SCHOOL OF SCIENCE AND ENGINEERING

ASSESSMENT OF BIOMASS POTENTIAL AS BIOENERGY SOURCE TO IMPROVE EPI IN ADGHAGH VILLAGE

Capstone Design

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My parents receive my deepest gratitude for giving me strength and supporting me throughout my undergraduate studies. I am thankful for their unselfish love and affection.

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ACRONYMS

EPI: Environmental Performance Index.

GHG: Greenhouses Gases.

ATP: Adenosine triphosphate.

AD: Anaerobic Digestion.

ABG: Above Ground Biomass.

DBH: Diameter at Breast Height.

LHV: Low Heating Value.

HHV: High Heating Value.

ANOVA: Analysis of Variance.

Abstract

In Morocco, especially in rural areas, there is a significant amount of crop and forest residues. This has prompted us to offer a promising alternative source of energy, which consists of biomass energy. Our project focuses on the assessment of biomass resources and technologies, as innovative solution for organic waste management, and as a potential source of clean and renewable energy in Adghagh village as well.

Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activities [1].

Climate change is a result of the increase in the average temperature of the atmosphere and of the ocean [2], which leads to the rise of see level and melting of ice. This situation is getting worse each year. Thus, this could be a serious problem in the future if it is not managed well. Among the solutions to protect the environment and take advantage of wastes is biomass energy.

Biogas is a technology that combines many advantages: waste management, reduction of greenhouse gases, and production of energy. The biogas produced is the result of anaerobic digestion that consists of breaking down the organic matter in a free oxygen milieu. This process can be divided to three steps: hydrolysis, volatile acid fermentation and methanogenesis.

Motivation

Most of Moroccan rural areas are firewood dependent, this dependence on firewood fuel for cooking and heating represents a risk of deforestation since trees are being cut at a faster rate, which intensify the effect of climate change. These areas also suffer from bad air quality that leads Morocco to rank in low position in the Environmental Performance Index ranking. In order to improve rural energy, biomass provides an economically and environmentally sustainable energy source. In addition, it can yield different forms of energy such as gas, heat and electricity. Moreover, rural areas people, especially women and children, waste a lot of time in gathering wood for cooking and heating. Therefore, Biomass will encourage these people to stay in their communities.

I. Introduction

Nowadays it is important to invest on renewable energies due to the increasing in energy consumption that results from increasing populations. However, burning biomass such as wood directly is still a common practice in rural areas especially in developing countries. Biomass can replace solid fuels consumption, as it is cleaner and do not yield greenhouses gases as conventional fuels, which reduce air pollution.

1. Zone of Study

Morocco depends on the importations of fossil energies, which is constantly rising, from 93% in 1994 to more than 95% today [3]. Since the country lacks conventional sources, it is better to consider renewable and clean energy resources. Wastes streams are not exploited in Moroccan rural areas, which represent major problems that prompt us to develop methods to take advantage of such waste. Without access to efficient and inexpedient sources of energy, many rural areas are unfortunately forced to use polluting energy sources, such as solid fuels. For lightning, some areas do not have access to electricity at all. On-grid system is not convenient in rural areas because it is costly for them. The aim of this work is to assess the energy potential of biomass resources in Adghagh village.

Adghagh is located in the Middle Atlas Mountains of Morocco, twelve kilometers north of Ifrane. Adghagh is a tribe composed of three families: *Ait Lahcen Oubrahim, Ait Hassou,* and, *Ait Amerou Aissa*. It encompasses approximately 91 households. The area around the village is used for grazing and cultivating crops. Adghagh‘s main crops are wheat and barley because they don’t require a huge amount of water to cultivate. In fact Crops like vegetables and fruits could be planted also but in areas nears water resources (well or river). However, due to the lack of water and the rocky nature of the land, these kinds of crops (fruits and vegetables) are difficult to cultivate. Adghagh's climate is cold in winter but warm in summer days. For livestock the region have mainly sheep and goats to earn their living and support themselves financially. [4]

In fact, Adghagh's population suffers from the bad quality of drinkable water they drink underground water retrieved from wells without any kind of filtration. Furthermore, water resources for their agriculture dried up year after year. During cold seasons, they use wood as a heating source. Actually, burning wood releases greenhouse gases, which eventually reduces the quality of air in the region. As a consequence, it can affect the respiratory system of the population from inhaling smoke resulting from burning wood. In addition, burning wood is not efficient as an energy source. In the hope of changing the current situation, we assess the biomass potential energy in the region of Adghagh. [4]

The following figure shows the map of the region of our study. This map was created using the Geographic Information system (GIS) by ARRGIS 9.3 software.

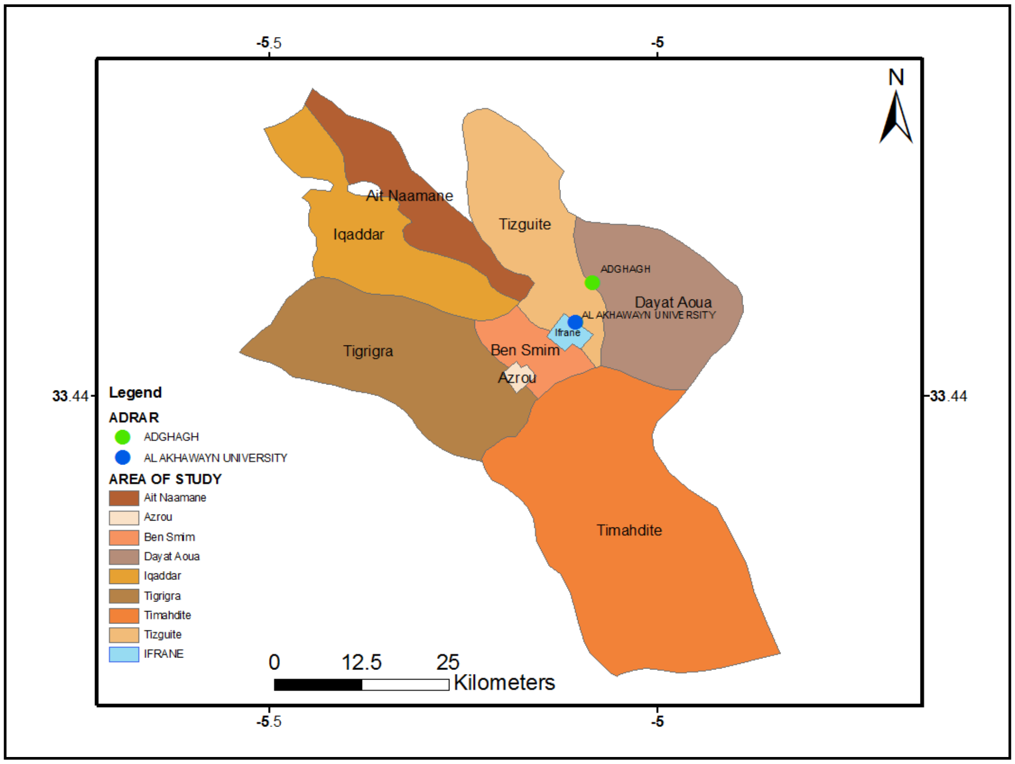

Figure 1: Localisation of Adghagh Village

2. STEEPLE Analysis

Steeple analysis stands for Social, Technological, Economic, Environmental, Political, Legal and Ethical. It is a strategic tool that assesses external factors, which may affect a business. In fact, Steeple analysis is an extension of PEST analysis (Political, Economic, Social and Technological).

- **Societal**: the main goal of this project is to improve Adghagh's population health by using biogas energy instead of fossil fuels. The extraction of methane from biomass will eventually reduce greenhouse gases. In addition, using biogas will reduce the workload especially for women who spend a lot of time collecting wood for cooking and heating.

- **Technical**: The project will involve a heating system that uses feedstocks to extract methane gas and use it for heating and cooking purposes.
- **Environmental**: the goal of this project is to improve the environmental performance index of the region, thus, improving the EPI of Morocco. Biogas production is a way to take advantage of organic waste, therefore avoiding pollution and reducing the emission of polluting gases.
- **Economical**: All solution implemented in this project are cost-effective. The project presents advantages at local level as an additional activity for the farmers who can develop economically and energetically their agricultural waste (crops residue and animal manure).
- **Political**: Most People in remote areas do not believe in their political representatives and government as they still suffer from a lot of problem and lack of necessary facilities (education, hospitals, clean water resources, electricity…). Hence, making these people trust their government, it should provide some solutions for the population.
- **Legal:** Article 2 of law 28-00 defines waste as "Any organic waste generated by agricultural livestock or gardening activities", which is the type of biomass to evaluate and access in this project.
- **Ethical**: the project is a non-profit project. The main goal of it is to improve the human health by reducing the emission of Carbon monoxide through the extraction of Methane from biomass. In addition, the project has many ecological benefits that would improve and develop the rural region of Adghagh.

II. Literature Review

3. The Environmental Performance Index

The Environmental Performance Index (EPI) is a tool of quantifying and numerically marking the environmental performance of a country. This method was developed by Yale University (Yale Center for Environmental Law and Policy) and Columbia University (Center for International Earth Science Information Network) in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission.

"The main goal of EPI is to direct countries and the world toward environmental sustainability" [5], EPI ranks countries based on performance indicators tracked by policy categories such as health impacts, water and sanitation, forests air quality, water resources, agriculture, biodiversity, ecosystem vitality climate and energy, and environmental public health.[5]

For Morocco, it is ranked 41 in the water resources indicator with a score of 39.3 %. In agriculture, Morocco is ranked 161, which is a very poor ranking with a score of 8.71% related to agricultural subsidies [5]. Concerning, climate and energy, the index puts morocco in the 67 rank, index on this part is measured by gathering trend in carbon intensity, change of trend in carbon intensity, access to electricity, and trend in CO2 emissions which is the most important aspect and morocco is ranked 45 for this indicator. Figure 2 shows the overall ranking of EPI of Morocco. [5]

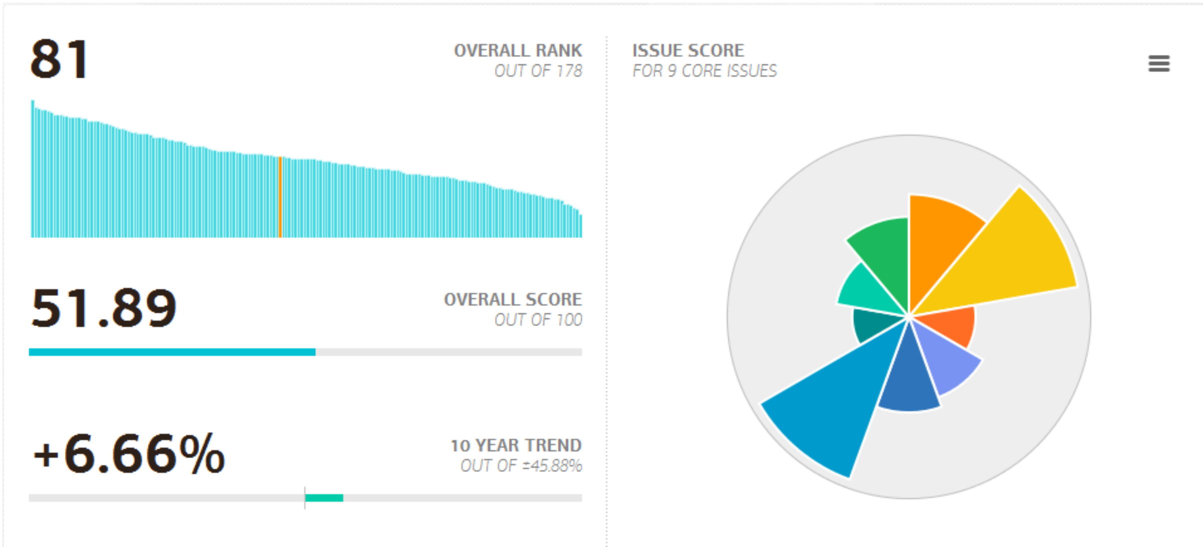

Figure 2: Overall Rank EPI Morocco [5]

4. Air Quality

"The EPI ranking of air quality measures the percentage of the population burning solid Fuel for cooking" [6]. Burning solid fuels for cooking exposes households to daily pollutant substances. Solid fuel combustion is a silent killer and it is considered as the primary reason behind death from pneumonia and other respiratory diseases among children and increases mortality causing lung cancer for adults. Actually, household air pollution is responsible for around 3.5 million premature deaths worldwide. [6]

The main cause of air pollution in developing countries is industrialization and urbanization, while in some countries is primarily related to the direct burning biomass during the combustion of organic materials such as wood, agricultural waste as shown in figure 3 below. The solution to decrease household air pollution emissions is going to be by using cleaner fuels.

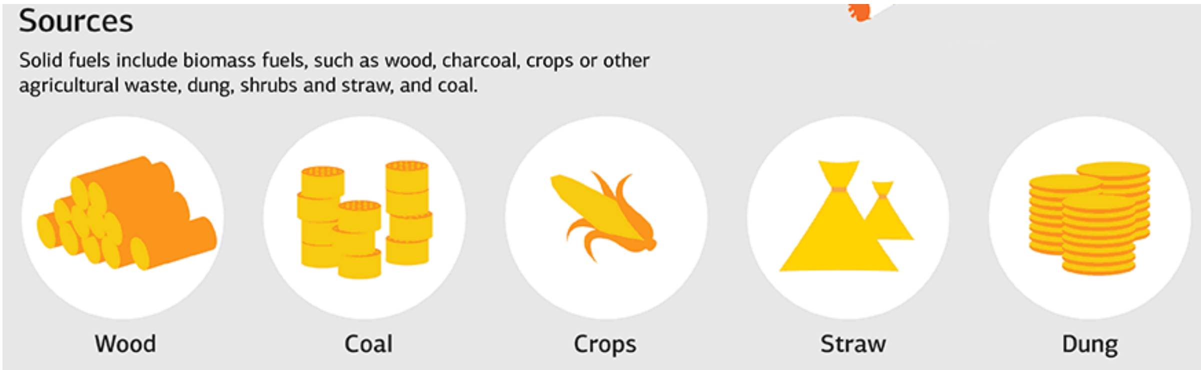

Figure 3: Sources of Air Pollutants [6]

Biomass and coal are usually burned directly in open fires. The smoke spreads not only in the whole house but also outdoors. The 2014 EPI indicator for Household Air Pollution shows that national income and household air pollution are significantly correlated. In other words, people that are most affected by solid fuels pollutants substrates are those who have low income. For instance 77% of sub-Saharan Africa use solid fuels [6]. Morocco is ranked in a good position in the air quality ranking. In fact, it is ranked 14 as shown in figure 4 below:

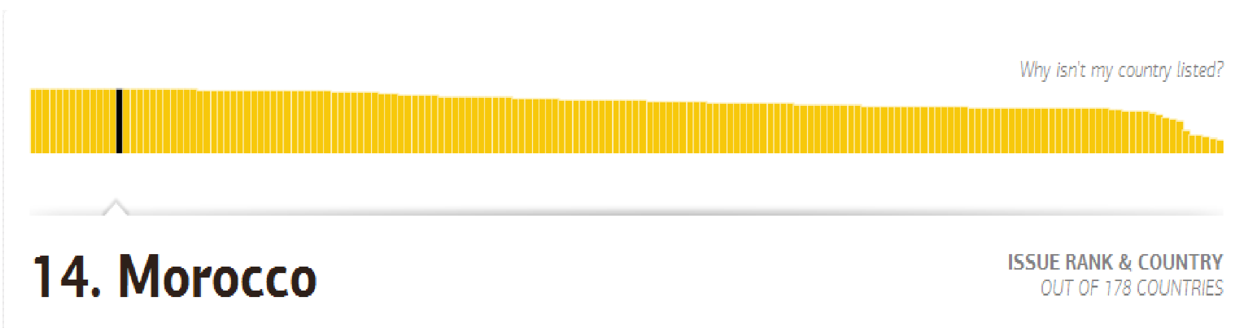

Figure 4: Morocco Air Quality Ranking [6]

5. Climate changing

Climate change is a result of the emission greenhouses gases. For over a decade, global warming took a large scale in media. This phenomenon is largely related to the production of greenhouse gases (GHG) by human activities. This phenomenon happens when carbon dioxide is emitted into the air and accumulates into the atmosphere. Therefore, there are many changes in climate such as yearly temperature rising. Consequently, it presents a threat and danger to both the terrestrial and marine ecosystems [7]. “Carbon dioxide is the main greenhouse gas resulted from human activities. The concentration of Carbon dioxide in the air is not constant over time “ [8]. Indeed, over the past 400000 years, atmospheric CO_2 rate varied from about 180 ppm during ice ages to 280 ppm during interglacials. However, “this concentration began to increase considerably since the beginning of the industrial growth up to almost 379 ppm in 2005” [7] due to fossil fuel use and land use change. This concentration has probably not been reached during the last 20 million years and unfortunately, it continues to grow at a rate of about 2 ppm per year [9].” Several models have predicted further increase in atmospheric CO_2 rate over the next hundred years resulting in 540 ppm to 970 ppm in 2100” [10]. During the last century, air temperature has increased about 0.7 °C; this increase seems to be related to the observed increase in the concentration of CO_2 in the atmosphere.

Figure 5:Emission of Greenhouse Gases [11]

6. Overview of Biomass

Biomass is any organic matter such as wood, crops, and animal wastes that can be used as an energy source. The energy of the sun is stored in the organic matter. During a process called photosynthesis, sunlight supplies plants with energy in order to convert water and carbon dioxide to oxygen and sugars. These sugars, or carbohydrates, supply plants and animals that eat plants with energy.

During the process of photosynthesis, plants convert light energy coming from the sun into chemical energy in the form of glucose (or sugar). Then, the glucose is converted into ATP (Adenosine triphosphate) by cellular respiration. The plant cells also convert some of the sugar into starch that is stored and can be used when needed. This chemical stored energy is used as a as biomass energy resource when the plant die. The overall equation of photosynthesis [12]:

$6CO_2 + 6H_2O$ ------> $C_6H_{12}O_6 + 6O_2$

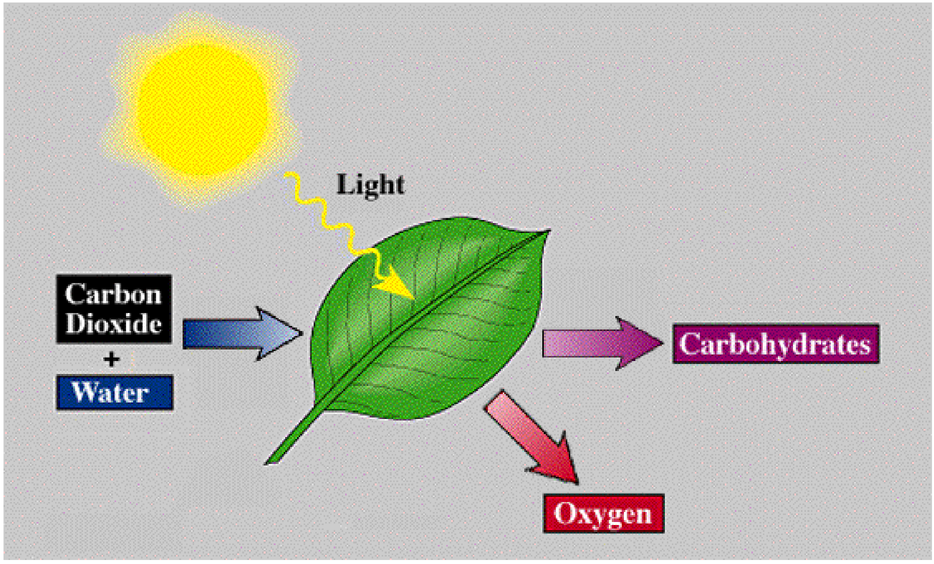

Figure 6: Photosynthesis Reaction [12]

7. Types of Biomass Resources

Materials that can be used to produce biomass energy come from different sources (animal, plant and human source), and in different forms (dry, wet...). All of these sources can be used to produce energy via different conversion technologies to name but few: combustion, gasification and the most important one anaerobic digestion. Some of biomass resources are as follow:

- *Agriculture residue*: refers to the residue left in fields during harvesting. It includes cereals straws, sugarcane, leaves and rhizome crops residues. These materials are processed to produce biomass fuels for instance ethanol and methanol or they can be used to produce electricity.
- *Forest residues*: this include wood, leaves, dead trees, branches and any biomass that is not harvested from the forest cite or resulted from forest management.
- *Organic Municipal Solid waste (MSW):* contains food waste and paper in landfills.
- *Animal wastes*: animal manure contains degradable organic materials and nutrient materials for instance phosphorus, nitrogen and potassium. "Depending on the kind of livestock and season the quality and quantity of manure differs". [13]
- *Industrial waste*: industrial plants produce a huge amount of waste that could be used to generate a clean energy instead of throwing the waste in the environment.
- *Slaughterhouse and Fishery Waste*: slaughterhouse and fishery, generates a big amount of organic waste. This constitutes a danger to the environment and human or animal health if it is not managed well. However, it could be used as a feed stream for anaerobic digestion. [13]

8. Thermal Properties of Biomass

The assessment of biomass energy requires the understanding of the types of biomass sources and their composition, characteristics and performance.

Each type of biomass has its properties that determine its performance. The main properties of biomass are the following:

- Moisture content: it refers to the amount of water present in the material. Moisture content is expressed as the percentage of materials weight. In other words, it is the mass of water per the mass of the material. "It could be also expressed by wet basis, dry basis, and dry and ash free basis". [14]
- Ash content: it refers to the inorganic matter present in the biomass and it is expressed as moisture content wet basis, dry basis, and dry and ash free basis.
- Volatile matter content: it is the part of biomass that is released when biomass is heated around 400 °C. During this phase the material, is broken down into volatile gases and solid. Biomass has a high volatile value it could reach up to 80%.
- Heating value: it is the most important property of biomass; it specifies the chemical energy bound in the fuel. It is expressed in Joule (J) per amount of matter (Kg). There are two forms of heating value: Lower heating value (LHV) in which water is in the gaseous state and higher heating value (HHV) where water is in the liquid state. Heating value depends on the moisture of the material. The less moisture content in the biomass, the higher heating value generated. [15]
- Bulk density: means that the moisture content is equal to zero. It refers to the weight of the material per volume [15]. Both heating value and bulk density assess the potential energy that exists per unit volume of the material.

III. Methodology

1. Feedstock Assessment

The main goal of biomass assessment is to assess and evaluate the characteristics and quantity of biomass resources in Adghagh region and assess technologies to produce biogas from existing resources. Feedstock assessments is based on collecting data on the quantity of feedstock in the region and then identifying the potential energy for each type and identify efficient technologies.

The methodology for identifying the types and quantity of biomass is to identify all the types of biomass resources that exist in the region of Adghagh that are suitable for biogas production. The region is rich in terms of biomass resources but due to time limitation, we chose to study one species holm oak, which is abundant in this region.

1.1 Crop residue

Crop residue refers to “the whole range of biomass produced as by-products from growing and processing crops” [16]. It covers all agricultural wastes especially from harvesting whey and barley. The efficiency and yield of crops residues differ from one crop to another.

Olive pits: are characterized by having low moisture; they can be used as a fuel. In fact, they can be burned in a process to produce heat and electricity. First, olive pits are stored and then they are feed into a burner at 800 °C where they can undergo combustion, the steam formed could be used to produce energy. Carbon monoxide and methane are produced; their densities are less than air so they flow up into a pipe toward gas turbines in order to produce electricity. Figure 6 shows olive pits.

Figure 7: Olive Pits [17]

1.2 Forest Biomass Resources

- **Quercus Ilex:**

Holm oak or Quercus Ilex is one of the most common species in the western Mediterranean. The acorns of Quercus Ilex were used with wheat to make bread but now it is mainly used as a feed for animals." Quercus Ilex grows in calcareous soils, yet it can adapt to almost all types of soils. It is adapted to Mediterranean climate, which is dry and hot in summer and cold in winter "[18].

It is abundant in North Africa (2.167 million ha) [18] of which 1.394 million ha is in morocco [19], 690000 ha in Algeria and 83 000 ha in Tunisia. Quercus Ilex is found also in the Cantabrian region of Spain [19], in the southwestern edge of the Massif Central in France [20] and in the Alps setbacks Italy. "In Morocco the holm oak is divided between the Middle Atlas (648 000 ha), the High Atlas (409 000 ha), the Saharan Atlas (90 000 ha), the Atlantic Region (88 000 ha), the Sous (75,000 ha) and the Rif (54,000 ha)". [21]

2. Results and findings

- **Study site:**

The objective of this study is to quantify the stock of carbon stored in Quercus Ilex in the ecosystem of the region. Thus, quantify the aerial biomass. Carbon is stored in branches, leaves and roots. In order, to estimate the stock of organic carbon in Quercus Ilex trees we chose a representative sample, a plot of land of $40\ \text{m} \times 40\ m$, in Al Akhawayn University's forest.

Due to the increase of global warming and tree biomass, carbon estimation becomes essential. There are different methods to estimate aerial biomass. For our study, we follow nondestructive method using allometric equations.

Figure 8: Measurementt of DBH

Statistical Analysis

Allometric equations for biomass estimation

Allometric equations are defined as the quantitative relationship between measurable tree variables such as the diameter at breast height (DBH) and other dependent variables such as total biomass, standing volume and carbon stock in the tree. [22] In other words, allometric equations are formulas that quantitatively formalize the relationship between the dendrometric characteristics of a tree [23].

Our main goal is to determine the total above ground biomass over the whole region. To estimate biomass the regression models should take into consideration the diameter at breast height, a factor value and the specific gravity [24]. Therefore, the regression equation developed by Chave et al. 2005:

$$\boldsymbol{AGB} = \rho * \boldsymbol{e}^{-1.499+2.148 \ln(\mathrm{D})+0.207 \ln(\mathrm{D}^2)-0.0281 \ln 3(D^3))} * 0.001$$

Where:

AGB stands for Above Ground tree Biomass.

ρ is the wood specific gravity in g/cm^3.

D is diameter at breast height in cm.

Data Collection

Above ground biomass data were obtained from a sample of 44 trees randomly selected of $40 \text{ m} \times 40m$ as shown in figure 8 below.

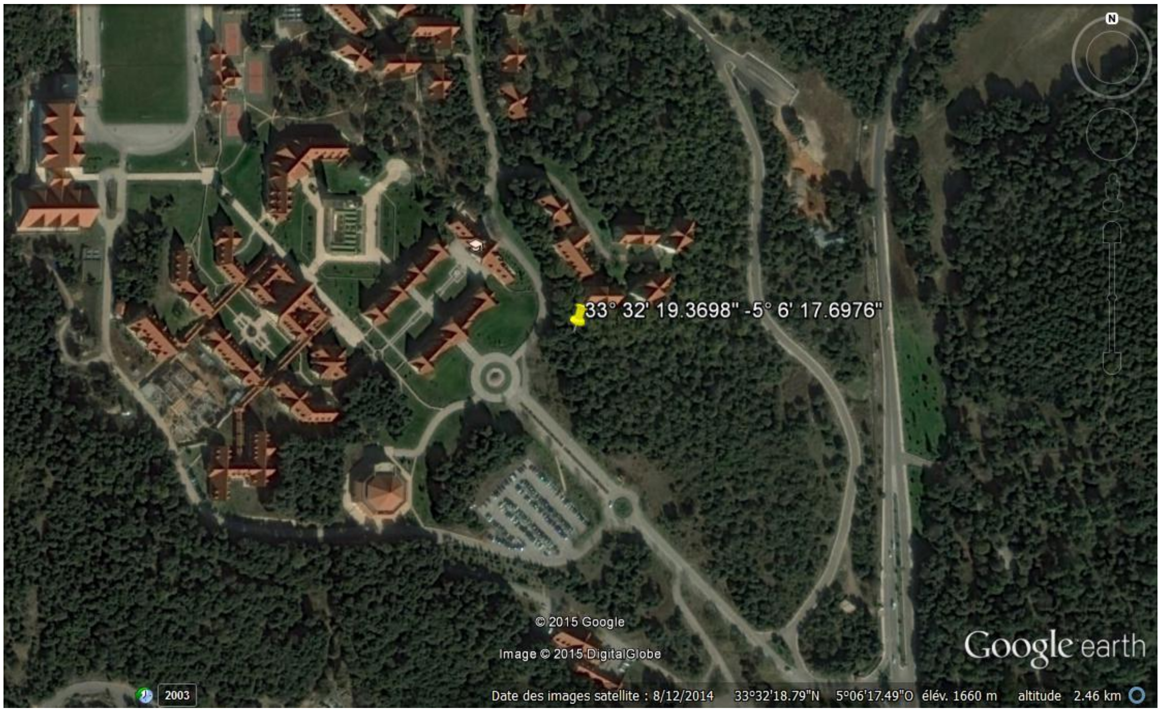

Figure 9: Localization of the placates of 40 m X 40 m for measuring Dbh

Figure 10: Localization of the placates of 40 m X 40 m for measuring Dbh

Plot Measurements

Using the equation of Chave et al. 2005, and given that the density of Quercus ilex is equal to 0,983 g / cm^3 [25].

Table 1:DBH and AGB of The Sample

Sample Trees	DBH(cm)	AGB tons
1	63,3	7,70483656
2	78	12,67520682
3	59,5	6,631342799
4	72	10,48984967
5	92	18,60356441
6	87,5	16,572687
7	72,2	10,55922316
8	75,3	11,6651629
9	53,4	5,089378429
10	76,3	12,03418131
11	94,5	19,78246876
12	74,6	11,41040594
13	81,7	14,12979263
14	101,5	23,27336628
15	90,6	17,95913498
16	97	20,99723629
17	108	26,7615411
18	122,7	35,4984436
19	94,5	19,78246876
20	94,4	19,73462234
21	90,5	17,91353872
22	54,5	5,350984184
23	78,8	12,98282251
24	121,5	34,74220899
25	78,8	12,98282251
26	104	24,58715112
27	95,3	20,16730453
28	67	8,833608766
29	105	25,12243482
30	87,4	16,52889551
31	52,9	4,972851118

32	103,2	24,16293625
33	59,8	6,712934323
34	86,5	16,13740368
35	76,6	12,14605118
36	60	6,767629227
37	70,5	9,977201049
38	93	19,07080659
39	77,6	12,52282761
40	76,2	11,99701073
41	132,5	41,95145061
42	49,5	4,219839912
43	96,5	20,75142591
44	48	3,909351148
Total AGB		**695,8664047**

- *Estimation of AGB per hectare:*

AGB is estimated per hectare; therefore, we use the following formula to convert it from ton to ton per hectare:

$$AGB_h = \frac{\left(\frac{Ah}{Ap}\right)}{AGB}$$

Where:

Ah: is the area of one hectare 10000 m²

Ap: area of our sample plot1600 m²

$$AGB_h = \frac{\left(\frac{10000}{1600}\right)}{695{,}8664} = 4349.165\ ton/ha$$

- *Carbon dioxide emission for the studied area:*

If the sample of trees studies in this area were cut and burned directly, they would emit:

$$CO_2 = AGB * \frac{PM_{CO^2}}{PM_c}$$

Where:

PM_{CO^2} is the molecular mass of carbon dioxide

PM_c is the molecular mass of carbon

$$CO_2 = 695{,}8664 * \frac{44}{12} = 2551{,}51 \text{ ton}$$

2551,51 ton of CO_2 is the stored amount of carbon in the sample plot we studied. In other words, it is the estimated amount of emitted CO_2 if the sample tress were all cut and burned directly.

A linear regression model was established to determine the relationship between the above ground biomass and diameter at breast height. Following the equation above of Chave et al. (2005), we adjusted the equation to natural logarithm:

$$\ln(AGB) = \ln(\rho) - 1.499 + 2.148 \ln(\text{ D }) + 0.207 \ln(\text{ D}^2) - 0.0281 \ln(\ D^3) + \ln(0.001)$$

The model was fitted to the log transformation and follow the method of the least squares at 95% confidence interval.

Table 2 :ANOVA Table of Regression Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,999795583
R Square	0,999591208
Adjusted R Square	0,999581474

Standard Error	0,011844087
Observations	44

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14,40694937	14,40694937	102699,62	8,5E-73
Residual	42	0,005891861	0,000140282		
Total	43	14,41284123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	-7,69879161	0,032216208	- 238,9726226	1,9E-67	-7,76381	-7,63378	-7,76381	-7,63378
ln(dhp)	2,347829306	0,007326256	320,4678163	8,499E-73	2,333044	2,362614	2,333044	2,362614

From table 2, the linear regression model can be written as:

$$\ln(AGB) = 2.3478\ln(D) - 7.6987$$

- **T-test for independence:**

This test is used to determine the relationship between the independent variable (DBH) and the dependent variable (AGB).

- Setting the hypothesis:

H0: Above ground biomass and diameter at breast height are independent.

H1: Above ground biomass and diameter at breast height are dependent.

- Critical values

From the ANOVA table 2 above t statistics is equal to 320, 46

We have n=44 sample trees

Using statistical tables at 5% level of significance, we find $t_{0.025,42} = 2.0181$

Since T statistics>$t_{0.025,42}$ we conclude that above ground biomass and diameter at breast height are dependent which mean diameter at breast height affects significantly the Above ground biomass.

- **F-Test for significance:**

This test is used to check if there is a significant linear relationship between the independent variable (DBH) and the dependent variable (AGB).

- Setting the hypothesis:

H0: $\beta = 0$ (no linear relationship between ABG and D)

H1: $\beta \neq 0$ (there exists a linear relationship between ABG and D)

- Critical values

From the ANOVA table 2 above F statistics is equal to 102699, 62

From statistical tables $F = 5.42$ with degrees of freedom df1=1 and df2=42

F statistics>$F_{0.025}$ we conclude that there exist a linear relationship between above ground biomass and diameter at breast height.

- **Test for correlation:**

- Setting the hypothesis:

H0: $\rho = 0$ (no correlation between ABG and D)

H1: $\rho \neq 0$ (correlation exists a linear relationship between ABG and D)

- Critical values

$$T=\frac{r-\rho}{\sqrt{\frac{1-r^2}{n-2}}}$$

Such that r^2 = 0, 999591208 (from ANOVA table 2)

T= 320.46

We already have $t_{0.025,42} = 2.0181$ so we reject the null hypothesis, which means that the two variables are significantly correlated. In addition, we have R^2 is 0.999 which means that the model is highly significant and suitable.

Conversion from biomass to biogas

From the literature review we found that each cubic meter (m^3) of biogas contains the equivalent of 6 kWh of heat energy. However, the conversion of electricity into biogas by an electric generator produces only 2 kWh (electricity), the rest of the energy is dissipated as heat. [27]

In addition, 5.5 kg of wood is equivalent to 1 m^3 of biogas [28]. In our case, we have 695, 8664047 tons above ground biomass (AGB of Quercus Ilex trees). Therefore using the fact that each 5.5 kg of biomass gives 1 m^3 of biogas, we get 126.52 m^3 of biogas which is equivalent to **253.04 Kwh** of electricity.

Example of daily electricity consumption for a rural household:

Table 3: Estimation of Annually Consumption of Electricity (Kwh) for a Rural Household

Appliance	Number of appliances	watt	Hours/day	watt-hours	Annual Consumption (kwh)
Bulbs	4	10	3	120	43.8
TV + satellite dish	1	15	3	45	16.425
Radio	1	10	4	40	14.6
Mobile Telephone	2	5	1	10	3.65
Total					**78.475**

For one rural household the annual consumption of electrical energy is equal to 78.475 Kwh.

Estimating biomass for 44 ha:

- 253.04 Kwh/ 78.475 Kwh=3.22≈ 3 households
- $44 \times 3 = \mathbf{132}\ households/year$

Converting the total AGB we found before into electrical energy we found that it is sufficient for $\mathbf{132}\ households/year$. Considering the small population of Adghagh village approximately 91 households [4], this amount of energy is sufficient for the village.

3. Animal Manure

Potential biogas is a very promising energy. The main aim of this project is to estimate the amount of resource in Adghagh and its energy potential of biogas. To estimate the biomass potential we determine first the theoretical quantity (maximum quantity) of the biomass and then we adjust it to find the available potential. It is calculated using the formula [28]:

$$aB\ (t\ /\ year) = tB\ (t\ /\ year)\ .\ f$$

Where:

aB is the potential in organic waste in other words the available biomass.

tB is the theoretical biomass

f is the percent recovery which is the rate of methane

- *Livestock waste potential*

The potential production in manure estimation is calculated using the following formula:

$$tB\ =\ Nh\ x\ Yw\ [28]$$

Where:

Nt is the number of livestock.

Yw is the waste in ton per head per year.

- *Estimation of the energetic potential*

We can estimate the energetic potential by the formula below:

$$Pe =\ Pd\ x\ Pb\ x\ PCI\ x\ Rt\ [28]$$

Where:

Pe: the energy potential of the waste in kWh per year.

Pd: the potential in available waste in tons per year.

Pb: the potential in biogas waste m3/ton of fresh matter.

PCI: the heating value of the biomass.

Rt: for electrical conversion of biogas.

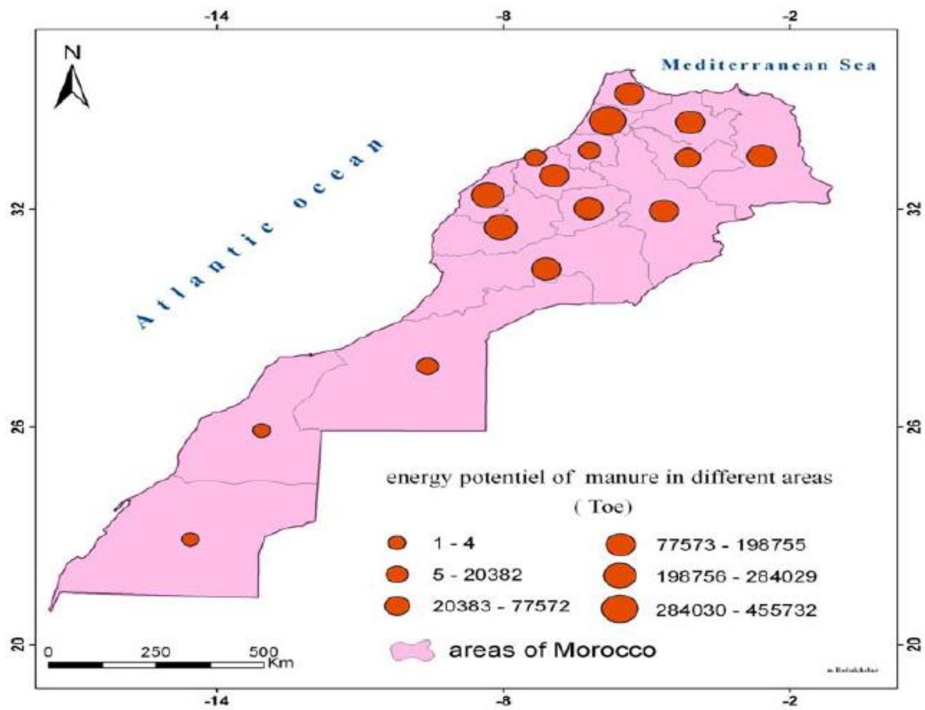

Figure 9: Energy Potential of Manure in Different Regions [28]

The organic wastes identified in Adghagh region are similar to those found in Ifrane. There are solid manure from animals, the residues of crops and forest residues. Total agriculture area in Ifrane is 82 044 hectare [29]. In order to determine biogas potential energy in the region we refer to the data from the monographs statistics of Meknes Tafilalt region. We found that the residues that exist in the region are mainly cereal straw such as whey and barley and forage crops such as oat and Lucerne.

For livestock, we found mainly goats 54.8 million head, sheep 648.1 million head and cattle 30.1 million head.From the quantities we got we can find the potential energy by translating these quantities into energy.

4. Technology Assessment

There are several technologies to produce bioenergy:

2.1 Biochemical

In biochemical conversion, biomass elements are broken down into smaller molecules by bacteria or enzymes. This process is slower than thermochemical conversion. There are two main biochemical conversions:

- Digestion (anaerobic and aerobic)
- Fermentation

Biogas contains mainly methane CH4 (60%-70%) which could be burnt for cooking and heating. It can also be used to power engines to drive a turbine generate electricity [30] .Anaerobic digestion is a way to manage organic waste.It happens in the absence of oxygen where microorganisms break down organic." This process yields biogas, in which methane constitute 50 to 70 percent" [31]. This biogas produced could be used as a source of energy for instance generating electricity and heating. Feedstock sources for this process include different organic wastes to name but few food waste, animal manure and grass.

During the process of anaerobic digestion, bacteria break down materials in a free oxygen environment. There are mainly three steps in this process: hydrolysis, volatile acid fermentation, and methanogenesis as shown in figure 10 bellow.

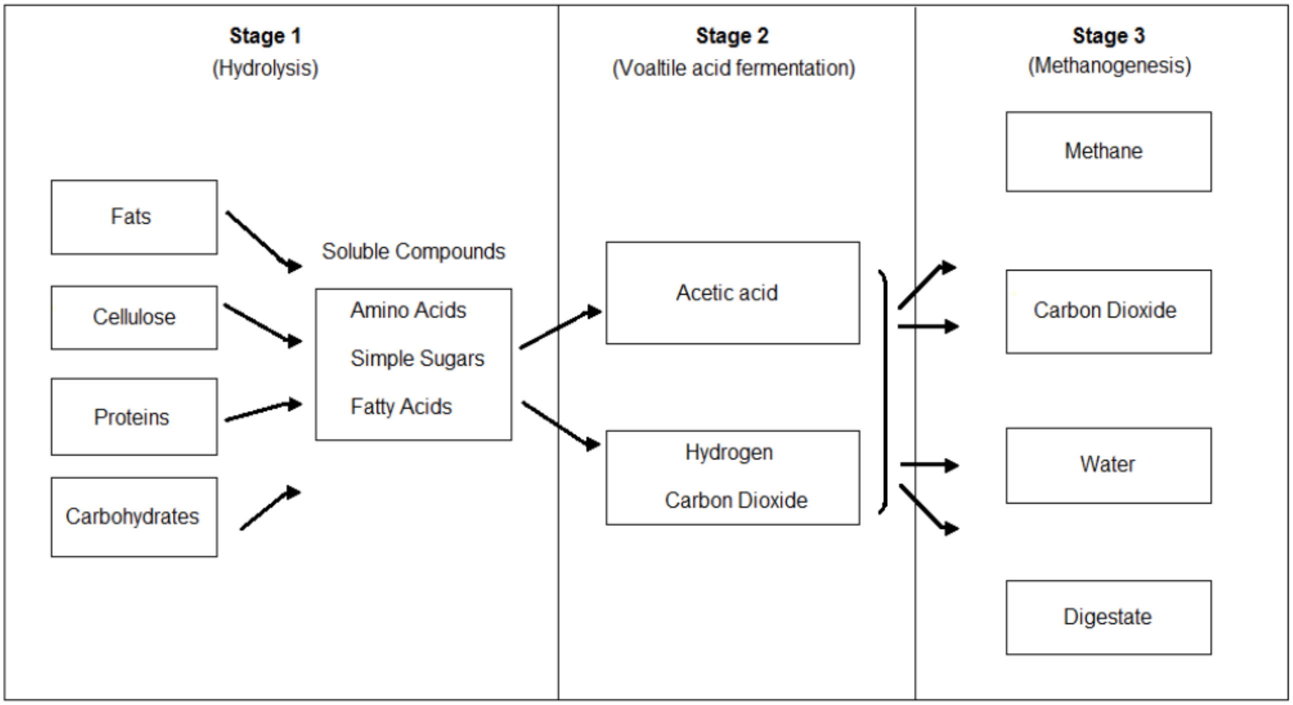

Figure 10: Anaerobic Digestion Process [32]

The first phase is Hydrolysis: in this step, biomass polymers are metabolized into small chains. These small chains are broken down by microorganisms. Biomass is composed of proteins, fats and carbohydrates. "The addition of water breaks these polymers into smaller molecules and soluble compounds, which are amino acids, simpler sugar (glucose), and Fatty acids". [32]

The Equation of the first process can be written as:

$$C_6H_{10}O_4 + 2H_2O \rightarrow C_6H_{12}O_6 + 2H_2$$

During the second process, which is volatile acid fermentation, the bacteria break down the compounds produced in the previous phase. This stage can be divided to two steps acidogenesis and acetogenesis. "In the first process, the bacteria create an acidic environment to produce ammonia, alcohol, carbonic acids and other byproducts at the end of this process ". [32]

Acidogenesis Equations:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH + 2CO_2$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH$$

During acetogenesis, fatty acids are converted to acetic acid, carbon dioxide, and hydrogen.

Acetogenesis Equations:

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H^+ + HCO_3^- + 3H_2$$

$$C_6H_{12}O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2CO_2 + 4H_2$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+$$

During this last step, which is Methanogenesis, microorganisms convert the acetic acid into methane acetic and carbon dioxide in the addition of water vapor, Ammonia and hydrogen sulfide. [32]

Equations of Methanogenesis:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

The efficiency of anaerobic digestion depends on the temperature, when the temperature is higher; it is more suitable for bacteria to grow. Biogas is very rich in energy (more than 6 kWh / m^3). Anaerobic digestion time vary between 35 and 60 days [26].

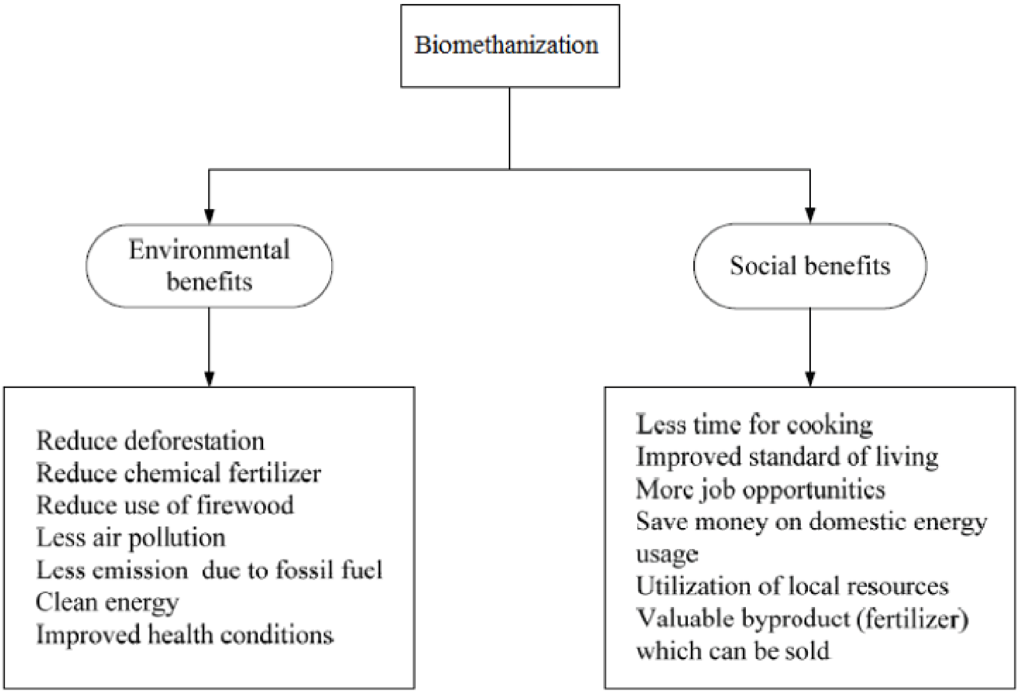

Figure 11: Biomethanization Benefits [32]

The figure above shows the benefits of anaerobic digestion for instance it has less greenhouse gases, which improves the air pollution. Anaerobic digestion also will save the population of Adghagh time for cooking and manage their wastes properly.

Aerobic digestion such as composting is a biochemical breakdown of biomass as well, except that it requires the presence of oxygen from the surroundings. The main products of this process are carbon dioxide and heat. "In fermentation, part of the biomass is converted into sugars with the help of bacteria. Then the sugar is converted to ethanol or other chemicals. The product of fermentation is liquid". [33]

2.2 Thermochemical

During this process, the biomass is converted into gases. Production of thermal energy is the main goal for this conversion. There are three main biochemical conversions:

- Combustion

- Pyrolysis
- Gasification
- Liquefaction

Combustion is an exothermic that requires the presence of oxygen. It is the most direct process for converting biomass into energy; it takes place in the furnace. The chemical bound energy in the biomass is converted into thermal energy Combustion consists of high-temperature conversion of biomass in the presence of air into carbon dioxide and steam [14]. “In this process, biomass is converted into two major compounds: H2O and CO2 with the release of heat. The production of electricity by combustion consist of using a steam turbine in which steam produced during burning biomass turns the turbines to generate electricity”.[14]

Contrary, Pyrolysis takes place in a low temperature compared to combustion and in an environment without oxygen. “It is a thermal decomposition of the biomass into gas, liquid, and solid. There are three types of pyrolysis: mild pyrolysis, slow pyrolysis and fast pyrolysis”. [14]

During mild pyrolysis or torrefaction, biomass is heated 300 °C in the absence of oxygen. The final products of this process are methanol, carbon dioxide, acetic acid, water and carbon monoxide. For fast pyrolysis, it produces primarily liquid fuels while slow pyrolysis gases and solid fuels. Pyrolysis conversion is not exothermic like combustion [14].

Gasification is a thermos chemical process that also converts biomass into beneficial gases and chemicals. The biomass is burned into a boiler at a temperature higher than 700 °C, producing a steam that flows into a turbine connected to an electricity generator. The blades of the turbine are turned by the steam, which generates electricity. Finally, Liquefaction also takes place in low temperature where large molecules are decomposed into small molecules in the form of liquids. Liquefaction requires the presence of a catalyst. [14]

- *Motivation for Biomass Conversion*

There are two motivating factors to convert biomass into energy:

- Renewability benefits: fossil fuels are limited and cannot be regenerated unlike biomass, which is renewable.
- Environmental benefits: it does not produce great amount greenhouses gases in comparison to fossil fuels. For instance for carbon monoxide emission gasification and combustion is less than 1 Kg/1000 MWh as shown in figure 10 bellow.[14]

Emission	Pulverized-Coal Combustion	Gasification
CO_2 (kg/1000 MWh)	0.77	0.68
Water use (L/1000 MWh)	4.62	2.84
SO_2 (kg/MWh)	0.68	0.045
NO_x (kg/MWh)	0.61	0.082
Total solids (kg/100 MWh)	0.98	0.34

Figure 11: Comparison of Emissions [13]

IV. Conclusion

During this capstone project, I gained new knowledge and skills. I learned many things about biomass energy. In this project, I tried to assess the biomass potential in the region of Adghagh and estimate the potential energy. Actually, encouraging the population of the region to use biomass instead of solid fuels will eventually improve air quality in the region and improve their health as well. Biomass is a clean and sustainable energy that can be used to produce biogas such as methane. The population of Adghagh can use methane for either cooking or heating. Also electricity can be generated from biomass using power turbines and generator. Moreover, this project has the potential to alleviate poverty by providing energy to fulfill commercial activities in order to generate additional income in rural areas. This will also contribute to greenhouse gas mitigation to combat global warming that causes the global atmospheric change.

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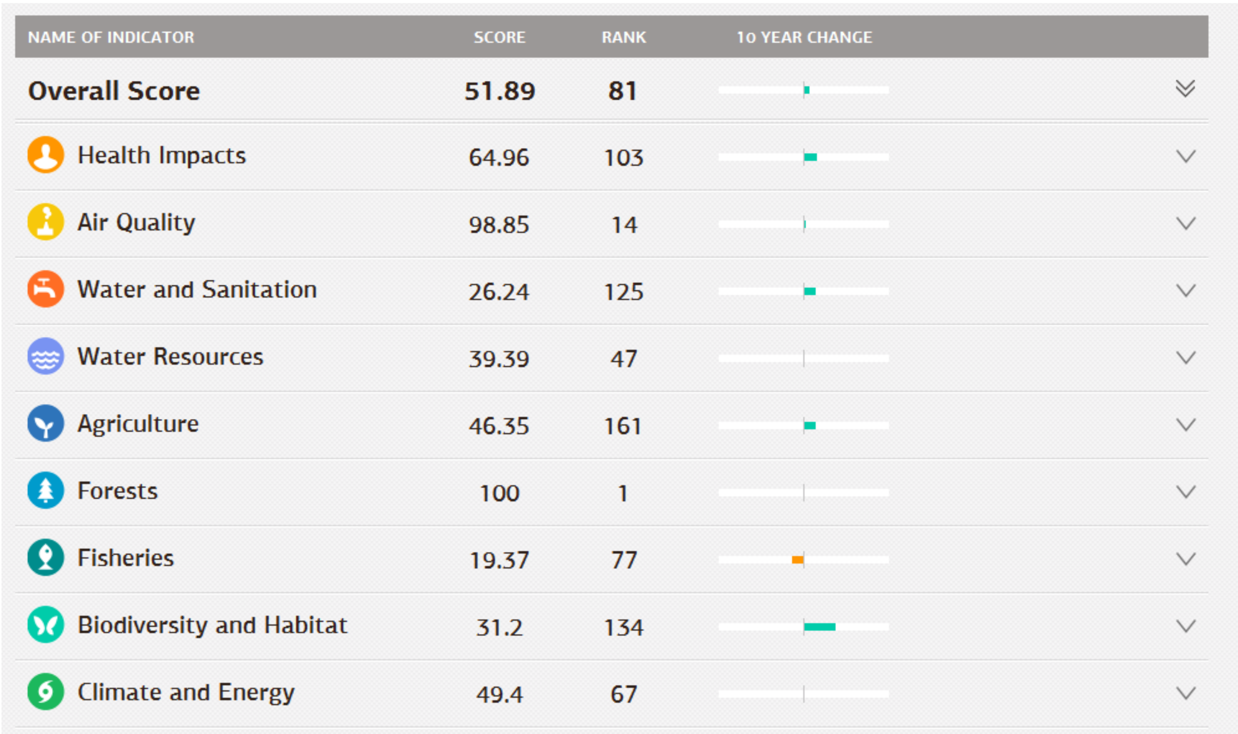
Appendices



NAME OF INDICATOR	SCORE	RANK	10 YEAR CHANGE
Overall Score	51.89	81	
Health Impacts	64.96	103	
Air Quality	98.85	14	
Water and Sanitation	26.24	125	
Water Resources	39.39	47	
Agriculture	46.35	161	
Forests	100	1	
Fisheries	19.37	77	
Biodiversity and Habitat	31.2	134	
Climate and Energy	49.4	67	

Figure 12: Detailed EPI Morocco Ranking [3]

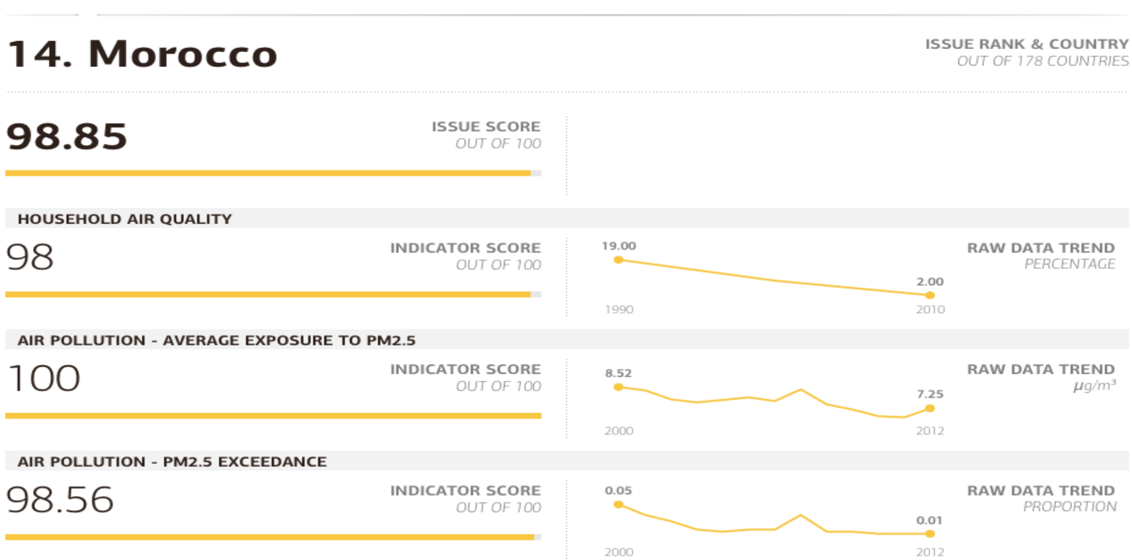


Figure 13: Detailed EPI Air Quality in Morocco Ranking [6]