PG}^{mx}(\cdot)\,\mathrm{d}(\cdot)-\sum_{\substack{com,\\row}}\int S_{com}^{row}(\cdot)\,\mathrm{d}(\cdot)\\
&-\sum_{z}C_{z}^{mx}(\cdot)\\
&-\sum_{\substack{sys,\\act,\\pz}}cattc_{sys,act,pz}^{mx}\cdot au_{sys,act,pz}+\sum_{\substack{sys,\\act}}herdc_{sys,act}^{mx}\cdot au_{sys,act}
\end{aligned} \tag{1}$$

The integrals in the first line of (1) represent the sum of the areas under the demand curves for vehicle kilometer traveled by type of fuel (VKT) and the demands for the rest of the fuels (RF) in Mexico (first and second integrals), the demands for fuels (FL) in U.S. and the ROW (third integral), the demand curves for agricultural commodities (Com) in the three regions (fourth integral). The sets are defined as follows: FL include the principal fuels, ie, petroleum, natural gas, ethanol, gasoline, diesel, jet fuel, LPG, fuel-oil, others; VKT only considers gasoline, diesel, and jet fuel; RF is the fuels without the part of VKT; com is agricultural commodities, ie, alfalfa, barley, beans, yellow corn, white corn, corn silage, grass, green chili pepper, mescal, oat, oat silage, orange, sorghum, soybean oil, soybean meal, sugar, soybeans, sugarcane, tequila, wheat, beef, chicken, hog, egg, and milk; mx is country index used for Mexico; row is country index used for U.S. and ROW; and cou is the union of all those (thus all three regions).

The second line includes the area under the price curves in U.S. and ROW (first integral), the area under the supply curves of: petroleum and natural gas (PG) in Mexico (second integral), and agricultural commodities in row (third integral).

The third line is a representation of all costs in the model ($C(\cdot)$) for crops/fuels/commodities (z). This term includes all taxes, subsidies, and marketing margins for fuel demand in Mexico, the cost of producing ethanol, the cost of marginal lands to cropland, the cost of collecting crop residues for conversion to biofuel, the cost of processing soybean to soymeal and soy oil, sugarcane to sugar, agave tequilana to tequila, agave mezcalero to mezcal, and the costs of transportation (within and between countries).

We depict the Mexico livestock module in the last line of (1). The first and second term are the annual cost of raising cattle and the rest of the livestock, ie, chicken, hog, laying hen ($cattc^{mx}_{sys,act,pz}$, $herdc^{mx}_{sys,act}$) respectively, measured in animal units (au), which depends on the total amount of pasture land in each system (sys), ranch activity (act), and in the case cattle, pasture type (pz). The sets sys and act include the extensive and semi-intensive systems and three ranching activities (namely finishing, complete cycle and weaning), respectively.

The maximization of (1) is subject to several constraints. For brevity, here we present only ten most relevant eleven, labeled by (2)-(12). Fuel consumers in Mexico consume gasoline, diesel, and jet fuel, so the total driving distance generation (D_{VKT}) results from the demand of kilometers that can be driven per liter (kpl) of each fuel type; D_{VKT} is assumed to be proportional to the amount of fuel consumed by each vehicle category (gasoline, diesel, and jet fuel vehicle), as shown in equation (2)

$$D_{VTK} = \sum_{FL} kpl_{VTK} \cdot (\gamma D^{mx}_{eth} + D^{mx}_{FL}) \qquad \forall VTK \tag{2}$$

Where kpl_{VTK} a parameter representing the energy efficiency (in kilometers per liter of fuel equivalent) for each vehicle type in Mexico, and γ is the energy content of ethanol (eth) with respect to gasoline, diesel, and jet fuel (fd) and γ will be 0 when $D^{mx}_{FL} \neq D^{mx}_{fd}$. Each type of fuel mixed is subject to technical (e.g. energy content of ethanol with respect to gasoline, ethanol and gasoline mixed has to be as large as 1:3 for conventional cars). And the demand for ethanol is restricted to a certain percent of demand of vehicle kilometer traveled of gasoline, as shown in the following equation

$$D^{mx}_{eth} = \alpha D^{mx}_{VTK_{gas}} \tag{3}$$

Equations (4) and (5) express the ethanol supply (ES) whose production depends on the ethanol yield $eyield^{mx}$ the feedstock FS^{mx}_{cr} and on the feedstock yield $fsyield^{mx}_{cr}$. Cellulosic feedstock includes biomass from agaves leaves, agaves that had no use and sugarcane residues.

$$ES^{mx} = \sum_{cr} eyield^{mx} \cdot FS^{mx}_{cr} \qquad cr = agaves\ waste,\ sugarcane \tag{4}$$

$$FS^{mx}_{cr} = fsyield^{mx}_{cr} \cdot (CL^{mx}_{cr} + NL^{mx}_{cr}) \qquad cr = agaves\ waste,\ sugarcane \tag{5}$$

Where feedstock FS comes from crop cr; CL and NL are existing and new croplands, respectively. The supplies of crop residues are restricted to the total area planted for agaves and sugarcane.

Commodity supply (CS^{mx}_{com}) is the sum of districts production ($CS^{mx,dt}_{com}$) variables which depend on the mexican crops (cr), yields ($rcyield^{mx,dt}_{cr}$), survival rate ($sr^{mx,dt}_{cr}$) and the amounts of land allocated to that crop ($CL^{mx,dt}_{cr}$), which is determined endogenously. The model includes a crop land expansion possibility in Mexico, which is represented by NL^{dt}_{cr}, where dt are the mexican districts.

$$CS^{mx}_{com} = \sum_{dt} rcyield^{mx,dt}_{cr} \cdot CL^{mx,dt}_{cr} \cdot sr^{mx,dt}_{cr} \qquad \forall com \tag{6}$$

All new land $NL^{mx,dt}_{cr}$ in Mexico that can be used for crop production must come from the pasture lands ($PL^{mx,dt}_{sys,act,pz}$) in each district. Pasturelands allocated to cattle production under all systems and activities and the converted lands cannot exceed the total amount of pastures available (pla) in each region as shown in constraint (7):

$$\sum_{\substack{sys,\\act,\\pz}} PL^{mx,dt}_{sys,act,pz} + \sum_{cr} NL^{mx,dt}_{cr} \leq \sum_{pz} pla^{dt}_{pz} \qquad \forall dt \tag{7}$$

The 'historical and synthetic crop mixes' constraint is represented by equations (8) and (9). The symbols λ^{dt}_{t} and β^{dt}_{n} are a non-negative endogenous variables which represent the weights assigned to the historical and synthetic crop mixes, respectively, in distict dt and year t or n. Equation (10) states that the sum of these weights must be less than or equal to 1 (convexity requirement).

$$CL_{cr}^{dt} = \sum_{t} \lambda_t^{dt} \cdot cpla_{t,cr}^{dt} + \sum_{n} \beta_n^{dt} \cdot syn_{n,cr}^{dt} \qquad \forall dt, cr \tag{8}$$

$$\sum_{t} \lambda_t^{dt} + \sum_{n} \beta_n^{dt} \leq 1 \qquad \forall dt \tag{9}$$

Finally, equations (10)-(12) describe the meat, milk, and egg production options in the Mexico module. Meat supply (CS_{meat}^{mx}) is obtained from the total number of livestock heads in the finishing stage, namely ($HCF_{lc}^{mx,dt}$) converted to animal units (au or 450 kg) times the carcass weight (cw), and slaughter rate (sr), similar to other livestock commodities supply such as milk and egg (CS_{olc}^{mx}), these two only are multiplied by a conversion factor of lt or kg per animal unit ($conv_{olc}^{dt}$). Where lc is livestock animals (beef-cattle, pig, chicken), ol is other livestock animals (milk-cattle, laying hens). The variable HCF includes livestock received in finishing from weaning farms and the ones in complete cycle farms (equation 8).

$$\begin{aligned} CS_{meat}^{mx} &= \sum_{\substack{dt,\\ lc}} cw_{lc}^{mx,dt} \cdot sr_{lc}^{mx,dt} \cdot au_{lc}^{mx,dt} \cdot HCF_{lc}^{mx,dt} \\ CS_{olc}^{mx} &= \sum_{\substack{dt,\\ ol}} au_{ol}^{mx,dt} \cdot conv_{ol}^{mx,dt} \cdot HCF_{ol}^{mx,dt} \end{aligned} \tag{10}$$

As cattle production is transformed from extensive to semi-intensive system, feed requirements (fr) will increase. The model assumes that feed comes from alfalfa, yellow corn, corn silage, oat silage, sorghum, and soymeal (fe). The key parameter here is $au_{sys,act,pz}^{dt}$ which is the number of au that can be raised per unit of pasture area in each farm type (equation 12) and determines the total herd size that each farm can have. This relationship is defined for each system, range activity, and type of pasture

$$FEED_{fe}^{mx} = \sum_{\substack{dt,\\ sys,\\ act,\\ pz}} fr_{fe,sys,act,pz}^{mx,dt} \cdot au_{sys,act,pz}^{dt} \qquad \forall fe \tag{11}$$

Equation (12) relates the total cattle stock (in heads) in each region to the pasture area equivalent. The key parameter here is the pasture area ($pah_{sys,act,pz}^{mx,dt}$) required per unit of cattle in the finishing stage, which is defined for each system, range activity, and type of pasture.

$$PL^{mx,dt}_{sys,act,pz} = pah^{mx,dt}_{sys,act,pz} \cdot HCF^{mx,dt}_{sys,act,pz} \qquad \forall dt, sys, act, pz \tag{12}$$

Finally, the pasture area in the model by type of pasture (planted and native) is restricted to not exceed the total pasture land availability observed in the base year in each region. Additionally, the model includes production functions for processed commodities, i.e. soy oil and soy meal from soybean and sugar from sugarcane, tequila from agave tequilana, and mezcal from agave mezcalero, and balance equations for all fuels and agricultural commodities. But all these constraints are not shown here for brevity.