An-Najah National University

Faculty of Engineering and Information Technology

Energy Engineering and Environment Department

Graduation Project II

Converting Municipal Solid Waste into Energy - Al-Minya Landfill as a Case study

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I. Abbreviations

Shortcut	Word
MSW	**Municipal Solid Waste**
ILS	**Israel New Shekel**
LPG	**Liquified petroleum gas**
GHG	**Green House Gases**
ppm	**Particles per Million**
OSW	**organic solid waste**
WTE	**Waste to Energy**
MARR	**Minimum Attractive Rate of Return**
RoR	**Rate of Return**
NPV	**Net Present Value**
SPP	**Simple Payback Period**
LCOE	**Levelized Cost of Energy**
UNRWA	**United Nations Relief and Works Agency for Palestine Refugees**
WB	**West Bank**
GS	**Gaza Strip**
JSC	**Joint Service Council**
ZAF	**Zahrat Al Finjan**
LGU	**Local Government Unit**
CH_4	**Methane Gas**
NO_x	**Nitrogen Oxides**
KSA	**Kingdom of Saudi Arabia**

II. NOMENCLATURES

Shortcut	Word
ppm	**particles per million**
Mt	**Million metric tons**
MJ	**Mega Joule**
kcal	**kilo calories**
kWh	**kilo Watt-hour**
GWh	**Giga Watt-hour**
MWh	**Mega Watt-hour**
TWh	**Tera Watt-hour**

III. Abstract

The global demand on energy resources is largely increased in the last century, especially fossil fuel products which deliver the world of 85% of its primary energy. This results in significant environmental problems like global warming, ozone depletion, acid rain and so on.

The amount of global MSW is predicted to reach 148 billion tons by 2025, which need a significant interest and management. Otherwise, the consequences will be very bad. In the developing countries, usually they treat the MSW by traditional methods (like open burning or throw it in a random dumpsites), which result in a negative environmental and social effects. The search for more sustainable MSW management techniques has high interest by the researchers and engineers. One of these techniques is converting of the MSW into energy sources by incineration, gasification, pyrolysis, anaerobic digestion or other converting methods.

In Palestine Territory (represented by West Bank and Gaza strip), there is a real problem related to the energy and MSW sectors. As it its occupied by Israel, the generation of energy in Palestine is very limited (a generating plant in Gaza strip which cover less than 8% of Palestine demand) due to political and economic challenges, which result in a significant shortage of Palestinian demand, where West Bank demand had reached 1.2 MW in in 2019. The amount of MSW in 2019 in West Bank is 957,030 tons/year, 485,450 tons/year in Gaza, and 110,421 tons/year in refugee camps in West Bank and Gaza strip.

There are 4 sanitary landfills in West Bank: Zahrat Al Finjan Landfill in Jenin governorate which serve the northern part of West Bank, Al Minya Landfill in Bethlehem Governorate which serve the southern part of West Bank, Jericho Landfill, and Beit Anan Landfill (which serve N-E&N Jerusalem and 5 local government units (LGUs) in Ramallah-Bireh governorate). Another suggested landfill is Rammun Landfill which supposed to serve all communities in Ramallah-Bireh governorate when it built, and due to the challenges face the construction of Rammun Landfill, many random dumpsites is distributed in Ramallah and Nablus areas. In Gaza strip, there are 4 sanitary landfills: Johr Al-Diek, Al-Fukhary (Sofa new and old landfills) and Deir Al-Balah landfills.

This project study the potential of energy generation from municipal solid waste that are received to Al Minya landfill -which receives near 1,050 tons/day in 2020- after MSW sorting (separation) process has been done. It is worth to mention that Al Minya landfill serves all the southern area of the West Bank and it is a relatively new landfill (2013). In particular, the project considers incineration and landfilling waste-to-energy technologies, and find out the total amount of available energy by adopting each technology.

The results show that the incineration plant capacity – which works for 30 years with 22% assumed conversion efficiency for electricity generation- to be 26.8 MW, depending on the daily available electric energy in the MSW in 2023 which is equals 642,427.5 kWh/day-.

The results also show that the available energy from the landfilling plant gas values varied through years 2023 to 2093 (1,293,796 kWh in 2024 to 96,065,480 kWh in 2054 and then decrease gradually) with power generation capacity (0.164 MW in 2024 and 12 MW in 2054), therefore, a multi generators will be used, each with 3 MW power capacity and 17 years life time, distributed over the plant life time, in order to obtain the highest possible generation efficiency.

Table of contents

List of tables

List of Figures

1. Introduction

Municipal waste and energy issues are regarded as a global challenge over decades, especially in the last two decades. Both issues resulting in environmental, health, economic and social problems. For example, in order to generate energy by conventional sources, fossil fuels or other conventional fuels are need to be burned which result in negative effects on environment (like ozone depletion, global warming, acid rain, etc.), in addition to the economic challenges. Global warming resulted from the emissions of greenhouse gases (GHG) which are largely increased in the last decade from more than 400 ppm in 2006 and it reached 417 ppm in May 2020 which is the highest value recorded in history **[1]**.

The most used energy source are fossil fuels; which are oil, coal and gas which supply near 85% of world population primary energy **[2]**. In the last decade, the world dependence on renewable energy sources increased, which rose from (1010 GW) in 2007 to (2017 GW) in 2016 **[3]**.

In 2010, the estimated amount of global sloid waste production was 10.4 billion tons and it is predicted to reach 148 billion tons by 2025 **[4]**. Waste mismanagement could results in accumulation and leaking of these wastes into under-ground water, agricultural soil and plants. Usually the MSW disposal done by leave it in open landfills which contribute to pollution in air and lands due to microorganisms and insects involved in huge quantity of dumped rubbish **[5]**. Furthermore, the open-burning of the solid wastes result in producing number of gases (like CO, CO_2, SO, NO, etc.) which cause many environmental problems **[6]**.

At the scale of Middle East and North Africa, waste management and energy development take place as an important interest for the researcher and socialists in this region. For example, after closing the Naameh Landfill in 2016, and without official solid waste management plan, the capital city of Lebanon Beirut and Mount Lebanon municipalities had to take responsibility of solid waste management without proper technical and financial resources, which result in random waste disposal and enforcement of environmental and health problems **[7]**.

Another example from Middle East is Qatar country, which face a rapid socio-economic growth after it had awarded the hosting of 2022 FIFA World Cup. Which resulted of more environmental concerns of this rapid developing **[8]**.

The political situation in a country plays an essential role in energy sector. The case study of this project is located in Palestine country, in the southern part of West Bank., and according to Oslo II Acord in 1995, West Bank is divided into 3 areas: A, B, and C, as presented in *Figure 1*. 60% of West Bank area is classified as “C” areas, which its civilian and security is controlled by Israeli occupation, including controlling of energy sources **[9]**.

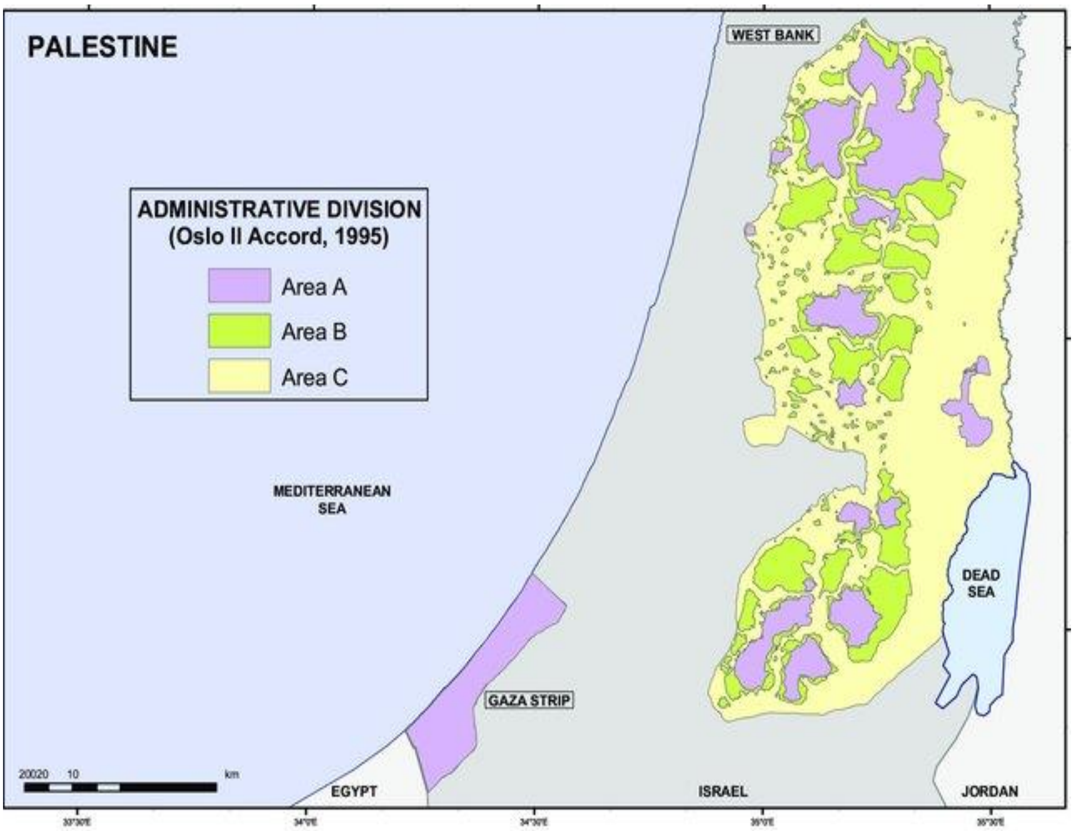

Figure 1 Map of Palestine, Oslo II Accord (1995). Administrative Divisions: Areas A, B and C.

Occupied Palestine country (represented by West Bank and Gaza strip) face many challenges in the field of waste management. While there are just three licensed landfills (Al Minya at south, Zahrat Al Finjan at north and Jericho landfills) in West Bank and Gaza strip, there are a considerable quantity of solid waste in these areas, the estimated amount of MSW in 2019 in West Bank is approximately 2622 ton/day (957,030 ton/year) with average per capita production of 0.91 kg/day and in Gaza approximately 1330 ton/day (485,450 ton/year) with average per capita production of 0.7 kg/day **[10]**.

The estimated energy consumption costs in West Bank and Gaza strip in 2019 is approximately 2,900,000,000 ILS **[11]**. For heating use, 50.2% of population depend on electricity and LPG, 18.7% use wood and average of 28.4% (4.8% in West Bank and 60.1% in Gaza) state that they do not use any type of energy for heating **[12]**, and these data are illustrated in *Figure 2*. For cooking, 98.9% used LPG, 0.3% used electricity and less than 1% of the population used wood for cooking in 2017 **[12]**.

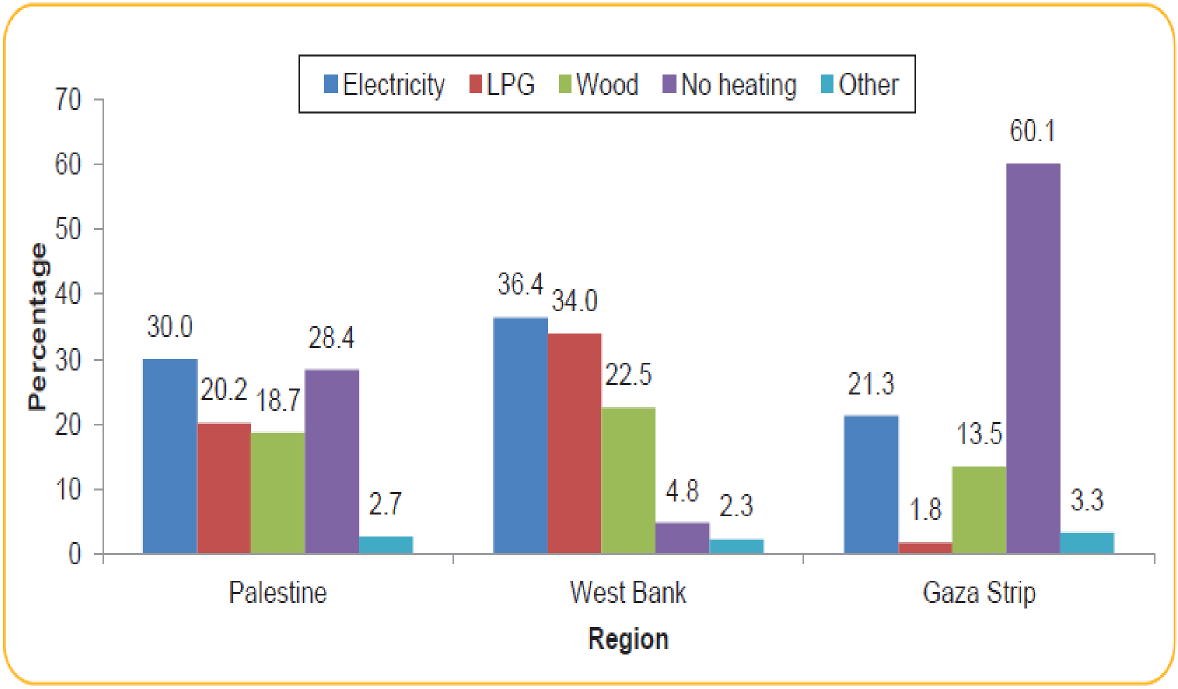

Figure 2 Percentage (%) Distribution of Population by Main Source of Energy for Heating, in 2017

The independence in energy sector requires the optimal achievements of generating, transmitting and distribution of energy, and searching for promising energy source which can contribute to reaching energy independency **[11]**.

So, it is clear that there is a need to work on solving the waste and energy problems in Palestine, and this is what this project tries to solve. The converting of waste into energy can take place by many techniques, for example, in converting food waste into energy sources, there are different approaches like anaerobic digestion and ethanol fermentation which are regarded as a biological technology. Some techniques depend on thermal and thermochemical technologies like incineration, pyrolysis, gasification and hydrothermal carbonization **[13]**.

2. Scope of Work

The scope of work of this project is Al Minya sanitary landfill which is located in Bethlehem governorate and serve the southern part of the West Bank. The project aims to study the feasibility and possibility of converting the MSW that end up at Al Minya landfill into energy sources from the potential energy aspect, using incineration and landfilling waste-to-energy technologies, after these MSW had been collected and sorted.

3. Objective

1. Propose a technical potential solution for MSW that received by Al Minya landfill, which is a new landfill and there is no previous works on it in order to convert MSW into energy – until the report was written-.
2. Establishing basics for future researchers in order to facilitate their researches and proposals for this landfill in the future.

4. Literature Review

It is seen that the MSW managements and energy production from MSW and other renewable sources have been taken care by local and global researchers in the field of environment science and energy.

Abdelaal [2019] study aimed to analyze quantitively and qualitatively the generated food waste from university campus in Qatar country. and food waste generation was estimated to be 329.5 kg/day or 80 ton/year. The majority of this waste could be avoided and the main reason for the excessive food waste was overproduction than the consumer wastage. The study found that the food providers in the universities in buffet-style meals misestimate the amount of food waste generated in their cafeterias **[8]**.

Alam [2020] study reviewed most of the studies on MSW management, treatment and disposal in Bangladesh country, which found that the MSW generating in urban centers about 23,688 tons/day with 70% of it is organic solid waste (OSW) with average moisture content of 50%. About 0.5 million people depend on recycling business for their livelihoods and save about USD 15.29 million/year, which are the disposal costs **[4]**.

In USA, Badgett [2020] study identifies the standards and practices related to handling and disposal of wet waste materials in USA, that from the following resources: 1) food waste, 2) fats, oils and greases, 3) sewage sludge, and 4) animal manure. The study find that the environment of each of these four materials extremely varying across geographic areas in all countries and regions, including USA **[14]**.

In the Palestine case, Salem [2020] paper study the MSW disposal behavior of poor people living in Gaza strip refugee camps. A total of 180 face-to-face interviews were made with people from eight camps in Gaza strip, 88% of the interviewees see that there is a link between the MSW proper disposal and their well-being and luxury. Interview respondents are aware of the negative effects of improper waste disposal on environment and health, and despite their low financial resources, they show a willingness to pay for the proper MSW management. In spite of that all of the interviewees are concern about the negative effects of improper waste disposal, only 23% of them aware of the environmental initiatives **[15]**.

The recent published paper of Tayeh [2021] investigates three waste-to-energy (WTE) options, two of them introduce the proposal of electricity generation by incineration of MSW, one plant in Zahrat Al-Finjan landfill in West Bank (1500 ton/day) and other plant in a transfer station (750 ton/day). The third option is focus on waste-to-heat for local industrial loads. After environmental and economic analysis of each option, the third option is found to be the most feasible. However, this option is impractical due to the demand unavailability. The MARR and life time for the first two options were assumed 10% and 30 years, respectively. And two options produced: First, if the plants will take responsibility of total costs of MSW collection and transferring, then the economic variables will be for Zahrat Al-Finjan plant and the transfer station plant as following: NPV of 25.2 and -2.63 million US dollars, RoR of 12% and 9.7%, and SPP of 8.5 and 11 years, respectively. The second option, if the Palestinian government will take that responsibilities, then the economic variables will be for Zahrat Al-Finjan plant and the transfer station plant as following: NPV of 207 and -12.5 million US dollars, RoR of 22% and 11.3%, and SPP of 4.6 and 9 years, LCOE of 0.0486 and 0.0497 $/kWh, respectively **[16]**.

There are many literatures worked on the technologies of converting MSW into energy. Lu [2020] paper was a review of the pyrolysis of the MSW, and it provide the future and challenges of the MSW pyrolysis process **[17]**.

Pham [2015] review collect the current methods used to convert food waste into energy, which are biological methods (anaerobic digestion and fermentation) and thermal and thermochemical methods (incineration, pyrolysis, gasification and hydrothermal oxidation), and it discussed the advantages and challenges of these methods. In addition, the paper review the future directions of converting food waste into energy sources **[13]**.

Lee [2020] review provides an overview on the Synergistics pyrolysis studies of MSW, which state that the pyrolysis synergy is proposed to be the key for success of pyrolytic practice of MSW which treat the waste with optimization between resource recovery and carbon emission **[18]**.

Coe [2020] paper investigate the converting of vegetable oils into biodiesel which is used as a cleaner alternative to conventional fossil diesel. The study compared three different chemical conversion process in terms of the financial feasibility **[19]**.

Sipra [2018] paper reviewed the pyrolysis process of MSW, and study the relations between the heating values of different components of MSW and the effects on the reaction. The study also review the effectiveness of pyrolysis process by comparing it to other methods **[5]**.

From environmental view, Tang [2020] study 4 MSW treatment methods, the first one is the incineration, and the others are gasification-based depend on 3 systems (combustion boiler, gas turbine/combined cycle, and internal combustion engine). The study compared these technologies using methods of environmental life cycle assessment and exergetic life cycle assessment. The results of the study show that gasification systems were more effective to mitigate the environmental impacts of acid rain increasement, nutrient enrichment, and ozone layer depletion, but caused higher global warming impacts **[20]**.

Foster [2020] paper reviews waste-to-energy sector in terms of feedstocks and processes. The paper discussed anaerobic digestion, gasification, pyrolysis, incineration and hydrothermal liquification. The paper show that manure ammonia, CH_4 and NO_x emissions make up 40%, 22.5% and 28%, respectively of the total UK's anthropogenic emissions. The paper also shows that anaerobic digestion is capable to reduce the manure and slurry pollutants potential with up to 90% methane emissions reduction and 50% NO_x emissions reduction, compared to no processing. In addition, The results shows that if biogas harvesting were carried out on 90 million tons of manure and slurry in the UK, more than 1,615 TWh of electricity could be generated. **[21]**.

Yaman [2020] study conducted an analysis of greenhouse gases (GHG) reductions and potential energy from MSW converting into energy, in KSA (Dammam area). The study includes

3 waste management scenarios, which are material recovery facility (MRF) with composting, landfilling and incineration. One of the important results from the study is that MRF and incineration have the least amount of GHG emissions (−2,142,618 tCO2-eq/year and −287,873 tCO2-eq/year, respectively) **[22]**.

5. Theoretical background

5.1. Waste-to-Energy conversion technologies

The waste conversion process into energy resources can occur by several methods and techniques, which varies by the nature and characteristics of these methods. Examples of these methods are shown in *Figure 3*.

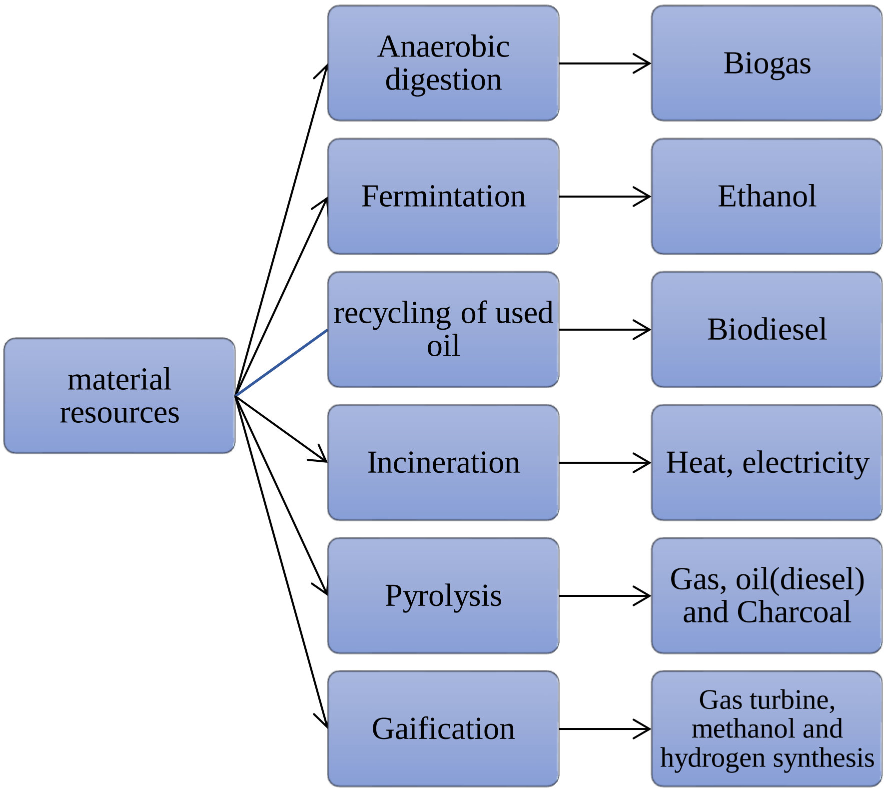

Figure 3 Waste-to-Energy conversion methods

5.1.1. Anaerobic digestion:

The anaerobic digestion is the breakdown process of organic materials by microorganisms in the absence of Oxygen, and the main product resulted from this process is Biogas (mainly consist of CH_4 and CO_2) **[13]** **[23]**.

The average caloric value of Biogas is 21 MJ/m^3 (5000 kcal/m^3), and assuming the generation efficiency is 35%, this value could generate 2.04 kWh of electricity **[13]**. Biogas composite of CO_2 (25-55%), CH_4 (40-70%) and other gases (N_2 (0-5%), H_2 (0-1%) and H_2S (0-3%)) [23].

The anerobic digestion process occur in a device called "Bio digester" which imitate the natural decay process of organic matter, see *Figure 4* & *Figure 5* . The main feedstock of process are animal waste (cows, horses, sheep, goat, etc.), sewage sludge, organic MSW, and so on **[23] [24]**.

The suitable digesting temperatures range inside the biodigester is (20-35 ⁰C). The retention time range is (40 -100 days, and the best range is 45-55 days for cattle dung), and the biogas generation range is (0.3-5) m^3 gas/ (m^3 digester volume) per day **[23]**.

We can find the biodigester tank volume using *Eq. 3:*

$$Digester\ size\ (m^3) = Loading\ Rate\ \left(\frac{m^3}{day}\right) * Retention\ time\ (day) \qquad \textit{Eq. 1}$$

Were the loading rate is the amount of feedstock produced each day and placed into the biodigester device **[24]**.

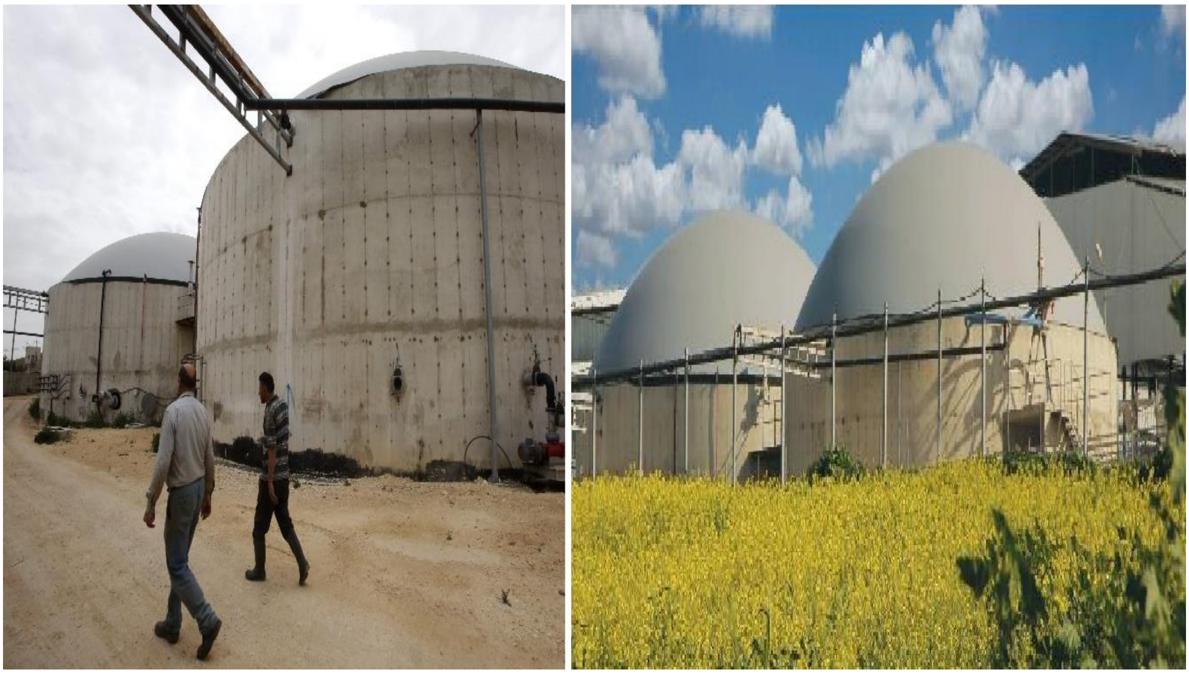

Figure 4 Biodigester Tanks at Al-Jebrini Farm, Dura-Palestine

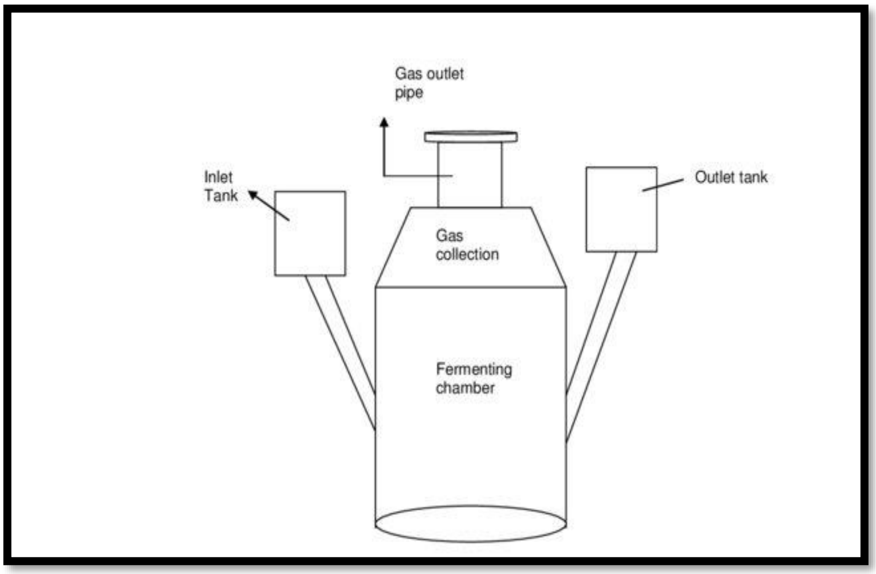

Figure 5 schematic diagram of a biodigester

5.1.2. Ethanol fermentation

The production of bioethanol can take place by different techniques depending on the feedstock source that converted to bioethanol. Assuming we want to convert biomass into bioethanol from 3 different sources: 1-) Woody/ cellulose materials, 2-) Fruit/sugar crops and 3-) Grain/ starchy crops, then the converting process is illustrated in *Figure 6* **[24]**.

Figure 6 show that the grain and starchy crops need first to be cracked to convert starch into sugar before fermentation process, the fruit crops go to purified and extraction process before fermentation.

After fermentation step, CO_2 result and extracted (which can be used in carbonated beverages production), then the solid residues separated (which can be used as a feedstock for animals), and after distillation process, dehydration process done on Alcohol to produce ethanol (which is not 100% pure ethanol, and it is found that the maximum ethanol concentration reach only 96%), and the additional purifying for ethanol may done by using special tools (e.g., size-selective molecular sieves) **[24]**.

As a rule-of-thumb, the production of 1 L of ethanol need 1.5 kg of sugar **[24]**. It is found that each gram of total solid food waste produces 0.43 g of ethanol if the feedstock is woody/cellulose materials which undergo hydration then fermentation processes, and 0.31 g of ethanol produced per each g of total solid food waste if the feedstock is the grain and starchy crops, which undergo saccharification then fermentation processes. So, if energy content in ethanol considered to be 26.9 kJ/kg, then each gram of total solid food waste produces 8.3-11.6 kJ of energy [25] [13].

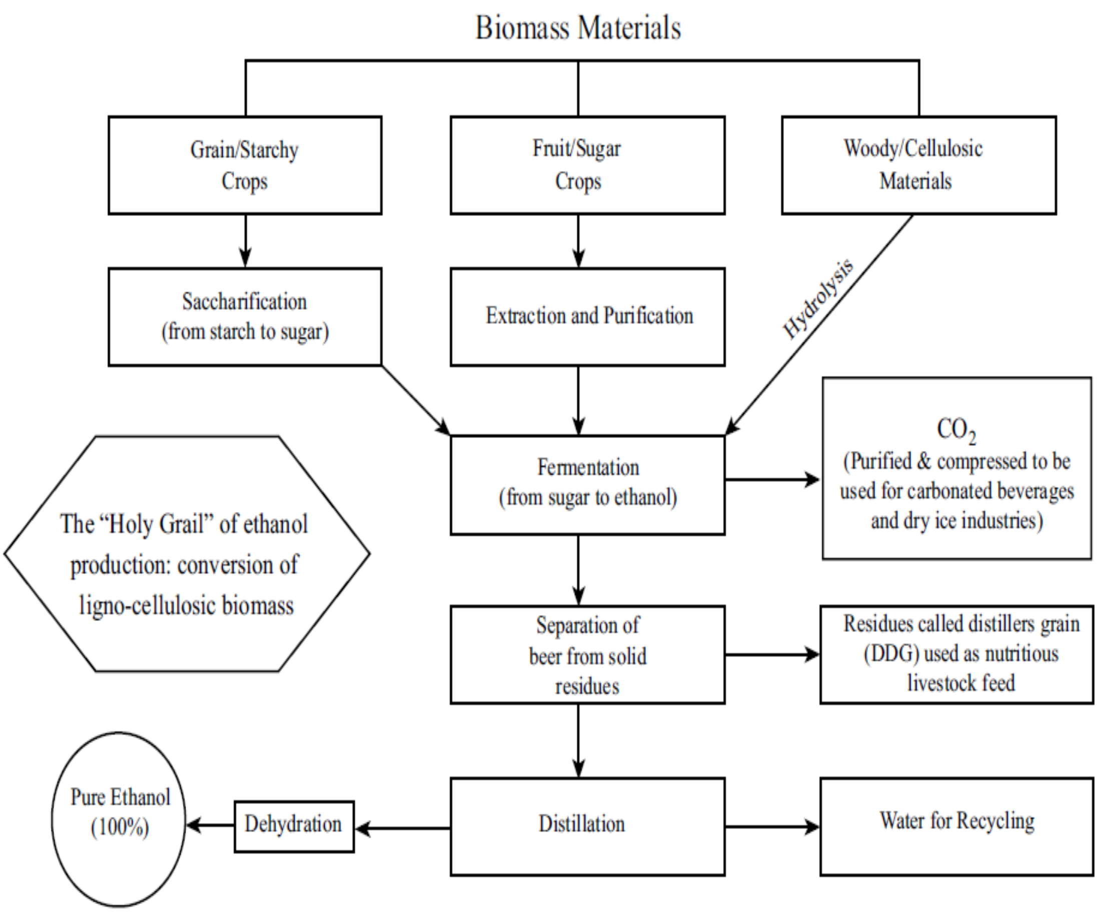

Figure 6 Ethanol Production Flow Chart

5.1.3. Biodiesel production from recycling of used oils

The oils used by restaurants, hotels, wedding halls and other sources of food waste, can be collected and converted to biodiesel by specific techniques. *Figure 7* show the converting process, starting from oils collection, passing through pretreatment and tests processes, then the transesterification process, which is the chemical techniques used by this sample methodology, including selection of catalyst (e.g., NaOH), selection of Alcohol (e.g., Methanol). After that, two main products result, Glycerin which is used in many fields (e.g., medical industries, skin care materials, etc.), and biodiesel which undergo purification processes.

The final step shown is the test for biodiesel product, which includes many tests like viscosity, acid value, cloud point, and so on [26] [27].

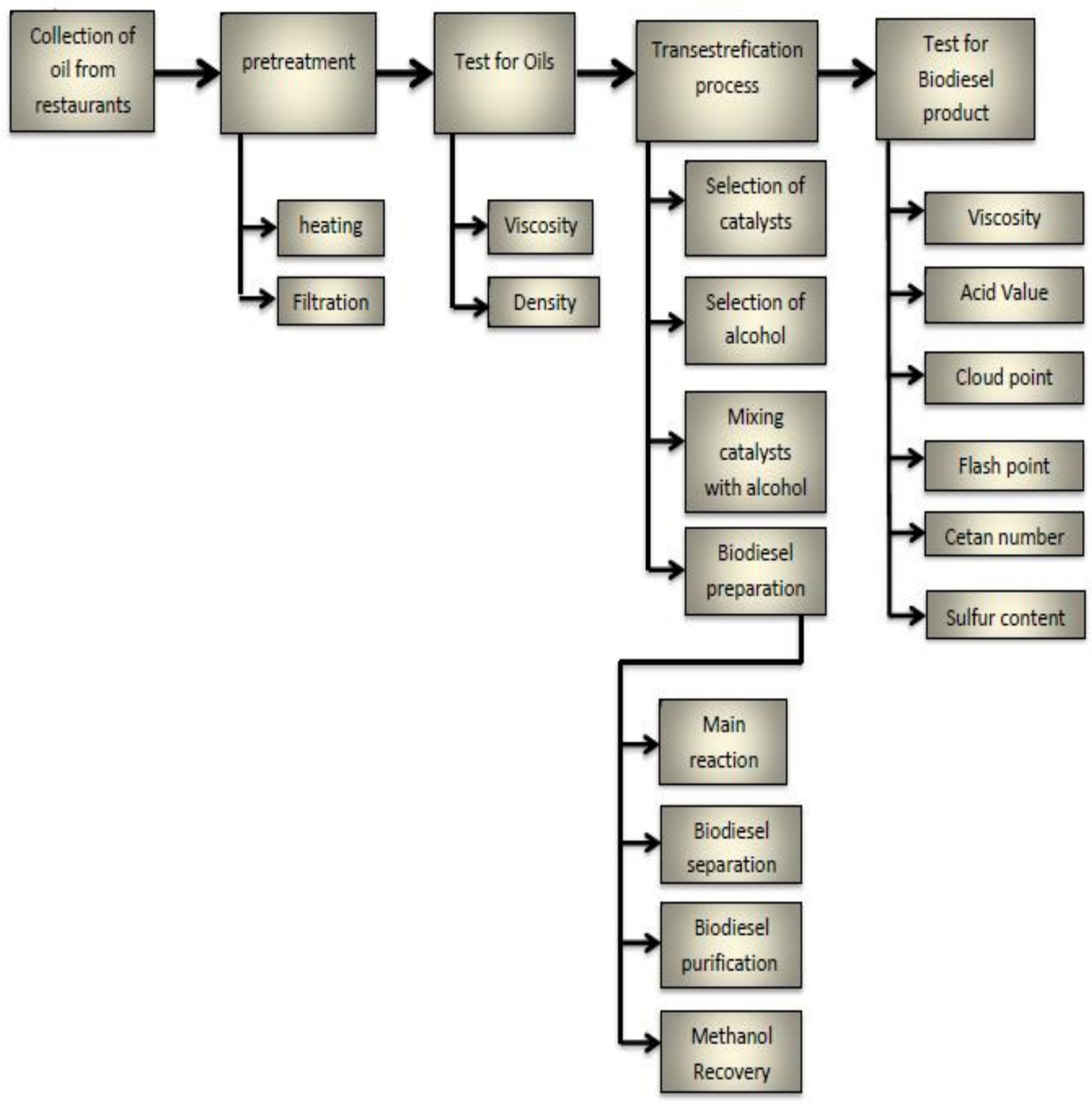

Figure 7 Biodiesel production from used oils

5.1.4. Incineration

Incineration process include the combustion of waste materials and convert it into heat and energy (mechanical power, electricity and so on) [13].

The feedstock for incineration process for effective results is the low moisture content biomass (<50%) like wood ships and tree barks, while the high moisture content biomass is more feasible to undergo biological conversion process, or undergo pre-dried (which need 27,920 MJ of electricity for drying of 1 Ton of solid waste [13]) or mixing with low moisture content materials like coal before undergo incineration [24] [23].

The general incineration process is shown in *Figure 8* [28].

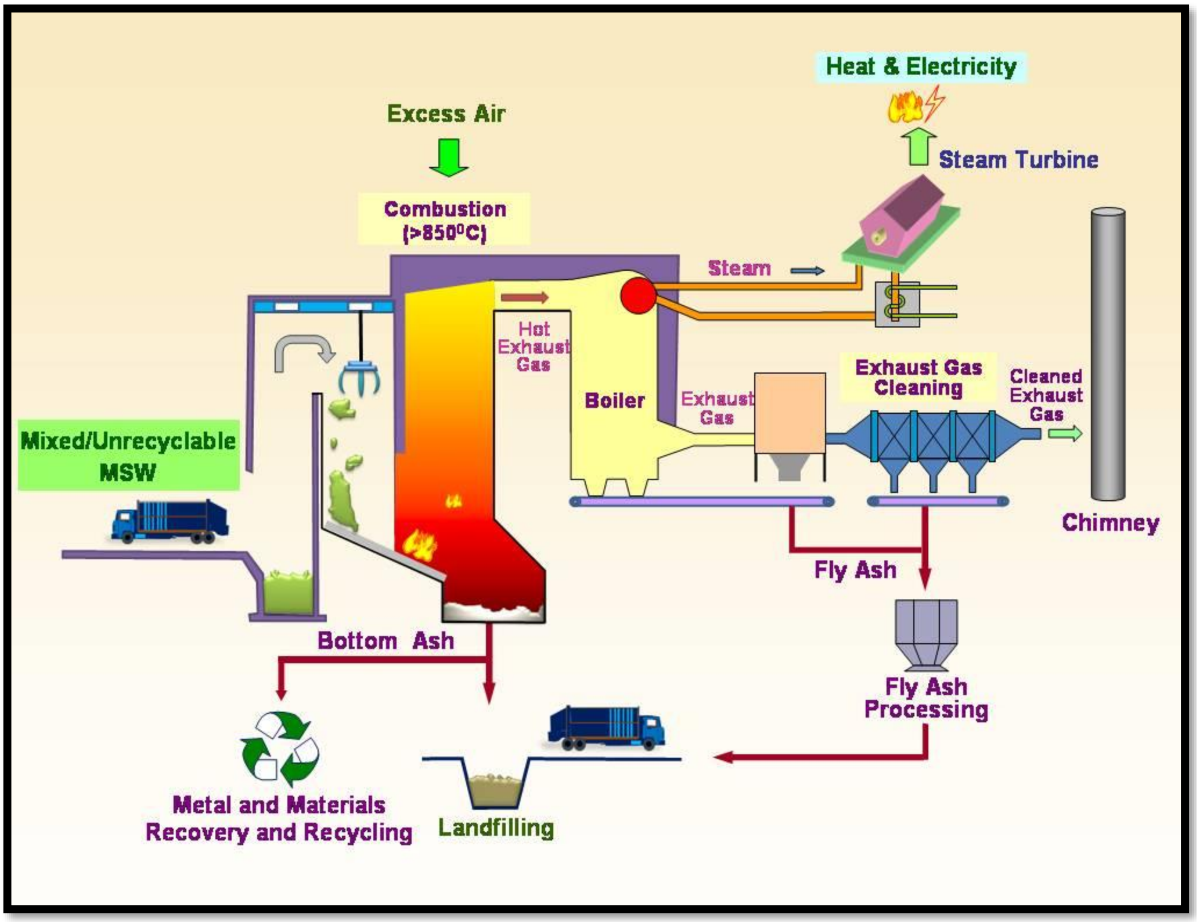

Figure 8 Typical Incineration Flow Chart

The incinerators can reduce the MSW up to 80-85%, which is an important advantage of the incineration process. However, the most challenge faces this technique is the resulting toxic and air polluting gases from burning solid waste that contain materials like plastics, and that result in making some countries prohibit this technique or force restrictions. In order to reduce the effects of this challenge, air pollution control measures can be used [13].

37.7 kJ of heat result from incinerating 1g of total solid waste, while for the environmental point of view, the CO_2-eq found to be -315 kg per 1 Ton of total solid waste [13].

5.1.5. landfilling

The disposal of MSW into landfills is the most common technology used worldwide to deal with MSW disposal and converting. The processes include the burying of the MSW -which undergoes separation and sorting- into a suitable sanitary landfill underground. Methane gas (CH_4) produces from Landfilling as a main product from the anerobic digestion process (AD) of the organic materials in the MSW. Which is –in addition of the need of large areas- one of the main problems of landfills, due to the dangerous of accumulation of CH_4 **[29]**.

A feasible solution of this negative effect, is the use of this CH_4 product in order to generate electricity by the combustion of methane gas to operate steam turbines. The amount of CH_4 produced from landfilling processes can be calculated using LandGEM® software, which estimate the amount of gas emissions from landfills.

The estimation of CH_4 amount based on a first-order decomposition rate equation as in *Eq. 3* below:

$$Q_{\mathrm{CH4}} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k . L_{\circ} . \left(\frac{M_{Li}}{10}\right) . e^{-ktij} \qquad \textit{Eq. 2}$$

Where:

Q_{CH4} = annual methane generation in the year of the calculation (m3 /year)

i = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j = 0.1year time increment

k = methane generation rate ($year^{-1}$)

L_o = potential methane generation capacity (m^3 /Mg)

M_i = mass of waste accepted in the i^{th} year (Mg)

t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g., 3.2 years)

5.1.6. Pyrolysis

Pyrolysis is the thermal conversion of biomass to liquid (bio-oil or bio-crude), solid and gaseous fractions, by heating the biomass in the absence of air (Oxygen), which take place at about 500 ºC **[23]**. There are three main products from the pyrolysis process: solid charcoal, liquid bio-oil and synthesis gas, the flow chart of pyrolysis process is shown in *Figure 9* & *Figure 10* **[30]**.

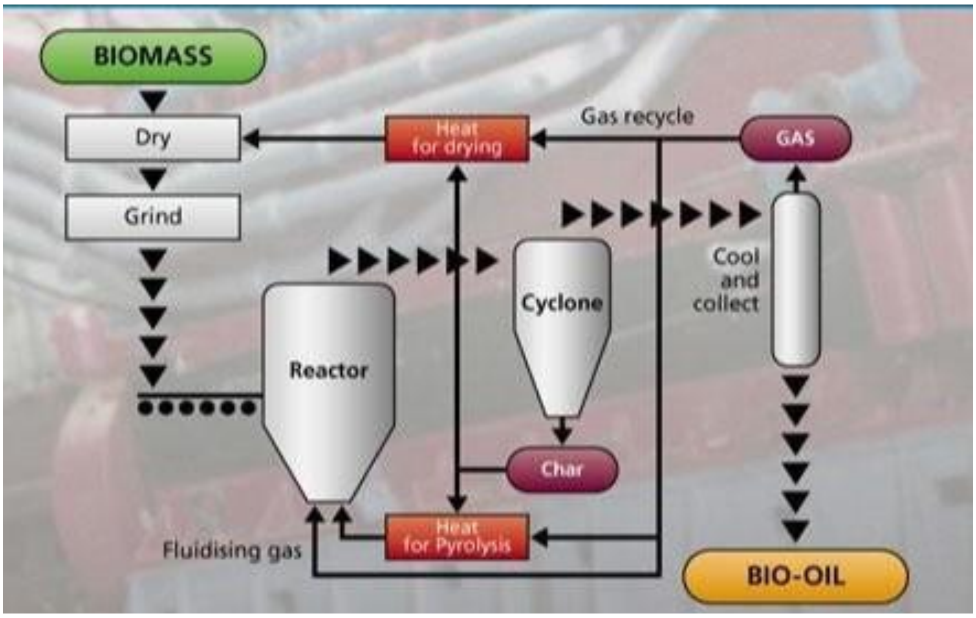

Figure 9 Flow Chart of Pyrolysis Process (1)

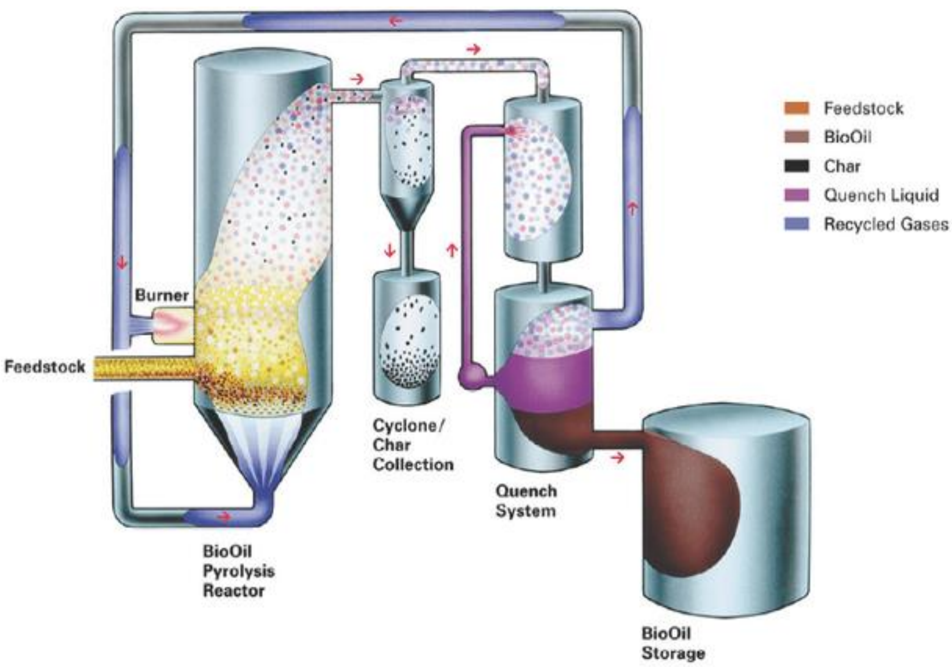

Figure 10 Flow Chart of Pyrolysis Process (2)

The percentage of output products depend on two factors, the temperature at which pyrolysis take place and the residence time which is the time at which the biomass is exposed to the higher reaction temperature. More amount of biochar produced at low temperatures, and more amount of syngas produced at high temperatures, while more amount of bio-oil produced at intermediate temperatures **[24]**. The residence time can be calculated by *Eq. 3* **[24]**:

$$Residence\ Time\ (s) = \frac{Reactor\ Volume\ (m^3)}{Flow\ Rate\ \left[\frac{m^3}{s}\right]} \qquad Eq.\ 3$$

5.1.7. Gasification

Gasification is the thermal conversion of biomass into a combustible gas mixture [CO, CH_4, CO_2, hydrogen, nitrogen and smaller quantities of hydrocarbons] with absence of oxygen or only about one-third the oxygen needed for efficient combustion of biomass. Gasification process occur at high temperatures (800-900 ºC) **[23]**. *Figure 11* show the general gasification process of different materials (biomass, coal, waste, petroleum coke) **[31]**.

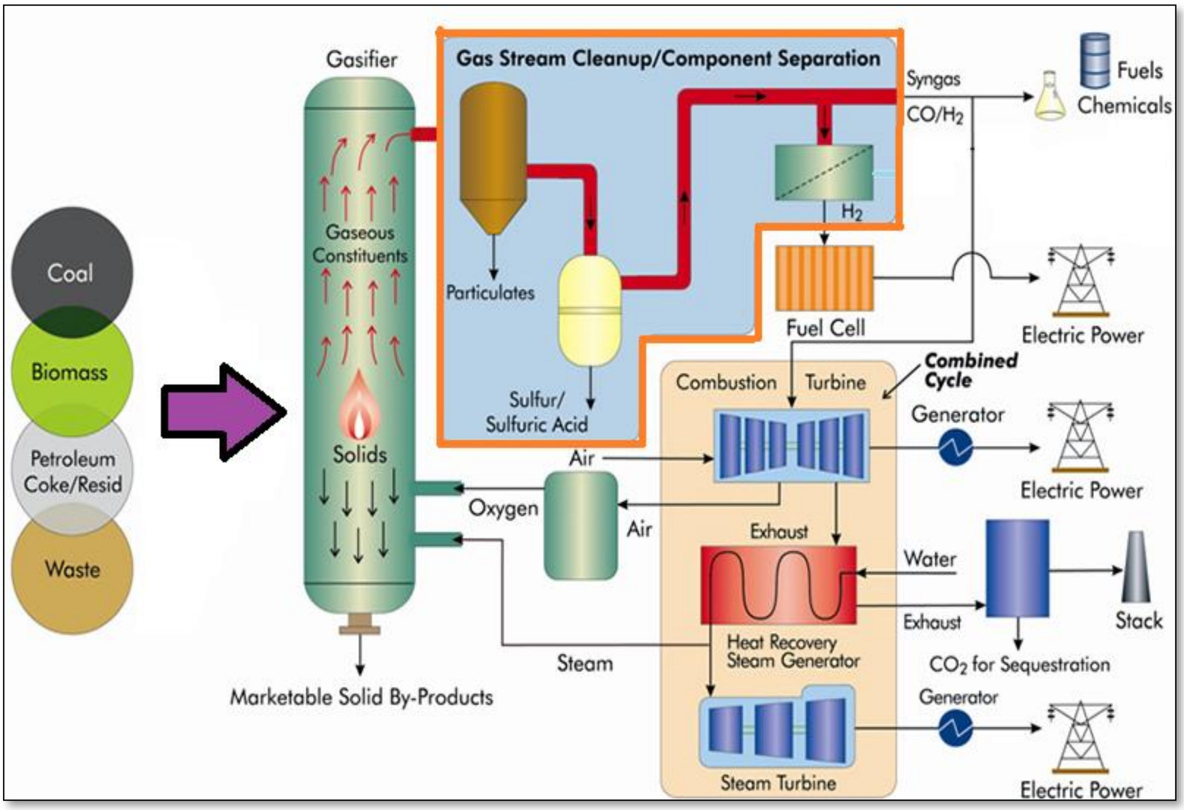

Figure 11 Gasification Process Flow Chart

There are many advantages of gasification process, for example, its flexibility of application, which it can be obtained many outputs and products like power generation, hydrogen production, and synthesis of fuels and chemicals [23]. Another advantage of gasification is the more cost feasibility comparing to the incineration process [13].

An important challenge faces the gasification process is the uncontrolled waste type, because the properties of solid waste have a significant effect on the gasification process. More clearly, the composition of solid waste, moisture content, ash content, and lower heating value are the most important properties of solid waste that related to the gasification process [13].

Figure 12 shows some types of gasifiers that are used in gasification process, which are the main types currently used [32]. The determination of the appropriate type of gasifiers depend on many factors, like moisture content, particles size, and the type of biomass [23].

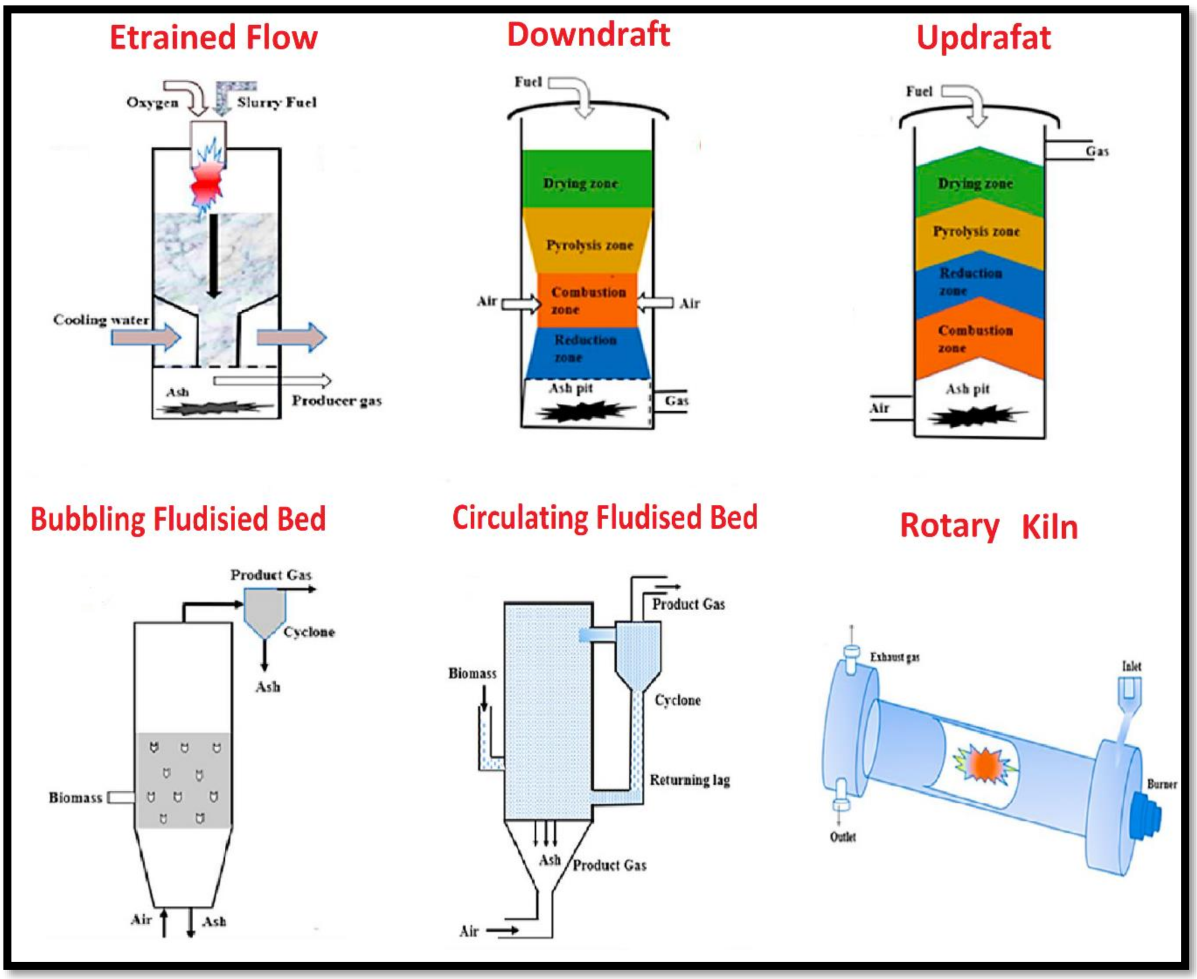

Figure 12 Different types of gasifiers

5.2. Statistics and Situation of Waste in Palestine

5.2.1. The amount of waste and its components in West Bank and Gaza strip

The estimated amount of MSW in West bank is approximately 2,622 Ton/day (957,030 Ton/year) with average per capita production of 0.91 kg/day, and Joint Service Councils are responsible of collecting 65% of these wastes, while the remaining amount are collected by Local Government Units and UNRWA (which has the responsibility of 19 refugee camps in West Bank and 8 in Gaza strip with estimated amount of MSW of 43,025 Ton/year and 67,396 Ton/year, respectively.). In Gaza strip, the estimated amount of MSW is approximately 1330 ton/day (485,450 ton/year) with average per capita production of 0.7 kg/day **[10]**.

50% of MSW in West Bank are organic matter, while the rest of the compositions are shown in *Figure 13*. There is no separation process of houses waste until yet, and the percentage of recycled materials is only 1% **[10]**.

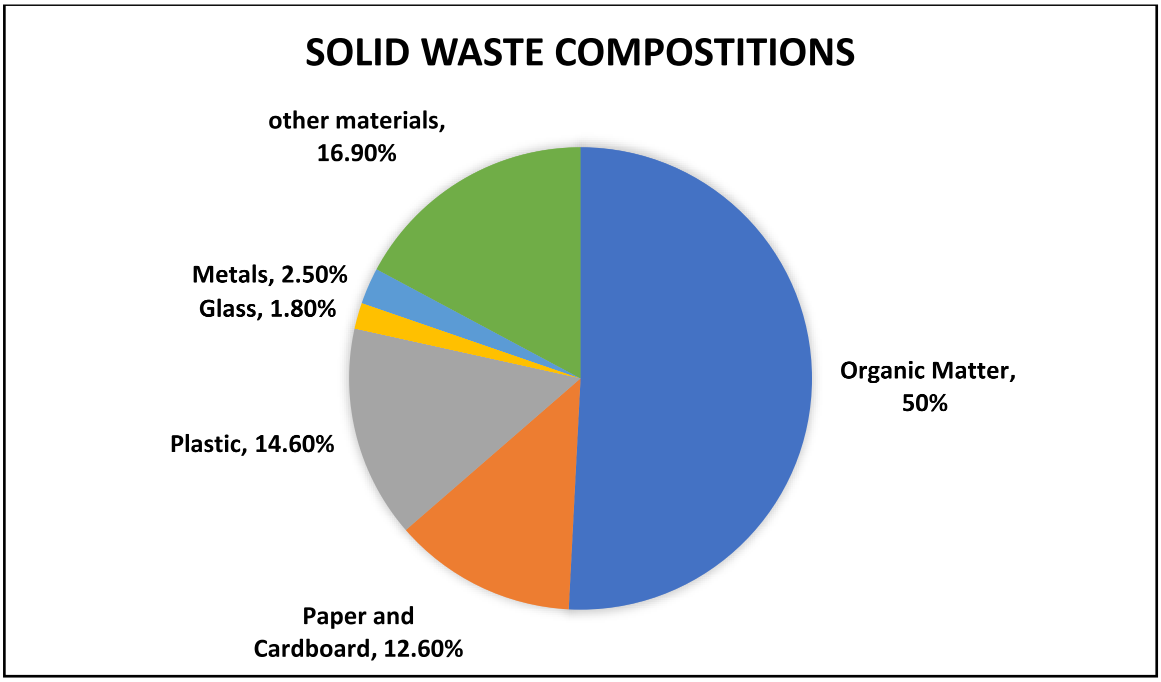

Figure 13 Solid Waste Compositions in West Bank

5.2.2. Sanitary Landfills, Transfer Stations, and Random Dumpsites in WB and GS

In West Bank, 4 sanitary landfills are currently used: Zahrat Al Finjan (ZAF) (which serve the northern part of WB), Al Minya (which serve the southern part of WB), Jericho and the small Beit Anan (which serve N-E&N Jerusalem and 5 local government units (LGUs) in Ramallah-Bireh governorate) landfills. Another suggested sanitary landfill is Rammun Landfill, which supposed to serve all communities in Ramallah-Bireh governorate when it built **[10]**. It is shown in *Figure 14* through *Figure 17* some pictures of WB landfills **[33]**.

Figure 14 ZAF Landfill

Figure 15 Al Minya Landfill

Figure 16 Jericho Landfill

Figure 17 Beit Anan Landfill

In Gaza strip, there are 4 sanitary landfills: Johr Al-Diek, Al-Fukhary (Sofa new and old landfills) and Deir Al-Balah landfills. *Figure 18* show Al-Fukhary Landfill [33].

Figure 18 Al-Fukhary Sanitary Landfill and Existing Dumpsite

Table 1 summarize the sanitary landfills and daily received quantity of MSW **[10]**.

Table 1 landfills and daily received quantity of MSW in 2019

Sanitary Landfill	Location (Governorate)	Target Area	Serviced Area	daily received quantity (tons/day)	Managed By
ZAF	Jenin	North of WB	Jenin area. Tubas. Tulkarem. Qalqilya area. Nablus area. Ramallah and Bireh.	1200	Jenin JSC
Jericho	Jericho	Jericho Governorate	Jericho area	55	Jericho JSC
Al Minya	Bethlehem	South of WB	Hebron. Bethlehem. N-E Jerusalem.	1000	Hebron & Bethlehem JSC
Beit Anan	Jerusalem	Part of Jerusalem and Ramallah Governorate	N & N-W Jerusalem	90	N & N-W Jerusalem Service Council
Johr Al-Diek	Gaza	Gaza and North Governorate	Gaza local municipalities	700	Gaza Municipality
Deir Al-Balah	Middle Governorate	Khan Younis and Middle Governorate	Khan Younis and Middle Governorate	430	South Gaza Service Council
Sofa Old	Khan Younis	Rafah Governorate	Rafah Governorate	170	South Gaza Service Council
Sofa New	Khan Younis	Rafah, Middle and Khan Younis Governorate	Rafah, Middle and Khan Younis Governorate	Not Available	South Gaza Service Council

There are 13 transfer stations in West Bank and 3 in Gaza strip, which are all managed by joint councils and cooperate with LGUs -except Al Abdaly station which is managed by Israeli side- **[10]**. *Table 2* summarize all transfer stations in WB and GS.

Table 2 Transfer Stations in WB & GS

	Transfer station	Location area	Managed By	Transferred Quantity	Transferring Distance	Final Disposal	Additional Information
1	Western Jenin	Jenin	Jenin JSC	50 tons/day	35 km	ZAF	
2	Tubas	Tubas	Tubas JSC	43 tons/day	28 km	ZAF	
3	Al Sayrafi	Nablus	Nablus Municipality	180 tons/day	40 km	ZAF	
4	Tulkarem	Tulkarem	Tulkarem JSC	132 tons/day	30 km	ZAF	
5	Qalqilya	Qalqilya	Qalqilya JSC	123 tons/day	60 km	ZAF	
6	Ramallah	Ramallah	Ramallah Municipality	120 tons/day	120 km	ZAF	
7	Al Bireh	Ramallah	Al Bireh Municipality	80 tons/day	80 km	ZAF	
8	Al Ram	N-E & S-E Jerusalem	Al Ram Municipality	60 tons/day	55 km	Al-Minya	covered surface area
9	Al Fahs	Hebron	Hebron & Bethlehem Higher Council	300 tons/day	33 km	Al-Minya	HCW treatment unit; weighing bridge
10	Yatta	Hebron	Hebron & Bethlehem Higher Council	200 tons/day	35 km	Al-Minya	weighing bridge, no pavement
11	Tarqumia	Hebron	Hebron & Bethlehem Higher Council	150 tons/day	39 km	Al-Minya	
12	Wadi El Nar (Sawareh)	N-E & S-E Jerusalem	SE Jerusalem JSC	Not operational yet	30 km	Al-Minya	
13	Al Abdaly (Ezzariye)	N-E & S-E Jerusalem	Israel	60 tons/day	35 km	Al-Minya	weighing bridge
				In Gaza Strip			
14	El Yarmouk	Gaza	Gaza Municipality	700 tons/day	15 km	Johr Al-Diek	
15	Khan Younis	Khan Younis	Khan Younis JSC	Not operational yet	24 km	Al-Fukhary	
18	Rafah	Rafah	Khan Younis	0	26 km	Al-Fukhary	

The random dumpsites in WB are mostly in Nablus and Ramallah areas, due to the problems and challenges that face the building of Rammun landfill. Number of random dumpsites are summarized in *Table 3* **[10]**. *Figure 19* show the landfills and transfer stations locations in WB.

Table 3 Random Dumpsites in WB & GS

Number	Governorate	Number of dumpsites	Number of local government	Population number	Quantity of MSW (tons/day)
1	Salfit	9	20	79,000	66
2	Nablus	12	20	92,410	77
3	Ramallah & Al Bireh	50	67	215,144	200
4	North Gaza	3	4	326,704	390
5	South Gaza	3	3	55,642	53
Total		77	114	768,900	786

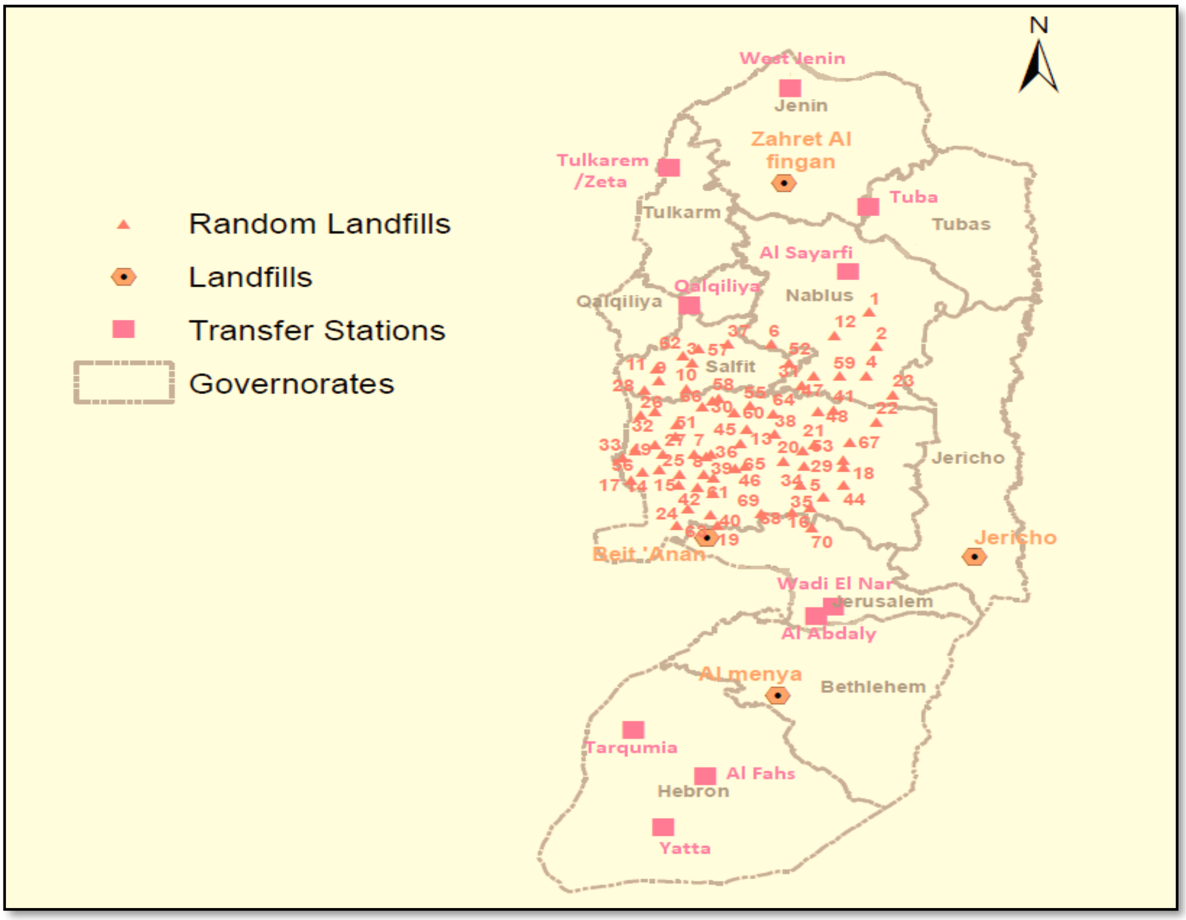

Figure 19 Locations of Landfills and Transfer Stations in WB

Review of the Energy Situation in Palestine

5.2.3. Electrical Energy Sources in WB & GS

Palestine Territory -as it is occupied by Israeli occupation-, mostly depend on the Israeli side in the energy sector (specially electricity), and it imports small part of energy from Jordan and Egypt, with the partial electrical energy production in Gaza Power Station. *Figure 20* show the current situation of electricity framework in Palestine **[34] [35]**. In 2019, The amount of energy from each source in WB & GS was estimated to be: Israel Electrical Company (6025 GWh), Gaza Power Station (591.275 GWh), Jordan (88.28 GWh), renewable energy sources (51 GWh in 2018) and Egypt (36 GWh in 2018) **[35] [36]**. *Figure 21* Shows the locations and demands for all electrical distribution companies in WB, while *Table4* Shows the quantity of electricity imported and purchased in Palestine by month and source in 2018 **[37]**.

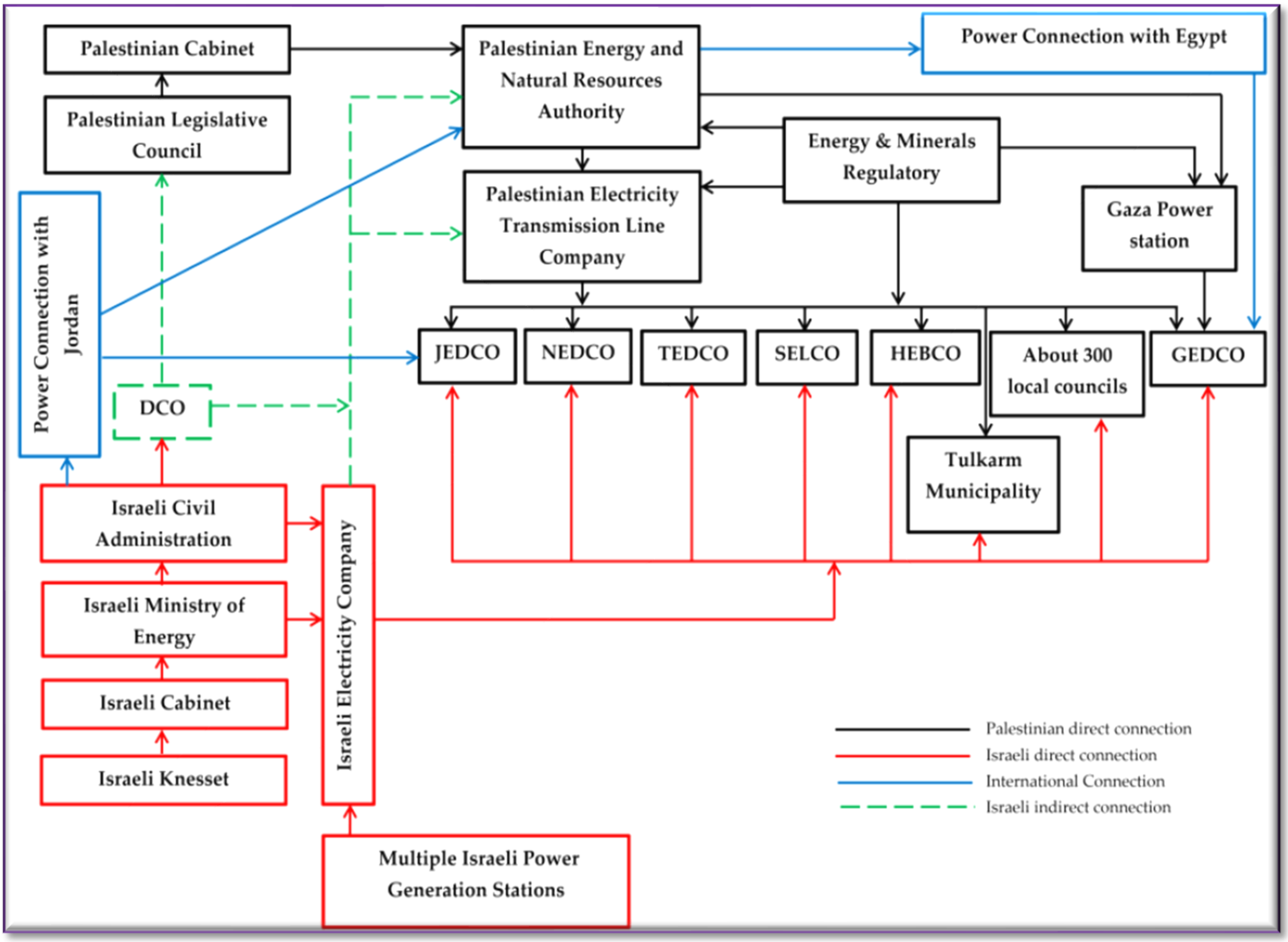

Figure 20 the current situation of electricity framework in Palestine

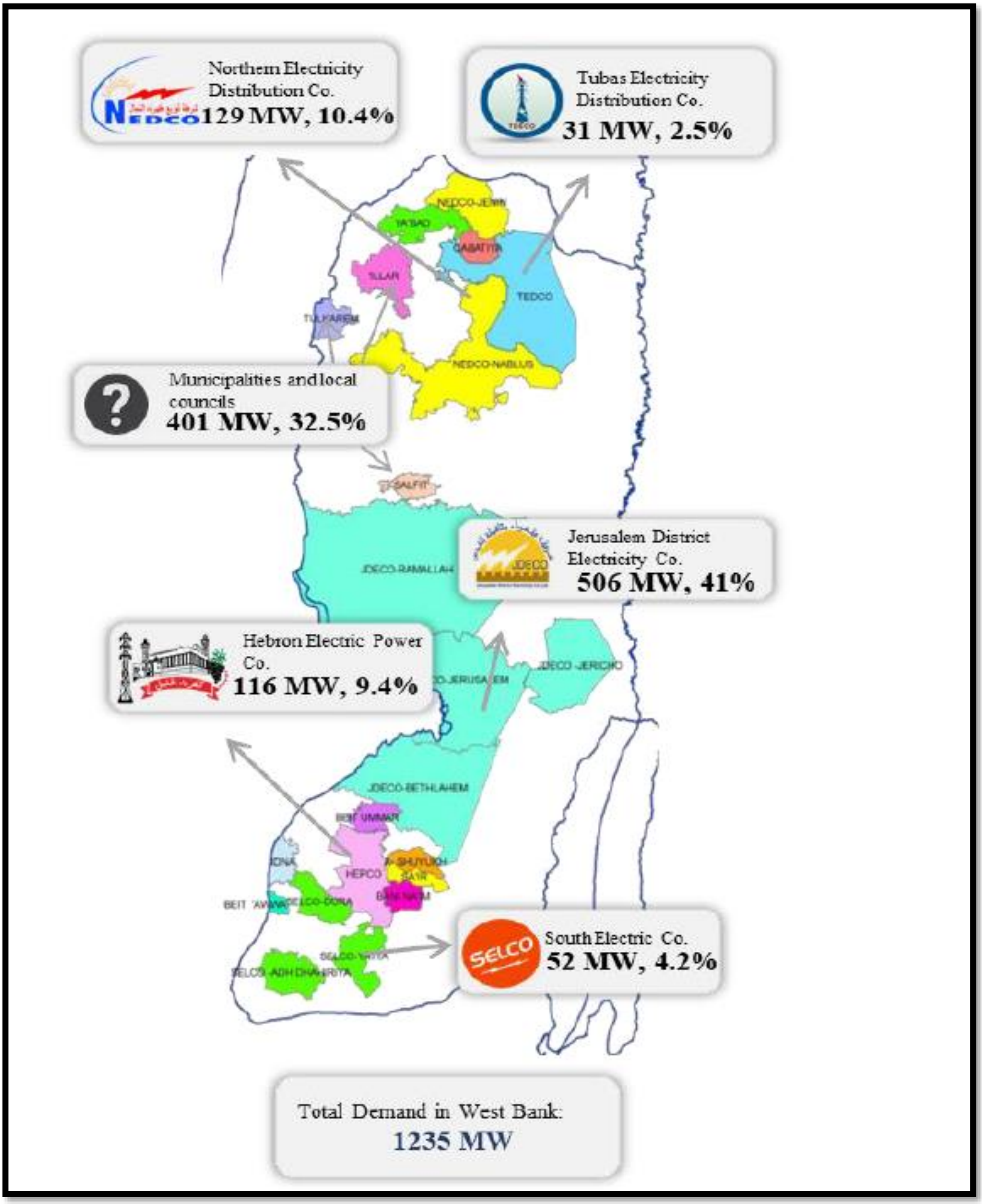

Figure 21 the locations and demands for all electrical distribution companies in WB

Table4 Quantity of Electricity Imported and Purchased in Palestine by Month and Source, 2018

Month	Purchased from Palestine Electric Company	Jordan	Egypt	Israeli Electricity Company	Total
January	29,571	10,291	36,520	539,173	615,555
February	12,478	8,702	-	455,008	476,188
March	16,675	10,492	-	450,760	477,927
April	6,201	11,497	-	396,774	414,472
May	778	7,662	-	467,888	476,328
June	7,063	3,424	-	464,979	475,466
July	12,648	7,139	-	520,848	540,635
August	15,859	7,529	-	524,357	547,745
September	15,113	7,009	-	495,474	517,596
October	22,866	6,446	-	504,066	533,378
November	55,373	1,021	-	432,801	489,195
December	58,900	6,887	-	539,011	604,798
Total	253,525	88,099	36,520	5,791,139	6,169,283

5.2.4. Energy Balance in Palestine

Table 5 Summarize the energy balance in Palestine in 2018, while *Figure 22* represents the percentage of energy consumed by each sector in Palestine in 2018.

Table 5 Energy Balance of Palestine in Physical Units, 2018

Flow	Solar Energy (MWh)	Wood and Charcoal (Ton)	Olive Cake (Ton)	LPG (Tons)	Fuel Oil (1000 Liter)	Gasoline (1000 Liters)	Diesel (1000 Liters)	Electricity (MWh)
1.1 Primary production	1,604,870	221,414	23,738	-	-	-	-	60,000
1.2 Imports	-	3,725	-	167,424	6,484	305,986	646,474	5,915,758
1.3 Exports	-	-626	-	-	-	-	-	-

1.4 Stock change	-		-	-	-	-	-	-
1.Total energy supply	**1,604,870**	**224,513**	**23,738**	**167,424**	**6,484**	**305,986**	**646,474**	**5,975,758**
2. Statistical differences	-	-	-	-	-	-	-	-
3.Transformation	-	-	-	-	-	**-7,128**	**-81,285**	**360,427**
3.1 Electricity plants	-	-	-	-	-	-7,128	-81,285	**360,427**
4. Losses	802,435	-	-	-	2	2,448	1,616	760,342
5. Final consumption	**802,435**	**224,513**	**23,738**	**167,424**	**6,482**	**296,410**	**563,573**	**5,575,843**
5.1. Final energy consumption	**802,435**	**224,513**	**23,738**	**167,424**	**6,482**	**296,410**	**563,573**	**5,575,843**
5.1.1 By industry	-	7,000	5,935	14,190	3,241	1,536	9,837	714,705
5.1.2 By transport	**-**	**-**	**-**	**4,500**	**-**	**289,925**	**539,465**	**-**
5.1.2.1 Road	-	-	-	4,500	-	289,925	539,465	-
5.1.3 By household and other sectors	**802,435**	**217,513**	**17,803**	**148,734**	**3,241**	**4,949**	**14,271**	**4,861,138**
5.1.3.1 Households	802,435	211,574	17,803	133,594	-	-	2,303	3,358,894
5.1.3.2 Agriculture	-	-	-	2,207	-	3,339	4,678	29,379
5.1.3.3 Commerce & public services	-	5,939	-	12,933	3,241	1,610	7,290	1,472,865
5.2 Non energy use	-	-	-	33,607	4,233	-	-	-

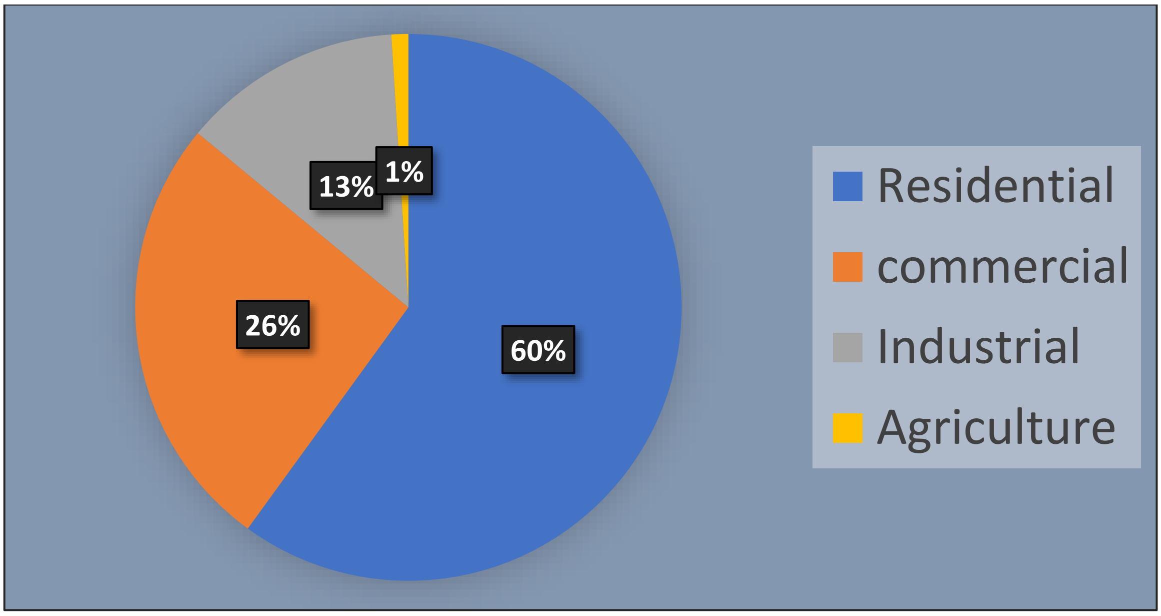

Figure 22 The percentage of energy consumed by sector in Palestine, 2018

5.2.5. Energy consumptions in WB & GS

The estimated amount of electricity consumption in WB was 3900 GWh in 2017, and 1700 GWh in GS, with total consumption of 5600 GWh **[38]**. In 2020, the average electricity price for residential users was 0.18 $/kWh, which is one of the highest values of electricity prices in the Middle East and North Africa **[38]**.

5.2.6. Renewable Energy Sector in Palestine

Due to the political, economic and technical challenges, renewable energy has been considered as a feasible energy alternative of the traditional energy sources in the Palestine Territory. Palestinian Energy and Natural Resources Authority (PENRA) saw that the renewable energy sources enhance the sovereignty of Palestine State from the Israeli occupation, and it developed a legislation that regulate the investments in the renewable energy sector, which result in increasing the demand for renewable energy **[36]**.

Palestine have a high potential of using renewable energy sources, specially the solar energy, and this is due to the high solar radiation of 5.4 kWh/m^2/day on average, which is one of the highest values in the region -and even in the world-, and it receive approximately 3000 sunlight hours in the year **[9] [38]**. *Figure 23* Shows the average solar energy in some WB regions in 2011. **[39]**

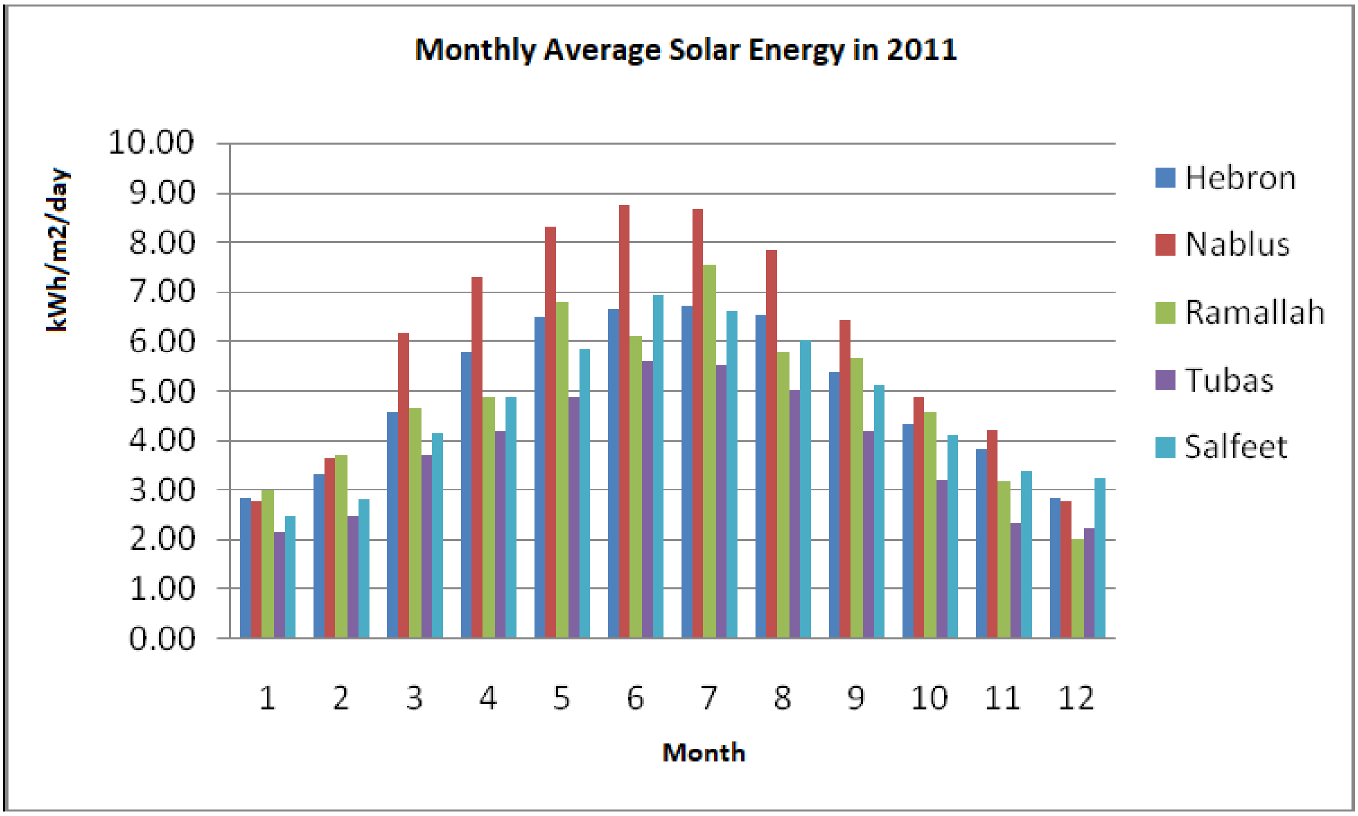

Figure 23 the average solar energy in some WB regions in 2011

For biomass energy, Palestine had already started to develop some generation systems depend on the biomass energy as a feedstock for the reactions. For example, Al-Jebrini farm biodigester reactor, which is located at Dura in the south of Hebron city, use the animal manure waste as a feed stock to produce biogas (methane) in order to generate electricity by steam turbines, and provide Dhahriya town partially with electricity. The capacity of the plant is 380 kW and its predicted to reach up to 1 MW (which represents approximately 10% of the Dhahriya town electricity demand) **[40]**.

Some other renewable energy sources are the wind energy and the geothermal energy, which are face challenges prevents the use of these sources. The high capital investment cost prevents the investments in the geothermal energy for heating and cooling applications **[38]**. And in order to generate electricity from wind turbines, the velocity of wind streams has to be sufficient to produce electricity, but GS region has low wind velocity (ranges from 2.5 to 3.5 m/s for annual average) which are not sufficient for electricity production using wind turbines. In WB, the political problems prevent the use of wind energy to produce electricity, because the wind speed that is feasible to generate electricity at small-plant scale, is on the high mountains and in the “C-regions” which are under Israeli occupation control **[9]**.

6. Methodology

The project was written after these steps:

1. Review previous works: this stage includes the reading of tens of previous research papers and literatures about the traditional and renewable energy, the environmental issues that resulted from the use of traditional energy sources, the solid waste management methods in number of countries around the world and then focusing on the literatures that studied the Palestinian case, which include the situations of energy and MSW sectors in Palestine. In addition, in the first stage the researcher reviewed the literatures about the converting technologies of waste into energy, and made a general background about this subject which enable the researcher to deal with these technologies on the practical ground.
2. Data collection: the data about MSW and energy sectors in WB and GS was taken from official reports which were published by the concerned Palestinian ministries, e.g., the data of the MSW and the sanitary landfills -especially Al Minya landfill- was taken from "SWM data in Shared Service Councils in the West Bank and Gaza. 2019" report which had published by ministry of local government–state of Palestine. Some other data during working on the project was taken from previous works and from some of my fellow engineers from the university and outside the university.
3. Potential energy and power capacity: after collecting the required data, the energy equation models and software simulations were taken place. The two technical converting methods from MSW into energy in this project (incineration and landfilling) were analyzed and potential energy from each process was estimated, therefore the power capacity of each plant.
4. Results, discussion, conclusion, and recommendations: at this phase, the results of models and software simulation were established. A discussion of some ideas had done, and a real technical dilemma in landfilling had been discussed, and a solution was proposed. Then some recommendations for future engineers and researchers on this landfill were introduced.
5. Report writing: after previous steps, the report was written. During writing the report, the references citation had done by "EndNote X9" tool, which some of these references were manually edited, and the other are imported from citation files that were downloaded from the paper in the publisher journals site. Some of the references has page numbers like (**133**: p. 110138) – as in reference **[1]**- which means that the paper is published on the

digital scientific journal –"Renewable and Sustainable Energy Reviews" in this case- in volume number of (133) at page (110138).

The potential energy estimation from incineration and landfilling had done by the following methodology:

6.1. Incineration potential energy estimation:

- In order to estimate the amount of daily thermal and electrical energies available in the MSW that is received by the landfill station, *Eq. 4* & *Eq. 3* below can be used **[16]**.

$$E_{therm} = \frac{Q_{MSW} * En * \frac{1000\ kg}{ton} * \eta_{therm}}{Diesel_{LHV}} \qquad \text{Eq. 4}$$

$$E_{ele} = \frac{Q_{MSW} * En * \frac{1000\ kg}{ton} * \eta_{ele}}{EleConv} \qquad \text{Eq. 5}$$

Where:

Q_{MSW}: the amount of MSW received (ton/day)

$Diesel_{LHV}$: is the diesel fuel lower heating value (MJ/L)

EleConv: is the unit conversion factor from kWh to MJ, which equals to 3.6 (MJ/kWh)

η_{therm} & η_{ele}: are the conversion efficiency for electricity and thermal generation, respectively.

E_{therm}: is the daily available thermal energy in the MSW (in liter diesel equivalent).

E_{ele}: is the daily available electric energy in the MSW (in kWh equivalent).

En: is the energy available in the MSW (MJ/kg), which can be calculated by *Eq. 3* bellow:

$$En = \sum_{composition=1}^{c} En_{composition} * percentage_{composition} \qquad \text{Eq. 6}$$

- The thermal energy output from incineration process is not useful in this project (Al-Minya station) because of the long distances between the station site and the factories and institutions that need hot water in large quantities, and that result in high losses of heat by transferring of hot water.

- Therefore, the project will consider just the electrical energy output from incineration processes, which is usually run by (20 – 25 %) overall conversion efficiency (electricity generation efficiency) [16].

6.2. Landfilling potential energy estimation:

50% of the MSW that received to Al-Minya landfill is organic matter, which will undergo landfilling process. In addition, the excess amount of MSW from the incineration plant capacity -which is 585 ton/day in 2023- will undergo landfilling process. For example, if the daily MSW received to the incineration plant in the second year (2024) equal (0.04*585 + 585 = 608.4 ton/day) then, 23.4 ton/day will undergo landfilling process.

In order to estimate the amount of methane gas production, LandGEM® software has been used, which calculate the production amounts during plant life (30 years), and after closing the landfill (which is assumed to be in 2053) for approximately 100 years (until reach year of 2163!).

As mentioned before, LandGEM® software use (*Eq. 2*) to calculate the annual methane generation in the year of the calculation (in m3 /year). *Figure 24* shows part of the "User Inputs" window of LandGEM® software.

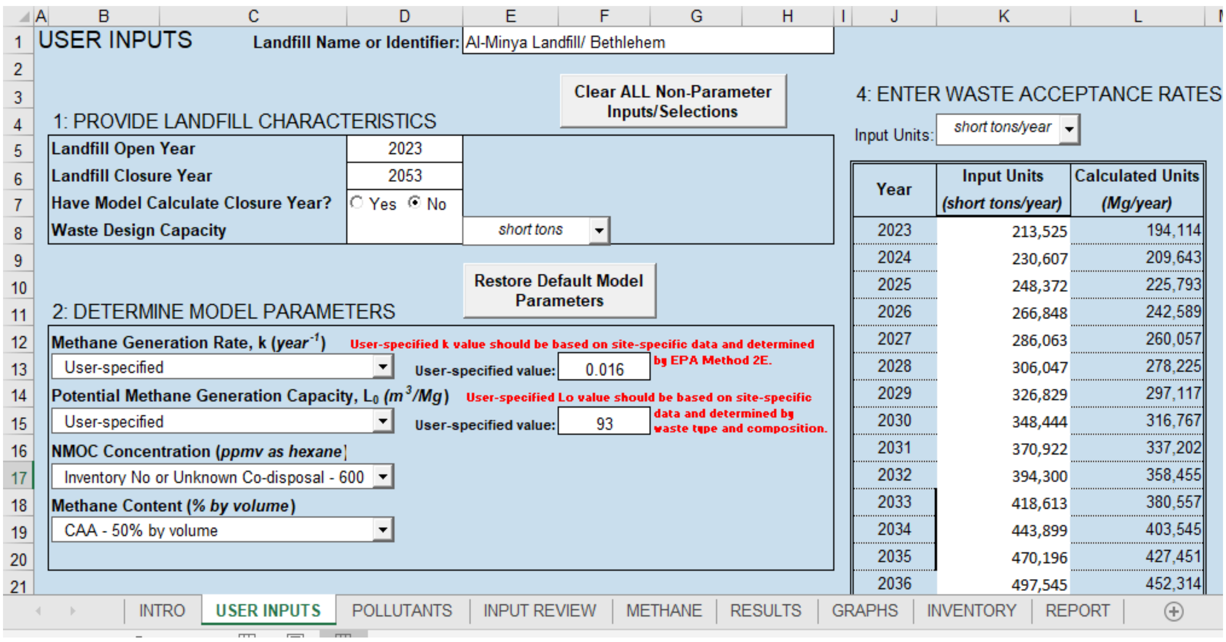

Figure 24 User Inputs Window in LandGEM software

7. Case study

7.1. Incineration inputs data

The amount of MSW received to Al-Minya landfill was estimated to be 1000 ton/day according to ministry of local government in Palestine in 2019 **[10]**. With annual growth rate of MSW amount equal to 4% **[16]**, the amount of MSW received to Al-Minya landfill estimated to be 1040 ton/day in 2020, 1081.6 ton/day in 2021, 1124.86 ton/day in 2022, and 1170 ton/day in 2023, which is the assumed starting year of the incineration plant.

In WB, the compositions of MSW in average are equals in all governorates, with 50% organic matter (4 MJ/kg caloric value), 14.6% plastic (35 MJ/kg), 12.6% paper and cardboard (16 MJ/kg), 2.5% metal (0 MJ/kg), 1.8% glass (0 MJ/kg), and 16.9% textile (19 MJ/kg) and other materials (11 MJ/kg) **[16] [10]**.

After the MSW are separated, all organic matter is assumed to undergoes a landfilling process, and the remain compositions will undergo an incineration process, and each composition now will be multiplied with 2 –after excluding the organic matter-.

7.2. landfilling inputs data

The value of K (methane generation rate) is estimated to be 0.016 ($year^{-1}$), and L_o (potential methane generation capacity) is estimated to be 93 (m^3 /Mg) **[41]**. The assumed starting year of the landfilling plant is 2023, with 30 years plant life, so, the landfill will close in 2053.

The daily amount of MSW came to the landfilling plant is 50% of total amount, in addition of the excess amount from incineration plant capacity. Assuming the daily received of MSW amount is equal over 365 day per year, then the input values of MSW for 30 years (from 2023 to 2053) were filled in the Excel sheet, *Table 6* show the first 10 years input values.

Table 6 the input values of MSW for 10 years

Year	Input Units	Excess from incineration	input
	ton/day	ton/day	(ton/year)
2023	585	0	213,525
2024	608	23	230,607
2025	633	48	248,372

2026	658	73	266,848
2027	684	99	286,063
2028	712	127	306,047
2029	740	155	326,829
2030	770	185	348,444
2031	801	216	370,922
2032	833	248	394,300
2033	866	281	418,613

8. Results and Discussion

The amount of MSW received to the incineration plant at Al-Minya landfill in 2023 -after excluding the organic matter– is estimated to be (585 ton/day), which is the base capacity for the incineration plant. The assumed conversion efficiency for electricity generation is 22%. The energy available in the MSW can be calculated as following -depending on the percent of each component as mentioned in case study section- :

$$En = \frac{2 * \ [(0.146 * 35) + (0.126 * 16) + (0.025 * 0) + (0.018 * 0) + (0.169 * 11)]\ MJ}{kg}$$

$$= 17.97\ \frac{MJ}{kg}$$

Then, the daily available electric energy in the MSW in 2023 (in kWh equivalent) equal:

$$E_{ele} = \frac{585\ (\frac{ton}{day})\ * 17.97\ (\frac{MJ}{kg})\ * \frac{1000\ kg}{ton}\ * \ 0.22}{3.6\ (\frac{MJ}{kWh})} = \ \mathbf{642,427.5\ kWh/day}$$

Assuming the plant will operate for 24 hours per day, then the incineration plant capacity will be **26.8 MW**, and run for 30 years (assumed plant life).

After modeling the landfilling data in LandGEM® software, number of tables and graphs were resulted. For example, *Figure 25* show the graph of 4 gas products amounts from landfilling (total landfill gas, CO_2, Methane, and non-methanic gases). *Table 7* includes the total landfill and methane gases production from 2023 to 2070.

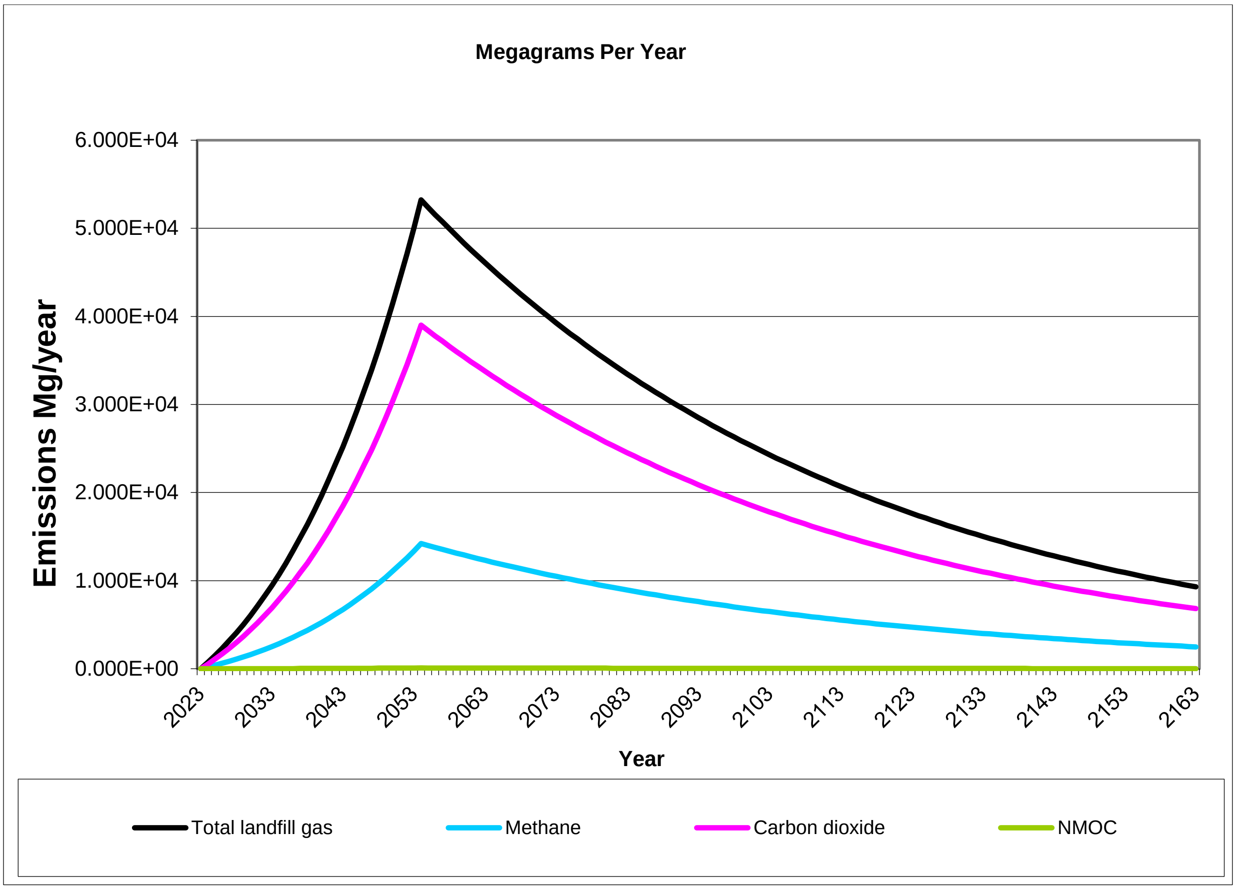

Figure 25 Gases amounts production in Mg/year from landfilling

Table 7 total yearly landfill and methane gases production from 2023 to 2070

Year	Total landfill gas		Methane	
	(Mg/year)	*(m^3/year)*	*(Mg/year)*	*(m^3/year)*
2023	0	0	0	0
2024	7.163E+02	5.735E+05	1.913E+02	2.868E+05
2025	1.478E+03	1.184E+06	3.949E+02	5.919E+05
2026	2.288E+03	1.832E+06	6.112E+02	9.161E+05
2027	3.147E+03	2.520E+06	8.406E+02	1.260E+06
2028	4.057E+03	3.248E+06	1.084E+03	1.624E+06
2029	5.019E+03	4.019E+06	1.341E+03	2.009E+06
2030	6.035E+03	4.833E+06	1.612E+03	2.416E+06
2031	7.108E+03	5.692E+06	1.899E+03	2.846E+06
2032	8.240E+03	6.598E+06	2.201E+03	3.299E+06
2033	9.432E+03	7.553E+06	2.519E+03	3.776E+06
2034	1.069E+04	8.557E+06	2.854E+03	4.279E+06
2035	1.201E+04	9.614E+06	3.207E+03	4.807E+06
2036	1.339E+04	1.072E+07	3.577E+03	5.362E+06
2037	1.485E+04	1.189E+07	3.966E+03	5.945E+06

2038	1.638E+04	1.311E+07	4.375E+03	6.557E+06
2039	1.798E+04	1.440E+07	4.803E+03	7.199E+06
2040	1.966E+04	1.574E+07	5.252E+03	7.872E+06
2041	2.142E+04	1.716E+07	5.723E+03	8.578E+06
2042	2.327E+04	1.863E+07	6.216E+03	9.317E+06
2043	2.520E+04	2.018E+07	6.732E+03	1.009E+07
2044	2.723E+04	2.180E+07	7.272E+03	1.090E+07
2045	2.934E+04	2.350E+07	7.837E+03	1.175E+07
2046	3.155E+04	2.527E+07	8.428E+03	1.263E+07
2047	3.387E+04	2.712E+07	9.046E+03	1.356E+07
2048	3.629E+04	2.906E+07	9.692E+03	1.453E+07
2049	3.881E+04	3.108E+07	1.037E+04	1.554E+07
2050	4.145E+04	3.319E+07	1.107E+04	1.660E+07
2051	4.421E+04	3.540E+07	1.181E+04	1.770E+07
2052	4.709E+04	3.770E+07	1.258E+04	1.885E+07
2053	5.009E+04	4.011E+07	1.338E+04	2.005E+07
2054	5.322E+04	4.262E+07	1.422E+04	2.131E+07
2055	5.238E+04	4.194E+07	1.399E+04	2.097E+07
2056	5.155E+04	4.128E+07	1.377E+04	2.064E+07
2057	5.073E+04	4.062E+07	1.355E+04	2.031E+07
2058	4.992E+04	3.998E+07	1.334E+04	1.999E+07
2059	4.913E+04	3.934E+07	1.312E+04	1.967E+07
2060	4.835E+04	3.872E+07	1.292E+04	1.936E+07
2061	4.759E+04	3.810E+07	1.271E+04	1.905E+07
2062	4.683E+04	3.750E+07	1.251E+04	1.875E+07
2063	4.609E+04	3.690E+07	1.231E+04	1.845E+07
2064	4.535E+04	3.632E+07	1.211E+04	1.816E+07
2065	4.464E+04	3.574E+07	1.192E+04	1.787E+07
2066	4.393E+04	3.517E+07	1.173E+04	1.759E+07
2067	4.323E+04	3.462E+07	1.155E+04	1.731E+07
2068	4.254E+04	3.407E+07	1.136E+04	1.703E+07
2069	4.187E+04	3.353E+07	1.118E+04	1.676E+07
2070	4.120E+04	3.299E+07	1.101E+04	1.650E+07

It is clear that the annual production of methane gas increases every year until reach of the year after the assumed closure year of the landfill (2054), then the production rate starts to decrease –but still produce methane gases due to the existence of the undigested matters-. This phenomenon leads to a real challenge, which is the non-fixed production rate of methane gas, which mean that a low efficiency working generator. *Figure 26* shows the relation curve between generator efficiency versus the percentage of maximum output for a diesel generator (which is valid for the methane/landfill gas generator) [42].

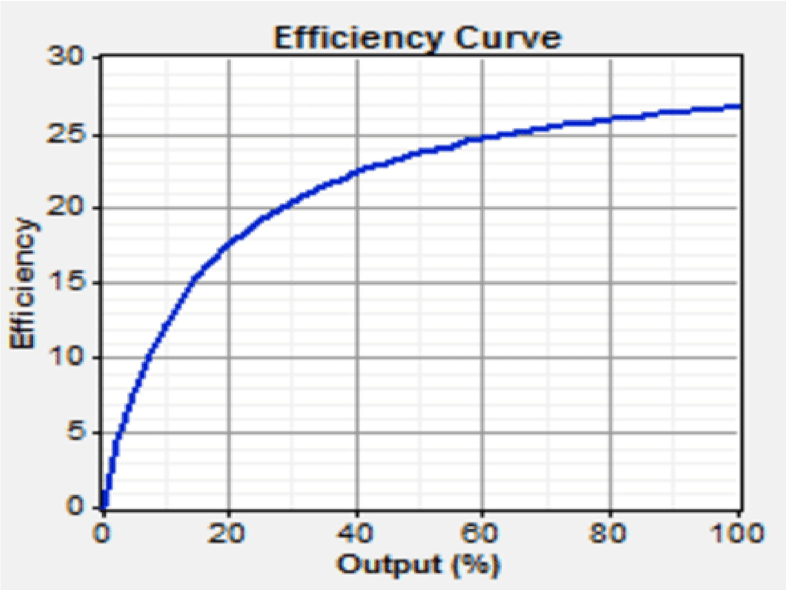

Figure 26 Efficieny curve for a diesel generator

In order to estimate the available energy from the landfill gases, *Eq. 3* below can be used [43].

$$E_{av} = \frac{LHV * Q_{LG} * \eta}{\gamma} \quad \text{Eq. 7}$$

Where E_{av} is the available energy from the landfill gases [in kWh/year], LHV is the lower heating value of landfill gases (biogas), Q_{LG} is the total landfill gas [in m^3/day], η is the electrical efficiency of the generating element in transforming thermal energy into electrical energy and γ is the conversion factor of MJ into kWh (1 MJ/0.28 kWh) [43].

The energy content in the biogas in terms of caloric value range from 20-26 MJ/m^3, depending on the percentage of other contents in biogas like CO_2 -where the LHV of pure methane is approximately 36 MJ/m^3 [44]- [45]. Taking the average value of (23 MJ/m^3), and assuming the electricity generating efficiency is 35% (which is within the normal range), then the available energy from the landfill gas values from years of 2023 to 2093, and the generation power capacity (in kW) which is the energy in kWh divided by (0.9 * 8760 hours. /year) -where the capacity factor of the plant is assumed to be 90%- are filled in *Table 8*:

Table 8 E_{av} *from the landfill gas values from years of 2023 to 2093, and the generation power capacity in kW*

Year	Total landfill gas		
	(m^3/year)	Available energy (kWh/year)	Generation Power capacity (kW)
2023	0	0	0
2024	5.74E+05	1293796	164.1040081
2025	1.18E+06	2668736	338.5002537
2026	1.83E+06	4129328	523.7605277
2027	2.52E+06	5680080	720.456621
2028	3.25E+06	7320992	928.5885337
2029	4.02E+06	9058826	1149.013952
2030	4.83E+06	10893582	1381.732877
2031	5.69E+06	12829768	1627.317098
2032	6.60E+06	14871892	1886.338407
2033	7.55E+06	17024462	2159.368595
2034	8.56E+06	19287478	2446.407661
2035	9.61E+06	21669956	2748.599188
2036	1.07E+07	24162880	3064.799594
2037	1.19E+07	26800060	3399.297311
2038	1.31E+07	29549940	3748.089802
2039	1.44E+07	32457600	4116.894977
2040	1.57E+07	35477960	4499.994926
2041	1.72E+07	38678640	4905.966514
2042	1.86E+07	41992020	5326.232877
2043	2.02E+07	45485720	5769.370878
2044	2.18E+07	49137200	6232.521563
2045	2.35E+07	52969000	6718.543886
2046	2.53E+07	56958580	7224.578894
2047	2.71E+07	61128480	7753.48554
2048	2.91E+07	65501240	8308.12278
2049	3.11E+07	70054320	8885.631659
2050	3.32E+07	74810260	9488.871131
2051	3.54E+07	79791600	10120.70015
2052	3.77E+07	84975800	10778.25977
2053	4.01E+07	90407940	11467.26788
2054	4.26E+07	96065480	12184.86555
2055	4.19E+07	94532760	11990.45662
2056	4.13E+07	93045120	11801.7656
2057	4.06E+07	91557480	11613.07458
2058	4.00E+07	90114920	11430.10147

2059	3.93E+07	88672360	11247.12836
2060	3.87E+07	87274880	11069.87316
2061	3.81E+07	85877400	10892.61796
2062	3.75E+07	84525000	10721.08067
2063	3.69E+07	83172600	10549.54338
2064	3.63E+07	81865280	10383.724
2065	3.57E+07	80557960	10217.90462
2066	3.52E+07	79273180	10054.94419
2067	3.46E+07	78033480	9897.701674
2068	3.41E+07	76793780	9740.459158
2069	3.35E+07	75576620	9586.075596
2070	3.30E+07	74359460	9431.692035
2071	3.25E+07	73187380	9283.026383
2072	3.20E+07	72015300	9134.360731
2073	3.15E+07	70888300	8991.412988
2074	3.10E+07	69761300	8848.465246
2075	3.05E+07	68656840	8708.376459
2076	3.00E+07	67552380	8568.287671
2077	2.95E+07	66493000	8433.916794
2078	2.90E+07	65433620	8299.545916
2079	2.86E+07	64396780	8168.033993
2080	2.81E+07	63382480	8039.381025
2081	2.77E+07	62368180	7910.728057
2082	2.72E+07	61376420	7784.934044
2083	2.68E+07	60407200	7661.998985
2084	2.64E+07	59437980	7539.063927
2085	2.60E+07	58491300	7418.987823
2086	2.55E+07	57567160	7301.770675
2087	2.51E+07	56665560	7187.412481
2088	2.47E+07	55763960	7073.054287
2089	2.43E+07	54862360	6958.696093
2090	2.40E+07	54005840	6850.055809
2091	2.36E+07	53149320	6741.415525
2092	2.32E+07	52292800	6632.775241
2093	2.28E+07	51481360	6529.852867

As mentioned before, the non-fixed production rate of methane gas, which mean that the production rate is growing yearly until year of 2053, and that lead to low efficiency working generator, *Figure 27* show the curve of yearly generation power capacity in kW from year 2023 to 2093.

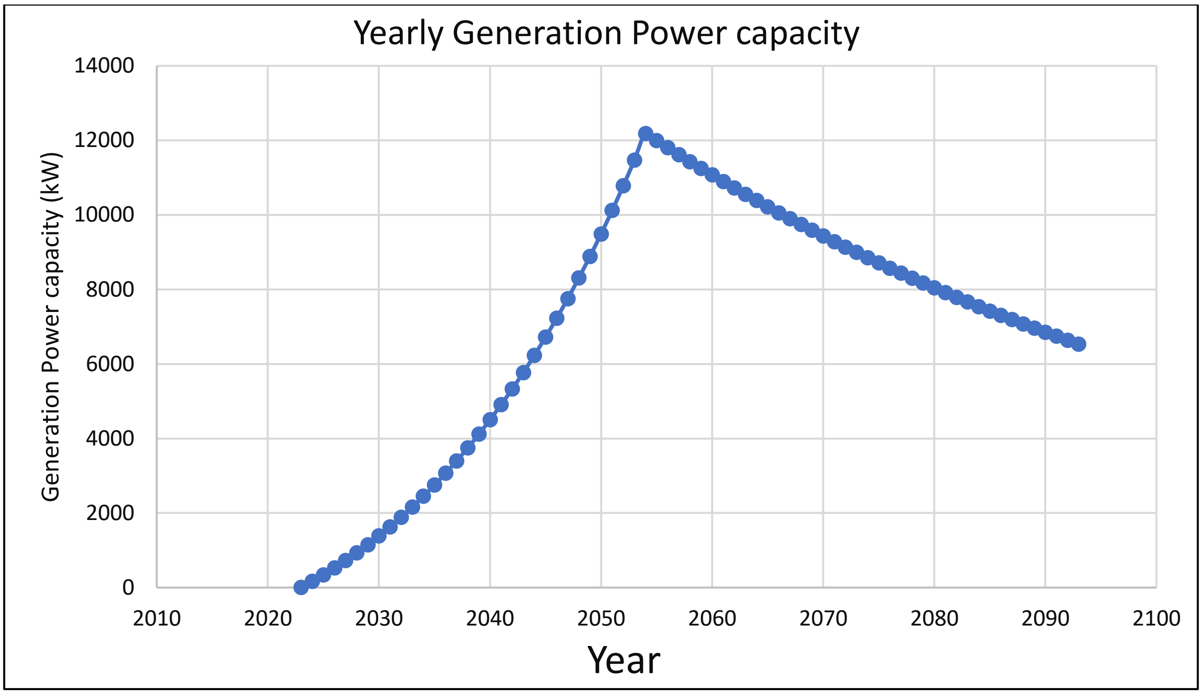

Figure 27 yearly generation power capacity in kW from year 2023 to 2093 curve

So, a proposal for this problem is the use of multi-stage generators, in another word, a number of 17-year life-time biogas generators each has a 3 MW power capacity could be used. *Figure 28* show 11 biogas generators each of 3 MW power capacity, distributed over all time periods from years 2023 to near 2093, with sufficiently high working efficiency. The figure shows the approximated start and end years of each generator.

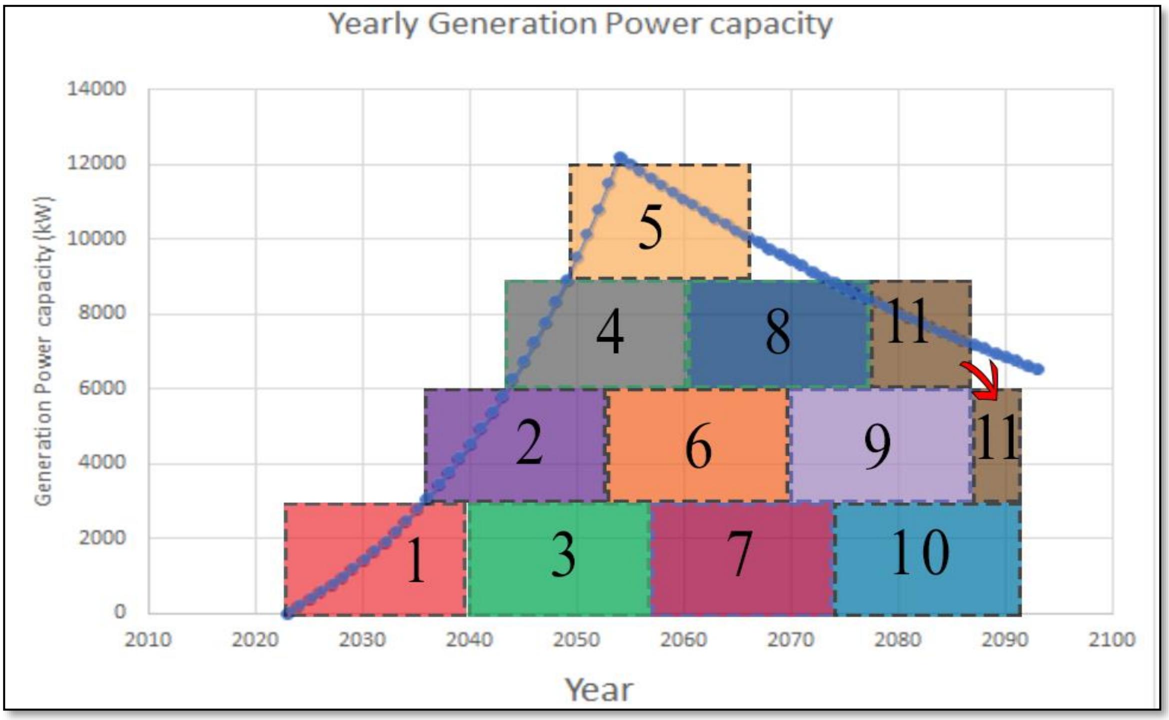

Figure 28 11 biogas generators distribution

9. Conclusions and recommendations

Since there is a need to work on solving the waste and energy problems in Palestine, this project was made to deal with one of the issues related to the energy and waste sectors together, which is the proper disposal of waste and its conversion into useful energy. This project report discussed the issue of waste and landfills, specifically Al-Minya landfill, which serves the southern part of West Bank.

This project studied the energy potential of converting the MSW that end up at Al Minya landfill into energy sources, from technical side. The conversion technologies proposed in the project case study are incineration and landfilling waste-to-energy conversion technologies.

This project report shows that the daily MSW amount received to Al Minya landfill was 1000 tons/day in 2019, and the annual growth rate of MSW amount equal to 4%. In WB, the MSW composite of 50% organic matter, 14.6% plastic, 12.6% paper and cardboard, metal, 1.8% glass, and 16.9% textile and other materials.

The MSW proposed to undergo sorting process, specifically the separation of the organic wastes from other waste types. After that, the project proposed that the non-organic waste will undergo incineration process, by an incineration plant starts work in 2023 and works for 30 years. With 22% assumed conversion efficiency for electricity generation, the daily available electric energy in the MSW in 2023 estimated to be 642,427.5 kWh/day, and based on that, the incineration plant capacity estimated to be 26.8 MW.

The incineration plant sizing depended on 2023 daily MSW amount, which is 585 tons/day. But in the next years, the amount will increase, so, the excess amount will be transferred to the landfilling plant. In addition to the excess amount from incineration, 50% of MSW -which are the organic waste- will undergo landfilling process. Since the available energy from the landfill gas values varied through years 2023 to 2093 (1,293,796 kWh in 2024 to 96,065,480 kWh in 2054) and therefore the power generation capacity (0.164 MWh in 2024 and 12 MWh in 2054), then a multi-stage generators will be used, each with 3 MW power capacity and 17 years life time, distributed over the plant life time, in order to obtain the highest possible generation efficiency.

After the potential energy from the MSW converting in Al Minya landfill by both incineration and landfilling technologies has been studied, then a number of projects and studies are useful to be achieved. One of these studies is the economic analysis of the project, that is, the evaluation of the project economic feasibility, by study the economic parameters and variables, e.g., project initial investment, net present value, simple payback period, internal rate of return, minimum attractive rate of return, and other economic variables, since the basis for the economic analysis is achieved by this project (the potential energy of the project).

In addition to the economic analysis, an environmental impact assessment (EIA) of the project is verry essential, in order to study the environmental effects due to the project implementation (before running (project building), during project operation life time, and after project end), and examine the negative -in addition to the positive- aspects of the project, from environmental and social side.

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