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Municipal Organic Solid Waste to Energy: A Case Study of the West Bank-Palestine

Iyad Abdul Jawwad Osaily[1], Husain Rashad Alsamamra[2, *], Jawad Hasan Shoqeir[3]

[1]Renewable Energy and Sustainability, Al-Quds University, Jerusalem, Palestine

[2]Physics Department, Al-Quds University, Jerusalem, Palestine

[3]Department of Earth and Environmental Sciences, Al-Quds University, Jerusalem, Palestine

Email address:

hsamamra@staff.alquds.edu (Husain Rashad Alsamamra)

[*]Corresponding author

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Abstract: Organic solid waste represents 50% of the Municipal Solid Waste (MSW) composition in Palestine. MSW in the West Bank (WB) are managed by municipalities, Local Governmental Units (LGUs), and Joint Service Councils (JSCs). MSW are collected and transferred to the existing four landfills along the WB, there are no waste separation or recycling in Palestine except small projects and enterprises. The collected MSW reaches the landfills as a mixed wastes with the composition of metal, paper, glass, plastic, and organic wastes. The current organic waste treatment in Palestinian territories is represented by composting and biogas generation, the small pilot projects of composting that have been implemented facing problems related to quality, competition, and financing. Biogas production from organic solid wastes is also limited and concentrated in producing biogas from animals manure. New proposals have been discussed regarding solid waste incineration in the field of Waste To Energy (WTE) projects, except the composting and bioenergy there are no another treatment for organic MSW in the WB. This study ensures about the importance of the concept of waste separation at source, and to adapt the concept of WTE operations. Due to the high moisture content and high organic proportion in the MSW; bio-drying processes are valuable as a pretreatment stage for organic waste treatment. This study also highlights on the Refuse Derive Fuel (RDF) as a product of bio-drying processes that could help in organic MSW treatment.

Keywords: Municipal Solid Waste Management, Palestine, West Bank, Organic Waste, Bio-Drying, RDF

1. Introduction

The total population all over the world have been reached 7.875 billion in 2021 (United Nations Population Fund) [1]. As the population increased, the economic growth and community living standards have increased, this increment have accelerated the rate of municipal solid waste (MSW) generation which causes a major world challenge for waste management [2]. According to the world banks specialists' global waste generation will reach 6 million tons per day by 2025 [3]. The increasing of generated municipal solid wastes that related to the increased world population leads to a major problems in various sectors like environment, human public health, animals and wildlife, water resources, and economy. With regard to the source classification, MSW can be divided into several types they are: commercial waste, institutional and service waste, residential waste, industrial waste, agricultural and animal husbandry waste, and construction- and –demolition waste [4]. This classification that related to the waste source is a valuable when considering the waste collection methods, waste treatment operations, and overall waste management. Considering the composition, municipal solid waste includes organic waste, glass, metal, cardboard, plastics, and textile [5]. This classification could differ from location to another, in other words there is a difference in the generated waste between villages and cities, and the waste composition depends on the lifestyle. The most common problems that related to the improper solid waste management

include: fire hazard, diseases transmission, atmospheric and water pollution, odor nuisance, aesthetic nuisance, and economic losses [6]. In order to eliminate the problems that resulted by wastes, a lot of waste management practices have been adapted overall the world. The waste management hierarchy considered as the most fundamental basis of solid waste management practice, waste management operations have been classified into ranks according to their benefits to the environment or energy aspects [7]. Figure 1 shows the waste management hierarchy, as indicated in the figure the most preferred level of solid waste management is the prevention of solid waste generation, coming after that the reduction of waste or reduction of its toxicity, then the reuse of the waste in its current form or recycling waste in case of the reuse after specified treatments, and then the energy recovery from that waste like incineration or other waste to energy processes, finally, the lowest level of waste management which is the least preferred is waste disposal, which is usually done in landfills. The entities and establishments who works in the waste management sector are encouraged to use the methods and practices that leads to minimize the waste generation and working to get the most preferred solution which is the prevention of waste generation.

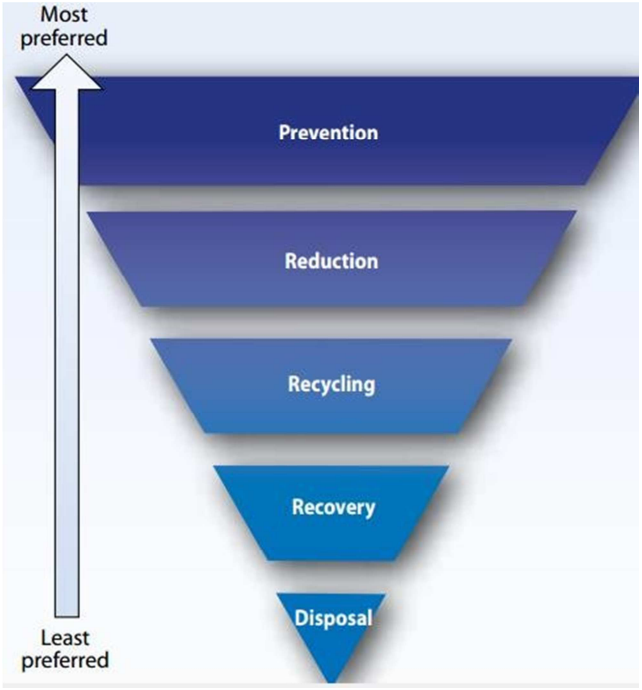

Figure 1. *The Waste Management Hierarchy [7].*

According to Juaidi et al. [8], in order to comply with the goals of waste minimization and reducing of final disposal amounts only two ways could be adapted to realize this goal, the first one could be achieved at earliest stage which is waste reduction at source, the another way is achieved by waste diversion which includes composting, recycling, and waste – to – energy (WTE), these measures known as the 3R principle of waste management (reduce, reuse, and recycle), figure 2 shows generalized idea of waste minimization trough introduction of 3Rs policy.

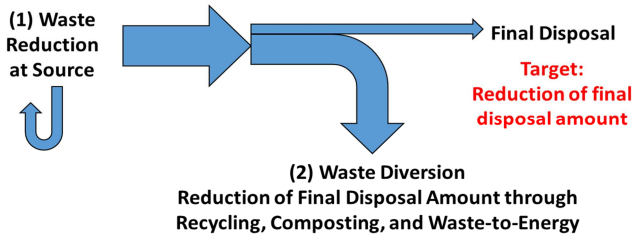

Figure 2. *Generalized idea of waste minimization trough introduction of 3Rs. (Reduce, Reuse, Recycle) policy [8].*

This study will reviews the efforts in the field of municipal organic solid waste treatment in Palestine. Highlight the treatments problem of the municipal organic solid waste in West Bank which is limited and concentrated in composting and bioenergy represented by producing biogas, financial problem, low quality compost, and weakness of competitively. This work focuses on other valuable treatment processes of waste along with the participation of those wastes in energy sector. This work also introduces the bio-drying as a pretreatment process for organic solid waste management due to the effectiveness of this method for the pretreatment of the MSW that contains high moisture content and high organic waste proportion in MSW composition. In addition to that this work highlights the refuse derived fuel as a product for Waste To Energy operations, which is appropriate for the next waste treatment like incineration or gasification which is easy for transportation and short-term storage which increases MSW management efficiency.

2. Solid Waste Management in Palestine

Palestine, as the other developing countries suffering from pollution problems caused by large amounts of waste generation which leads to serious challenges in dealing with solid waste management [9]. In fact solid waste management is one of the main problems due to continuous increase of population density, weak Local Authorities, lack of financial resources, lack of skills and experience in solid waste management and Israeli occupation under which solid waste sector had been ignored for a long time. [10]. The actors in solid waste management field in Palestine are divided into two main groups the first one is the actors at the national level: Ministry of Local Government (MOLG), Environment Quality Authority (EQA), Ministry of Health (MOH), Palestinian Standards Institute (PSI), Palestinian Central Bureau of Statistics (PCBS), and Municipal Development and Lending Fund (MDLF) [11]. The another group is the actors at the operational level of solid waste management: Local Government Units (LGU) including municipalities, village councils, and project committees, Joint Service Councils (JSC), and United Nation Relief and Works Agency for Palestinian refugees (UNRWA), those actors responsible for waste collection and transportation [12]. In the West Bank (WB) there are 13 Joint Service Councils (JSCs) responsible for solid waste management that includes waste collection, and transferring those wastes to the transfer stations or to the landfills directly [13]. Among West Bank and east – Jerusalem there are 12 transfer stations (TS), seven transfer

stations in the West Bank are managed by JSCs, four transfer stations managed by municipalities and one is managed by Israeli side, at those transfer stations separating and sorting some of waste (plastic and metals for example) done, the rest is loaded and transferred to the nearest disposal site. Table 1 represents a summary of the transfer stations in West Bank in 2018, this table shows the name of transfer station (TS), location, transferred quantity, transferring distance, final disposal, and management responsibility. It is noted that the lowest transferred quantity is at Tubas transfer station with 36 tons/day, and the highest transferred quantity is at Alfahs transfer station in Hebron district with 350 tons/day which is directly related to the population. It is also noted that all the transferred wastes are disposed even in Zahret Al Fenjan landfill or Al Menya landfill since that they are the only two main and large Palestinian landfills in the West Bank. With regard to the transferring distance the table shows that the average transferring distance is about 40 km except Ramallah and Al Bireh TSs, this is an accepted distance for transferring wastes, while in Ramallah and Al Bireh TSs the wastes are transferred to Zahret Al Fenjan landfill that located at Jenin district with a transferring distance about 120 km which is long distance that affected on solid waste management operations regarding vehicles maintenance, consumed fuel, transferring time, roads traffic, environment impact, and other affected fields in this regard.

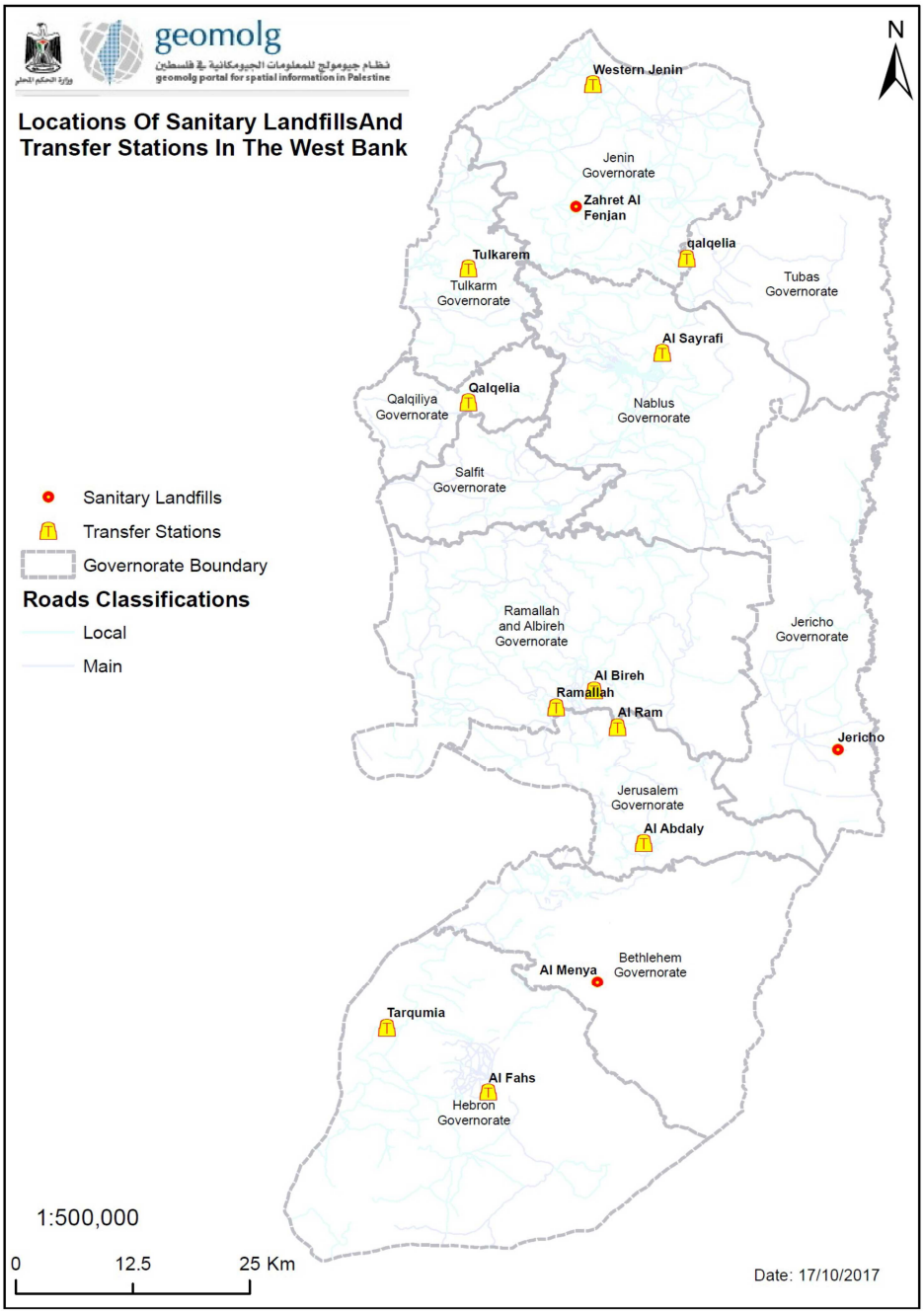

Figure 3. *A map represents the landfills and transfer stations location at the West Bank.*

Table 1. *List of Transfer Stations in the West Bank, (MOLG – JICA, 2017a).*

Area	Name of TS	Transferred Quantity (tons/day)	Transferring Distance (km)	Final Disposal	Management Responsibility
Jenin	Western Jenin	50	35	Zahret Al Fenjan	Jenin JSC
Tubas	Tubas	36	35	Zahret Al Fenjan	Tubas JSC
Nablus	Al Sayrafi	180	40	Zahret Al Fenjan	Nablus Municipality
Tulkarem	Tulkarem	120	35	Zahret Al Fenjan	Tulkarem JSC
Qalqelia	Qalqelia	85	80	Zahret Al Fenjan	Qalqelia JSC
Ramallah	Ramallah	130	120	Zahret Al Fenjan	Ramallah Municipality
	Al Bireh	130	120	Zahret Al Fenjan	Al Bireh Municipality
Northeast and Southeast	Al Abdaly	100	25	Al Menya	Israeli Side
Jerusalem	Al Ram	40	50	---	Al Ram Municipality
Hebron	Tarqumia	100	35	Al Menya	Bethlehem & Hebron Higher Council
	Al Fahs	350	25	Al Menya	Bethlehem & Hebron Higher Council

In 2019, four Palestinian sanitary landfills are located in the West Bank: Zahrat Al Finjan (ZAF), Al Minya (AM), Jericho, and a very small one in north – west Jerusalem (Beit Anan). Figure 3 shows a map represents landfills and transfer stations location at the West Bank.

Several Palestinian laws and agreements related to the waste management have been formulated within the Palestinian legislations and laws like: Basel agreement for dangerous waste transportation and moving across the borders; Environmental Law Num.8, 1999; Law num.20 for Public Health, 2004; Law num.1 for LGU's, 1997; Bylaw num.10 for Medical waste, 2012; Bylaw num.9 for SWM, 2019 and Bylaw for hazardous wastes management, 2021. Most of the laws highlight on waste reduction as a key for waste management in Palestine, Summary of related articles in Palestinian laws regarding waste reduction;

Article 8, Environmental Law, 1999: Encouraging waste reduction and using 3Rs approaches.

Article 5, Medical Waste Bylaw, 2012: The institutions should apply waste separation and follow waste reduction 3Rs activities. Also, reducing the quantity of hazardous wastes as reducing using mercury tools, PVC material reduction and using recyclables materials.

Article 3 and 27, Solid Waste Management Bylaw, 2019: The responsible institutions should establish polices, strategies, programs and plans for waste reductions and promote the reuse, recycle and treatment of wastes. Developing guides for wastes generation sources for the purpose of waste reduction within the national strategy. The ministry should follow up with concerned institutions to consider reducing wastes. Encouraging waste reduction using 3Rs. The recycling, composting and energy projects should get environmental approval.

Article 3, 13 and 14, Hazardous Waste Bylaw, 2021: Establish national plan for Hazardous Waste Management includes defining recovery, treatment and disposal activities. Promote using the safe technology for reducing hazardous waste generation. The generation source should follow reducing hazardous waste methods as follow cleaned technology which generate less wastes, using un-harmful raw material for environment and public health, reducing generation the non-biodegradable wastes. The hazardous waste generators can utilize 3Rs approaches for wastes reduction or other approaches can reducing the hazardous waste.

The environment sector strategy (2017- 2022) planned by Environment Quality Authority (EQA) aims to reduce the pollution through solid waste reduction, encouraging reuse, recycling and recovery, developing waste awareness, and investing into the legal frame work [1 environ]. The national strategy for solid waste management in Palestine (NSSWM) (2017-2022) is considered as the global framework for solid management sector in Palestine, table 2 shows the achievements by 2022 [14].

Table 2. *NSSWM 2017-2022 Achievements by 2022, (PNA 2017, page 42).*

	Status in 2017	Status in 2022
Percentage of recycled materials	< 1%	30%
Percentage of transferring organic materials into low quality compost for the purpose of coverage	2.5%	15%
Coverage of residential areas	95%	100%
Service coverage by JSCs	76%	100%
House separation of SW	0%	20%
Coverage of sanitary landfills	53%	100%

Table 3. *Solid waste Collected Quantities in the 12 JSC Areas, (MOLG – JICA, 2017a).*

#	Collected Quantities							
	Item	JSC						
		Jenin	Tubas	Nablus	Tulkarem	Qalqelia	Salfit	Jericho
2.1	Annual Collected Quantities (ton)	85,837	13,113	30,600	21,984	31,025	24,000	13,500
2.2	Daily Collected Quantities (ton)	235	36	84	60	85	66	37
2.3	Daily Collected Waste/ Person (kg/capita/day)	0.86	0.63	0.62	0.8	0.77	0.94	0.69

Table 3. *Continued.*

#	Collected Quantities						
	Item	**JSC**					
		Ramallah	**NE&SE Jer.**	**N&NW Jer.**	**Bethlehem**	**Hebron**	**12 JSC**
2.1	Annual Collected Quantities (ton)	0	13,200	2,500	46,552	105,321	387,632
2.2	Daily Collected Quantities (ton)	0	36	7	128	289	1062
2.3	Daily Collected Waste/ Person (kg/capita/day)	---	1.09	0.82	0.9	0.59	0.73

The per capita MSW generation in the WB is 0.73 kg/day, with estimated generated MSW around 2190 ton/day (799,350 ton/year) [15]. Table 3 shows annual collected quantities (ton), daily collected quantities (ton), and daily collected waste/person (kg/capita.day), distributed on the 12 JSCs.

According to Sawaftah [15] the solid waste generation in Palestine could differ from one season to another and from one place to another. The MSW generation in Palestinian territories is 1.423 million tons/year with the rate of (0.85 – 1.2) kg/capita/day in urban Palestinian areas and (0.5 – 0.7) kg/capita/day in rural Palestinian areas with basis of wet volume. MOLG – JICA data book report estimated that 2,622 tons/day of MSW generated in the West Bank, with a daily solid waste generation per capita of 0.9kg/day in 2019. According to (MOLG – JICA data book, 2019), the municipal solid waste composition are: 12.6% paper, 50% organic, 14.6% plastic, 1.8% glass, 2.5% metals, and 18.5% others. Figure 4 represents MSW composition in the West Bank.

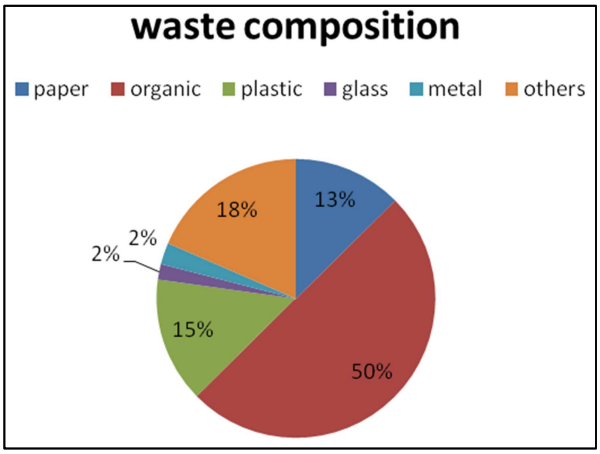

Figure 4. *Solid Waste Composition in the West Bank.*

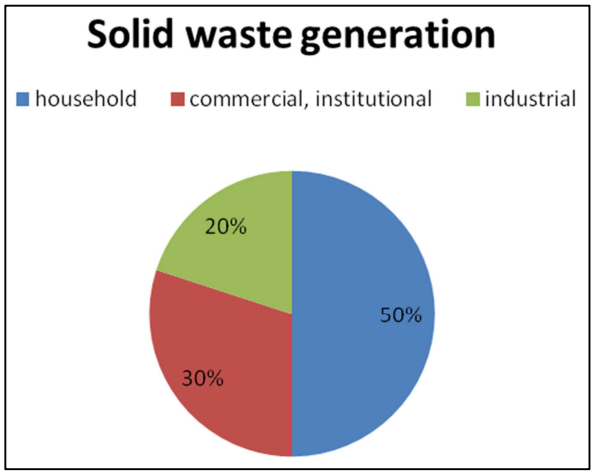

Figure 5. *Solid waste generation.*

The ITAU/UNEP reports mention that local surveys and estimates indicate in the West Bank that household waste accounts for 45-50% of the total SW, with the construction and industrial sectors together constituting 20-25%, and remaining types (e.g. commercial, institutional) about 25-30% [16]. Figure 5 represents Solid waste generation with regard to the waste source.

Solid waste management systems sustainability is one of the main challenges in Palestine [17], 92% of wastes that collected by JSCs among the WB (979 ton/day) are sent to an organized sanitary landfills, 7% (79 ton/day) sent to non-organized or random dumpsites, and 1% (13 ton/day) are recycled as shown in figure 6.

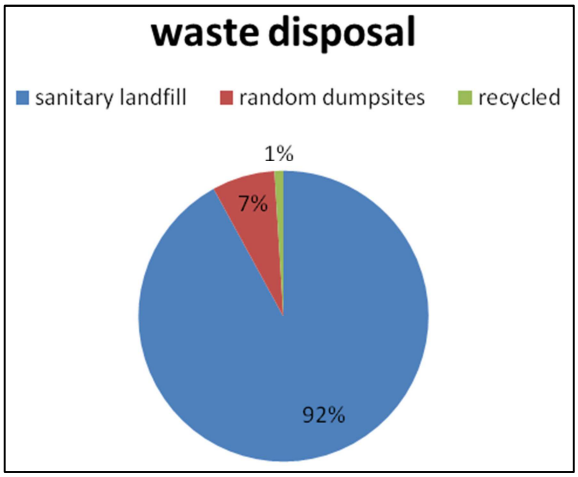

Figure 6. *Waste disposal.*

The ministry of local government reports showed that the current dumping sites are either almost fully utilized, or will be fully utilized within the coming five years [18]. With no possibility to expand those dumping sites or generate new landfills because either of the political restrictions as indicated in Oslo accord, or to the bad experience of Palestinian citizens regarding those landfills. The trends and problems of SWM in seven Palestinian districts as a case study of developing countries were studied and found that 98% of the studied areas have been covered by solid waste collection service, but there are no appropriate treatment for the waste, the study shows low priority for solid waste management at the studied municipalities, such the budget for MSW management was (2 – 8%) of the total budget. The segregation of municipal solid waste from the source could easily encourage the waste reuse and recycling, as well as waste reduction. In the case of the efforts of developing the waste management system in Palestinian territories, (TADWEER) which is a Palestinian company for waste recycling has been established in 2009 by

the Palestinian Development and Investment Limited (PADICO) [18]. Despite of that efforts the 3R principle of waste management (reduce, reuse, and recycle) is still not applied on reality in Palestine. The Joint Service Council of Hebron and Bethlehem (JSC-H&B) has constructed sorting plant of around 1,000 m^2 in area at Al Minya landfill. The plant is equipped by simple sorting equipment including conveyor, trammel, and manual sorting platform. The trammel separates the organic waste of dimension less than 10cm from inorganic waste, while inorganic waste moves to the sorting platform for manual sorting. The large objects of organic waste is sorted manually before loading the waste into the conveyor in order to have it clean for composting. Currently, the following fractions are separated: metals, cardboard and paper, wood, and some types of plastics. All of the sorted materials are sold to the dealers for recycling [19]. The sorting plant is shown in figure 7.

Figure 7. *Sorting plant at Al Minya landfill (annual report 2016 from environmental authority folder).*

A study conducted in 2019 [20], the researchers illustrates the barriers on the implementation of solid waste recycling practices at house level in Palestine as a case study of developing countries, the study concluded that although the recycling is a valuable in minimizing the municipal solid waste amounts that transferred and disposed in landfills but the idea of recycling the wastes is still new to the society in Palestine and it is still not a culture.

2.1. Organic Solid Waste

Organic solid wastes are a solid wastes materials containing organic compounds resulted by resident's activities including: municipal organic solid wastes, industrial organic wastes, and agricultural organic wastes [21]. Organic solid waste treatment methods include pyrolysis, gasification, anaerobic digestion, landfill, composting, classified recycling, and incineration. [22, 23]. the organic proportion in municipal solid waste has the highest percentage among the waste composition, organic solid waste needs a specific and special measures in case of treatment since it couldn't be used or recycled, and having a high percentage of liquids. Leachate which is a toxic liquid that generated from organic waste decomposition have a harmful effect on environment especially the pollution of underground water, the odor emanating from organic waste decomposition is a disturbing for the workers in landfill and the surroundings. The organic matter fraction at Zahrat Al Finjan landfill lays on the range of (34 – 62%) out of the total amount of solid waste that mentioned organic waste produces large amounts of leachate [24-27]. Zahrat Al Finjan landfill was a trend in the Palestinian news in the recent years and still, the current Palestinian government held a lot of meeting and conferences in this regard, they met a consultants in this field in order to solve the problem of leachate generation. In Palestinian territory in 2018, organic waste represents 50% of total municipal solid waste as represented in figure 4. [28], presents the MSW in Nablus district, it found that 65.1% of wastes by weight was organic waste, which encouraging the potential of producing compost and animal feed as resource recovery. The recyclable waste was 16.7% by weight which encouraging the source separation. Fobil et al. [29] found that the organic wastes including food wastes accounting more than 90% of the residential solid wastes in Palestinian territories, the high percentage of this organic wastes providing an opportunity for waste utilization through composting or biogas generation.

2.2. Composting

Composting is a recycling method for organic waste with a positive effect to the environment [30]. As a part of NSSWM (2017 – 2022), organic waste is included, the strategy encouraging composting as a solution for organic waste volume and having a natural fertilizer. The most pilot projects in reuse/recycling solid waste in Palestine in the last

10 years focused on composting mainly [25]. Feasibility studies conducted in various places in the West Bank show that the possibility of waste composting as a realistic option for the future [31]. Adani et al. [32] described the success and the lessons achieved from a pilot composting project in Al Jalameh village at Jenin district as a part of a 200 tons/day of wastes used for recycling plant, the study concluded that although the compost production was adequate and meets the local farmer's needs, but it has limited and small financial returns. Mafarjeh [20] found that composting is a feasible solution for solid waste management at a study done at Beit Liqia village in Ramallah district. "Green Tulkarem Project" is a project that has been implemented in tulkarem district in the north of the West Bank (2014-2017), it has been use the concept of separating the composition of solid waste at the source, they have been separated the organic wastes and the cardboard from the mixed solid waste, the organic wastes have been used to produce compost, and the cardboard has been sent to paper factory for recycling [33, 34]. At Al Minya landfill there is a sorting plant with a separation line for plastic, cardboard, metals, and organic wastes. A composting unit at Al Minya landfill used to generate compost from organic waste. The compost production activities are still limited due to the absence of sorting equipment. The only organic fraction used in compost production is the fruit and vegetable waste that is sorted manually before loading the conveyor in order to insure it is clean from other fractions such as plastics and glass. The quantity doesn't exceed 3 tons per day and of high quality due to the manual sorting of this organic fraction. The compost production is performed by using compost piles as shown in figure 8. The site is paved and all of the leachate generated through the composting process is diverted to the leachate pond [35].

Figure 8. *Compost piles at Al-Minya landfill site (annual report 2016 from environmental authority folder).*

Zawadzka et al. [36] provide that in the Palestinian territories there is no household or commercial composting, while several studies conducted under the supervision of ministry of local government and JICA in the previous recent years to experiment the potential of home composting and to measure the residents awareness, the studies concluded that the composting is feasible, but it remains currently at a micro level. the results that have been achieved from the conducted pilot projects of home composting through (MOLG – JICA) in Bethlehem and Hebron districts indicating that around 10% of organic wastes that generated by target group could be reduced at source [33]. Sugani et al.[34] measured the quality of compost and the potential to use it for agricultural use in Hebron district, the study shows that the available compost in Palestinian market has a medium quality due to partial or non- compliance with quality and guidelines standards. Centralized composting is the composting that done out of the waste source. A pilot projects for centralized composting have been implemented in several locations in Palestinian territories, most of those projects facing financial problems [25], however, the researchers confirms that the using of centralized composting for collected MSW is worthfull issue which could be taken in consideration in near future. Referring to agricultural waste as a part of organic waste. To this date, it is difficult to estimate the total quantity of agricultural waste nor the amount of green waste generated from agricultural activities in Palestinian territories. Despite of that there are several agriculture waste composting plants in the West Bank: Jericho, Jenin, Ramallah, and Hebron district. In a study done by [37], the characteristics of organic waste control the compost process, the presence of a robust mixture of wet and dry fractions, and with (60 – 70%) wet fraction by weight decreases the opportunity to generate high quality compost. According to Ragazzi [38], for the achievement of composting or recycling, a separation of solid waste must be done, even in the source or by sorting plants, the study indicates that there are several small scale sorting plants have been installed in Palestinian territories by public or private sectors, those sorting facilities have limited possibility for sustainable operation due to financial problems and limitation of recycling local market. From the previous studies and pilot projects it is concluded that the composting market in Palestinian territories still weak, with small composted quantities, and low quality comparing with nearby countries [30].

2.3. Bioenergy

Bioenergy is the energy that generated or produced through biological processes, MSW is considered a renewable energy resource by producing biogas by using the suitable technology to convert municipal solid waste into energy [39]. Few implemented projects in Palestine that considered the bioenergy production through its resources. Al-Jebrini company for dairy and food industry have been started the production of bioenergy from animal's manure in order to generate electricity by installing two digesters. As like Al-Jebrini Company, a small farm in Tulkarem district has been use the animal waste to generate electricity [30]. "The Auja Eco Center Home" in Jericho district has implemented a house biogas plants uses small digesters in selected Palestinian families at rural areas in Hebron and Jericho districts, the implemented project that funded by the European Union in the years 2013-2015 has been selected 37 families as a target group [40] producing methane from

Zahrat Al Finjan landfill will start in 2022, the expected 2000 m^3 of methane gas will generate around 3Mw/h [24]. In Hebron district, the uncontrolled dumpsite in Yatta city was closed in 2013, a gas collection system with a flaring system has been installed, the system could allow for generating electricity [14]. A study conducted by Al-Khatib et al. [16] aimed to measure the potential of producing biogas from biomass organic wastes in the West Bank, the study included the agricultural waste, animal manure, municipal solid waste, and municipal sewage sludge, according to this study, the 550,000 ton/year of organic solid waste generated in Palestine could produce a biogas that generate electricity with around 44,323 Mwh/year or 81,260 Mwh/year of heat generation. Velis et al. [41] found that there are no large bioenergy projects carried out by Palestinian government till now, and few implemented projects in this field, however, the potential of producing bioenergy is considerable, in addition to that 19% of total energy demand in Palestine can be covered by adopting bioenergy in Palestinian districts.

3. Waste to Energy (WTE) Approach

As the population increased, the energy demand increases, by economic development and large scale of industry trend all over the world the need to energy increased more and more. The growth of energy demand as well as the bad impact of conventional resources of energy to human public health and the environment, researchers are encouraging the investment in renewable energy resources. These days, the orientation towered clean energy became a trend all over the world. Clean energy have a positive impact towards environment through decreasing the dependency on conventional energy sources that causing CO_2 emissions and greenhouse gases. The types of renewable energy depends on the source of that energy and they are classified into wind energy, solar energy, geothermal energy, hydropower, bioenergy, tidal energy, and other types of renewable energy. Waste to energy become a renewable energy source in the world, this source has appositive impact on both environment and economic [42].

Traditional landfill method that used for waste disposal became non easy method through the land shortage crisis. [43]. Waste To Energy (WTE), simply known as a process used to achieve the energy from waste. Municipal solid waste are classified into biodegradable and non-biodegradable, which is comply with waste to energy processes (thermochemical and biochemical processes) [44]. Municipal solid waste (MSW) considered as a source of bioenergy [24]. In order to utilize the energy from the waste, conversions technologies could be used like direct combustion, biochemical processes, or thermochemical processes. Biochemical processes include digestion and fermentation, while the thermochemical processes consist of pyrolysis, direct liquefaction, gasification, and supercritical fluid extraction [22, 23], figure 9, shows bioenergy conversion technologies.

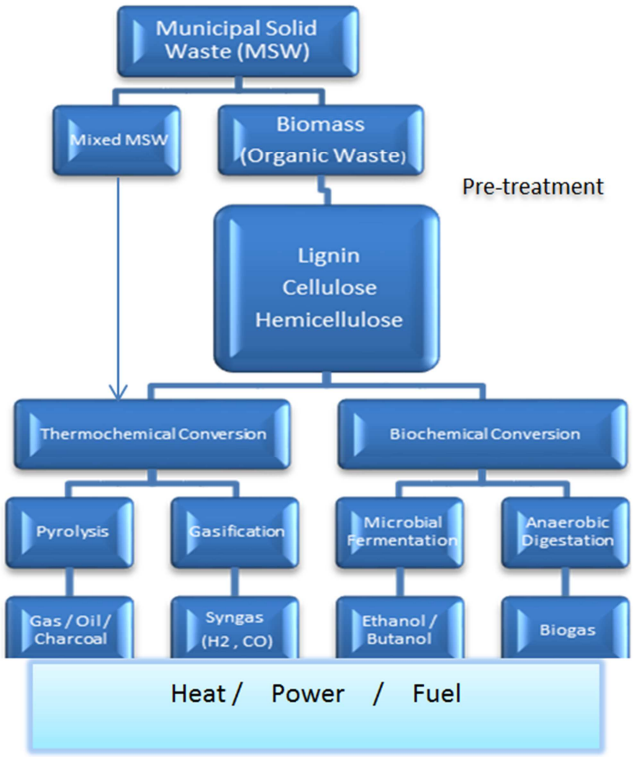

Figure 9. *Summarized pathway of the different bioenergy resources [24].*

WTE plants adopted a non-harmful process to generate energy [45]. United States of America, Japan, and China generate electricity from their solid wastes [46]. According to Liu [26], the waste to energy methods having an increased global concern. WTE technology could reduce the original volume of the waste by 90%, depending on the solid waste composition by recovering the energy [27, 28]. The energy yield that produced through WTE conversion processes are affected by the waste density, composition, and moisture content [47]. About 81.64% of municipal solid waste are physical combustible fractions [44], this percentage indicates the importance of using waste to energy operations for better solid waste management. With regard to Palestine, except the small scale incineration for the infections medical waste, there are no incineration projects for solid waste, as well as no projects have been attempted regarding the other technologies of waste to energy, however there are some proposals conducted by private sector and local government to construct power generation plant through waste incineration [25]. In a study conducted by Salman et al. [47], the researchers studied the potential of incineration technology as a WTE option in Palestinian territories. According to the environmental protection agency [48], the mixed organic solid waste considered as one of the highest energy content in the total Low Heating Value (LHV) among waste fractions. This result has a good indicator to use waste to energy technologies, which is appropriate for Palestinian case and the developing countries since the organic waste proportion is the highest among municipal solid waste in those countries.

3.1. Bio-Drying

Bio- drying is an aerobic convection evaporation process that reduces the moisture content of waste matrix with minimum aerobic degradation [46]. Bio-drying is an appropriate solution for treating wastes with high moisture content, this humid waste could generate large amount of leachate if this waste has not be pretreated before burned [30]. The concept of bio-drying of organic waste with high moisture content has not been fully understood [39, 41]. According to Velis et al. [41], bio-drying, solar drying, bio-stabilization, and thermal drying are the most common drying methods recently used over all the world for improving the municipal solid waste quality. the major difference between compost and bio-drying processes is that the major objective of bio-drying is to degrade the waste enough to generate biological heat in order to dry the waste, while in the composition process the degradation of organic wastes are maximized [31]. The output product of composting process is stabilized organic matter, while the output product of bio-drying process is partially stabilized [17]. As the moisture content of organic waste compound increased the total moisture content of the waste matrix increases, bio-drying process could be a very promising solution for the treatment of mixed MSW that contains a high proportion of organic compounds. the waste with high moisture content could contaminated by bacteria like E-coli which leads this pathogen to spread to animals and may be causing infectious diseases that could affect humans [48], so the removing of that moisture content is an essential measure to serve the health of both humans and animals. The study conducted by Velis et al. [40] has been focused on the using of bio-drying and maturity processes for food waste treatment, the study shows the potential of those methods for accelerating the composting course of food waste into reusable organic fertilizer and decreasing the energy consumption. Calorific value is an important indicator regarding the selection of solid waste recovery processes such as combustion, it is also related to the moisture content in the solid waste matrix [36], and using bio-drying process to increase the waste's calorific value as well as to reduce the moisture content will increase the efficiency of waste to energy (WTE) operations. According Negoi et al. [37], by using a lab bio-drying reactor, the bio-drying process could rise the lower heating value (LHV) of raw waste from 7,000 KJ/kg to 15,000 KJ/kg, which rise the possibility to use the waste to energy operations as appropriate solution for solid waste management. The study of the United Nations environmental programs [49] used the bio-drying process in order to get a treatment of MSW with high moisture content, a pilot scale bio-drying reactor has been used, the treated sample had a reduction of 56.5% of original volume of the sample, the weight of the original mixed MSW sample has been reduced by 33.94%, an increase of 52% of bulk density of the substrate, and 20.81% of the average moisture reduction of the matrix. The high water content in kitchen wastes lower the yield of recoverable material and increases the combustion's operating cost [44]. food wastes as a part of municipal solid waste that have low calorific value and high moisture content is unsuitable for incineration and landfill processes [43, 44], so the pretreatment processes are needed in order to reduce the moisture content and rising the waste calorific value. Leachate is not only a problem in case of degradation of waste at landfill, but also leachate production considers as a problem in most of solid waste treatment systems and especially in WTE conversion systems [17]. One of the most important achievements for bio-drying process [37] is the zero leachate, all of the moisture content in the waste matrix has been evaporated, which considered as an earliest stage of leachate disposing. The wet mass of bio-dried waste is less than the wet mass of the original waste, which encouraging to transport the bio-dried waste to a distant incinerator due to its lower due to its lower mass comparing with non-bio-dried waste [45]. Bio-drying is an energy–saving method, such that the produced material with high calorific value is suitable for incineration or combustion processes [23]. bio-drying became a preferable solution by most researchers in case of the treatment of MSW with high organic waste proportion and high moisture content, this method used to reduce the moisture content of organic waste and controlling the organic degradation in order to preserve the energy level in the solid matrix for further utilization like producing solid recovered fuel (SRF) [38-40]. The following options are used to produce energy by WTE plants: gasification, anaerobic digestion, pyrolysis, incineration, and Refuse-Derived Fuel (RDF) [37, 50, 51]. Referring to Negoi et al. [36], gasification and pyrolysis of high moisture content MSW that pretreated by auto thermal bio-drying process was an appropriate choice as biofuel.

3.2. Refuse Derived Fuel (RDF)

Refuse Derived Fuel (RDF) is a fuel that generated from wastes, Bio-drying reactor used to produce Refuse Derived Fuel (RDF) with high quality as a pre-treatment step of the waste at earliest time, the energy content of the waste matrix increases by maximizing the removing of moisture content in the waste as well as maintaining the level of calorific value of the organic proportion through minimal biodegradation [32]. In order to produce RDF, bio-drying processes are adapted using the internal energy that generated by the biodegradation of organic waste proportion without using an external source for the drying [37, 45, 48-50] have been studied the potential of producing RDF from municipal solid wastes with high moisture content and high organic proportion. The solid derived fuel produced by bio-drying process is the best renewable fuel [32-35]. Incineration is one of the most used methods for thermal treatment processes of municipal solid waste, bio-drying used as a pretreatment stage of MSW before incineration in order to produce RDF with higher calorific value [45]. with regard to the economic wise, RDF or SRF that produced by bio-drying process has a positive impact on the economic due to decreasing the cost of waste transportation through weight reduction of waste after the removal of the moisture content, and the produced

material is more suitable for short-term storage [50, 51]. It can be noticed that the using of bio-drying process to produce RDF is an appropriate solution for resolving the solid waste crises as well as to produce energy from renewable resource.

4. Conclusion

The current MSW management in the WB is limited in waste landfilling, the transferred MSW to the landfills are mixed wastes due to the limited separation or recycling of wastes at source, however small sorting plants founded in some of landfills or small projects for recycling of plastic wastes and metal wastes. The concept of organic solid waste treatment in the WB are limited and concentrated in composting and bioenergy, composting projects facing the inadequate of financial, low quality compost, and weakness of competitively. Limited bioenergy projects have been implemented in the WB, those projects are concentrated in generating biogas through animal manure, its concluded that the separation of wastes at source is valuable action in MSW management. Recently, proposals for solid waste incineration have been discussed, however, no incineration projects have been implemented yet. This study concentrated on the bio-drying as a pretreatment process for organic solid waste management due to the effectiveness of this method for the pretreatment of the MSW that contains high moisture content and high organic waste proportion in MSW composition, the study also highlights on the Refuse Derived Fuel (RDF) as a product for Waste To Energy (WTE) operations, which is appropriate for the next waste treatment like incineration or gasification, RDF is easy for transportation and short-term storage which increases MSW management efficiency. Due to the difficulty to apply a full separation of solid wastes at source which related to the residents culture and attitude in the local Palestinian citizens, the study encouraged the separation of organic MSW from the other recyclable MSW, the recyclable wastes could be collected together and then distributed to recycling units depending on the wastes nature, such plastic, glass, cardboard, and metal. While the organic wastes could be separated and treated alone, using the concept of bio-drying of organic waste and producing RDF to be transferred to incineration plants or selected organic waste landfills that could be constructed with special specifications and specialized for organic solid wastes.

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