DESIGN OF A BIOGAS PILOT UNIT FOR AL AKHAWAYN UNIVERSITY

EGR 4402_Capstone Design

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DESIGN OF A BIOGAS SYSTEM FOR AUI

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Approved by the Supervisor(s)

Dr. El Asli
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Finally, I would like to warmly thank my family and friends who supported me during the whole semester and helped me to overcome my stress.
ABSTRACT

Nowadays, electricity is an essential resource to carry out daily tasks, which is why it is so precious. Unfortunately, global energy consumption significantly increased these last 10 years, it is also becoming increasingly costly for the economy and for the environment. Researchers have tried to replace fossil fuels by renewable energies, which are less costly and more environmentally friendly. Yet, fossil fuels remain the most widely used resource in the world. Among the renewable energies, we have biogas as a bioenergy. This is an entirely natural resource produced by the fermentation of organic waste with the help of biological tools such as bacteria in a digester. The objective of my project is to produce biogas as an electricity and heating resource for Al Akhawayn University in Ifrane based on the available biomass resources. To realize this, I will be designing a digester that will fit with the local cold environment of Ifrane and the nature of the biomass at AUI to meet partially the AUI’s community needs of energy and heating. The advantages of producing biogas are that it respects the environment by reducing the greenhouse gas, it is also cheaper and less polluting.

INTRODUCTION

Energy consumption is a major problem since it can harm our planet and its individuals. Reducing the use of fossil fuels with small changes can make a big difference for our planet. The main purpose of this project is to find a way to use biogas as an electricity and heating resource in order to minimize the long term environmental and money cost of the current energy resource.
The fermentation process can be naturally made in nature in landfills or swamps. Fortunately, we learnt how to voluntarily provoke it to produce a natural energy resource which is biogas. According to the website biogas-renewable-energy, the anaerobic fermentation is a biological process aiming to transform organic matter into methane. It is an anaerobic process made in a neutral and oxygen free environment. The result of this transformation is the digestate which corresponds to a solid or pasty liquid residue composed of non-degraded organic elements and minerals, and biogas which is a mixture of different gases (Peterson, 2017). In this project, we are mainly interested in the production of biogas and the process the organic matter goes through. In a context where the environment is at the forefront, biogas can play a major role when it comes to preserving our planet. In November 2015, COP 21 and COP 22 introduced the subject by inviting world leaders to focus on environmental issues that might be encountered in the future if we do not act immediately. All countries are mobilizing and striving to find the best way to reduce the use of fossil fuels that are bad for the environment and for our health, that is why we have chosen to focus on biogas.

In an introduction we talk about the context of the project starting with a global view on it and narrowing it towards your project (funnel effect) I saw only one reference

An introduction should always end with the objective of work

The main purpose of this project is to find a way to use biogas as an electricity and heating resource in order to minimize the long term environmental and money cost of the current energy resource.
In this chapter, I will explain the basic concepts of Biogas. I will start by explaining what it is then I will give its components, the type of waste that can be used and finally the place of biogas in the world. The aim of this chapter is to introduce my project and clearly define the terms that I will be using throughout the report.
What is biogas?

Biogas is produced by the fermentation of organic matter. Biogas is a natural energy resource and is mainly composed of methane (CH$_4$). The production of biogas is an eco-friendly energy and heating resource. Indeed, it is possible to obtain between 105 to 130 m$^3$ of biogas for one metric ton of organic waste. This innovative fuel is almost free of CO$_2$ emission.

Composition of Biogas

Biogas is a mixture of different gases. Depending on the organic matter used for its production, the proportions of the following gases can change. As stated in the website biogas-renewable-energy, biogas produced is composed of the following gases:

- Methane, CH$_4$ is the main compound of biogas. It has a high energy value equal to 802 kJ/mol.
- Carbon Dioxide, CO$_2$, is a non-corrosive gas that doesn’t have any energy value. It has both advantages and drawbacks. Even though it is a non-corrosive gas, it has a bad impact on our health and on the environment, this is why we should find a way to use it in order to minimize the risks. However, CO$_2$ is an anaerobic agent, and can be used to preserve food, or as a refrigerant.
- Hydrogen sulfide, H$_2$S, is a gas derived from the catabolism of sulfur-containing amino acids. It is a dangerous gas because its inhalation is fatal. It is also very corrosive.
- Water vapor, H$_2$O, can also be found in Biogas. It can damage the digester when it is in the liquid state (Solenoid valves, regulators, burners …).
- Siloxanes can be found in biogas. These are silicon derivatives resulting most generally from the degradation of cosmetic products. ("Biogas composition", 2017)
• Discharge biogas (ISDN) is often rich in siloxanes; Agricultural biogas are exempt. They can be very detrimental to the biogas recovery elements because they vitrify at high temperatures in the heating bodies of biogas boilers or in the cylinders of cogeneration engines.

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Percentage of the volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>$CH_4$</td>
<td>50-70%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>$CO_2$</td>
<td>25-45%</td>
</tr>
<tr>
<td>Water vapor</td>
<td>$H_2O$</td>
<td>2-7%</td>
</tr>
<tr>
<td>Sulfide</td>
<td>$H_2S$</td>
<td>0.002-2%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>$N_2$</td>
<td>&lt;2%</td>
</tr>
<tr>
<td>Ammoniac</td>
<td>$NH_3$</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>$H_2$</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

Table 1: Biogas composition and percentages of produced gases ("Biogas composition", 2017)

How to produce biogas?

The biomethanization consists on the transformation of organic matter into biogas thanks to an anaerobic microorganisms in a digester. This complicated process is done in a specific environment free of oxygen, it is called anaerobic digestion. The products of the anaerobic digestion are the biogas and the digestate. The digestate is valued as organic amendments and is spread on agricultural lands.

For the digestion, the organic matter is inserted into the digester on a regular basis.

Anaerobic digestion can be catalyzed in specific temperatures and in a neutral environment (pH should be equal to 7). It can be done in a mesophilic environment, corresponding to 32 -42 °C
or a thermophilic one, 50-57 °C, which is favorable to biochemical kinetics. Under the action of microbial populations, the organic matter undergoes successive transformations until the final transformation into methane CH₄ (Begum, 2017).

The transformation of organic matter takes place in three main phases which are:

**Hydrolysis and Acidogenesis**

The first phase, known as hydrolysis and acidogenesis, is carried out by hydrolytic bacteria. These bacteria transform complex organic matter (lipids, cellulose, starch, proteins ...) into simpler compounds, namely volatile fatty acids (AVG) (acetic acid, propionic acid, butyric acid ...) and alcohols (methanol, ethanol, etc.). The production of hydrogen (H₂) and carbon dioxide (CO) resulting from the reduction of lipids and proteins is also observed.

**Acetogenesis**

During the second phase, the products of the acidogenesis require another transformation before being transformed into the wanted methane. The role of acetogenesis is to reduce the bacteria to produce acetates CH₃COO- and hydrogen H.

**Methanogenesis**

During the third and final phase, hydrogenophilic methanogenic bacteria reduce CO₂ to methane (CH₄). At the end of the digestion, we produce biogas, mainly composed of CH₄ and CO₂, and a digested substrate, the digestate.
Types of organic waste that can be used

All organic matter is likely to be decomposed and therefore to produce biogas. Different types of waste are actually containing organic matter, especially agricultural wastes, such as slurry, manure, or crop residues. Even agri-food industry waste, such as slaughterhouses waste or obsolete products from large areas, as well as industrial waste, in particular paper products, sludge from sewage treatment plants, household waste from our garbage can be sources of organic matter. It is important to choose wisely the type of organic waste that we will be using to produce biogas because the quality of gas produced is directly linked to the nature of the matter to be transformed. Indeed, the methanogenic power is variable according to the type of organic matter, that is to say, not all of them have the same capacity to generate methane. For
example, kitchen waste is likely to produce more methane than cardboard. On the other hand, the constituents of wood such as lignin have a very low methanogenic power because they are very stable compounds.

The methanogenic potential is the maximum volume of methane produced per ton of fresh matter. This mainly depends on:

- The organic matter content: the higher the organic matter content, the greater the volume of biogas produced.
- The composition of organic matter: fats are more methanogenic than proteins or carbohydrates.

We distinguish two major types of waste that can be digested:

**Liquid effluents waste**
- wastewater, whether urban or industrial
- Livestock manure (slurry)
- Sewage sludge which is often mixed sludge composed of primary sludge and biological sludge
- Agri-food effluents

**Organic solid waste**
- Industrial waste: processing waste from the plant and animal industries
- Agricultural waste: solid plants, substrates, animal droppings
- Municipal waste: newspapers, textile, food waste, green waste, packaging, by-products of urban sanitation (Deresa, Libsu, Chavan, Manaye, & Dabassa, 2015).

**Methane yield of different organic matter**

The table below shows the methanogenic potential depending on the type of waste in $M^3$ of $CH_4$ per ton of raw material.
The graph shows that fats and agri-food residues are the ones that have the highest methanogenic potential compared to animal dejections and municipal residues. Hence, we will focus more on those two elements in our project. We will try to use plantations the campus restaurants waste as the base for our biogas.

**STEEPLE Analysis**

A STEEPLE analysis is the acronym of Social, Technological, Environmental, Economic, Political, Legal, and Ethical. It is the base of any engineering project and aims to have a global view of the project. Before starting the implementation, it is important to do this analysis in order to prevent any negative impact that the project can have, and to make sure that it will beneficial for the previously cited fields.
### Social
- The project consists on designing a biogas system. It is in fact a social project since it could create jobs especially in rural areas where biogas could be used, for example people could work in the maintenance of the digester or as technicians. It can also prevent people from carrying heavy firewood that they used for heating and avoid inhaling toxic smoke. Furthermore, biogas is an easy cooking resource which could be good for restaurants and homes in general.

### Technological
- The production of biogas requires the use of a specific equipment that would be able to transform organic matter into fuel. This innovative equipment is called a digester. Hence we can say that it is a technological project.

### Environment
- One of the main advantages of Biogas is that it is an eco-friendly energy source. As a matter of fact, it reduces greenhouse gases since we can use the gases produces in landfills to produce biogas. It is also a non-polluting source of energy unlike fossil fuels and it is a renewable source of energy because there can be absolutely no waste. Even the non-desired matter can be used in plantations.

### Economical
- The use of biogas is a very economical project when compared with the use of fossil fuels. Biogas is actually much less expensive. The electricity bill can be considerably reduced thanks to the use of biogas. This can be very interesting for small-scale energy uses.

### Political
- The production of Biogas can resolve some political issues. The first political benefit of biogas is that it is a renewable energy which means no money waste and no waste of matter. Moreover, biogas is a cheap way of providing energy to rural areas. It is also good for our country since hosted COP 22 in Marrakech in November 2016. The project of producing biogas could also contribute to the creation of «smart cities».

### Legal
- The legal part of our project is mainly concerning the Moroccan laws and norms about renewables energies. Before starting the implementation of our project, we have to make sure that we are respecting the Moroccan legislation.

### Ethical
- Among the previous cited advantages of Biogas, there is the fact that biogas respects the environment, it is also good for our health; which means that it is not as harmful as using fossil fuels of firewood for heating. Biogas is also a clean energy source that does not release toxic smoke.
SWOT analysis

The acronym SWOT stands for Strengths, Weaknesses, Opportunities and Threats that could be encountered during the project. The strengths correspond to the advantages that your company has over competitors and unique factors that will help you perform the project in good conditions. The weaknesses are the things that can be improved or changed in order to have better results. The opportunities are the changes that the project can bring and the innovations. Finally, the threats represent the obstacles that you can be confronted to during the implementation of the project.

**Figure 3 : SWOT Analysis**
Production of biogas in the world

The total biogas production in the world is 10 085.8 ktoe/year. According to EurObserv’ER, an online European journal about renewable energy, “As much as 50.2% of the whole production is done by Germany (5,067.6 ktoe y-1). United Kingdom (1,764.8 ktoe y-1) is the second EU producer, followed by Italy (1,095.7 ktoe y-1) and France (349.6 ktoe y-1)”. In 2016, Germany leads the biogas market with more than 8000 installations in the country. Germany is followed by the United States according to the website Planetoscope (Percebois, 2017).

To explain the evolution of Biogas production in the world it is essential to give more details about each country. The use of biogas is widespread throughout the world, even though the technologies used are very diverse.

China

China was one of the first country to introduce the innovative technology of biogas. At the end of 19th century, rudimentary fermenters were built in the coastal areas of southern China. Apart from China, other developing countries followed their example to use the same mechanism especially in rural areas for industrial projects. South America was one of them !(Bugat, 2016).

Europe

The first industrial installations were set up during the first oil crisis in Europe, mainly for the treatment of liquid effluents of agri-food origin. In 2006, there were 2,500 installations placed in industrial sites. 10 years later, waste treatment started to develop.

Germany, Austria and Denmark produce much of their biogas with the use of farms waste, using energy from crops, by-products from agriculture and slurry. Whereas the United
Kingdom, Italy, France and Spain use mainly gases resulting from the burial of waste (Bugat, 2016).

**Germany**

In the early 1990s Germany set up a biogas plan based on the use of corn as the main source of carbon, it was sometimes mixed with animal manure. This was a wise choice of raw material because corn has the advantage of having a high methanogenic potential. This development has enabled Germany to rapidly become the leader producer of Europe with 6,718 ktoe produced and 8,000 installations in 2013 (Bugat, 2016).

**France**

As for France, EurObserv'ER indicates a biogas primary energy production of 465 ktoe for the year 2013, an increase of 11% compared to 2012. France is ranked 4th in the production of biogas just after Germany, United Kingdom and Italy (Marchais, 2011).

In the news also, biogas became very popular with the launch of COP 21 which took place in Paris in November 2015 and the COP 22 which took place in Marakech in November 2015. Indeed the whole world wants to take advantage of this innovative and eco-friendly method of methanization.
This chapter summarizes the work done on Sustainable Development in Morocco. In this chapter I will talk about an involved Moroccan organization, ADEREE and its works. I will also give an overview of biogas in Morocco.
« L’Agence Marocaine pour l’Efficacité Energétique Développement des Energies Renouvelables et de l’Efficacité Energétique » is a public institution, governed by Law 16/09. ADEREE's main mission is to contribute to the implementation of the national policy for the development of renewable energy and energy efficiency. According to ADEREE, biogas consumption represents 20% of the overall energy balance in Morocco. (ADEREE, n.d.)

ADEREE is currently working on a biomass strategy, and more precisely biogas. The 5 targeted regions that will benefit from this strategy are Sous-Massa-Draa, Rabat-Sale-Zemmour-Zaer, Tadla-Azilal and Meknes-Tafilalet.

<table>
<thead>
<tr>
<th>Projets</th>
<th>Capacité installée (m²)</th>
<th>Production biogaz</th>
<th>Puissance moteur</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogaz agricole</td>
<td>~3000</td>
<td>16500m³/an</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Projet Ben sergao – Agadir</td>
<td>1500</td>
<td>43000m³²/an</td>
<td>10 KW</td>
<td></td>
</tr>
<tr>
<td>STEP RADEEM – Marrakech</td>
<td>4 x 6000</td>
<td>7300Mm³²/an</td>
<td>4 x 834 = 3.336 KW</td>
<td>Energie électrique générée: 30 000 KWh/aj</td>
</tr>
<tr>
<td>STEP OCP – Khouribga</td>
<td>5300</td>
<td>949Mm³²/an</td>
<td>265 KW</td>
<td></td>
</tr>
<tr>
<td>Décharge de Fès</td>
<td>-</td>
<td>~730Mm³²/an</td>
<td>165 KW (tendance 1MW)</td>
<td>Raccordement au réseau MT de 22 KV, commercialisation électrique</td>
</tr>
<tr>
<td>Décharge Oulja</td>
<td>-</td>
<td>142Mm³²/an</td>
<td>700KW + Torchage</td>
<td>Raccordement au réseau MT de 22 KV, Vente électricité</td>
</tr>
<tr>
<td>Décharge Agadir</td>
<td>-</td>
<td>1752Mm³²/an</td>
<td>Torchage</td>
<td>Débit biogaz vers torche : 200m³/h</td>
</tr>
<tr>
<td>Projet STEP RADEE = Fès</td>
<td>-</td>
<td>10512Mm³²/an</td>
<td>2750 KW</td>
<td>Projet en cours de réalisation</td>
</tr>
<tr>
<td>Digesteur CMCP - Kenitra</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Projet en cours de réalisation (Veolia)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>33800</strong></td>
<td><strong>21.6 millionsm³²/an</strong></td>
<td>≥ 7 MW</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: List of biogas projects in Morocco and the production of biogas involved

Projects in progress
According to Generizon, a « Moroccan biogas project development company » , Morocco counts 300 biogas installations mainly used for agricultural plantations. 100 installation have been implanted in Souss-Massa-Draa region in the 90s within the framework of a vast program which was then co-operating with German technical cooperation.

The autonomous Water and Electricity Authority of Marrakech has equipped its waste water treatment plant with a cogeneration unit of electrical energy from biogas produced by methane digesters. It released 20,000 Nm3 per day, that is to say 30,000 KWh / day.

Fes is illuminated thanks to the valorization of its household waste via a biogas power plant produced by the landfill center of the municipality. This plant covers a third of the city's lighting needs. The autonomous Fes Water and Electricity Authority is also investing 1.08 billion MAD to equip itself with the same installation as Marrakech. Also in Fes, the private operator Ecomed plans to build a biogas plant in the landfill ("generizon. biogas. Morocco. Africa. | clean. sustainable. feasible.", 2017).

*Figure 4 : Technical potential of energy production from biomass in Morocco*
This chapter will be about digester plants. I will start by giving a quick description of each type of digester. Then I will do a comparative study of the three main digesters that are available in the market and finally I will choose the best alternative.
Batch vs continuous systems

For the production of biogas, there are many ways to perform the anaerobic digestion. In fact, the types of digesters are numerous and differ a lot in terms of size, shape and construction. However, we can categorize them in two main categories which are batch and continuous digesters. The main difference between the two is that a batch digester is filled and operates for a long period of time whereas a continuous digester is filled regularly. A batch digester should have a higher volume than a continuous one to digest the same amount of feedstock. Another disadvantage of a batch digester is that the initial cost and the cost of producing the same amount of biogas is higher than the continuous digester, approximately two times. Also a continuous digester is better suited for a cold weather as Ifrane, and is more adapted for liquid feedstock. Nevertheless, a batch digester can handle more diversified feedstock compared to continuous digester but since we are using only two types of biomass in our project (food waste and green waste), the continuous digester is more adapted to our case.

Types of continuous digester plants

Fixed dome Plant

Fixed dome digesters are the most ancient, therefore the most known and the most used type of digester plants in the world. The first fixed dome digester has been launched in China in 1936. ("Fixed dome digester - Appropedia: The sustainability wiki", 2017). The popularity of the fixed dome digester is due to the fact that the raw materials used for the construction are very easy to find.

As showed in figure 6, the fixed dome digester is constructed underground and its surface over the ground level resembles a dome. It is composed of a mixing tank constructed above the
ground level, inlet and outlet chambers and an overflow tank. Inside of the dome, there is a fixed gas holder which holds the produced biogas wanted.

**How does it work**

1) The organic matter is mixed with water into the mixing tank to create slurry and then introduced through the fixed dome digester through the inlet chamber. The digester is not completely filled, but only partially filled with slurry.

2) The slurry will stay into the digester for two months to help the decomposition of OM by the anaerobic bacteria. The anaerobic decomposition also called fermentation lead to the formation of biogas which start to accumulate inside the dome. The more biogas aggregate inside the dome, the more used slurry is pushed inside the outlet chamber and then into the overflow tank.

3) The matter collected in the overflow tank is called digestate and can be used for plantations. When biogas is needed, the gas valve placed at the top of the dome opens.

**Material of construction**

One of the main advantages of the fixed dome digester is that the material used for the construction is simple and easy to find. The needed material is:

Natural material

- Cement
- Sand
- Gravel
- Water

Equipment

- Cobblestones
➢ Pipe
➢ Galvanized iron pipe
➢ Valve
➢ Bricks
➢ High density polyethylene pipe (HDPE)
➢ Rubber hose
➢ Brass nipple
➢ Biogas burner

Advantages

The advantages of the fixed dome digester are that it is a cheap technology that involves low budget for the initial investment and the construction. It also has a long lifespan that can go over 20 years. Its main strength is the easy construction and the availability of the material used. It also has the advantage of creating jobs for it needs skilled workers. (Working of Biogas Plants, n.d.)

Drawbacks

The disadvantages that can be disconcerting for the production of biogas are as followed: The construction needs skilled bricklayers and high skilled technicians to make sure that the construction is well insulated and that the gas does not leak. The structure should be very well insulated to avoid gas escaping from the plant. Moreover, the fact that the construction is underground can limit the access to the digester in case of damage and finally, the gas can be confronted to pressure fluctuations. (Working of Biogas Plants, n.d.)
Floating Drum Plant

Floating drum biogas is commonly considered as Indian type of digesters because it was first introduced in India in 1962 by Khadi and Village industry. (Working of Biogas Plants, n.d.). This type of digester is polyvalent since it could be used in small scale purposes for farms and in larger scales such as agro industries.

Material used

- Gallon drums
- Smaller drum (for the gas holder)
- PVC pipes
- Plastic tubes
- Valve
How does it work

The Floating drum digester is mainly composed of six elements. Similarly, to fixed dome digester, the floating digester has also a dome shape at the top. The difference between the two is that in this case, the gas holder (also called drum) is floating over the digester so that it can move freely. The presence of a mixing tank above the ground level is used to mix the organic matter and transform it into slurry. The digester tank is located under the drum. Finally there are two pipes, inlet and outlet pipes that are used for the entering of the raw material and the exit of the wanted biogas. When biogas is produced, the floating gas holder moves up which facilitate the collect of the gas. (ONONOGBO, NWUFO, NWAIWU, & IGBOKWE, 2015)

1) Water is added to the organic matter in the mixing tank to be transformed into slurry.
2) The slurry produced will go inside the digester passing through the inlet pipe.
3) The slurry aggregated inside the digester will be left for two months to let the fermentation happen.
4) The anaerobic fermentation leads to the formation of biogas which rises up in the gas holder. The rising up of the biogas enables the gas holder to move up.
5) The increase of pressure inside the digester pushes the spent slurry in the outlet chamber.
6) The excess of used slurry goes through the outlet pipe and is pushed in the overflow tank.
7) To get access to biogas, the valve must be opened.

Advantages
The advantages of using a floating drum plant are that it is easy to understand and construct so it doesn’t necessary need the work of skilled technicians, the gas is at constant pressure and it is very easy to use since the moving up of the drum is an indicator of the production of biogas.

**Drawbacks**

Unfortunately, every technology has its disadvantages. For the floating drum, the disadvantages are the expensive material and maintenance, the short lifespan (15 years maximum) and the risk of the gas holder to be stuck into the floating waste.

*Figure 6 Floating drum biogas plant*

*Balloon Plant*
A balloon plant, also called tube digester or ball type digester is a digester plant that consists on a long tube generally made in plastic. It is very popular and is widely used around the world for it is cheaper than the other technologies and easier to construct. The first balloon plant was designed in Taiwan in the 1960s with the aim of avoiding some problems encountered with the classical fixed dome and floating drum digesters. However, this innovative technology was introduced in African regions in 1993 “throughout a technical cooperation program conducted by the FAO (Food and Agriculture Organization of the United Nations) in Tanzania. This program aimed to transfer and adapt technologies that had been previously validated in other tropical developing countries” (Cheng and al., 2014)

**How does it work**

A balloon digester plant is a long tube made of plastics. The gas holder and the digester are both part of the tube. The gas holder is at the top and the digester part is just below it. Unlike fixed dome and floating drum digesters, the two parts are in the same container and are directly communicating. As for the inlet and the outlet pipes they are made of the same material as the « balloon » and are directly linked to it. The high gas pressure that we can find in fixed dome and floating drum digesters can be increased by weight placed on the balloon. To avoid damage in the balloon, it is preferable to use safety valves in the case of high gas pressure.

**Material used**

- Long tube made of PVC (Polyvinyl Chloride), or in Polyethylene or Red Mud plastic
- Safety valves
Advantages

The Balloon plant is well known because it is a cheap digester plant, it is very light (generally less than 30 kg), hence very easy to transport. The construction is low cost and doesn’t need experts in the field. It is easy to use and easy to maintain.

Drawbacks

Among the disadvantages of the balloon digester plant there is the low gas pressure that needs the use of gas pumps of safety valves, the impossibility of removing scum during the digestion, the short life span (2 to 5 years), and the low gas pressure.

Comparison among the most used digester plants

In order to choose the type of digester that suits Al Akhawayn University the best, we compare the digesters. In this section, we will focus on the comparison between the different digesters available on the market and the best known. To do this, we will rely on some characteristics that we think are important to evaluate the performance of the digester. The characteristics that can be used to evaluate biogas plants are as follows:
• Lifespan
• Size
• Investment costs
• Cost of maintenance
• Gas pressure
• Skills required
• Methane emission

To be able to compare the digester, we used a weight ranking method. The first thing to do in this method is to define the selection criteria and rank them according to their importance for our project. After ranking the criteria, they are put in a table with the different digesters to be compared. The digester that ends up with the highest final score will be retained.

<table>
<thead>
<tr>
<th></th>
<th>Fixed Dome Plant</th>
<th>Floating Drum Plants</th>
<th>Balloon Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifespan</td>
<td>20 years or more</td>
<td>15 years maximum</td>
<td>2-5 years</td>
</tr>
<tr>
<td>Size</td>
<td>5 – 200$m^3$</td>
<td>5 – 15 $m^3$</td>
<td>4-100 $m^3$</td>
</tr>
<tr>
<td>Investment costs</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Cost of maintenance</td>
<td>low</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>Between 60 and 120 mbar</td>
<td>Up to 20 mbar</td>
<td>Low gas pressure!!!</td>
</tr>
<tr>
<td>Skills required</td>
<td>High</td>
<td>High</td>
<td>low</td>
</tr>
<tr>
<td>Methane emission</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 3 Comparative table of the digesters
### Table 4 Ranking of the selection criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Methane emission</th>
<th>Investments cost</th>
<th>Size</th>
<th>Maintenance cost</th>
<th>Gas pressure</th>
<th>Lifespan</th>
<th>Skills of contractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 5 Weight of the selection criteria

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane emission</td>
<td>Low</td>
<td>Medium</td>
<td>high</td>
</tr>
<tr>
<td>Investment cost</td>
<td>High</td>
<td>Medium</td>
<td>low</td>
</tr>
<tr>
<td>Size</td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Lifespan</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Skills of contractors</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Table 6 Weight method table

<table>
<thead>
<tr>
<th>Type of digester</th>
<th>Methane emission</th>
<th>Investment cost</th>
<th>Size</th>
<th>Maintenance cost</th>
<th>Gas pressure</th>
<th>Lifespan</th>
<th>Skills required</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed dome</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td><strong>82</strong></td>
</tr>
<tr>
<td>Floating drum</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>Balloon</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>55</td>
</tr>
</tbody>
</table>

The table above sums up perfectly the method used. After doing our calculations, we note that the digester with the highest score is the fixed dome digester, followed by the balloon plant and finally the floating drum. This tells us that the fixed dome digester is the most suited to the needs of the university and the most efficient. This result is logical because this type of digester is the most used in the world. Later in our report, we will establish a more complete and specific analysis on this type of digester, while adapting it to the environment as much as possible.

### Other alternatives

The main goal of the project is to design a digester adapted to the needs of Al Akhawayn University. We therefore carried out a comparative study between the most famous digesters and then we will use the best alternative and use it as a base by adding some modifications to make it even more innovative. However, for people who have neither the time nor the budget...
to make a digester at home there are other alternatives that can be as interesting as conventional digesters. These types of digesters are prefabricated which can save a lot of time. Our university produces a lot of waste from restaurants. Here are two types of digester for food waste.

**Green Cone Food Waste Digester**

Green Cone is a small scale food waste bio digester created by a British company called Great Green Systems. It is very easy to use and environmental-friendly. This type of digester is useful for people who want a device to digest their food without producing any waste. It has the ability of digesting any type of food waste from meat wastes to vegetable wastes.

The Green Cone digester can handle up to 80 l of food waste and is very light. Unfortunately, the amount of biogas produced is very low.

*Figure 8 Green Cone digester*
Ecofys Plastic Bag Digester

This new technology coming from Netherland is an interesting alternative because it is a cheap technology compared to other types of digester: the price is 300 Euros maximum, but depends on the localization and the environment where it is installed. The installation is also very easy and quick. The plastic bag digester is similar to a balloon digester plant as presented earlier, but differs in the fact that it is portable. The amount of waste digested can be up to 30kg per day. Its lifespan can go over 8 years and it is made of a solid, nontoxic and recyclable plastic.

Figure 9 Ecofys Plastic Bag Digester
This chapter will emphasize on the dimensions of the fixed dome digester chosen and the innovations that will be added to the classical design to make him more performant and more adapted to AUI’s needs.
Size of the digester

Volume

In order to calculate the volume of the digester, we need two parameters which are the daily feedstock (in liter) and the retention time (RT).

As mentioned previously, the organic matter used is coming from kitchen waste and grass.

\[
V_d = Sd \left(\frac{l}{day}\right) \times RT(\text{days})
\]

with:

- \(V_d\): Volume of the digester in liter
- \(Sd\): daily feedstock in liter per day
- \(RT\): Retention time in days

The daily feedstock corresponds to the quantity of organic matter produced per day and is equal to:

\[
Sd = \text{biomass} + \text{water}
\]

The biomass corresponding to the total solid waste and the water have a 1 :1 ratio, therefore:

\[
Sd = \text{Kitchen waste} + \text{green waste} + \text{water}
\]

\[
Sd = \left(133 \frac{kg}{day} + 1.6 \frac{kg}{day}\right) \times 2 = \left(134.6 \frac{l}{day}\right) \times 2 = 269.2 \text{ l/day}
\]

The retention time (RT) refers to the time that the organic matter passes inside the digester. It can vary depending on the climate of the region studied and on the digester used. The digester that we will be using in our study is a fixed dome digester and has a retention time of 2 months on average. For a cold region as Ifrane, the retention time is between 50 and 75 days.

\[
RT = \frac{50 + 75}{2} = 62.5 \text{ days}
\]

Then the final digester volume is equal to:

\[
V_d = 269.2 \left(\frac{l}{day}\right) \times 62.5 \text{ days} = 16825 \text{ l} \approx 17 \text{ m}^3
\]

The volume of the digester that we want to build is \(17 \text{ m}^3\).

Dimensions

According to the calculations above, the size corresponding to the quantity of biomass produced in AUI is \(17 \text{ m}^3\). To facilitate the construction, we will be using the same dimensions as a \(20 \text{ m}^3\) fixed dome digester. The sketch below, shows the required dimensions for a fixed dome digester in a general biogas plant.
Figure 10 Top view and front view of a general biogas plan

Dimension of Different Components of Various Sized Bio-Gas Plants

<table>
<thead>
<tr>
<th>Components</th>
<th>Plant Size (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td>A</td>
<td>140</td>
</tr>
<tr>
<td>B</td>
<td>120</td>
</tr>
<tr>
<td>C</td>
<td>135</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
</tr>
<tr>
<td>E</td>
<td>154</td>
</tr>
<tr>
<td>F</td>
<td>162</td>
</tr>
<tr>
<td>G</td>
<td>185</td>
</tr>
<tr>
<td>H</td>
<td>86</td>
</tr>
<tr>
<td>I</td>
<td>112</td>
</tr>
<tr>
<td>J</td>
<td>151</td>
</tr>
</tbody>
</table>

Note: All dimensions are in centimeters.

Figure 11 Dimensions of different components of various sized biogas plants
The table above shows the dimensions for each part of the digester. Since we decided to use a 20 \( m^3 \) digester, the radius of the dome will be 233 cm, the dimension of the digester will be 115*398, the outlet chamber will be 264*176*86 cm\(^3\).

Construction cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Number of units</th>
<th>Cost/unit (MAD)</th>
<th>Cost (MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construction materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick</td>
<td>piece</td>
<td>2800</td>
<td>4</td>
<td>11200</td>
</tr>
<tr>
<td>Cement</td>
<td>bag</td>
<td>68</td>
<td>67</td>
<td>4556</td>
</tr>
<tr>
<td>Gravel</td>
<td>m(^3)</td>
<td>4</td>
<td>180</td>
<td>720</td>
</tr>
<tr>
<td>Sand</td>
<td>m(^3)</td>
<td>5</td>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>Paint</td>
<td>litre</td>
<td>4</td>
<td>200</td>
<td>800</td>
</tr>
<tr>
<td><strong>Appliances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet PVC pipe 10cm</td>
<td>piece</td>
<td>2</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Iron bars ( \varnothing ) 6</td>
<td>kg</td>
<td>20</td>
<td>7</td>
<td>140</td>
</tr>
<tr>
<td>Binding wire</td>
<td>kg</td>
<td>0.5</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Outlet pipe</td>
<td>piece</td>
<td>1</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>G. I. nipple</td>
<td>piece</td>
<td>6</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Main gas valve</td>
<td>piece</td>
<td>1</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>PVC 90° elbow</td>
<td>piece</td>
<td>12</td>
<td>3</td>
<td>81</td>
</tr>
<tr>
<td>Glue for PVC connection</td>
<td>bottle</td>
<td>1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Water drain</td>
<td>piece</td>
<td>1</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>PVC pipe ( \varnothing ) 0.5</td>
<td>metre</td>
<td>10</td>
<td>13</td>
<td>130</td>
</tr>
<tr>
<td>Gas hose pipe ( \varnothing ) 0.5</td>
<td>metre</td>
<td>2</td>
<td>13</td>
<td>26</td>
</tr>
<tr>
<td>Biogas burner</td>
<td>piece</td>
<td>1</td>
<td>6000</td>
<td>6000</td>
</tr>
<tr>
<td>Male/Femal socket</td>
<td>piece</td>
<td>6</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>Gas tape</td>
<td>piece</td>
<td>2</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>Teflon tape</td>
<td>piece</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Tee ( \varnothing ) 0.5</td>
<td>piece</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Liquid gas rubber</td>
<td>bottle</td>
<td>1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Lamp</td>
<td>piece</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>HDPE</td>
<td>metre</td>
<td>50</td>
<td>7</td>
<td>350</td>
</tr>
</tbody>
</table>

**Total cost**

| Skilled Labour | person | 5 | 3000 | 15000 |

Table 7 Construction cost of a fixed dome digester plant

3D representation of the chosen digester on Solidworks
Proposed innovations

When biomass is digested, the released biogas contains not only methane but also carbon dioxide, hydrogen sulfide and other gases. The emission of these gases can have serious consequences on health, which is why it is important to avoid direct contact. Among the risks caused by the production of biogas, there are risks of explosion, asphyxiation, disease and poisoning.

The production of biogas has many advantages as I mentioned previously in the STEEPLE analysis. However, like any other technology, a biogas digester has some disadvantages. For the anaerobic digestion of our waste we decided to use a fixed dome digester because it is the most suitable for the university. The fixed-dome digester, however, has some disadvantages,
such as probable gas leakage and pressure fluctuations due to lack of insulation, and a lack of visibility of the inside of the digester. In order to make our digester more efficient, we will try to find innovations that could improve it and avoid these few problems.

**PVC construction**

In order to avoid gas leaks, a good insulating and airtight material must be used. I based my research on the design of the balloon digester which is entirely made of PVC and has the advantage of being light, easy to maintain and low. The fixed dome digester is entirely made of cement and brick. The innovation that we could bring to our fixed dome digester is to replace the concrete and brick construction with a PVC digester because we think this could solve the problems of gas leakage and insulation. Indeed, the PVC, being a polymer, has the following physical properties:

- It resists time and has a long lifespan: it does not rot, or corrode.
- It resists fire: there is a low risk of fire incident.
- Low maintenance requirements.
- It is a good thermal insulator
- It is light
- Easy to replace and maintain
- Low cost
- Respects the environment: unlike concrete that can produce carbon dioxide, which is a greenhouse gas.

Moreover, if we use transparent PVC for the dome, we will have a better visibility of the inside of the digester, which can be useful to control and to be sure that everything goes as planned. The low cost of PVC is also a good advantage as it would allow us to reduce construction costs.
Hydrophobicity

Hydrophobicity is the tendency of non-polar molecules to aggregate in aqueous solutions and repel water molecules. It is different from waterproofness in the fact that the matter keeps exactly the same aspect before and after being in contact with water. In other words, a hydrophobic matter rejects water. Hence, in a hydrophobic matter, water has no impact at all. For example, if a material is rusted by water, making it hydrophobic will cancel the water impact and the material will stay intact. Fortunately, there is a way of creating a hydrophobic solution that can be spread in the targeted material. If we make the dome, the inlet and outlet parts of the digester that are exposed hydrophobic, they will resist to water, rain, and snow. Hydrophobicity will also make the material auto clean because the hydrophobic solution spread make the material rough and as a result, when water drops fall from it they will take with the dirt and dust with them. Since our project will be performed in Ifrane which is a very cold region where snow and rain are very frequent, adding hydrophobicity can significantly elongate the lifespan of the digester and protect it from the environment. This idea has already been implemented on solar panels so I thought that using this idea on our digester could be very interesting in reducing maintenance costs.

Gas sensor

A PVC construction can significantly reduce gas leakage. However, we are never completely safe from an explosion or another disaster. To avoid this type of incident, there is a gas leak detector equipped with a camera that has the possibility of warning with an alarm when a gas leak occurs. "The survey is conducted using a methane sensitive camera and IR devices to detect every leakage on the biogas plant" ("Gas Leakage Detection | For Farmers UK |", 2017). For our project, we believe that a gas detector could prevent any kind of incidents such as poisoning, explosion or fire.
CHAPTER IV
APPLICATION ON AL AKHAWAYN UNIVERSITY
IN IFRANE

This chapter aims to apply the previous design chosen on Al Akhawayn University by using the specific waste that is produced in AUI and using the data provided by the university in order to choose the best way to implement a biogas system in our university.
Description of the environment

Al Akhawayn University is an American university based in Morocco. It is located in Ifrane, a quiet city and ideal for studies. In order to adapt our methanization unit project to the university, we believe that we should carry out a preliminary analysis of the environment where the biogas will be produced.

Since the performance of the bio digester may depend on the environment, i.e. the ambient temperature as well as the climate, it is essential to determine which type of digester matches Ifrane climate the best.

Ifrane, located in the Middle Atlas, a very mountainous zone has cold winters with temperatures as low as -10 °C but also warm springs and summers. It is also a very wet area with an annual rainfall that can attain 1498 mm per year. Ifrane is considered the rainiest city in Morocco. ("Ifrane", 2017).

The region of Ifrane being cold and humid, requires a slower digestion and therefore a digester of great capacity which can handle a long digestion time (150 days instead of 60) because the cold climate makes the digestion twice slower. Apart from the reasons cited above in the comparison, the cold climate confirms that we must use a fixed dome digester.

Feasibility study

The objective of a feasibility study is to show the possibility of a project to be implemented and all the necessary resources in order to meet the goals that have been listed at the beginning. My
feasibility study aims to show the technical limitations, a cost analysis, the available resources, the time needed and the external factors that would or wouldn’t be helpful.

As a quick reminder, my project is about producing biogas by designing a digester adapted to Al Akhawayn needs in energy. To do so, I need to know what are the exact technical characteristics of a digester and what are the changes that need to be done to innovate and improve the actual digesters that are available in the market. I will also probably need the help of a technician to build the model of my digester.

The design of my digester will be done on a 3D modeling software which is SolidWorks. This is a software that we learnt in computer aided engineering course. I think it could help me visualize better the prototype so I can easily make changes and improve it before starting to build the model.

Concerning the cost, one of the main objectives of my project is to be able to construct an economic and performant digester. Depending on the budget that we have and depending on the needs of energy, we will try to focus on the performance while using economic material.

My project requires the help of several external resources. The first thing I have to do before starting my design is to do a waste analysis at the campus restaurants. Indeed, we will need organic matter to produce biogas so I would like to know the exact amount of organic matter available in the wastes of the restaurants as well as the exact content of these waste i.e. grease, waste of fruits and vegetables, Etc. I will also need to know the energy consumption of our university.
The design of a digester and the building of it can take a lot of time. At the beginning of my project I wanted to build an actual digester in the university. Unfortunately, I will not have enough time to actually get to the building of the digester so I will try at least to design a prototype and build a model.

One of the main problems that I will be facing in my project is the budget. I wanted to produce enough biogas to be able to replace the actual energy resource in AUI, but unfortunately it will be too costly so I decided to work on designing a more economic digester.

Organic waste in AUI

Al Akhawayn University is a large university with a surface area of 75 hectares and counting more than 2000 students and 175 teachers. In order to preserve its reputation, AUI University has to meet the needs of the people inside the university by providing a sufficiently large and diversified catering service to welcome its students and teachers. Indeed, the university has not broken its promise since it hosts two food service companies which are Newrest and Sodexo with a totality of 4 restaurants as well as a cafeteria. Students can choose between a fast food, a pizzeria, an international restaurant and a club house.

One of the main points of my project is to make a complete analysis of organic waste having a methanogenic potential in order to produce biogas. As the goal of my project is to produce renewable energy, I must use only the resources available in the university. To do this, I ask the managers of the university restaurants to help me determine the quantity and the content of the waste of the restaurants. Here is the information that I gathered:
As mentioned earlier, we have two main catering companies on campus, so I thought it would be wiser to separate the waste from the two restaurants in order to have a more general view of the resources available.

**Newrest restaurant_ Club House**

This restaurant offers a wide variety of choices. Students can choose between fast foods such as pizzas or sandwiches or international dishes. According to the restaurant manager, the restaurant counts on average 35kg of fruit and vegetable scraps as well as 5kg of waste return from consumption.

**Sodexo restaurant_Toms, Pizzeria, International Restaurant**

This company has three restaurants on campus, so it is normal for organic waste to be more numerous. The manager of the restaurants *Maria Boussouaf* as well as *Nadia El Mesbahi* informed me about the amount and content of waste per day. On average, the restaurant holds 28 kg per day of vegetable peelings in the kitchen and 4 bags of about 15 kg each of fruits and vegetables plus 5 kg of meat (fish, chicken or red meat depending on the daily menu). This corresponds to a total of 88kg of fruits and vegetables with high methanogenic potential and 5 kg of meat.

**Green waste**

Concerning the green waste present in AUI, the university gathers a total of 300 kg each month for a period of 7 months which corresponds to 2100 kg per year. The green waste is coming from the grass and plants present in the garden. Which corresponds to a total of 5.8 kg per day.

**Conversion to electricity**

Once the biogas has been produced and collected, it can be used as efficiently as possible.
Biogas can be used for three main purposes: thermal energy, electricity and Biodiesel. In our case, we would like to use it for electricity and heat.

Regardless of the use of the biogas, it is virtually impossible to use it as it is produced. The only valuable gas is the methane while the other components are useless, or harmful. One or more purification steps are therefore necessary to be able to use biogas as an electricity or heating resource.

The purification consists of removing unwanted substances and pollutants (ammonia, sulfur elements, minerals, etc.) and increasing its methane content (by removing CO2 and other gaseous compounds) to produce a gas comparable to natural gas. The bio methane thus obtained constitutes cleaned and enriched biogas with a calorific value equivalent to natural gas.

There are many ways to convert biogas into electricity. The most used heat engines for biogas conversion into electricity are gas turbines and combustion engines. However, combustion engines are more interesting than gas engines because they are less expensive and more efficient. In order to transform our biogas into usable electricity and heat, we can use a biogas burner that has the ability to minimize the quantity of dangerous substances such as hydrogen sulfide and CO2 in biogas and use the biomethane essentially for electricity and heating. This type of device can cost between 5 000 to 7 000 MAD. The following biogas burner is an Indian product and costs around 6 000 MAD.
Economic impact of the project

Methane yield and energy production of the biomass used in the project

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Methane produced in m³/t</th>
<th>Quantity kg/day</th>
<th>Quantity t/year</th>
<th>Methane produced m³/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food waste</td>
<td>220</td>
<td>133</td>
<td>48,545</td>
<td>10679,9</td>
</tr>
<tr>
<td>Green waste</td>
<td>110</td>
<td>5,8</td>
<td>2,1</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total</td>
<td>total</td>
<td>10910,9</td>
</tr>
</tbody>
</table>

*Table 8 Methane produced per year with AUI's waste*

- **Calculation of energy production per year**

It can be calculated by using the calorific value (CV) of methane. « The amount of energy produced by the complete combustion of a material or fuel. Measured in units of energy per amount of material » ("calorific value - Wiktionary", 2017). The caloric value of methane is 9.94 kWh/m³.

\[
E_{\text{tot}} = CV_{H_4} \cdot V_{CH_4} = 9.94 \, \frac{kWh}{m^3} \cdot 10743.191 \, m^3 = 106787.32 \, kWh
\]
• **Calculation of the energy saved in one year**

We will consider 5% of energy loss to make sure that the engine is overfed rather than underfed (Solagro 2001). The exploitable energy by the engine is therefore:

\[ E_{\text{saved}} = 0.95 \times E_{\text{tot}} = 0.95 \times 108454.346 \text{ kWh} = 103032 \text{ kWh} \]

• **Calculation of the energy supplied by the biogas in one hour**

\[ E_{t=1h} = \frac{E_{\text{saved}}}{365 \times 24} = \frac{103032}{365 \times 24} = 11.7 \approx 12 \text{ kW} \]

• **Calculation of the energy supplied by the biogas in one month**

\[ E_{t=1\text{month}} = 12 \text{ kW} \times 24 \times 30 = 8640 \text{ kW} \]

**AUI energy consumption**

The table in appendix A shows the energy consumption and its cost from August 2015 to July 2016 per month and per year. If we consider that the energy supplied by the biogas is around 8640 kW/month, then the university could go from an energy consumption of 9,559,853 kWh to 9,456,821 kWh for one year. Or as an example for the month of August 2015 it could go from an energy consumption of 384,333 kWh to 375,693 kWh. This difference is not huge but can make a difference in the energy bill. If the average cost/unit of energy is 1 MAD/kWh, then the University could save around 100,000 MAD per year.
Figure 14 Online Simulation from Biogas Calculator

Biogas Calculator

**Biogas Plant Specifications**

- Feedstocks: 45 tons/year of Vegetable waste, 4 tons/year of Chicken layer, 1 tons/year of Garden waste
- Digester Type: Wet
- Contaminants Level: 5%
- Biogas Usage: CHP (combined heat and power)
- Digester Usage: Directly to land
- Solid Content Before Digestion: 25% (solid content should be adjusted for the digester type)
- Contaminants to Landfill: 2 tons/year
- Greenhouse Gas (GHG) reduction will be around 11 tons CO2 eq./yr for landfill diversion and 3 tons CO2 eq./yr for renewable energy production

**Potential Revenue per Year**

8 760$ from electricity sales and 1590$ from heat sales.

Figure 15 shows the results of the simulation of our biogas system for AUI. After entering the type of waste used with its quantity, the calculator gives an approximate result of how much the biogas system will reduce CO2 emission and the potential revenue per year. Here, the reduction will be around 11 tons of CO2 per year which corresponds to a carbon offset of 2195 MAD saved per year according to AUI carbon calculator (Appendix). As for the potential revenue per year, the simulator gives a result of 8760$ from electricity sales and 1590$ from heat sales, which corresponds to a total of 10 350$. This result is relatively close to the results found previously. In fact, our calculations gave a saving of 100 058 MAD.

\[
\% \text{ error} = \left| \frac{\text{experiment} - \text{theoretical}}{\text{theoretical}} \right| \times 100
\]

\[
\% \text{error} = \left| \frac{1000000 - 104089}{104089} \right| \times 100 = 3.9\%
\]
The percent error is very low, we can consider that our result is correct.

Localization of the digester plan

![Image of Al Akhawayn University empty land dimensions]

The dimensions of the digester chosen are 20 m³, which corresponds to an area of at least 5 * 5 m², we must then choose a place at AUI which is large enough to handle such a big volume. Al Akhawayn has a vacant lot with a total area of 3918 m². This vacant land is large enough to place the digester.
One of the main benefits of biogas production is the fact that it is a renewable energy source. In fact, all that is produced from the methanization of biomass is used. After being digested for approximately two months, the biomass entered in the digester transforms into biogas and digestate. The digestate contains non-biodegradable organic matter, minerals, and water. This digester is collected in the outlet chamber of the fixed dome digester and can be used as fertilizer for plants. Here are the properties of the digestate.

**Properties of digestate**

- **Bad smells of biomass disappear**: Bad smells come from volatile fatty acids. However, in the process of biomethanization these molecules are decomposed. Nevertheless, to completely eliminate odors, it is advisable to cover the storage tank.
- **Hygienic**: methanization reduces pathogenic germs
• **Fertilizer:** fertilizing value increases since the content of N (nitrogen), P (phosphorus), K (potassium) content of the inputs is conserved.

• **It protects the environment:** Using the digestate as a fertilizer for plants in agriculture, can decrease the greenhouse gases. In fact, the greenhouse gases such as CO2 are used in biogas and had been destroyed with its purification. Hence the digestate does not contains or contains few quantity of greenhouse gases.

• **Plants are healthier:** The pH of the digestate is greater than the pH in manure used for plantations. That means that the pH is less acidic and more neutral. Hence, risk of harming plants decreases.

• **Spreading becomes easier:** Thanks to the modification of the viscosity during biomethanization, the digestate is spread more uniformly on the soil than a mineral fertilizer.

• **Less expensive:** The digestate produced by the methanization make the user save a lot of money because it is a free organic fertilizer.

**RECOMMENDATIONS**

Al Akhawayn University is a very modern university that is constantly evolving. It keeps bringing new changes to facilitate students’ life. In recent years, the university has been going green, trying to use renewable energies in order to be in line with the new expectations of COP 22. The university possess currently 19 solar panels that can generate enough electricity to power an entire building. From this point of view, we believe that bringing a biogas system to the University could not only protect the environment but also reduce the costs of electricity.

The biogas that will be produced will generate up to 8000 kW per month which can be very interesting. However, Al Akhawayn University is still not at the forefront of modernity since
we do not sort our waste. Indeed, waste management could bring a lot of help to the production of biogas and would significantly change the amount of electricity produced.

The type of waste that we are using in our project is food waste generated by restaurants as well as green waste from gardening. The waste produced is important because we have many students and several restaurants. However, bringing more waste could make our project even more profitable. The university has 22 residential buildings, 9 buildings of the academic area, 4 administration buildings and 2 gymnasium buildings. This corresponds to a total of 37 buildings. If we were to sort the waste in each of the buildings, we would be able to isolate organic wastes with high methanogenic potential.

Unfortunately, AUI’s community is not sufficiently aware of the benefits that waste management could bring to our university. In order to raise awareness in AUI, we could suggest a training for the university staff that usually takes care of waste but also gather the students and present them the benefits of waste management and how this could be performed. We could organize an awareness day about the benefits of sustainable development.

CONCLUSION

The main purpose behind a Capstone project is to apply the concepts learnt during my bachelor into real life examples. My project supports the initiative of making our University sustainable and environmentally friendly. It consists on creating a Biogas system for Al Akhawayn University that would be both eco-friendly and environmentally-friendly. To do so, I had to use Biotechnological, Engineering and Management concepts that I studied in my years passed at AUI. In a context where Morocco is developing in the environment field, my project is deeply
ingrained in the perspective of sustainable development. Indeed, creating a biogas system for AUI could significantly decrease the university electricity bills and will help manage the university’s wastes. Also, the results of my capstone project could be used in my colleague’s capstone that is about Composting and Cogeneration. To implement my project, I did a literature review to understand very well the situation in Morocco and how biogas is used around the world then I did a comparative analysis of the different biogas technologies so I could base my design on one of them and last but not least, I adapted my research to the case of Al Akhawayn University with specific measures and innovations. Even though my project was very interesting, I have to admit that I faced some challenges. For example, I had difficulties in finding the exact amount of waste produced in AUI and in finding some of the construction costs. Fortunately, this project taught me a lot not only academically but also socially. To conclude, I can say that a biogas system could encourage AUI’s community to take care of the university and evolve step by step in the domain of sustainable development.
REFERENCES

ADEREE., PLAN D’ACTION DE L’ADEREE POUR PROMOUVOIR LES ENERGIES RENOUVELABLES - CAS DE LA BIOMASSE-ENERGIE –. Morocco: ADEREE.


Working of Biogas Plants (1st ed.)
# APPENDIX

## Table 9 Energy consumption and cost for year 2015/2016

<table>
<thead>
<tr>
<th>Mois</th>
<th>K-points</th>
<th>H-Plaine</th>
<th>H-Creuse</th>
<th>Énergie Activ. (GWh)</th>
<th>Prix Unitaire MDH (HT)</th>
<th>Montant MDH (HT)</th>
<th>Montant TTC</th>
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</table>

Total: 2208691.00 4279453.00 3071599.00 9559853.00 14.27 10.01 6.81 2624473.76 3575623.48 1746240.78 10.125,393.94

## Table 10 Energy consumption and cost for year 2015/2016 after implementing the project

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Figure 17 Front view of 3D representation of a fixed dome digester

Figure 18 3D representation of a fixed dome digester
Figure 19 Countries with reported domestic biogas activity according to GIZ
Night soil based biogas plants are suitable option for improving the sanitation in houses as well as Public and Private Institutions. It will help to prevent the emission of methane from the human excreta to the atmosphere.

The biogas captured from human excreta can be utilized to replace other fuels. Different models with different capacities are available from 1 cum meter to any higher capacities.

Figure 20 Fixed dome digester from Biotech India
Foldable Bio Gas Plants

A suitable model for the speedy installation and operation. A customer friendly design, available in different capacities.

Specially designed insulated digesters are also available under this category for cold climate regions.
Welcome to the Carbon Offset Calculator of AUI.

AUI is inviting you to calculate how much it costs you to offset your carbon consumption and consider purchasing trees to be planted. Please follow the steps below in order to complete the purchasing:

1. User Preferences
2. Carbon Emissions - in tonnes
3. Offset Now

Enter your carbon consumption in tonnes to calculate the cost to offset it.

Currency: EURO GBP MAD USD

Number of Tonnes: 11

2195.60 cost to offset

Page 1 of 3

Figure 23 Carbon offset calculator of AUI results

Figure 24 Data entered in Biogas Calculator - Online software