Cotton stalks for power generation in Baja California, Mexico by SWOT analysis methodology

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Abstract

Baja California is a state located in the northwestern region of Mexico. From 2003 to 2013 the average cultivated area reported was 228,094 ha; 9.5% of that area was used for the cotton crop Gossypium Hirsutum variety. Cotton harvesting generates considerable amounts of cotton stalks as biomass residuals. Cotton stalks have a high energy potential currently unexploited productively, and whose disposition is open burning. This activity is performed because it reduces the costs of land preparation for the next agricultural cycle and also prevents the spread of pests and diseases in future crops. The use of agricultural biomass waste has acquired more international relevance as a source of renewable energy. The replacement of fossil fuels and mitigation of greenhouse gas emissions responsible for climate change are among the most important environmental benefits of bioenergy. Therefore, the aim of this work was to analyze the factors that would affect the development of a transformation industry of biomass into energy by SWOT methodology. The energy potential for heat and power generation from cotton stalks was estimated. The results highlighted that from cotton stalks it is feasible to obtain an average of 1.40 PJ annually, equivalent to 39,082.67 m^3 of diesel, and thus supply a power plant with 14.78 MW of installed capacity. This energy would contribute to the

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diversification of the energy matrix of Baja California, which currently depends on the external supply of fuels because it does not have proven reserves of petroleum resources.
Keywords: bioenergy, cotton stalks, power, renewable energy, SWOT analysis.

1 Introduction

Biomass is a renewable energy source whose utilization nowadays is being promoted and used worldwide. It is defined as organic matter generated from agricultural activities, livestock, and forestry, among others [1]. Biomass resources are highly available, and they have the advantage that can be exploited energetically in order to produce solid, liquid and gaseous fuels. It can be done through the implementation of thermochemical or biochemical processes. Biomass covered approximately 10% of the global energy supply by 2012. Roughly two-thirds (34 EJ/a) of the energy use of biomass took place in developing countries for cooking and heating. The remaining use of biomass (about 18 EJ/a) took place in industrialized countries, where biomass is utilized both in industrial applications within heating, power and road transportation sectors and for heating purposes in the private sector [2]. It is estimated that biomass could contribute from 20% to 25% of the global primary energy supply by 2030, doubling its share from 10% in 2010. Therefore, it will constitute one of the main components of energetic transition [3, 4].

Power generation from biomass has acquired importance worldwide. By 2012, the global installed biomass power generation capacity reached 83 GW, equivalent to 1.5% of global power generation capacity. Europe accounts for about the half of the biopower capacity share, as a result of strong policies to support its development. Asia Pacific and Latin American regions through 2020 are expected to reduce Europe's share [3].

1.1 Mexico energy outlook

In Mexico, primary energy supply was 9,020.21 PJ by 2013. Its energy matrix relied mainly on petroleum and natural gas resources with a share of 88.1%. The biomass share was 4.2% considering only firewood and sugarcane bagasse; it represented more than half of renewable sources in the energy matrix, as can be seen in fig. 1 [5]. So far in Mexico, the energetic use of biomass is limited to food cooking processes in rural areas and as fuel in sugar refineries [6]. Currently, Mexico has a total electrical installed capacity of 44,270 MW from fossil fuels and 15,896 MW from renewable energy sources. The 27% of national electricity generation is renewable and includes by order of importance hydro, geothermal, wind and biomass.

The biomass electricity generation is 1,324 GWh/year, and its total capacity is 634 MW. Private sugar producers mainly generate it through the direct combustion of sugar bagasse for self-power supply. The States from Mexico that produce biopower are Tabasco, Veracruz, Morelos, Jalisco, Michoacán, Colima, Tamaulipas, San Luis Potosí, Oaxaca, Quintana Roo, Sinaloa, Nayarit, Chiapas, and Puebla [7].

Actually, given the challenges that Mexico is facing in terms of energy security, decreasing of dependence to conventional energetics, as well as the reduction of greenhouse gases emissions, it is necessary to find alternatives in order to diversify the energy sources. For that reason, the Mexican government committed to sustainability has empowered the Secretariat of Energy based on international trends that postulate changing patterns of production and use of energy, to develop a national strategy for the energetic transition due to environmental, social, and economic issues. The energetic transition involves major changes, including the promotion of renewable energy sources e.g. solar, wind, biomass, hydraulic and the rational use of energy as key strategic actions. Therefore, it is essential to assess the availability of these resources and its feasibility of exploitation for energy production.

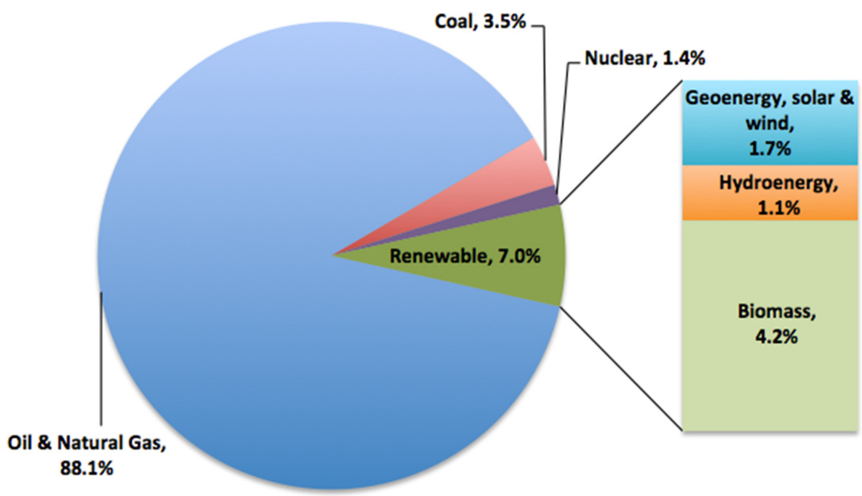

Figure 1: Primary energy supply of Mexico by 2013.

In 2014, the energy situation in Mexico had experienced a radical change with the approval of the Energy Reform. Its aim is to maintain the energy security of the country, economic connectivity and makes to the energy as a motor of the Mexican economy to create jobs and attract investments and technology. The main structural changes are established in the Reform such as the opening of the electricity market. It allows the private electricity producers to sell energy, not only in the self-supply modality as previously, but openly. Also, it removed entry barriers of the energy sector, allowing greater flexibility for private sector investment, promoting equitable and competitive conditions for all private generations including the Federal Electricity Commission.

In 2014, the Energy Transition Law was enacted. It regulates the sustainable use of energy and the obligations on renewable energy that will reduce the pollution emissions of the electric power industry. Also, it aims to keep the competitiveness of production sectors. Its main goal is to increase the share of clean energy production to 25% by 2018, 30% by 2021, 35% by 2024 and 40% by 2035.

1.2 Baja California energy situation

Baja California is located in the Northwest region of Mexico and is bordered to the north by the state of California, USA (as is illustrated in fig. 2). It does not have proven petroleum reserves at the moment. It is entirely dependent on fuels that are transported from the Port of Salina Cruz, Oaxaca to the Port of Playas de Rosarito. The electrical system of Baja California is off the grid of the national electric power distribution system. However, it is interconnected with two transmission lines of 230 KV to the electric grid of California, USA. The electrical system of Baja California has a total installed capacity of 2,280 MW. It counts with renewable and non-renewable power generation plants e.g. geothermal, wind, solar, gas turbine and combined cycle [8]. The geothermal field "Cerro Prieto", located in the Mexicali Valley, Baja California, is one of the largest fields in the world with a total installed capacity of 720 MW.

Figure 2: Baja California geographic location.

Baja California, despite having a high potential for biomass resources, does not have any industrial development for its utilization in energy production. Biopower is an alternative to produce green electricity compared with the conventional processes that burn NG, coal or fuel oil. Hence, it represents an opportunity to promote sustainable development especially in those regions with large areas of cultivated lands and important dynamics in the agriculture sector. That is the case of Baja California. From 2003 to 2013 had an average cultivated area of 228,094 ha, with 9.50% destined to cotton crop (*Gossypium Hirsutum*). The cotton crop is produced totally in the Mexicali Valley. The cotton harvesting generates cotton stalks as the main residue with a significant energy potential currently unexploited, and whose disposition generally is open burning or reincorporated to the soil. It is carried out to reduce costs in the land preparation for the next agricultural cycle and to prevent the spread of pests and diseases in future crops.

Therefore, the aim of this work was to analyze the factors that would affect the development of a transformation industry of biomass into energy by applying the SWOT (Strengths, Weaknesses, Opportunities and Threats) methodology. It was estimated the availability of waste biomass generated from cotton crop and its energy potential for heat and power generation.

1.4 Biomass energy conversion technologies

The use of biomass for electricity generation has its origin in the 70s as a result of the global energy crisis. The current situation requires the search and development of alternatives to oil and its derivatives. One of them is the use of residual biomass, which has a range of proven technologies for exploitation. Among the technologies mentioned are the following [9]:

- Pyrolysis. The process is carried out by the thermal decomposition of biomass in an anaerobic environment to produce steam or gases and condensable vapors. Combustion of these gases occurs in a gas turbine, usually combined cycle.
- Gasification. Biomass is partially oxidized by controlling the oxygen from the addition of steam to produce combustible gases, which have a high calorific value. Gases are fed to a gas turbine power plant in a combined cycle.
- Direct combustion. Direct combustion is the complete oxidation of biomass with excess air to produce carbon dioxide and water. The hot combustion gases are used to heat water and produce the steam process that feed a turbine, typically according to a Rankine cycle. This technology is the most ancient and simple, but inefficient. The gasification and pyrolysis have higher efficiencies but require significantly more process control and investment costs.

2 Materials and methods

2.1 Residual biomass estimation and energy potential

The estimated energy potential of cotton stalks depends on the cotton harvested surface, residue generation index and low heating value (LHV). Therefore, the database information related to cotton harvested surface from the State Office of Information for Sustainable Rural Development was analyzed. The period selected was 2003-2013. The table 1 highlights the cotton harvested surface of Baja California [10].

Table 1: Cotton harvested surface from 2003 to 2013.

Year	Harvested surface (ha)
2003	13,327
2004	17,686
2005	20,112
2006	23,194
2007	20,458
2008	19,672
2009	16,741
2010	18,659
2011	32,461
2012	32,125
2013	21,962

The cotton stalks LHV considered was 14.79 MJ/kg [11]. The residue generation index used was 4.42 t/ha of grown cotton [12]. According to eqn (1), it was estimated the amount generated from cotton stalks:

$$Q_{cs} = S_c\ I_r \tag{1}$$

where Q_{cs} is the quantity of cotton stalks (t), S_c is the surface of the cotton crop (ha), and I_r is the residue generation index (t/ha). For the determination of the cotton stalks energy potential, eqn (2) was used:

$$E_p = (Q_{cs}\ 1000)\ LHV \tag{2}$$

where E_p is the energy potential (MJ), and LHV is the low heating value (MJ/kg).

Once the energy potential was obtained, the electricity generation capacity from residual biomass was determined. It was considered a power plant that could operate under a Rankine cycle, with a conversion efficiency of 30% and an operation time of 11 months [13]. This plant would use direct combustion of biomass due to its technology requires less investment in physical and thermochemical treatment equipment for the processing material compared to pyrolysis and gasification.

The calculation of power generation capacity was based on eqn (3):

$$P_{gc} = (E_p/T_{op})\ E_f \tag{3}$$

where P_{gc} is the power generation capacity (MW), T_{op} is the operation time (s), and E_f represents the conversion efficiency. A comparison was made between the existing sources of electricity production in Baja California and a power plant operated with the estimated residual biomass.

2.2 SWOT analysis

The SWOT methodology was applied to evaluate the internal and external factors affecting the development of an industry for energy production and use from waste biomass, such as waste of cotton. The strengths and weaknesses of an industry are internal characteristics and are controllable while opportunities and threats are external factors that the industry has not direct control, but can react at a determining moment in their favor.

The implementation of SWOT analysis allows an industry to understand their strengths and exploit their opportunities and plan based on them, as well as recognizing, treating or avoiding their weaknesses and defend against any threat known. These factors were analyzed qualitatively [14].

3 Results and discussions

3.1 Residual biomass estimation and energy potential

Table 2 shows the results of cotton stalk generation, the energy potential and the equivalent in diesel for each year. The cotton stalk generation highlighted strong variations due to the changes of harvested cotton surface from 2003 to 2013. It can be observed that 15.45 PJ have been released by the traditional agriculture open burning practices of 1,044,870.76 t of cotton stalks, an amount equivalent to 429,909.41 m^3 of diesel. The annual average cotton stalk generation was estimated at 94,988.25 t with an energy potential of 1.40 PJ. They represent a considerable amount of waste biomass and energy potential that were unexploited.

From cotton stalks it would be feasible to supply a biopower plant in Baja California, in order to exploit these valuable energy resources productively. Figure 3 depicts the estimation of the installed power capacities related to cotton stalk generation from 2003–2013. The installed maximum power capacity was estimated at 22 MW by 2011 while the minimum was 9.17 MW by 2003.

The installed average power capacity was 14.78 MW for the entire period under study. It represents 1.48 times the installed capacity of the wind farm La Rumorosa, located in Baja California. A biopower plant with the average power installed capacity would generate 117,073.02 MWh. It is capable of covering the electricity demand of 33,555 residential users of Baja California, who have an annual average power consumption of 3,489 kWh per household [15].

Table 2: Cotton stalk generation and energy potential from 2003–2013.

Year	Cotton stalk generation (t)	Energy potential (PJ)	Equivalent diesel (m^3)
2003	58,905.34	0.87	24,236.45
2004	78,172.12	1.16	32,163.72
2005	88,895.04	1.31	36,575.64
2006	102,517.48	1.52	42,180.56
2007	90,424.36	1.34	37,204.87
2008	86,950.24	1.29	35,775.45
2009	73,993.45	1.09	30,444.42
2010	82,472.78	1.22	33,933.21
2011	143,477.62	2.12	59,033.50
2012	141,992.50	2.10	58,422.45
2013	97,069.83	1.44	39,939.13
Total	1,044,870.76	15.45	429,909.41
Average	94,988.25	1.40	39,082.67

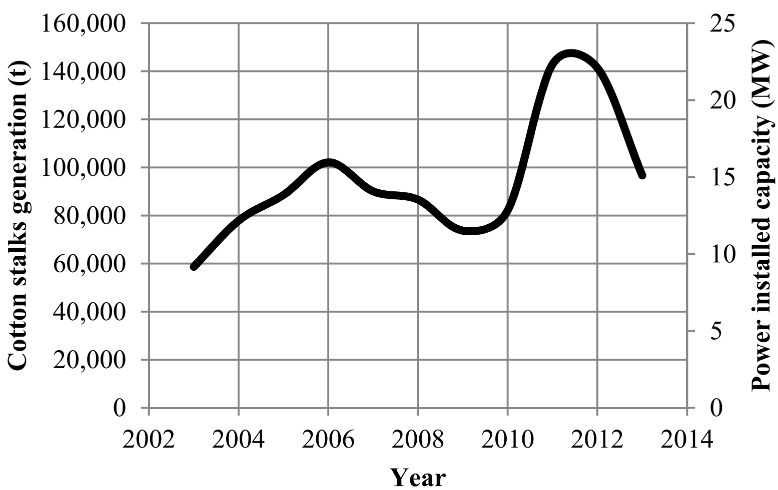

Figure 3: Power installed capacities related to cotton stalks from 2003–2013.

Table 3 shows the estimated energetic consumption for different types of existing power plants in the region, besides the biomass power plant, taking as basis the aforementioned gross electricity generation. As can be seen, the residual biomass utilization for electricity generation would significantly benefit the replacement of conventional fuels and emissions reduction.

Table 3: Energetic consumption by type of power plant.

Power Plant	Energetic	Consumption	Units
Geothermal	Geothermal vapor	939,924	t
Combined cycle	Natural gas	23,802,080	m^3
Simple cycle	Natural gas	28,471,387	m^3
Gas Turbine	Diesel	65,760	m^3
Biopower	Cotton stalks	94,988	t

3.2 SWOT analysis

Table 4 illustrates the SWOT analysis, which identifies each of the internal and external factors involved in the development of a biopower industry from residual biomass Baja California.

The main strength identified for the use of residual biomass as energetic for biopower in Baja California is its high availability. It favors the protection of the environment, because the pollutant emissions reduction, and sustainable development by avoiding the open burning of agricultural residues and by replacing a significant fraction of fossil fuels. The energetic use of biomass would help to ensure energy security and, on the other hand, to foster the economic development of the agriculture sector.

As relates to the weaknesses, the high cost of power generation from biomass is mentioned [9], since the latter has to be collected in agricultural fields, which involve machinery costs, labor, and fuel, among others. It also requires adequate conditioning of the biomass as the formation of briquettes or pellets to increase the density and to facilitate its transportation and processing. In addition, large spaces for storage should be considered for ensuring optimal safety conditions.

In order to mitigate the costs and boost the power generation from residual biomass, it is essential that the government being involved in the implementation of incentives and subsidies for producers and farmers (residual biomass suppliers) that, instead of agricultural waste disposal by burning, prepare it for biopower generation utilization.

The lack of experience in projects of this nature can cause projected investment costs to be exceeded. Therefore, training and increasing research and developing technologies for the use of biomass in the production of energy are required. Among the main threats to the development of a biopower industry are the biomass supply ensuring, crop harvested surfaces variations and social acceptability by farmers and rural communities. Hence, it is necessary to build win-to-win commercial alliances with farmers to assure the biomass supply using long-term contracts. Also, it is important to involve the rural communities in the awareness and importance of biopower generation by showing them the implied benefits.

Public policies and the establishment of mandates are necessary to promote and guarantee biopower production and consumption by public or private sectors in a competitive environment. If this is not possible in the short term, it is

Table 4: SWOT analysis.

Strengths	Weaknesses
Intensive agriculture activity in Baja California. Sustainable exploitation of residual biomass. Proven technologies for biopower generation. Fostering economic development of agriculture sector. Greenhouse gas emissions reduction by fossil fuels replacement. Pollutant emissions reduction by avoiding open burning of crop residues. Substitution and reduction of fossil fuels use. Ensure energy security.	Biomass is not concentrated. Low bulk density of biomass. High cost of biopower generation. Large distances from biomass generation place to biopower plant. Biomass collection, handling, conditioning, packaging, storage and transportation. High cost of biomass collection. Lack of experience in biopower plants in the region.
Opportunities	**Threats**
Increasing trend of electricity demand. National Law of Energy Transition. Interconnection to electrical grid of California. Openness of electricity market guaranteed by the recent Energy Reform. Ambitious goals of energy sector to increase the electricity share from renewable sources. Favorable policies for the development of renewable energy in Baja California. Research and development infrastructure available.	Low national investment level in biopower plants. Few funding channels. Traditional open burning crop residues practices. Lack of mandates for biopower consumption. Lack of public policy to foster the development and use of biopower. Ensuring the biomass supply with farmers/long contract terms. Social acceptability by rural communities. Price of residual biomass. Crop harvested surface variations.

feasible to exploit the existent electrical interconnection between Baja California and California, with the possibility of exporting energy to that state since its objective for 2020 is to supply 33% of its electricity from renewable sources, even when it is imported.

The current economic situation of the energy sector of Mexico is leading to a number of opportunities to increase the renewable energy share in the energy matrix. Renewable energy is an alternative to a petroleum-based economy that in the recent years has shown high prices fluctuations of crude oil. The regulatory framework was already established, and it is comprised in the laws of energy transition, promotion and development of bioenergy and renewable energy from Baja California. However, there is the need to pass from laws to mandates in order to encourage and increase the renewable energy market in Mexico.

4 Conclusions

The SWOT analysis for the development of a transformation industry of biomass into energy was applied. The energy potential for heat and power generation from cotton stalks was estimated. The energy potential of cotton stalks from Baja California highlighted a significant value, which is currently unexploited by open burning practices performed by farmers. The use of these resources for biopower generation involves important advantages to replace the use of fossil fuels, to reduce greenhouse gas emissions and to foster the development of the agriculture sector. To break the status quo in terms of the development and the use of biomass for power generation in Baja California, it is necessary an ideal platform for the promotion of projects of this nature, including public policy and mandates that establish the obligation to consume biopower. Therefore, it is necessary for the government that productive and educational sectors form a synergy to promote and to encourage the participation of renewable energy aimed toward an energy transition based on sustainability. It is recommended to perform technical and economic evaluations with the objective of determining the feasibility of biomass energy use of cotton stalks.

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