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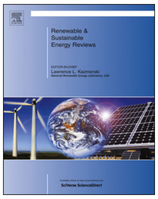

Sustainable bioenergy options for Mexico: GHG mitigation and costs

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ABSTRACT

Appropriately implemented bioenergy could be a renewable source of energy contributing to fossil fuels substitution and greenhouse gas (GHG) mitigation in Mexico. This work explores eleven bioenergy options with environmentally sustainable biomass production potential. Mature and widely used technologies for biomass transformation are selected. Mitigation costs and investments are calculated for each option. The options cover electricity, heat, and mobile power for use in the agricultural, industrial, transport, services and residential sectors. By the year 2035 the set of bioenergy options considered could replace 16% of the final energy consumption currently provided by fossil fuels, and could mitigate 17% of GHG emissions compared to the baseline. Wood pellets for industrial, efficient cook stoves and efficient charcoal kilns show negative mitigation costs and low investment requirements, and are thus promising as regards implementation in the short to mid-term. Liquid biofuels on the other hand show high mitigation costs and low to high mitigation potential, depending on the feedstock, although most of these options also offer important sustainable development co-benefits.

Contents

Abbreviations: BAU, business as usual; CFE, Comisión Federal de Electricidad (public electric company); CH_4, methane; CO_2, carbon dioxide; CO_2e, equivalent carbon dioxide; DM, dry matter; DOE-EIA, Department of Energy-Energy Information Administration; EUF, energy use factor; gCO_2e, gram of equivalent carbon dioxide; GHG, greenhouse gas; km, kilometers; LCA, life cycle assessment; LULCC, land use land cover change; M, million; MAI, mean annual increment; Mbpd, million barrels per day; Mha, millon of hectares; MJ, megajoule; $MtCO_2e$, million tonne of equivalent carbon dioxide; MUSD, Million of United States Dollar; MW, megawatt; NPV, net present value; PEMEX, Petróleos Mexicanos (public petroleum company); PJ, Petajoule; RE, renewable energy; t, tonne; tCO_2e, tonne of equivalent carbon dioxide; TW h, terawatt hour; USD, United States Dollar; yr, year

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1. Introduction

The Mexican energy system is based on fossil fuels, which supply 92% of the primary energy (65% from oil, 24% from natural gas and 2% from coal) [1]. Mexico holds the 14th place in absolute terms among GHG emitting countries [2].

National energy security is currently at risk, since crude production fell from 3.8 million barrels per day (Mbpd) in 2004 to 2.5 Mbpd in 2011 [3] and it is uncertain whether current exploration efforts will lead to the discovery of the levels of proven oil reserves and high production that have marked the past decades [4]. As for natural gas, domestic production is also insufficient, imports accounted for 33% of national consumption in 2011 [3]. Although Mexico ranks fourth in the list of countries with potential shale gas reserves [5], there is uncertainty about the real size of these reserves, as well as the economic viability of their exploitation and the associated environmental impacts.

In response to this situation, the Mexican Government has focused efforts on increasing oil and gas prospecting and extraction [6,7] giving much less attention to renewable energy (RE) sources, whose potential contribution to mitigation of GHG and energy security has not yet been properly acknowledged. However, a goal of 35% share of RE plus nuclear power in the electricity mix for year 2024 has already been set [8]. Moreover, the Mexican Climate Change Law of 2012 set goals for reducing GHG emissions by 30% in 2020, and 50% in 2050, taking 2000 as baseline year [9].

In 2010, the share of biomass in Mexican primary energy supply was 4.3%, mainly relating to the use of fuelwood by households and bagasse by the sugar industry [1]. Fuelwood is used for cooking by about 25 million people, mostly in rural areas, but also in many small scale industries and shops such as charcoal making for commercial and residential grilling, brick and tile kilns, bakeries, mezcal, pottery, tortillas, among others [10]. Most of the biomass technologies presently used in Mexico have low efficiencies and are harmful to human health as a result of smoke pollution and in some cases to the environment, as a result of deforestation. However, experience from other countries demonstrates that efficient and clean technologies can be introduced [11–13]. In the area of renewable energy in Mexico, most public attention has focused on liquid biofuels for transportation, but there are many other mature technologies, such as processed solid biofuels (fuel-chips, wood pellets, charcoal) which could be used to produce electricity, industrial and household heat, pig iron, ceramic materials, among others.

In view of the negative environmental impacts of fossil energy sources, RE options should aim to achieve positive impacts on climate change. In the case of bioenergy, sustainability needs to be considered as a critical aspect, because depending on the specific option, bioenergy development can pose risks such as biodiversity loss [14–16], deforestation and increased CO_2 emissions due to land use change [17–19] soil erosion, depletion and contamination of aquifers [20,21], high costs [22], and deterioration of food security [23].

Developing "what-if" scenarios is a useful way to explore energy options and their potential impacts. Several published articles have applied this tool to bioenergy [24–27], in Mexico [10,26] as well as in other countries (e.g. [28]). However, most of these studies have not considered sustainability criteria when assessing biomass production potential, and did not perform cost analysis.

In this work, we built two scenarios to explore the long-term impacts of bioenergy in Mexico. The first is the business as usual (BAU) projecting current trends up to the year 2035 in the sectors in which bioenergy options are proposed. The second is the Alternative scenario that is composed of eleven options for bioenergy replacing fossil fuel use or increasing the efficiency of fuelwood end-use devices in the residential sector. The alternative scenario was constrained by a set of environmental and socio-economic sustainability criteria regarding both the biomass production potential and the technologies for transformation and end-use. We calculated primary energy demand and GHG emissions between 2015 and 2035 for both scenarios. To explore the financial viability of bioenergy options, we performed detailed benefit/cost analyses.

2. Methodology

2.1. Sustainable biomass production potential in Mexico

Three bioenergy sources were considered: (1) sustainable forests management of natural forests as a source of wood-energy (direct wood-energy), (2) wood-energy as a byproduct of current forest operations (indirect wood-energy), and (3) energy plantations.

The sustainable production of wood-energy from native forests was calculated as the potential woody biomass annual growth (or Mean Annual Increment, MAI) usable for energy purposes. The organic carbon in forest biomass stock and soil are assumed to remain constant in time. MAI assumptions depend on forest type and annual rainfall. Only a fraction of MAI is assumed to be usable for energy, indicated by an energy use factor (EUF) by forest type. The EUF depends the extent to which higher value-added wood products (e.g. for construction, furniture and paper) compete for the use of the timber. Only forests near settlements (less than 5 km radius), near major and interconnected roads (less than 3 km each side), and over flat areas (less than 30% slope) were considered suitable for management for bioenergy. Protected and high conservation value areas [29] were excluded.

Indirect wood-energy a by-product of commercial forest logging and sawmilling, was calculated as 0.3 of the dry weight of logged wood plus 0.5 of logs processed at sawmills.

Energy plantation potential was calculated on the basis of the area available for expansion of five crops: sugarcane, grain sorghum, *Jatropha curcas*, oil palm, and *Eucalyptus spp.* Three yield levels were defined for each crop, depending on hydric balance and soil quality (see Supplementary material for details). Each crop was assigned only to areas where it shows high yields, calculated on the basis of climatic conditions (maximum and minimum temperatures, frost period, number of dry months), soil quality and terrain slope.

Three exclusion criteria (masks) were applied to determine areas not suitable for each crop, other than those previously mentioned above: (1) altitude; (2) slopes; (3) frost frequency. In addition 3 sustainability criteria were set: (1) areas not requiring irrigation, (i.e. only rainfed areas are considered suitable; (2) protected areas are not suitable; and (3) only grasslands and pasturelands were considered suitable for dedicated energy crop establishment, assuming a nationwide transition from extensive to