Exploitation of Agricultural Crops and Waste for the Production of Biofuels in Libya

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ABSTRACT

This study aims to analyze the possibility of exploiting productive agricultural crops and agricultural waste in Libya to produce biofuels, and to evaluate the technical aspect associated with this technology. The study sheds light on seven agricultural projects located in the Libyan desert; the projects contain number of agricultural portfolios of crops such as wheat, barley, palm, willow, beans, with a total area of about 41000 hectares. From the reviewed agricultural projects, potential of modern biomass to produce various biofuels is investigated. Bioenergy Simulator tool developed by International Renewable Energy Agency (IRENA) was used to determine the potential of biofuel production from agricultural waste in Libya. The study shows that the agricultural residues available in Libya such as grain straw, palm trees, and others are of high potential in the production of biochar and methane gas, using pyrolysis techniques. The highest production of biochar and methane gas was for the date palm crop, where about 2 tons of biochar and about 6000 m^3 of methane gas can be produced per hectare of the crop. In economic perspective, the technology can be cost-effective in terms of increasing agricultural land productivity, and creating new job opportunities.

الملخص

تهدف هذه الدراسة إلى تحليل إمكانية استغلال المحاصيل الزراعية المنتجة والمخلفات الزراعية في ليبيا لإنتاج الوقود الحيوي، وتقييم الجانب الفني المرتبط بهذه التكنولوجيا. تلقي الدراسة الضوء على سبعة مشاريع زراعية تقع في الصحراء الليبية؛ وتحتوي المشاريع على عدد من المحاصيل الزراعية مثل القمح والشعير والنخيل والصفصاف والفاصوليا، بمساحة إجمالية تبلغ

حوالي 41000 هكتار. من خلال المشاريع الزراعية التي تمت مراجعتها، تم دراسة إمكانات الكتلة الحيوية الحديثة لإنتاج أنواع مختلفة من الوقود الحيوي. تم استخدام أداة محاكاة الطاقة الحيوية التي طورتها الوكالة الدولية للطاقة المتجددة (IRENA) لتحديد إمكانية إنتاج الوقود الحيوي من النفايات الزراعية. تبين الدراسة أن المخلفات الزراعية المتوفرة في ليبيا مثل قش الحبوب وأشجار النخيل وغيرها ذات قدرة عالية في إنتاج الفحم الحيوي وغاز الميثان باستخدام تقنيات الانحلال الحراري.
وكان أعلى إنتاج للفحم الحيوي وغاز الميثان لمحصول نخيل التمر، حيث يمكن إنتاج حوالي 2 طن من الفحم الحيوي وحوالي 6000 م3 من غاز الميثان لكل هكتار من المحصول. من المنظور الاقتصادي، يمكن أن تكون التكنولوجيا مناسبة من حيث التكلفة من حيث زيادة إنتاجية الأراضي الزراعية، وخلق فرص عمل جديدة.

Keywords: Agricultural waste, biochar, bioconversion, methane gas, sustainability

Introduction

Libya is a member of the OPEC organization; with 48 billion barrels and 1.5 trillion m^3, the African nation holds the largest and fifth-largest of proved oil and gas reserves in the continent, respectively [1]. Nevertheless, this is only equivalent to approximately 77 and 100 years, based on the pre-war production levels, before they diminish. As the production of electrical power in Libya is entirely dependent on fossil fuels, this situation has severe consequence on sustainability and social welfare. Moreover, the primary contributor of greenhouse gas (GHG) emissions is carbon dioxide (CO_2) that is 90% of its stake stem from traditional fuel combustion [2]. Figure 1 depicts the GHG emissions in Libya between 1990 and 2015.

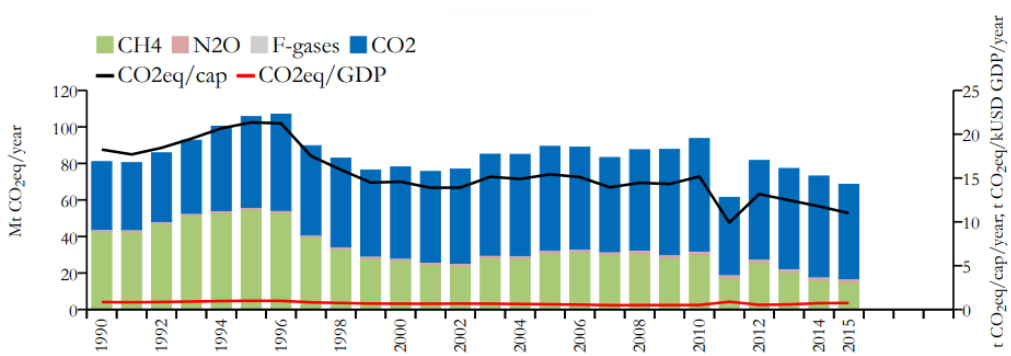

Figure 1. Greenhouse gas emissions in Libya [3]

Nevertheless, in recent years, there has been great interest in biomass specifically Jojoba to be planted in southern Libya. Besides its contribution to the environment and spatial development of the Libyan desert, Jojoba or Simmondsia chinensis can produce an organic oil and liquid wax ester that are extracted from its seeds. Biomass or bioenergy electricity generation spans a wide range of technologies and feed stocks which range from low-cost, mature option, like the combustion of agricultural and forestry residues (traditional biomass), to more expensive, and/or less mature options, like modern biomass energy, including methane, biological fuel oil, fuel ethanol, etc. While the direct combustion of biomass has a lower efficiency of 5–15% and produces large amounts of GHG emissions; modern biomass, on the contrary, has a higher efficiency typically 60–90% with stringent emissions control [4]. For this reason, more and more countries turn to utilize the modern biomass.

Bioenergy is an important source of energy, which can be utilized in various uses such as electricity generation, cooking and heating, transport using biodiesel, etc. In Libya agricultural land including permanent meadows, pasture and cultivated land covers a total of 15.35 million hectares constituting 9% of the total area of the country. The cultivated area which include arable land and area under permanent crops extends over 2.1 million hectares [5]. Though bioenergy has a significant potential in Libya, it has no contribution in the time being. Pertaining to fruit trees, they can be used as lignocellulosic feed stocks. In Libya the available fruits are: apple, peach, date palm, figs, olives.

As mentioned earlier, Libya relies heavily on fossil fuels as a dominant source of energy which makes it vulnerable to fluctuations in oil and gas prices, and contribute in harmful emissions. Therefore, bioconversion technology to produce biochar and methane gas could be a good option to promote renewable energy in Libya and achieve energy security and economic sustainability.

1. Biofuel Production in Literature

Very limited works have been carried out to study the modern biomass potential in Libya and all the available works have focused on the quantitative estimation of MSW and its management. Hamad, et. al. [6] have analyzed the potential of methane production from organic waste to provide both electricity and heat for the Omar Almukhtar University campus. Through anaerobic digestion of organic feedstock such as food waste, wastewater, agriculture and animal waste, which have been estimated at Al-Baida city, could produce 674 m^3/h and 37 MJ/m^3 of methane and heat, respectively. In another study, polyethylene and polypropylene plastic waste were quantified throughout Libya and its conversion into fuels and chemicals was estimated [7].

Municipal solid waste (MSW) is a type of biomass that mainly consists of waste and residue of food, plastics, glass, metals, wood, paper, yard, rubber, leather, and textiles. Generally, incineration (combustion), gasification, and pyrolysis are the three thermochemical conversion processes of MSW [8]. The waste discard is still a tremendous issue in all Libyan cities. On the other hand, share of modern biomass and liquid biofuels in total final energy consumption in Libya was reported at 0 % in 2012, according to the World Bank collection of development indicators, compiled from officially recognized sources. This situation has not changed as of 2023.

Libya has huge agricultural areas of date palm and olive trees. A qualitative analysis study conducted in the third largest city in Libya, Misrata, indicated that the yearly generated MSW in the city amounts to 0.155 Mt of which organics were identified as the major component (56%), followed by plastics (26.5%), and the paper had the third highest percentage of solid waste (8%). While only 10% of the collected MSW, as a current practice, ends up with organic fertilizer plants while the rest is either buried or combusted in open landfills; the study proposed an incineration plant that could generate about 36 GWh/year using 70% of the waste input [9]. The quantity of solid waste generated in Benghazi is estimated to be 750 tons per day of which 28-30% was found in bio-degradable materials. The bio-degradable materials include food and kitchen waste, green waste, and recycled paper [10].

Regarding the productive agricultural projects in Libya, most of the projects have been established and managed by the government aiming at self-sufficiency. The fields of these projects are mostly in the form of circles and the irrigation system used is of the center pivot one. The projects include Al-Kufra agricultural project, Al-Ariel project, Maknousa, Tawasawa, Barjouj, and Eraun with a total cultivated area of about 40,000 hectares. Generally, wheat and barley cover a total of 20% of the cultivated area of the aforementioned projects, maize covers nearly 15% of the total area while 10% of the total area are devoted for date palm besides other miscellaneous crops. As for the expected production of biochar and bladder gas, it depends on the conditions surrounding the project and the technologies used in production, and therefore it is difficult to determine with great accuracy [11].

2. Average Production of Biochar and Methane Gas

The expected amount of biochar and methane gas production from the six productive projects can be calculated based on the expected proportion of each type of crops, and the expected efficiency of the biochar and methane gas production process.

The following mathematical formulae can be used to produce biochar and methane from different crops [12]:

$$Biochar\ production\ (bp) = raw\ material\ quantity\ (q)\ x\ carbonization\ rate\ (cr)\ x\ biochar\ yield\ (by) \tag{1}$$

where:

bp and q are estimated in tons, cr is the refining percentage (%), and by is the proportion of biochar from raw materials (%).

The following expression estimates the methane gas production [13];

$$Methane\ gas\ production\ (mgp) = raw\ material\ quantity\ (q)\ x\ methane\ yield\ (my)\ x\ methane\ content\ (mc)\ x\ correction\ factor\ (cf) \tag{2}$$

Where mgp is the amount of methane produced (million cubic meters), my is the percentage of methane production from raw materials (%), mc is the percentage of methane in the produced gas (%) and finally cf is the correction factor (reflects losses in the production process).

if it is assumed that the efficiency of biochar and methane gas production from willows is about 20% [14], then it is expected to produce about 1.6 tons of biochar and about 4800 cubic meters of methane per hectare of willows. For other crops, available data on biochar and methane gas production efficiency from different crops can be used and determined accordingly. Table 1 tabulates the anticipated production for the dominating crops.

Table 1: *Biochar and methane production of different crops [14]*

Crop	Biochar Production (tons/hectare)	Methane Production (m^3/hectare)
Wheat	0.5	1,500
Barley	0.4	1,200
Maize	0.8	2,400
Beans	0.3	900
Palms	2	6,000

3. Production of Biofuel from Agricultural Waste

A tool for bioenergy [15] which was developed by IRENA has been used in this paper to study the biomass potential for Libya, Figure 2, with the focus on the region extending from Benghazi to Darna eastward including the Green Mountain. The eastern region has been gifted with forests, rain fall and vegetation diversity. The potential of crops, agricultural residues, livestock waste, and forest plantations can be obtained by the bioenergy simulator. In this study, potential of bioenergy crops and agricultural residues has been calculated. On the contrary, the livestock waste bioenergy potential was not carried out due to the lack of accurate data related to the number of animals' heads. Types of crops and biomass feedstock are a key driver in determining the bioenergy output performance along the supply chain. Table 2 shows the types and average yield of different crops within the confined area considering rain-fed condition.

Figure 2. Confined study area for biomass potential

Table 2: *Bioenergy crops and average yield in Libya [15]*

Crop	Harvested product	Average yield (t/ha)	Bioenergy end-use	Conversion technology
Maize	Grain	0.1	Transport	Ethanol-engine
Sugarbeet	Sugar	0.9		
Groundnut	Groundnut in shells	0.2	Heat & power Electricity Transport	Biodiesel CHP-engine Vegetable oil CHP-engine Biodiesel engine Vegetable oil engine Biodiesel engine
Rapeseed	Seed	0.5		
Soybean	Grain	0.2		
Sunflower	Seed	0.3		

The solid biomass can exhibit a variety of characteristics depending on its origin (e.g. sawdust, wood, leaves, dried animal dung, agricultural residues) and on conditions during the harvest and storage phases of the crop (e.g. growth status of the plant, temperature, humidity). Bioenergy potential from agricultural residues in Libya was also obtained from the Bioenergy Simulator and the results are tabulated in Table 3. Energy yield is represented as minimum which resulted from maize husk and maximum value which obtained from wheat straw. The energy yield also depends on the conversion technology. For example, for electricity production using gasification steam turbine, the gross electricity production ranges from 108 GWh for maize husk feedstock to 7567 GWh when wheat straw feedstock is used. The maximum electrical energy yield for wheat straw is gained when combustion steam turbine technology is involved where the gross electricity production is 10926 GWh. For H&P or cogeneration utilization, biomethane-CHP-gas turbine is the suitable technology for maize husk which can produce 118 and 151 GWh of gross electricity and heat respectively. On the other hand, combustion-CHP-steam turbine is the most appropriate technology for wheat straw which can produce 10926 and 27314 GWh of gross electricity and heat respectively. Considering that the average annual electricity consumption in Libya is 3.9 MWh per capita [16], the estimated electricity production could supply 2,782,594 people a year [10].

Table 3: *Bioenergy agricultural residues and average yield [15]*

Crop	Residue (feedstock)	Average yield (t/ha)	Bioenergy end-use	Conversion technology	Energy yield (GWh)
Barley	Straw	0.4	Electricity	Biomethane-engine	101(maize husk) - 6292(wheat)
				Biomethane- gas turbine	118-7340
				Biomethane-steam turbine	67.4-4194
				Combustion-steam turbine	21.8-10926
				Gasification-steam turbine	108-7567
			Heat	Biomass- combustion boiler	98-49165
			Heat & power	Biomethane-CHP engine	[101P,151H]-[6292P,9438H]
				Biomethane-CHP- gas turbine	[118P,151H]- [7340P,9438H]
				Biomethane-CHP-steam turbine	[67P,168H]-[4194P,10486H]
				Combustion-CHP-steam turbine	[22P,54H]-[10926P,27314H]
				Gasification-CHP-steam turbine	[108P,243H]-[7567P,17027H]
			Transport	Ethanol 2nd gen.-engine	6.6-520 L/ha (ethanol)

Bioethanol is an alcohol obtained by sugar fermentation or starch produced from certain crops (e.g. wheat, maize, sugarcane, sugar beet). The least complex technology for bioethanol production involves sugar feedstock, e.g. plants containing simple sugars, which can be fermented by yeast or other microorganisms directly into ethanol. The addition of a second enzyme is required for starchy plants to convert the starch to fermented glucose (saccharification process). An internal combustion engine (ICE), which can be fed with fossil fuels such as diesel, gasoline, or natural gas, can also be fed with renewable energy sources such as bioethanol, biomethane, biodiesel, and vegetable oils.

4. Conclusions and recommendations

Sustainable agricultural projects that use bioconversion technology to produce biochar and methane from agricultural waste represents one of the promising solutions to generate clean and sustainable energy (heat and power) and reduce greenhouse gas emissions. The conducted quantifying study found that the highest production of biochar and methane gas was for the date palm crop, where about 2 tons of biochar and about 6000 cubic meters of methane gas can be produced per hectare of the crop.

For the total crop area, it is projected that up to 60% of crop residues can be converted into biochar and methane using bioconversion technology, which means that about 67 hectares of agricultural crops can be converted into clean and sustainable energy source. The estimated values suggest that producing biochar and methane from different crop types could generate varying levels of revenue. Due to the growing interest in renewable energy and sustainable development, this technology may become cost-effective and thus receive great attention in the future. However, detailed feasibility analysis is needed for the technology. Also, establishment of some prototype especially in large cities would give more seriousness and concern for the technology.

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