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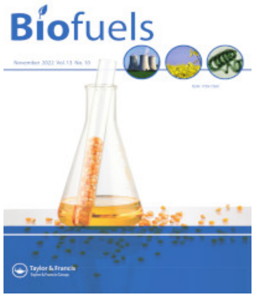

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# The feasibility of renewable energy recovery from municipal solid wastes in Palestine based on different scenarios

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**ABSTRACT**

Management of municipal solid waste (MSW) and energy constraints are the most pressing issues for Palestine's sustainable development and environmental protection. Palestinians are harmed by the environmental and health risks associated with the dumpsite. In addition to imported electricity, natural gas and crude oil are also used to generate electricity in Palestine. This study aimed to assess the viability of recovering energy from MSW through various processes, such as anaerobic digestion, incineration, and gasification. Consequently, this study investigates the viability of recovering and utilizing landfill gas. In addition, the potential advantages of four types of energy generation technologies, namely incineration, gasification, landfilling, and anaerobic digestion, are evaluated. According to the findings, gasification and landfilling recovered about 1,027.5 and 634.1MWh per day, respectively, and incineration recovered about 1,772MWh per day on average. Anaerobic digestion produced the least amount, at about 345.5 MWh per day. Additionally, the environmental assessment revealed that gasification and incineration only produce about 5,240,042.1 and 10,143,446.5 tons of CO2 per year, respectively, while landfilling produces about 10,143,446.5 tons of emissions annually. Anaerobic digestion produces the least amount emissions, about 3,234,444.5 tons annually. As a result, the perfect scenario for generating energy includes both anaerobic digestion and incineration.

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**KEYWORDS**
Waste to energy; energy recovery; sustainable economy; waste management; landfilling; emission

## Introduction

Energy is now the world's most important resource and the most important factor to consider when planning any project. This is due to the fact that energy is the only field related to communication, economics, politics, and the environment that is considered a trend, because of the widespread usage of fossil fuels and the repercussions of environmental contamination around the world. International organizations have begun to prioritize the use of sustainable and alternative energy resources over traditional resources [1–3]. Energy security is still a relatively new issue on the global platform, yet it has a substantial impact on both the local and global levels [4]. There are different types of renewable energy resources, including the sun's energy in the form of photovoltaic systems, which is the most widespread renewable resource, in addition to the solar heater type. Wind energy, this source generates a large amount of energy but has a few limitations, including the need for a large area, infrastructure equipment, and experts [5]. Bioenergy is the third category, and it is a very appealing energy choice for countries at all levels of development because of its great flexibility and ability to be integrated into a wide range of energy systems [6]. Besides this, it can also be used for both fuel and electricity generation [7, 8]. Solid waste management is currently one of the most difficult issues confronting authorities in developing countries such as Palestine [9, 10].

Palestine is located in the Middle East. Historically, Palestine has been known for its plentiful agriculture, which is still its predominant economic source. Therefore, the waste management sector in Palestine can play a major role in sustainable energy in the long term, especially bioenergy. Generally, biomass energy makes up 9–13% of the world's energy supply and about 8% of the energy supply in Palestine [9]. Solid waste is one of the key environmental issues to which the Palestinian state is increasingly paying attention, not only because of its negative effects on public health and the environment but also because of its social and economic implications. [11]. Besides this, there are many rural areas in Palestine where people living on and owning farms can benefit from energy products produced from residual and animal waste [12–14].

Palestine faced a critical situation regarding energy use, and many districts suffered from daily electricity cuts due to the full control of the energy sector by the Israeli electricity company. The reliance on imported energy from a single source led to insecurity, which has direct and indirect effects on the energy sector and the local economy [15]. Figure 1 shows the monthly imported energy in Palestine by type of energy during 2019. It can be clearly observed that Palestine imports a large amount of fossil fuel used for both electricity

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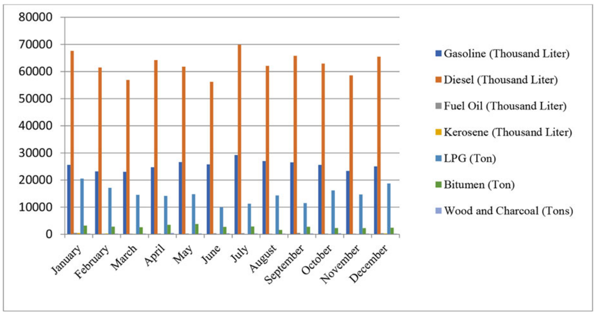


**Figure 1.** Imported energy in Palestine by energy type during 2019.

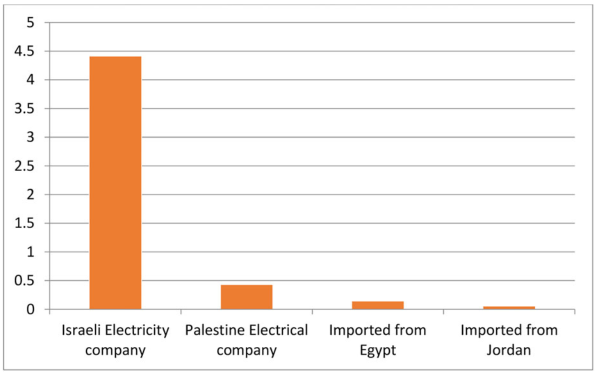


**Figure 2.** Quantity and country of electricity purchases (TWh) in Palestine.

and vehicle fuel. For these reasons, it's essential to start finding new sustainable, clean, and dependable resources [16].

In reference to the aforementioned energy status, there is a lack of information regarding the potential energy recovery from MSW in Palestine based on different scenarios, including landfilling, incineration, gasification, and anaerobic digestion. The viability of implementing several waste-to-energy technologies in Palestine is therefore quite worrisome. The analysis of these approaches could help investors and decision-makers in hastening the growth of waste management and energy enterprises.

Palestine's solid waste generation is estimated at 2 million tons/year, which is sourced only from householders. In addition, about 500,000 tons per year are sourced from the health and economic sectors [16]. Furthermore, in the West Bank, there are around 678,746 Israeli settlers distributed among 150 settlements, which generate an average of 2 kg/c/day, which makes around 500,000 tons yearly. Despite this, the majority of these wastes, which come from settlements, are dumped at random [17]. A large amount of waste comes from the animals' wealth since Palestine is an excellent place for animals to grow due to its helpful environment. According to the Palestinian Central Bureau of Statistics [16], the number of cows exceeds 22,170. Each cow produces waste weighing around 29.5 kg per day. This will result in a total of around 2.4 million tons of waste a year from cows. In addition, around 4,253,775 sheep and goats generate a waste of around 3.3 kg per person daily, which produces a total waste of 5.1 million tons yearly.

Including the aforementioned sources in the calculation will result in approximately 2 million tons of waste in the West Bank and Gaza. This study aims to analyze the feasibility of managing waste in Palestine and its impact on health and the environment. Furthermore, the potential of utilizing waste as a new, dependable source of energy is explored using various scenarios. The performance of each scenario was evaluated and discussed. Additionally, based on the national solid waste management policy, this study emphasizes the technical and economic constraints that Palestinians face in the area of energy and the potential use of solid waste as a sustainable energy source.

## Energy status in Palestine

Palestine is a developing country with a large annual population increase. The demand for all types of energy is increasing every year. Palestinian energy is primarily reliant on conventional supplies, which are purchased from Israel's electrical utility [18, 19]. Figure 2 displays the total amount of power purchased (TWh) in Palestine. It is clear that the majority of the power dependency is on the Israeli electrical company, which presents around 87% of the total purchased energy. Also, the Palestinian electrical company provides 9% of the total electricity, and the rest of the energy supply is provided by Egypt, with a percentage of 3%, and Jordan, with a percentage of only 1% [9, 15, 16].

Palestine consumes 13.68 million Btu per person [20], and the political situation has a significant impact on its economy [16]. There is a link company called the Palestinian Electric Transmission Company, which transmits the electrical energy between the Palestinian cities. Besides this, there is the Palestinian Energy Authority, which sets the rules regarding energy management and use [21, 22].

## The status of waste management in Palestine

Because of its environmental, economic, and social consequences, solid waste management has become a key issue [23]. This issue is highly concerning in developing countries like Palestine, which is planned to be independent [24]. The management and energy recovery of waste have been highlighted by much research in the past few years, especially the bioenergy type [25]. Brito and Barros [26] investigated the economic feasibility of generating electricity from landfill gas and anaerobic reactors while managing municipal solid waste in Brazilian states. In their study, LandGEM software was used to estimate landfill gas generation. The investment prices for both landfills and anaerobic reactors were computed for the economic analyses, and the respective net present value (NPV), internal rate of return (IRR), and payback period for the various consortiums were produced. The results showed that electricity generation from landfill gas (LFG) is economically viable, as the annual generation is around 3,900,000 MWh [27, 28].

MSW landfills are the third greatest source of methane produced by humans [29] and according to the German agency for international cooperation (GIZ) [17], the yearly generation is 1.387 million tons of municipal solid waste only from households, with a per capita generation of 0.94 kg/day and a municipal solid waste growth rate of 4% per year. There are five landfills in Palestine, three of them in the West Bank, which are: Zahrat Al-Finjan, which received 1200 tons/day, Al-Minya, which received 1100 tons/day, and Jericho, which received 50 tons/day. Furthermore, two other landfills are located in the Gaza Strip. Figure 3 shows Zahrat Al-Finjan landfill site where the collected waste was finally disposed.

Figure 3. Waste disposal at Zahrat Al-Finjan landfill.

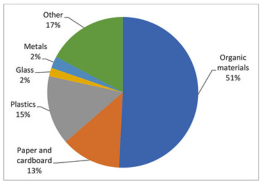


Figure 4. Solid waste compositions for Palestine, 2018.

Generally, MSW contains organics, paper, plastics, glass, metals, and other wastes generated by citizens or farms. Figure 4 shows the percentage of the solid waste composition in Palestine in 2018 [22]. The landfills in the West Bank and Gaza are shown in Table 1, which also illustrates how each landfill receives different compositions of waste.

LFG is mainly a product of the decomposition of organic waste. From Figure 4, the organics represent around 51% of the waste composition generated in Palestine. In general, there is a significant difference between the waste generated in urban and rural areas. In other words, rural areas produce less waste (approximately 0.75 kg per capita per day), but urban areas such as Ramallah or East Jerusalem produce 1–2 kg per capita per day. The generation rate in the Gaza Strip is about 1 kg/capita in urban areas, compared to about 0.5 kg/capita in rural regions [17, 28].

It is crucial to emphasize that the most fundamental interruption to efficient solid waste management is the political situation. This is due to the fact that most of the landfills in Palestine are mainly located in the occupied part, which is fully controlled from the Israeli side. Aside from that, the financial and infrastructure status of these projects are critical [17].

Unfortunately, the Palestinian MSW system still needs support as it is mainly dependent on external donors such as international organizations, government agencies, and NGOs. These institutions normally provide the needed support, mainly in the form of financial and technical resources and experts. These institutions have contributed to upgrading the collection equipment, improving facilities, and rehabilitating dumpsites. Yet, they raise public awareness about waste management and its impact on the environment.

## Methodology

### *Study area*

In Palestine, there are five landfills, which are located in Jenin, Bethlehem, and Jericho, in addition to two landfills in the Gaza Strip. Figure 5 shows the location of landfills in Palestine and the total amount of MSW received. The scope of the analysis of different scenarios in this study is based on these landfills. In addition, the data collected from these landfills are used to estimate energy consumption.Palestine mainly consists of 14 governorates, and each has local government units (LGUs), which include either municipalities, village councils, or project committees. These institutions are responsible for the MSW's collection, transportation, and disposal. MSW management primarily entails collecting waste from cities and villages as arranged by local government units. Some of these wastes are moved to transfer stations and then moved to the main landfill. These operations are summarized in Table 2.

Table 1. Analysis of all WB landfills during 2017–2018 and Gaza in 2012 [30].

| | Al-Minya landfill | Zahrat Al-Finjan landfill | Jericho landfill | Gaza strip landfills |
|---|---|---|---|---|
| Organic | 46% | 55% | 45.9% | 56.6% |
| Plastic | 18.3% | 12% | 26.4% | 13.9% |
| Paper | 10.9% | 14% | 11.1% | 7.6% |
| Glass | 2.3% | 1.5% | 1.3% | 1.96% |
| Metals | 1.8% | 2% | 4.9% | 2.27% |
| Others | 20.7% | 15.5% | 10.6% | 17.67% |

Anaerobic digestion technology can benefit from the high composition of the organic fraction. Other waste-to-energy (WTE) processes, such as incineration and gasification, which essentially exclude organics, metals, and glass from their WTE operations, can employ the other components. In contrast, landfilling technology takes into account the complete garbage, including all of its parts. In order to determine the ideal situation that should be applied in Palestine, four technologies were examined, as shown in Figure 6.

### *Landfill gas energy basics*

Landfill gas (LFG) is formed when organic waste is disposed of in a landfill under particular conditions of temperature and pressure. LFG is regarded as the most advantageous gas and the main supply of bioenergy. It primarily contains more than 90% of methane and carbon dioxide [31]. The LFG generation increases with the increase in temperature and moisture, and it reaches its peak generation in 5–7 years of landfill age [32]. Figure 7 demonstrates how landfill gas can be utilized to power buildings or as a medium-Btu fuel for boilers or other industries. To be ready for use, the generated gas must go through three phases of treatment. In the first step of primary treatment, the gas is passed through a pot, a filter, and a blower, which removes the moisture [29, 33, 34]. Numerous applications for the LFG exist [13, 35]. The main objective of the LFG project is to convert it into a form of useful energy [36]. Figure 8 clarifies a typical diagram of the production and use of LFG.Electrical energy from LFG is mainly generated by three main generation devices. The first is the reciprocating internal combustion engines (ICE) that are used for a capacity between 800 kW and 3 MW; multiple engines are used for capacities larger than 3 MW. The second one is the gas turbines (GT), which are used for capacities equal to or greater than 5 MW, and lastly, the micro turbines (MT), which are smaller in size. These turbines are used for capacities less than 1 MW [29]. High-Btu gas is known as compressed natural gas (CNG) and liquefied natural gas

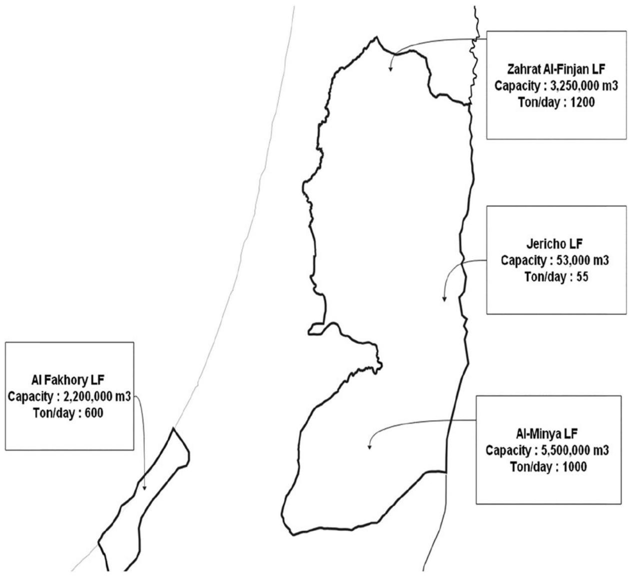


**Figure 5.** Location of Landfills in Palestine and Total received MSW.

(LNG). These gases can be used in gas stations as vehicle fuel [37, 38].

A trustworthy calculation of LFG production should be carried out in order to evaluate the technical and environmental viability of the LFG valorization. However, the LFG production estimations by mathematical models, which are carried out in this research, are complicated and take a long time due to the anaerobic degradation of the organic matter contained in MSW.

## Waste generation and compositions

The main focus of this research was on how to make the best use of the MSW generated in Palestine. To achieve this target, four different scenarios for energy generation are being investigated, taking into consideration their economic and environmental impacts. These scenarios were landfilling, incineration, gasification, and anaerobic digestion. Each one of these technologies has its own uses, benefits, and limitations.

**Table 2.** MSW collection system in West Bank in 2018 [28].

| City | Population | Percentage of MSW | Destination of transportation of the collected MSW |
|---|---|---|---|
| Jenin | 321,950 | 100 % | Zahrat Al-Finjan |
| Tubas | 62,430 | 100 % | Zahrat Al-Finjan |
| Nablus | 396,210 | 88% | Zahrat Al-Finjan, 8.4% dumpsite, 3.6% recycling |
| Tulkarem | 190,169 | 98% | Zahrat Al-Finjan, 2% recycling |
| Qalqilya | 115,184 | 99% | Zahrat Al-Finjan, 1% recycling |
| Salfit | 77,473 | 100% | random dumpsite, no transfer station |
| Jericho | 50,946 | 94.3%, 5.7% | Jericho landfill, Zahrat Al-Finjan, respectively |
| Ramallah & Al Bireh | 336,835 | 50% | Zahrat Al-Finjan, 50% dumpsite |
| NE & SE Jerusalem | 118,000 | 100% | Al Minya landfill |
| Bethlehem | 222,624 | 100% | Al Minya landfill |
| Hebron | 733,537 | 50%, 50% | Al Minya landfill, Yatta and Torqumia, respectively |

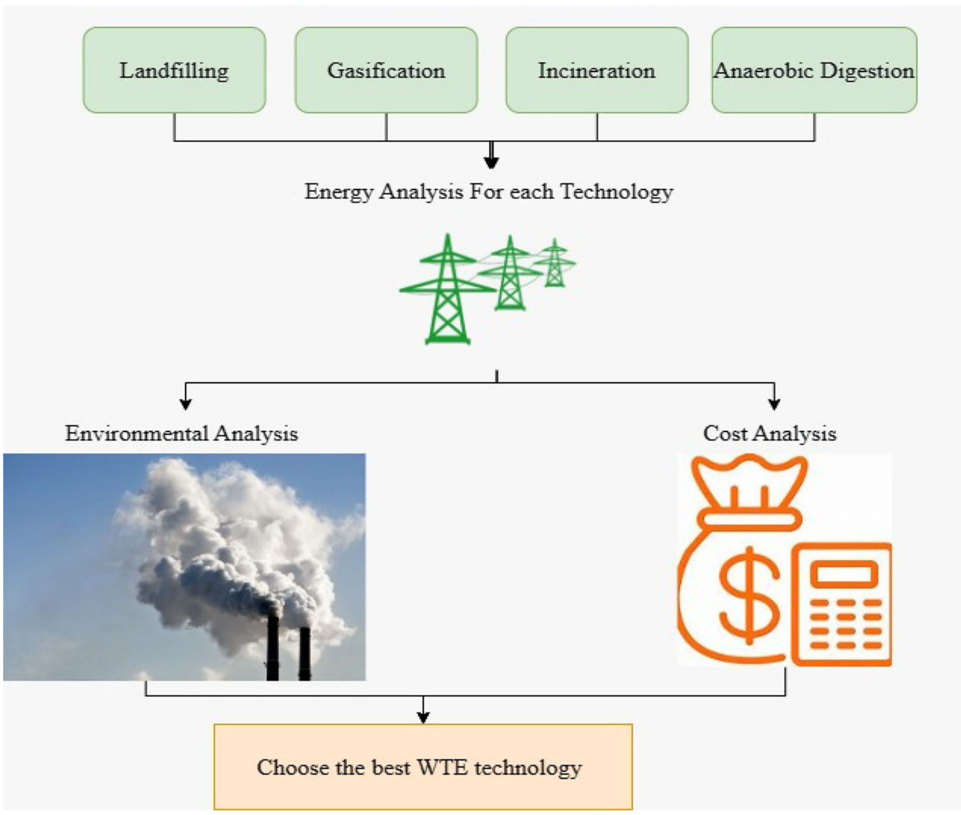


**Figure 6.** Data collection and analysis flow-chart.

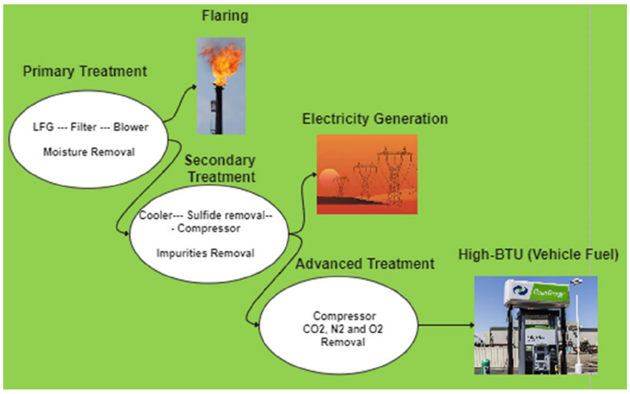


**Figure 7.** Landfill gas treatment stages.

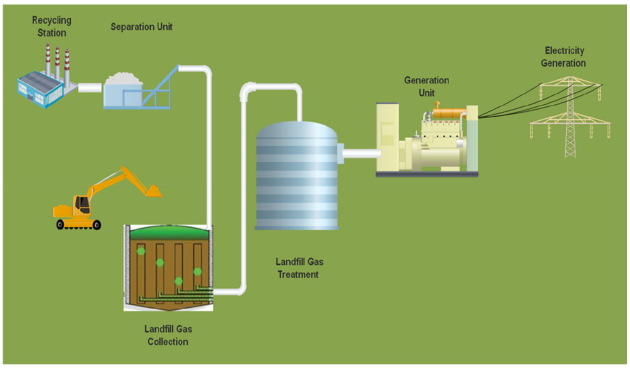


**Figure 8.** Typical diagram of the LFG generation and usage.

As mentioned before, due to the complexity of estimating LFG, a mathematical model was used. In this study, the estimation curve for gas generation by year is determined. Then, LandGEM 3.02, a software for LFG estimation, is used. The following steps in the process are determined by the environmental protection agency (EPA).

## Estimation of energy recovery potential using various technologies

Determining whether the landfill is likely to create enough methane to sustain an energy recovery project is the first stage of any energy project. There are several technologies with potential for energy recovery, including landfill gas, incineration, gasification, and anaerobic digestion. Each of these technologies is investigated in order to find the best case for energy generation in Palestine, according to the MSW produced. Then, by utilizing the LandGEM 3.02 software tool, the amount of annual methane and LFG is evaluated.

### Landfill gas (anaerobic digestion)

*LandGEM* is a Microsoft Excel-based software application designed by the EPA. It uses a first-order decay rate equation in order to estimate the methane and LFG production (Equation 1). *LandGEM* software is used in many industrial applications for LFG models; it gives the relationship between the emission of methane, carbon dioxide, and landfill gas.

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} KL_{\circ} \left[\frac{M_i}{10}\right] e^{kt_{ij}} \qquad (1)$$

$Q_{CH_4}$ : Annual methane generation in the year of the calculation ($m^3/year$), i: 1 year time increment, n: (year of the calculation) - (initial year of waste acceptance), j: 0.1 year time increment, k: methane generation rate ($year^{-1}$). This value varies from 0.02 to 0.65 based on the waste conditions and moisture. In this study, it is assumed to 0.03 $year^{-1}$, $L_{\circ}$ : methane production potential ($m^3/Mg$) EPA has set a value for this parameter between 56.6 and 198 $m^3/Mg$. In our case, it assumed 120 $m^3/Mg$, $M_i$ : mass of waste accepted in the $i_{th}$ year (Mg) which equal 1 million ton, $t_{ij}$ : age of the $j_{th}$ section of waste mass $M_i$ accepted in the $i_{th}$ year.

**Table 3.** Parameters used in the landfill scenario.

| Parameters | Value of the parameters | Units |
|---|---|---|
| $LCV_{biogas}$ | 5.56 | $kWh/m^3$ |
| $Q_{CH_4}$. | 7E + 05 | $m^3/day$ |
| γ | 80 | % |
| ŋ | 33 | % |

According to the software guidelines, methane generation reaches its peak value after initial waste placement, and the rate of methane generation decreases exponentially (first order decay) as the organic is consumed by bacteria over time. Equation 2 was used to determine the annual amount of methane generation for electricity production:

$$ERP_{LG} = LCV_{biogas}.Q_{CH_4}.\gamma.\eta \qquad (2)$$

where is the potential energy recovery in (MWh/day), biogas is specified in kWh/, what is the efficiency of the biogas recovery system (80%), and what is the electrical efficiency of the electricity-generating technology (33%). All waste compositions are taken into account in landfilling technology [39]. Table 3 lists the main parameters used in the landfill scenario estimation and analysis.

### Incineration technology

In both incineration and gasification, the organic, metal, and glass compositions are excluded from the calculation due to the high energy consumption through the process of the WTE. Equation 3 is used to determine the amount of electricity generated from incineration:

$$ERP_i = \eta.M.\frac{LCV_{MSW}}{1000} \qquad (3)$$

where ŋ the efficiency of the process is 18%, M is the total mass of dry solid waste (ton/day) and $LCV_{MSW}$ is the Lower Calorific Value (LCV) of the waste (kWh/kg) [39, 40]. Table 4 shows the main parameters used in the incineration scenario analysis.

### Gasification technology

Equation 4 was used to calculate how much power can be obtained through gasification:

$$ERP_G = 0.28.G.R_f \ \eta.LCV_{MSW} \qquad (4)$$

where G means the daily tonnage processed in (ton/day) $R_f$ is the ratio of excluded after the mechanical handling. The efficiency for this route is 23% [39]. The main parameters used in the gasification scenario are listed in Table 5.

### Anaerobic digestion technology

This approach takes advantage of the organic percentage of MSW, which has a potential for producing electricity according to Equation 5:

Table 4. Parameters used in the incineration scenario.

| Parameters | Value of the parameters | Units |
|---|---|---|
| ŋ | 18 | % |
| $M$ | 1790.1 | ton/day |
| $LCV_{MSW}$ | 5.5 | kWh/kg |

Table 5. Parameters used in the gasification scenario.

| Parameters | Value of the parameters | Units |
|---|---|---|
| $G$ | 3978 | ton/day |
| $R_f$ | 45 | % |
| ŋ | 23 | % |
| $LCV_{MSW}$ | 5.5 | kWh/kg |

$$ERP_{AD} = P.R_{AC}.f.M_{OFSW}.Q.ŋ \quad (5)$$

where P is the number of population (capita), $R_{AC}$ is the amount of waste produced annually per capita in (ton/capita.day); f is the organic fraction of the solid waste (%); $M_{OFSW}$ is the methane generation per ton of organic fraction of solid waste (OFSW) ($m^3$/ton); Q is the LCV of biogas due to the methane (kW/$m^3$); and ŋ is the efficiency of the process, which is set to 26%. All these technologies will be found from technical and economical point of view in order to find the best case and use it in Palestine [41]. The main parameters used in the anaerobic digestion scenario are clarified in Table 6. Table 7 shows the percentage and utilization of MSW based on the waste composition for each WTE technology. The table clearly illustrates that only landfilling uses the entire amount of waste.

### *Environmental impact for each technology*

In order to study the impact of each technology on the environment, there are various factors and criteria that should be taken into consideration, such as Abiotic Depletion Potential (ADP), Global Warming Potential (GWP), Ozone Layer Depletion Potential (ODP), Human Toxicity Potential (HTP), Acidification Potential (ACP) and Eutrophication Potential (ETP). According to some studies in reference to the $CO_2$ emissions, the landfills have a more significant negative environmental impact than other waste-to-energy methods, but based on the aforementioned criteria, anaerobic digestion is the best WTE method, followed by incineration, gasification, and landfill gas. When compared to other technologies, the WTE technologies might achieve $CO_2$ emission reductions ranging from 4.07% to 48.16% [39].

The Intergovernmental Panel on Climate Change (IPCC) developed three models based on available data to estimate emissions from incineration. The IPCC is a United Nations intergovernmental body dedicated to providing objective scientific information relevant to understanding the scientific basis of the risk of human-induced climate change, its natural, political, and economic impacts and risks, and possible response options. Among these impacts is global warming resulting from the emissions of certain gases such as carbon dioxide $CO_2$, methane $CH_4$, and nitrogen oxide $N_2O$ [31].

$$CO_2Emissions = MSW \times \sum (WF_i.dm_i.CF_i.FCF_i.OF_i)\frac{44}{12} \quad (6)$$

where $CO_2Emissions$ calculated in (ton/year), $i$ is the MSW composition type, $WF_i$ amount of organic material 89 type in (ton/year), $dm_i$ is the dry matter content in the MSW

Table 6. Parameters used in the anaerobic digestion scenario.

| Parameters | Value of the parameters | Units |
|---|---|---|
| $P$ | 4.685E + 06 | capita |
| $R_{AC}$ | 0.85 | kg/capita. day |
| $f$ | 50 | % |
| $M_{OFSW}$ | 120 | $m^3$/ton |
| $Q$ | 5.56 | kW/$m^3$ |
| ŋ | 26 | % |

type, $CF_i$ is the fraction of carbon in the dry matter, $FCF_i$ is the fraction of fossil carbon in the total carbon of component $i$ and $OF_i$ is the oxidation factor (fraction). The MSW incineration $CO_2$ emissions model estimating factors shown as in Table 8.

$$CH_4(or\ N_2O) = \sum (IW_j.EF_j).10^{-6} \quad (7)$$

Emission in ton/year, $IW_j$ is the amount of solid waste (ton/year), $EF_j$ is the aggregate emission factor of methane (or Nitrous Oxides) (which is 0.188 kg CH4/ton of waste for methane and 0.068 kg of N2O/ton of waste for nitrous oxides) [31].

## Results and discussion

As mentioned before, about 50% of the waste in Palestine is food or organic waste. The other 50% of the waste, which consists of plastic, glass, and metal, should be recycled in order to get the highest benefit from the waste. Figure 9 shows the stages of using the waste by first collecting it, sorting it for recycling, and transporting the rest of the waste, which is organic, to the landfill in order to generate the gas.After setting all input values ($M_i$, $L_◦$, k) in the *LandGEM* software, the estimated landfill gas, methane production, carbon dioxide, and non-methane organic compound (NMOC) emission rate were used to determine the biogas production. The study duration is from 2022 until 2036 (15 years). Figure 10 shows gas emissions productions; note that each mega grams equal 1 ton.Figure 10 shows the landfill gas, methane, and the carbon dioxide generation. There is no NMOC generation during the generation period. The results for the landfill are as follows: LPG generation will start increasing exponentially due to the first-order decay equation, which has an exponential relation, and it will reach its highest value, which is 2,400,000 megagrams per year, in the year 2037. In terms of carbon dioxide generation, it will perform similarly to the LFG increasing exponentially; it will also reach its peak value of 1,700,000 megagrams per year in 2038. The same is true for methane generation. It will also reach its highest value, which is 700,000 megagrams yearly, in the year 2037. The result shown in the figure indicates that waste can generate a very large amount of LFG and methane, which can be used for either heat, vehicle fuels or electricity generation. All of these sources suffer from severe shortages around the world. Therefore, utilizing waste to energy technologies could contribute to solving these issues, in addition to clean disposal of the generated waste [42].

### *Electricity and heat generation*

Practically, around 70% of the LFG projects are used for the generation of electricity *via* internal combustion

Table 7. Percentage and utilized composition of the waste for each WTE technology.

| MSW Composition | Percentage in Palestine | Anaerobic digestion | Gasification | Incineration | Landfilling |
|---|---|---|---|---|---|
| organic | 51% | √ | | | √ |
| Paper | 13% | | √ | √ | √ |
| Wood | 2% | | √ | √ | √ |
| Plastics | 15% | | √ | √ | √ |
| Metals | 2% | | | | √ |
| Glass | 2% | | | | √ |
| Other inert wastes | 15% | | √ | √ | √ |

Table 8. MSW incineration CO2 emissions model estimating factors [31].

| Composition | $dm_i$ | $CF_i$ | $FCF_i$ | $OF_i$ |
|---|---|---|---|---|
| Food | 0.40 | 0.38 | _ | 1.0 |
| Paper | 0.90 | 0.46 | 0.01 | 1.0 |
| Wood | 0.85 | 0.50 | _ | 1.0 |
| Plastics | 1.0 | 0.75 | 1.0 | 1.0 |
| Metals | 1.0 | _ | _ | 1.0 |
| Glass | 1.0 | _ | _ | 1.0 |
| Other inert wastes | 0.90 | 0.03 | 1.0 | 1.0 |

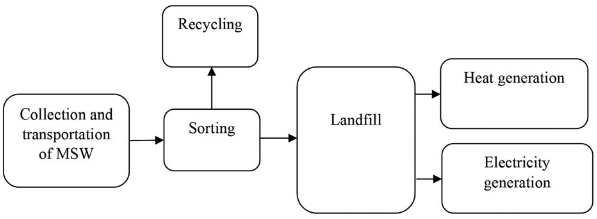


Figure 9. Stages of treatment the waste.

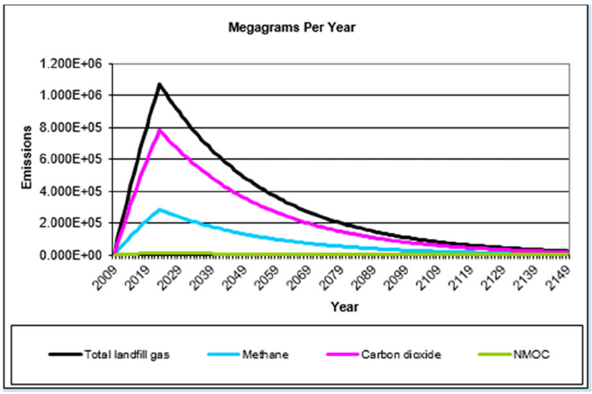


Figure 10. LFG, Methane, carbon dioxide generation using LandGEM.

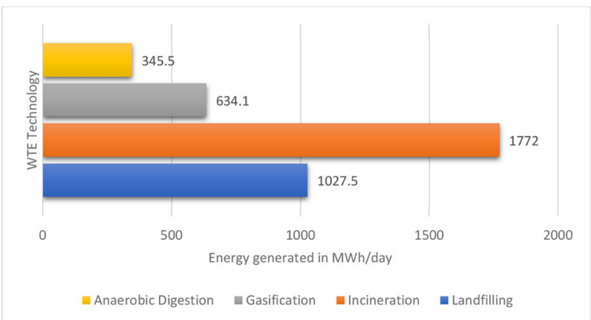


Figure 11. Energy recovery potential by various processes.

engines, gas turbines, and micro turbines. In the electricity generation process, the gas from the landfill is supplied directly into the generator engine [43].

Figure 11 shows the results of the energy recovery potential when involving the total MSW in Palestine. It is clear that the highest amount of energy comes from incineration with an energy of 1772 MWh/day, then landfilling and gasification with an energy recovery of 1027.5 and

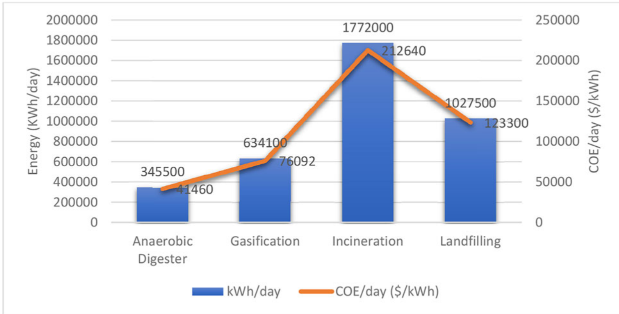


Figure 12. Daily energy recovery potential and cost of energy by various processes.

634.1, respectively, while the least energy recovery result was from anaerobic digestion with an energy of 345.5 MWh/day.

## Economic impact

Figure 12 shows the daily energy recovery and the cost of energy from each technology used. This study's tariff cost is the same as that of the Palestinian electricity company, which is 0.12 $per kWh generated. The cost of energy (COE) for each technology was calculated, and the results revealed that incineration had the highest cost of energy to sell at 212640 $, implying that using this technology in conjunction with anaerobic digestion would be the best scenario.

## Environmental impact

Each sort of solid waste for the Palestine case study has been computed based on its percentage, and the results are displayed in Figure 13. As was previously established, landfilling produced the most emissions. However, incineration produces more energy. Pollutant emissions from anaerobic digestion were the lowest.Based on these results and the energy generation results, the best technology that should be used in Palestine is anaerobic digestion together with incineration. When using these two combined technologies, all the waste composition is used well, resulting in the highest energy generation and the lowest emissions. In addition to this, Table 9 shows the savings from each type of fossil fuel.

## Challenges and recommendations

There is no doubt that energy recovery from waste can contribute to the environmental protection and circular economy [44–46]. The application of the analyzed WTE methods in Palestine to compensate for power shortages in most districts across the country faces a variety of

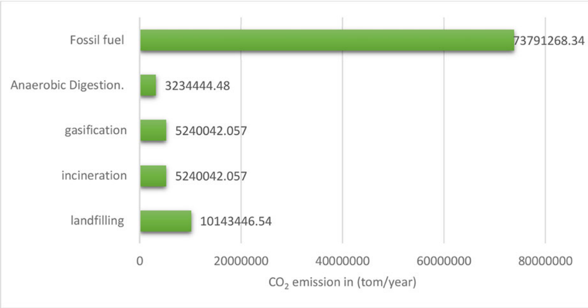


**Figure 13.** $CO_2$ emission from each waste to energy technology compared to the conventional technology.

**Table 9.** The $CO_2$ saving from each type of fossil fuel.

| Fossil fuel source | $CO_2$ emission yearly (ton) |
|---|---|
| Coal | 546,387.0953 |
| Petroleum | 1,015,866.042 |
| Natural gas | 242,932,135.5 |
| total | 244,494,388.6 |

challenges and obstacles. The obstacles can be grouped into four categories: financial, geographic, political, and public awareness issues. Thereafter, these obstacles are further discussed, and a recommended solution is highlighted to help the decision maker and planning institution ease these obstacles.

### Financial issues

As a developing country, Palestine experiences a lack of financial funding for most projects. Energy recovery using incineration or gasification, in particular, is considered to be among the most expensive projects to set up. In the meantime, waste management is carried out in accordance with the national waste management strategy. A lot of attention must be paid to the objective of turning trash into energy. The best-case scenario would involve combining incineration with anaerobic digestion because the economic study's findings revealed that incineration had the highest cost of energy to sell, which came to 212640$. A thorough, cost-effective assessment for constructing WTE projects for energy generation in the near future should be done to account for the daily increase in demand for electricity.

### Geographic issues

Because Palestine is still not a completely independent country, the majority of its land is not under its jurisdiction. As these projects are designed to be away from residual buildings, the availability of land that can be used for waste management is quite limited. The majority of the available area is outside of government control, making it difficult to access municipal waste. Furthermore, transportation between villages and cities within a district is difficult. All of Palestine's cities are separated by Israeli settlements in the West Bank, which can make energy production from garbage in rural areas problematic. Despite this, there are two recent prominent examples: Al-Jebrini biofuel production and the Zahrat Al-Finjan landfill site. The mentioned 2 projects indicating that a small scale plant could be more feasible to a void the issue related to accessibility and transportation of waste.

### Political issues

The uncontrolled majority of land, as well as the occupation's objective of making Palestinians reliant on imported resources from the occupied sector, are all political barriers. This high level of disagreement creates a significant delay in any attempt to take a step ahead in the application of WTE technology to reduce dependence on imported energy, which is generally produced from non-renewable supplies.

### Public awareness

Households in Palestine require education and training in order to have a positive attitude toward waste management. As a result, this might be a problem that affects their lives or a resource that could be used to address the issue of electricity power supply insufficiency. Waste utilization in the energy sector has a lot of promise. The primary benefit of public awareness is that it reduces waste disposal at random, which eventually results in waste being burned in an uncontrolled manner, posing environmental and health risks. As a result, public awareness must be raised as soon as possible at all levels of society. To make this happen, there needs to be a lot of cooperation between all parties involved, including the commercial sector and non-governmental organizations that focus on environmental and health issues.

## Conclusion

In the current state of waste and energy consumption in Palestine, bioenergy as a sustainable energy resource is a very realistic and valuable option. This study took into the possibility of using the entire amount of solid waste created annually in Palestine in order to fully utilize it as an energy source. The influence of technical and environmental factors was also considered in this investigation. The results show that more energy can be recovered by incineration, followed by landfilling, gasification, and anaerobic digestion. However, from an environmental standpoint, landfilling produced the most emissions, totaling around 10,143,446.5368 tons per year, while incineration and gasification produced less emissions, totaling around 5,240,042.1 tons per year. Anaerobic digestion produced the lowest emissions, with a yearly value of 3,234,444.5 tons. From a technical and economic angle, the results showed that the best-case scenario was to use a combined technology of both incineration and anaerobic digestion. Advanced biological techniques could be used to treat the biodegradable portion of solid waste while simultaneously producing bioenergy like biohydrogen, biomethane, and bioelectricity, as well as other value-added goods that will contribute to the sustainable circular economy. Using a combination of different technologies will lead to the use of all organic waste and other non-biodegradable combustible waste with high calorific values, such as plastic and packaging materials, to get the highest energy amounts and the least greenhouse gas emissions. Effective management of MSW will reduce the hazards to the environment and health, besides producing dependable, secure, and clean energy. It can be concluded that the country's economy will be boosted by the circular economy's policies.

## Disclosure statement

No conflict of interest has been declared by the authors.

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