Bakhta RECIOUI/*Afr.J.Bio.Sc. 6(14) (2024)* *ISSN: 2663-2187*

https://doi.org/10.48047/AFJBS.6.14.2024.9077-9089

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Assessment of biomass's potential in Algeria: energetic valorization and CO_2 emissions mitigation

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Volume 6, Issue 14, Aug 2024

Received: 15 June 2024

Accepted: 25 July 2024

Published: 15 Aug 2024

doi: 10.48047/AFJBS.6.14.2024.9077-9089

Abstract

Biofuels remain a promising option in the quest for alternative energy sources. Biofuels are produced using sustainable techniques, in contrast to fossil fuels. Using biomass to generate biofuel stands out as a particularly attractive choice among the several production methods. In the context of a circular and sustainable economy, Algeria offers enormous potential for valorizing animal and vegetable waste. These waste supplies, mainly from the agri-food and agricultural industries, can be converted into fertilizers, energy sources, or raw materials for other goods. Utilizing these energy sources will significantly reduce greenhouse gas emissions into the atmosphere and contribute to preserving the nation's resources. This study aims to investigate Algeria's biofuel potential as an alternate energy source by evaluating the deposits of organic fractions from generated animal and vegetable waste and their potential for energy recovery. The recycling of waste has allowed the generation of 8.727 TWh of energy annually, resulting in a 12% increase in primary energy. The decrease in CO_2 emissions is significant, with an estimated annual reduction of 5 million tons of CO_2. This reduction in CO_2 emissions provides a 7% decrease compared to the present situation.

Keywords: Organic waste, Biofuel, Power, Potential, CO_2 emission

1. Introduction

The economic development associated with population growth and lifestyle changes has led to increased energy consumption in Algeria in recent years (Recioui et al., 2016). The country consumes an enormous amount of fossil energy, representing more than 90% (Ghedamsi, 2016). Thus, Algeria plans to steer its energy policy recently and further increase the use of renewable energies. The capacity of the renewable energy program needed to meet the national market's needs from 2015 to 2030 is estimated at 22,000 MW (CDER, 2011). The implementation of this program will allow for achieving, by 2030, a share of renewables of nearly 27% in the national electricity production balance. Biomass will contribute to implementing this program, which has a capacity of 1,000 MW (CDER, 2016). Using biomass as a renewable energy source is essential for Algeria's sustainable energy policy development (Recioui, 2017). The use of organic residues or energy crops for energy production is very diverse, whether to generate heat and electricity or to produce certified biofuels (Ghedamsi, 2024). Furthermore, this source's energy recovery addresses energy concerns and environmental and health issues.

The current potential of biomass is estimated at around 37 Mtoe in Algeria (MATE, 2010). The recoverable potential is on the order of 3.7 Mtoe. The recovery rate hovers around 10%, resulting in the non-recycling of 5 million tons of urban and agricultural waste. This potential represents a resource of approximately 1.33 Mtoe/year (ME, 2012). However, based on specific environmentally more sustainable processing methods that are technologically and economically accessible in Algeria, these deposits can be preferentially quantified in terms of resources. Indeed, mechanization not only allows for the treatment and stabilization of organic waste but also provides the opportunity to valorize this waste as a source of energy (cooking, lighting, electricity) and as a source of fertilizing materials for agriculture. Methanization has the merit of being simultaneously a renewable energy production pathway and an alternative method for treating organic waste.

The aim of this work is to estimate the energy potential of organic waste in Algeria. This source is sustainable and available in enormous quantity. This study will only utilize vegetal waste from olive trees, palm trees, and citrus fruits, as well as animal waste from cattle. The study also investigates the impact of waste conversion on energy production and carbon dioxide emissions in Algeria. This study represents a deeper analysis, which is often necessary for understanding energy policies.

2. Biomass: source of energy (bioenergy)

Biomass currently accounts for about 12% of global primary energy needs. According to the hypotheses and scenarios, it could meet 15 to 35% of global energy needs by 2030–2050. (Couhert, 2007). Energy production from biomass can be achieved through direct combustion, thermochemical processes, or biological processes such as ethanol fermentation and anaerobic degradation, which produce biogas or biohydrogen (Ghizzi, 2011). The different ways to use bioenergy are (RMT, 2012):

Production of electricity and heat using power plants that utilize biomass (primarily wood as raw material), biomass heating plants (wood, peat; they can also be decentralized), biogas plants. (biogas is produced by fermentation). Fuels in the form of:

- 1st generation: bioethanol (fermentation of sugar), vegetable oils (rapeseed, soybean), biodiesel (transesterification of vegetable oils), biomethane (derived from biogas);
- 2nd generation: fuels from the BTL (biomass-to-liquid) process and cellulose-derived bioethanol;
- 3rd generation: fuels obtained from algae.

According to forecasts from the International Energy Agency (IEA), biomass is the renewable energy source that will grow most by 2030. It could provide 30% of the energy consumed in the world by 2050, compared to 10% today (AIE, 2011).

3. Different pathways for energy conversion from biomass

Two families of biomass energy conversion processes are commonly distinguished: on the one hand, the thermochemical pathways, also known as dry pathways, which transform biomass under the action of heat, and on the other hand, the biochemical pathways, also known as wet pathways, which rely on biological conversion processes (Benoist, 2009; Chieng et al., 2020). Figure 1 shows different pathways of biomass conversion.

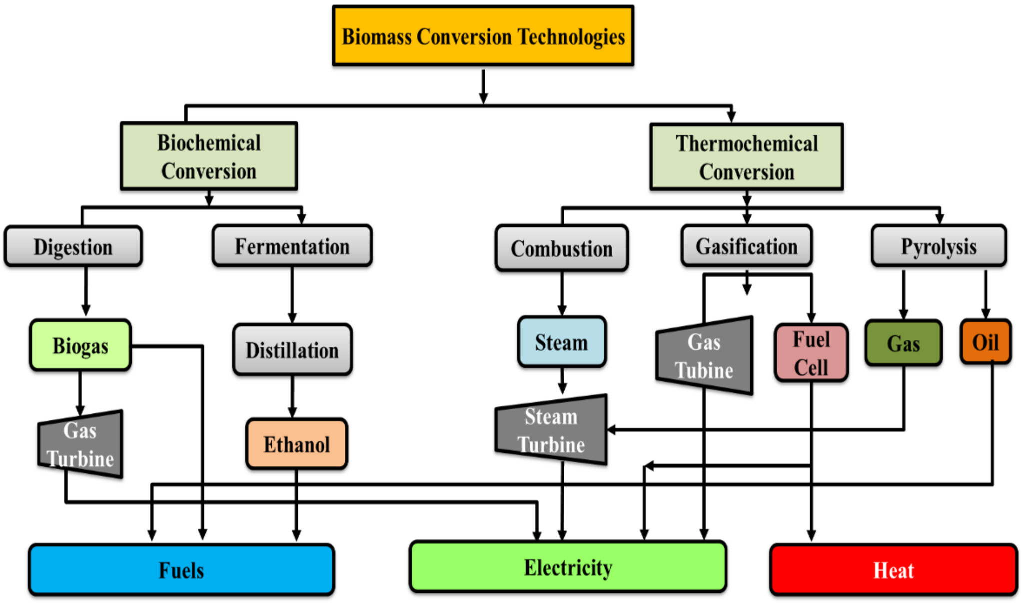

Figure 1. Energy conversion of biomass (adapted from (Morency, 2011)).

3.1. Thermochemical conversion of biomass

a. Direct combustion

Combustion is the simplest way to recover the energy contained in biomass. It directly releases the heat contained in biomass. At the same time, other valorization methods operate on the principle of converting biomass into an energy carrier that is easier to store or transport, with the final transformation into sound energy occurring at a different time and place. The raw material is burned to produce heat and electricity through a steam turbine (Chieng et al., 2020).

b. Pyrolysis

Pyrolysis is the first step in any thermal treatment of biomass that does not involve oxidizing agents. Under heat action, biomass is decomposed into three main phases, whose relative importance varies depending on the operating conditions (Couhert, 2007). In contrast to combustion, pyrolysis is a thermal degradation of biomass without oxygen, so it does not undergo oxidation (Benoist, 2009).

c. Gasification

Gasification is a thermochemical transformation of a solid fuel (coal, wood, straw, etc.) in the presence of a gaseous compound (O_2, air, CO_2, water vapor, etc.). It involves transforming the raw material into synthesis gas, or syngas. This gas mainly contains water, carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), and methane. (CH_4) ((Benoist, 2009; Chieng et al., 2020). An initial pyrolysis stage precedes it, producing a mixture of condensable and non-condensable gases through thermal decomposition and char, a type of residual charcoal. Gasification then transforms a part of this coal into syngas. Since the pyrolysis reaction is endothermic, it requires the heat supply to continue. Different gasification technologies exist: fixed bed, fluidized bed, and entrained flow (GRDF, 2013).

3.2. Biochemical conversion of biomass

a. Fermentation

Fermentation is a biochemical reaction that involves releasing energy from an organic substrate through the action of microbial enzymes and expelled products. This reaction does not involve oxygen, so it takes place without air (anaerobiosis). It is distinguished from respiration, which requires oxygen and occurs in the presence of air (aerobiosis), particularly by its low energy yield and the diversity of synthesized products (Awasthi et al., 2021; Chieng et al., 2020)

b. Digestion

Anaerobic digestion, or mechanization, is the transformation of biomass into biogas (methane and carbon dioxide) by a complex natural microbial community in organic matter. Methanization produces 4 to 5 times more energy than it consumes (Couhert, 2007).
Consequently, biomass can be used for various purposes (Morency, 2011; Awasthi et al., 2021), such as:
• heat production (heating of facilities, industrial processes, etc.).
• electricity production.
• the simultaneous production of heat and electricity (cogeneration); and
• as fuel in the transportation sector (cellulosic ethanol).

4. Overview of waste potential in Algeria

This study aims to identify and quantify the potential for organic waste. Within the scope of this work, we will analyze potentials from agriculture, forestry, waste management (household waste), and animal waste and assess possibilities for sustainable usage.

4.1. Vegetable waste

Vegetable waste refers to raw kitchen waste such as coffee grounds, tea leaves, peels, leftover food, and garden waste like grass clippings and branches. Cooked kitchen waste is accepted in anaerobic digestion (Awasthi et al., 2021). Valuable vegetal waste can be processed using two distinct techniques.

Composting is the treatment in the presence of oxygen, while mechanization is the treatment in the absence of oxygen. These two treatment methods allow a portion of the organic matter extracted by human activities to be reintroduced into the material cycle. For calculating the agricultural potential of biomass, plant waste is a source of energy; we can consider the following types of waste (Couhert, 2007; Chieng et al., 2020):

• Those that appear in the primary processing of the harvest (everything that remains after the extraction of cereal grains, sunflower seeds, etc.)
• Those we leave in the fields during the harvest. (straw etc.).
• Those who remain in the ground (roots etc.).

a. Olive trees

In 2016, the olive grove reached 471,657 hectares. The total number of olive trees has increased by 10% since last year, reaching nearly 6,200,000. The wilayas of Béjaia, Skikda, Saida, Djelfa, and Chlef had the most growth in the number of olive trees planted nationally, accounting for 64% of the total (NOS, 2015; 2020). Furthermore, the number of olive trees has increased, rising from 32 million in 2015 to nearly 35 million in 2016, indicating that 2,439,033 olive trees have entered production. Figure 2 illustrates the evolution of olive trees in Algeria from 2000 to 2020.

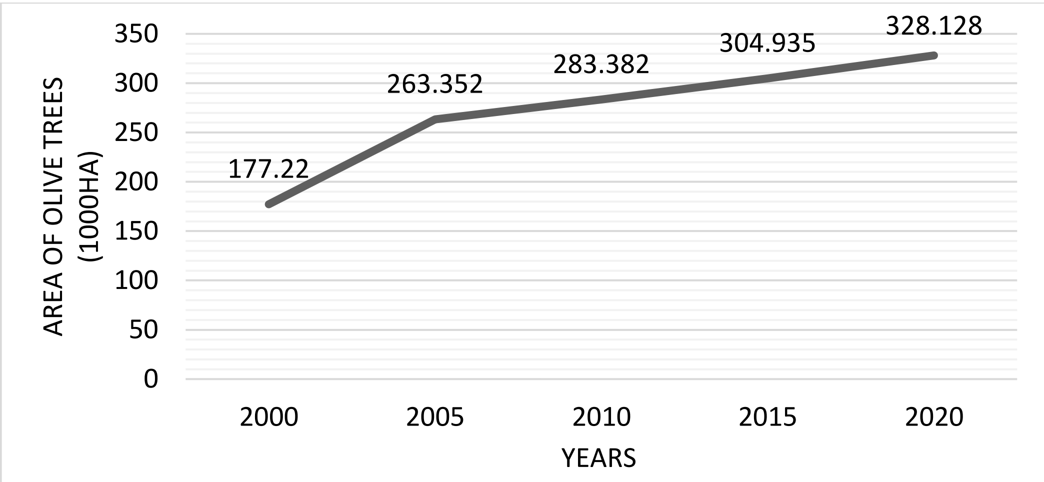

Figure 2 : Evolution of the area of olive trees (2000-2020) (NOS, 2015; 2020).

In Algeria, the area of olive trees was approximately 177 220 hectares in 2000, which has significantly increased each year to 328128 hectares in 2020.

b. Palm trees

In Algeria, the date palm is primarily grown in the Saharan provinces. The Algerian date palm potential is experiencing significant growth, with a population that, in 2020, approached 21 million date palms over an area of 187,287 hectares (NOS, 2015; 2020).

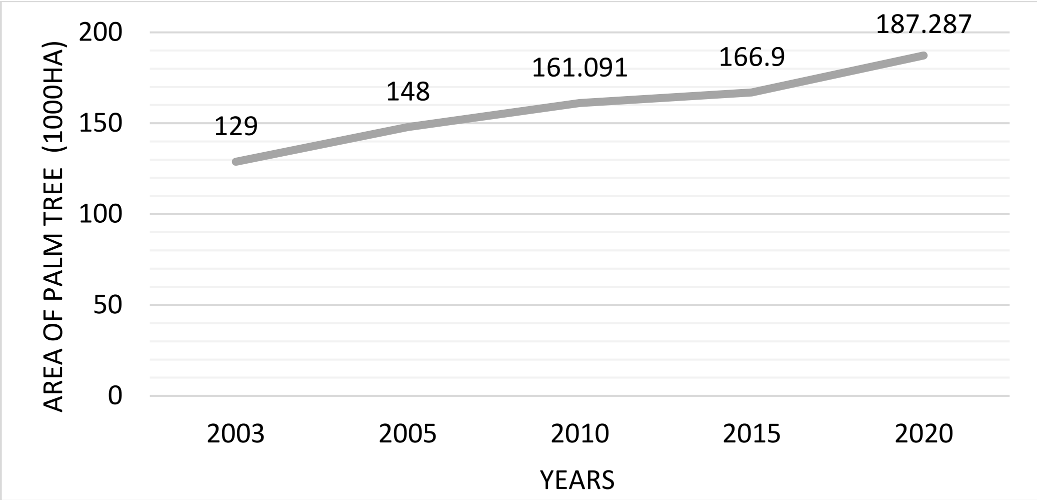

Figure 3: Evolution of palm tree area (2003-2020) (NOS, 2015; 2020).

Figure 3 illustrates the notable rise in palm tree coverage from 128,800 hectares to 148,000 hectares between 2003 and 2005. The area remained constant between 2010 and 2015 before rising to approximately 187,287 hectares in 2020. The date palm regions are generally located south of the Saharan Atlas and cover 17 wilayas: Biskra, with 27.4% of the total area, 23.1% of the total number of date palms, and 41.2% of the national date production, followed by the wilaya of El Oued with 22%, 22.4%, and 25%, respectively (NOS, 2015; 2020). These two wilayas alone account for over two-thirds (2/3) of the national date production.

c. Citrus trees

At the time of independence, Algeria had 45,000 hectares of citrus fruit. Indeed, in 2011, the citrus fruit area spanned 63,323 hectares. Out of 63,323 hectares, only 55,000 are currently productive (NOS, 2015; 2020). The country's center accounts for 56% of this citrus area, 30% is in the east, and 14% is in the west. (NOS, 2020). highlights the excellent methods our forefathers employed in their orchards in the past. Furthermore, he highlights the high appreciation for the taste of Algerian oranges.

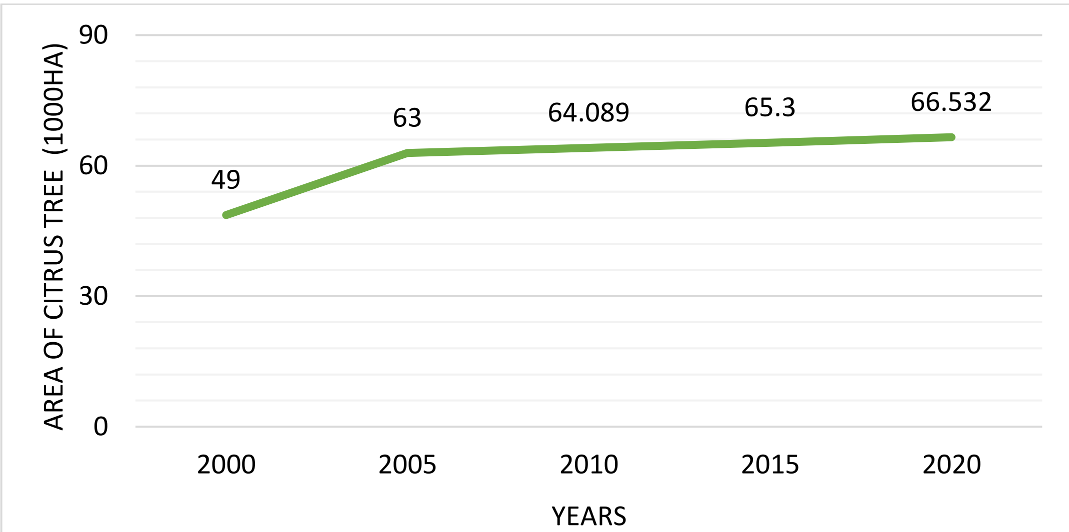

Figure 4: Evolution of citrus tree area (2000–2020) (NOS, 2015; 2020).

The citrus area in Algeria was approximately 48,640 hectares in 2000 and then gradually expanded to 66,532 hectares in 2020. The main citrus-producing wilayas are: Blida (15,809 ha), Chlef (5,777 ha), Algiers (5,065 ha), Relizane (4,417 ha), Mascara (4,232 ha), Mostaganem (4,079 ha), and Tipaza. (3725 ha).

4.2. Animal waste

a. Cattle

The livestock sector, particularly sheep, goats, and camels, plays an essential role in the economies of certain countries because it produces biogas from animal manure. In this study, we focus on bovine waste. Cattle farming in Algeria has seen remarkable development from 2002 to 2020, as shown in the figure below.

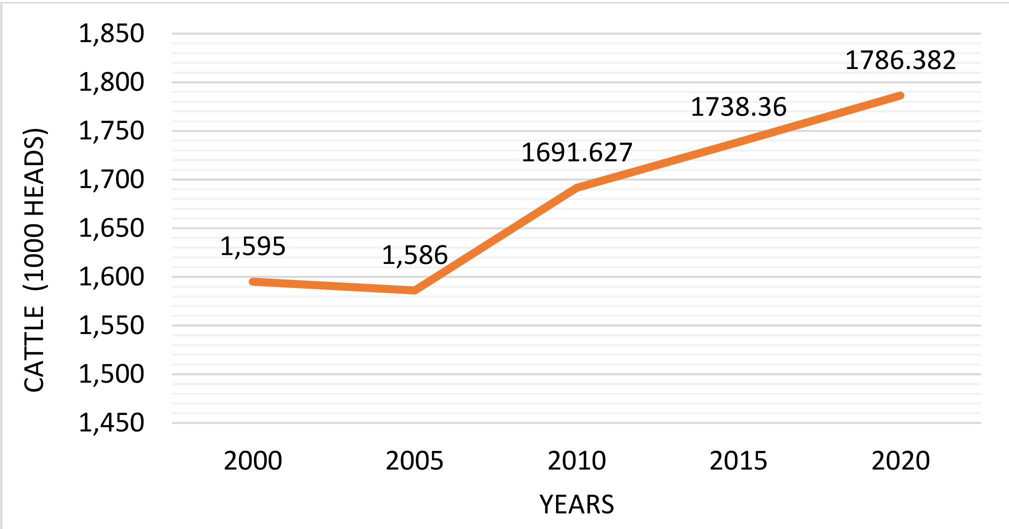

Figure 5: Evolution of the cattle population from 2000 to 2020 (NOS, 2015; 2020).

According to NOS, The cattle herd reached 1.68 million heads in 2009 compared to 1.64 million heads in 2008, representing a decline of 2.3%, thus extending its upward trend (NOS, 2015; 2020).

5. Methodology

The methodology for evaluating organic waste deposits of plant and animal origin is based on a data cross-referencing approach using fruit trees (olive, citrus, and palm) and animals (cattle). We use the year 2020 as a reference point. The calculations for Algeria's biomass potential are based on data from the National Office of Statistics (NOS). The method applied in this perspective aims to construct representations of possible futures and the pathways that lead to them. These representations aim to shed light on the trends in waste production and valorization, as well as their impact on the environment. In our study, electricity is the only energy to be evaluated.

5.1. Power production assessment

According to published scientific reports and reference papers, the determination of the quantity of vegetal waste (olive, citrus, and palm trees) $Q_{vegetal\,waste}$ is estimated from cultivated area $A_{cultivated}$(ha) and waste yield Y_{waste} (tons/ ha) is as follows (Ardebili 2020) (Yaqoob, Teoh et al. 2021) (Ali, Ndongo et al. 2020):

$$Q_{vegetal\,waste} = A_{cultivated}.Y_{waste} \qquad (1)$$

$$P_{Power} = Q_{vegetal\,waste}\,.F_{powre} \qquad (2)$$

Where: P_{Power} (TWh) is the theoretical power potential and F_{powre} (kWh/m^3) is the conversion coefficient biogas to power. Table 1 and 3 shows the values of the conversion coefficients for each type of waste used to calculate the total quantities of organic waste and the theoretical energy potential.

Table 1: vegetal waste yields (GTZ, 2010; 2011; Ashur et al., 2019 ; Makkawi et al., 2019)

Vegetal waste	Waste quantity Yield [tons/ha/year]	Calorific power [MWh/tons]
Olive trees	**2,7**	**3,96**
Palm trees	**3,5**	**3,28**
Citrus trees	**2**	**3.96**

The scenario for energy recovery from waste first requires the collection of organic matter. Next is the installation of industrial digesters for the methanization of organic waste materials. For cattle farming, we will use the LCU factor (Large Cattle Unit), which corresponds to approximately 1 LCU per bovine, to determine the total number of units. An approximate value for biogas production from cattle farming residues is around 1.11 m^3 per day per bovine (Afilal et al., 2013). The determination of the volume of biogas Q_{biogas} (m^3) for animal waste (cattle) is based on the LCU number N_{LCU} (LCU) and the yield of biogas Y_{LUC}(m^3/LCU/ day).

$$Q_{biogas} = N_{LCU}\ .Y_{LUC}\,.365 \qquad (3)$$

$$P_{Power} = Q_{biogas}\,.F_{powre} \qquad (4)$$

Where: P_{Power} (TWh)is the theorecal power potential and F_{powre} (kWh/m^3) is the conversion coefficient biogas to power.

5.2. CO_2 emissions evaluation

Energy recovery from waste allows for neutral energy production (electricity, heat) regarding CO_2 emissions. Indeed, just like biomass, the CO_2 released by biogas combustion is offset by the CO_2 absorbed by plants during their growth. However, the following equation determines the reduction of greenhouse gases (GHG):

$$R_{GHG} = E_{power} \cdot F_{GHG} \qquad (5)$$

Where:
R_{GHG} : Reduction of emissions (Million tons of CO_2eq);
E_{power} : Electricity produced (kWh);
F_{GHG} : Emission factor (gr of CO_2eq/kWh).

For Algeria, the value was taken according to the International Energy Agency (IEA), which considers the supplied electrical and thermal kWh. The assessment of greenhouse gas (GHG) reduction is obtained by using the emission factor, indicated in gr per unit of energy (g/kWh), estimated at 548 g CO_2 eq/kWh (AIE, 2013; ADEME, 2005; 2014).

6. Results and discussion

The knowledge of future biomass deposits remains a vital element in the context of environmental policies adopted by governments. According to tables 2 and 3, the energy potential in vegetal and animal waste is around 8.727 TWh/year, of which 2.55 TWh/year comes from cattle waste (manure) and 1.92 TWh/year comes from olive waste.

Table 2: Theoretical energy potential of vegetal waste in Algeria. (2020)

Waste	Cultivated area [ha]	Total amount of waste [ktons/y]	Theoretical energy potential [TWh/a]
Olive trees	**328128**	**885.945**	**3.50**
Palm trees	**187287**	**655.504**	**2.15**
Citrus trees	**66532**	**133.064**	**0.527**

Table 3: Cattle manure for biogas production in 2020

Animal population (head)	1786382
LCU per head	1
Total LCU	1786382
Yield of biogas [m^3/LCU/day] (Afilal et al., 2013)	1.11
Biogaz total [Mm^3/day]	1,98
Day the barn (days)	215
Total amount of biogas [Mm^3/y]	425.7
Conversion coefficient biogas to power [kWh/m^3] (Afilal et al., 2013; GTZ, 2011; Khalil et al., 2019).	6

Puissance calorifique (totale) [TWh/y]	**2.55**

As we can see, producing biogas from manure or slurry is sustainable energy production. Due to the biogas unit, it is possible to implement efficient nutrient management for spreading on fields with very low losses compared to composting.

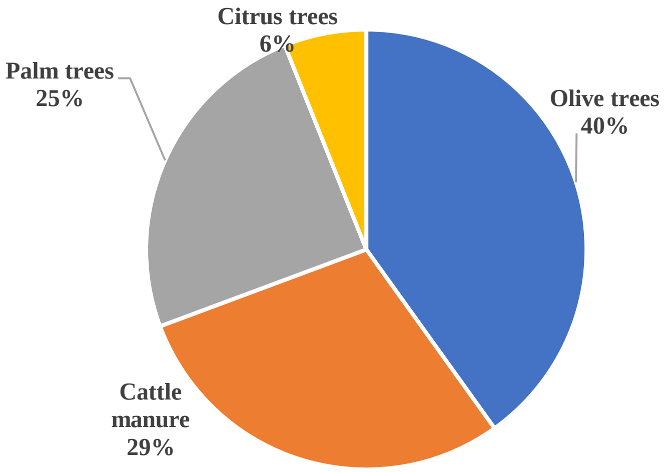

Figure 6: Distribution of organic waste-producing energy

As shown in Figure 6, olive waste contributes to 40% of the total amount of power (8.727 TWh), followed by animal waste (manure) at 29%, palm waste at 25%, and citrus waste with only 6%. The valorization of biogas through cogeneration has generated 8.727 TWh of electricity, corresponding to over 12 % of the electricity consumed in 2020 (73.8 TWh) ((ME, 2021). The energy resource is therefore estimated at 8.727 TWh, corresponding to a power of 1163 MW based on an average operating time of 7500 hours.

Table 4: Distribution of avoided emissions.

Waste	**Energy potential [TWh/a]**	**Reduction of emissions (Million tons of CO_2eq)**
Olive trees	3.50	1.92
Palm trees	2.15	1.18
Citrus trees	0.527	0.288

Cattle manure	2.55	1.40
Total	**8.727**	**4.788**

According to the table above, the overall potential for CO_2 savings is approximately 5 Million tons of CO_2. Almost a reduction of 7% (72 Mt of CO_2 in 2020 (IEA, 2021)). The analysis estimated that the total mitigation of CO_2 using olive waste was about 1.92 Mt/ year which (40% of total) followed by cattle waste with 1.40 Mt/ year (30%) and palm waste with 1.18 Mt/ year (25%). This reflects the environmental interest in recovering and recycling waste in Algeria. This study provides perspectives and important information for policymakers looking to develop a long-term energy policy by recycling this vital waste in Algeria.

7. Conclusion

In quantitative terms, knowledge of the different categories of waste is a major step in mitigating environmental and health impacts, contributing to the reduction of greenhouse gas (GHG) emissions compared to current conditions of organic waste treatment, and planning the logistics and economics of management. The assessment of recoverable fraction deposits also contributes to self-financing strategies and treatment actions' sustainability.

This work proposes a conservative methodology for evaluating organic waste in Algeria, which allows for significantly larger deposits than the estimated values obtained. Biomass has always contributed to meeting human energy needs since they learned to master fire. Biomass is currently the leading renewable energy resource on the planet. Moreover, its introduction into energy systems offers clear advantages in terms of reducing greenhouse gas emissions. In our study, we calculated the energy potential of cattle manure, plant waste from olive trees, citrus fruits, and palm trees. The results of this study highlight the real benefits of waste energy recovery. In Algeria, the potential for resources to produce raw biogas from vegetal waste (olive, palm and citrus) amounts to at least 1.67 Million tons/year, and potential of 425.7 Million m^3 of biogas per year from animal waste (cattle manure).

The analysis of material flow in the waste sector has shown that Algeria has a theoretical potential of 8.727 TWh. Therefore, olive waste generates 40% of the total energy, followed by animal waste (manure) at 29%, palm waste at 25%, and ctrus waste at 6%. Cogeneration's valorization of biogas produced 8.727 TWh of power, or 1163 MW of electricity, which represents 12% of 2020's electricity consumption (73.8 TWh). (ME, 2021). . A reduction in CO_2 emissions is very notable in 2020, estimated at 5 million tons of CO2, representing 7% of global CO_2 emissions. The potentials represented must, however, be considered differently due to their material composition and often seasonal production.

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