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Evaluation and Recommendation of Appropriate Technologies for Municipal Solid Waste Treatment in Bandung, Indonesia

Master's Thesis

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Declaration

I hereby declare that this Thesis entitled “Evaluation and Recommendation of Appropriate Technologies for Municipal Solid Waste Treatment in Bandung, Indonesia” is my own work and all the sources have been quoted and acknowledged by means of complete references.

Prague, 26. 4. 2019

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Kryštof Mareš

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Abstract

The literature part of the Thesis summarizes and describes the main municipal solid waste treatment technologies, including their advantages and disadvantages. Specifically, this Master's Thesis is focused on municipal solid waste management (MSWM) and waste services in Bandung city, Indonesia. According to the references, it is not well documented and examined field. The research was based on questionnaire survey among the Bandung's residents with total amount of 334 respondents and interviews with both government and public sector, supported by observation and photo documentation of public MSWM services, transportation and collection services as well as disposal sites. Necessity of improvement of MSWM is obvious. Despite the highest economic growth across Indonesia, MSWM lacks investments in new and better waste treatments technologies. Since the Leuwigajah disaster in 2005 only changes happen through was an opening of new (un)sanitary landfill, Sarimukti. With no other solution, the same problem could occur easily. In a planning of new waste treatment technologies are important preferences and opinion of public to avoid rejection or misunderstanding of usage of these technologies. Among respondents, the most preferred waste treatment method was recycling centre (40 % of respondents), which points to the interest of people in solution of MSWM situation in Bandung. Recommendation of technologies should be complex, not focused on one specific technology and at least should by inspired by public opinion and preferences. Knowledge and preference of treatment methods and technologies by public is influenced by cultural behaviour: historically burning of waste in front of the house and open dumping of mainly organic waste, and by education: people are aware of new treatment methods, mainly recycling. Through multivariate probit model, it was found out that acceptance of various technologies is linked among them. Knowledge and acceptance of one lead to acceptance of other technology. Government could have the major impact on MSW handling with full confidence of public and power to change MSWM in Bandung.

Key words: waste management, waste treatment technology, open dumping, landfill, incineration, compost, waste handling, questionnaire survey

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List of abbreviations

3R – Reduce, Reuse, Recycle

5R – Refuse, Reduce, Reuse, Recycle, Rot

AD – Anaerobic Digestion

GHG – Green House Gases

HDPE – High-Density Poly Ethylene

LCA – Life Cycle Assessment

LFG – Landfill Gas

MSW – Municipal Solid Waste

MSWM – Municipal Solid Waste Management

MVP – Multivariate Probit

PVC – Polyvinyl Chloride

SCR – Selective Catalytic Reduction

TPA – Temporary Waste Station/Temporary Disposal Site (translate from Bahasa)

TPS – Final Disposal Site (translate form Bahasa)

VIF – Variance Inflation Factor

WtE – Waste-to-Energy

1. Introduction

Waste management is very important and crucial field in today's world. Developed countries in front with Germany, Sweden, Netherland and others are using modern technologies focused on recycling of waste and Waste-to-Energy (WtE) processes instead of disposal methods as landfilling and open dumping. Mainly used WtE technology is incineration facility, but currently the term Waste-to-Energy is much broader (Malinauskaite 2017). The problem is that worldwide are mostly used landfills and worse open dumping as the main waste treatment method, even in Europe in average, one of the most used method is landfilling (Castillo-Giménez 2019).

Currently, many developing countries are transforming due to huge economic rise and rapid population growth mainly, but almost none of them is well prepared in the terms of waste management infrastructure, services and facilities. In developing countries like Indonesia, there is almost no other option how to handle the waste than landfilling, or more inappropriate open dumping (Kumar 2017). For that reasons it is no wonder that most polluting countries in the terms of waste in the ocean (mainly plastic) are China, Indonesia, Philippines, Vietnam and Thailand. The problem is also on land, landfills are overloaded and still used, in some cases there are landslides with deaths as for example Leuwigajah landfill landslide in 2005, Bandung's biggest landfill in that time, in other cases there are long time open fires (Lavigne 2014). Open dumping is more inappropriate because of easy transportation of waste by wind, rain, river etc. Also, there are many cases that people don't have any services in their town or village, so waste is open dumped, directly burned or dropped in rivers (Chen 2018).

Indonesia is developing country experiencing economic boom hand in hand with population growth. Situation of municipal solid waste is not changing because in this country, in general, waste is useless material, with no economic value that is not worth to care about. In the foundation on waste management there is huge lack of money and infrastructure with municipal solid waste management is dropped behind. Mainly big cities are in pressure to take care of increasing amount of waste. Insufficient knowledge of modern waste treatment methods and technologies is also disadvantage in development of sufficient municipal solid waste management. With landfilling as a predominant waste treatment method is the situation in the country critical (Munawar 2018).

Bandung is the major city of West Java province with high density of population. This city faces the same problems in terms of waste management as numbers of cities in developing countries. People there have very limited options for waste handling. Waste management services are not sufficient, in remoted areas are not at all. From approximately 1,600 tons of waste produced daily, only about 60 % is collected and in better case transported to landfill. The rest of waste is untreated, burned or dumped in rivers. One and the only treatment method for municipal solid waste is landfill and in worse case open dumping, both fully supported by the local government. Bandung city is in urgent situation and needs new strategies and solutions to overcome its municipal solid waste management problem. One of biggest problem, Bandung city is facing is underfunding of waste management in West Java province since 2008 (Tarigan 2016). This Thesis is focused on description and evaluation of current situation of municipal solid waste management in Bandung and perception of public to new waste treatment technologies.

2. Literature review

2.1. Municipal solid waste

Municipal solid waste (MSW) is classified as household, commercial, institution and public waste, under waste regulations. In numbers, world generation of MSW is 1.3 billion tons per year, in average 440 kg/capita/year and it is estimated an increase in the global generation up to 2.2 billion tons per year, in average 550 kg/capita/year in 2025 (AlQattan 2018). In European Union, average amount of waste is about 480 kg/capita/year (Eurostat 2017), in United States the numbers are much higher, in average 720 kg/capita/year (AlQattan 2018). Indonesia in comparison has about 270 kg/capita/year in total about 70 million tons yearly (Sudibyo 2017a).

In European Union MSW presents about 10 % of total amount of waste, but because of diversification of this waste it is very important to take proper care about it (Malinauskaite 2017). In Indonesia up to 60 % of MSW is produced by households only, rest is from commercial, institution and public waste (Sudibyo 2017b). Predictions for further years in developing countries such as Indonesia are the same as now: growing population (mainly urban), increasing energy consumption, raising goods consumption and in terms of waste: increasing of total volume and decreasing of an organic part of waste. Situation will copy the developed countries standard as we know nowadays (Sudibyo 2017; Aleluia 2017; Castillo-Giménez 2019).

2.1.1. Municipal solid waste composition and generation

Municipal solid waste is classified into organic and inorganic (i.e. plastic, glass, metals). MSW composition varies in each country, depending on economic development, culture, climate and energy sources. Low and middle-income countries have higher amount of organic waste whereas high income countries have majority of inorganic waste (Moya 2017a). Indonesian average amount of organic waste diverses 50-70 % depending on place (Sudibyo 2017b). Problem of higher consumption is related to the growth of inorganic waste, serious problems are plastic packaging and bottles, which are expanding the total amount of waste and portion of inorganic waste is increasing (Damanhuri 2009). In **Figure 1**, we can see an average composition of MSW generation in Indonesia which is very similar to other Southeast Asia countries. As it was mentioned Indonesia produces in average 60% of organic waste currently but the number is reducing quickly, as more new materials are used, and organic materials are replaced. We can see that amount of inorganic materials in the leading position with plastic (14 %) is similar with European countries, but for the future in this trend, these numbers are going to rise (UNEP 2017).

Municipal solid waste **generation** is strongly linked to urban areas. There are indicators as population size, average local income and even cars' density, connecting MSW generation with urbanization (Chen 2018). Indonesia today faces urbanization. Cities population grows very fast and infrastructure of those cities is in bad conditions. Other problems are increasing municipal solid waste generation and growing electricity demand (Farizal 2018).

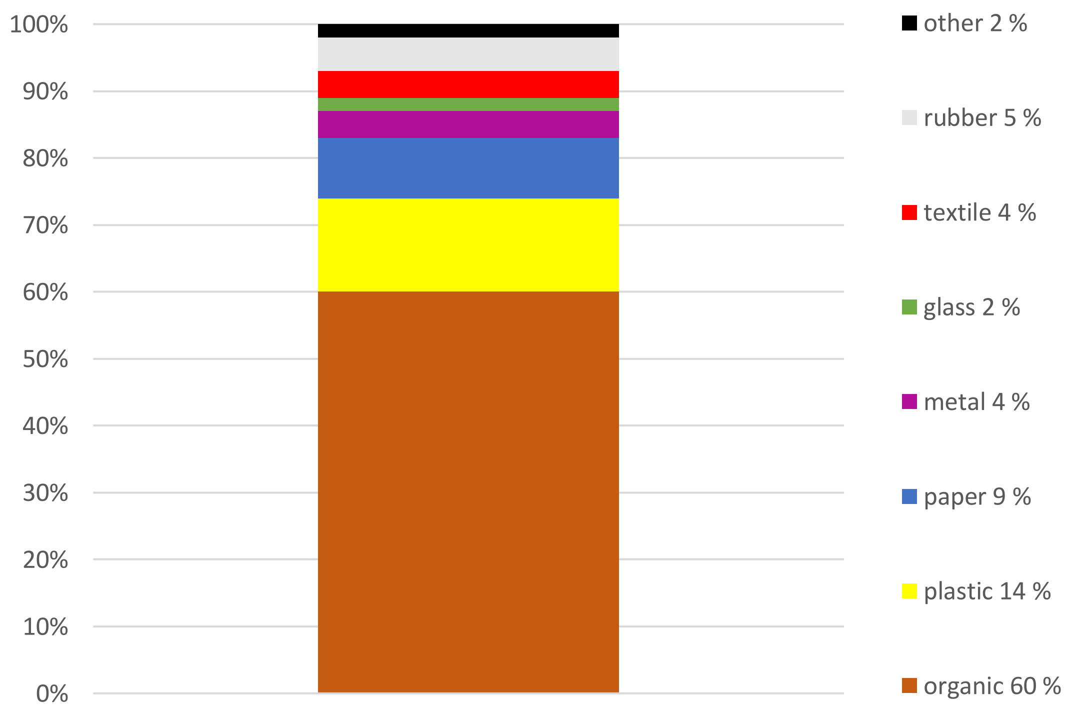


***Figure 1**.: Composition of MSW in Indonesia (UNEP 2017), adjusted by author.*

2.1.2. Municipal solid waste management

Municipal solid waste management (MSWM) is one of the global challenges that each country, developed or developing, must carefully face (Cucchiella 2017). Fast global increase of population leads to rapid industrialization, urbanization and economic growth that are the main factors of expanded municipal solid waste generation worldwide. Mainly in urban areas generation of MSW is growing rapidly (Khandelwal 2019). Huge problems appear in growing cities in developing countries, where increasing of municipal solid waste literally floods these cities. MSWM there have many problems as lack of understandings or even lack of a foundation which affect the whole waste handling. Generally, MSWM solutions must be financially sustainable, technically feasible, socially and legally acceptable as well as environmentally friendly (Abdel-Shafy 2018).

General objectives of waste management are the protection of human health and environment as well as we also must think about conservation of resources. Unfortunately, priority of waste management is strongly dependent on the local economic situation of each country (Turcott Cervantes 2018). MSW management is not only environmental issue, it is also socio-political problem. Higher MSW generation throughout the world creates more environmental problems in countries. Particularly in developing countries where the cities are not able to manage MSW due to the lack of institutional, financial, technical, regulatory, knowledge and public participation. The consequences caused by inadequate disposal of wastes are huge in the terms of environmental degradation and citizens living. The impacts of disposed waste have significant adverse effect on atmosphere, contaminate surface and groundwater resources, contaminate the soil through direct contact or leachate, pollute the air through waste burning. Indirect consequences are spreading of diseases by animals, birds, insects and rodents. There are also another problems as odour from landfills, uncontrolled release of methane from anaerobic decomposing of wastes (Karak 2012). Nowadays in developing countries there is the aim to increase the coverage of the waste collection service and to minimize uncontrolled or illegal dumping. On the other hand, in developed countries the main goal is to minimize and to prevent generation of waste at all. It is also important to accept MSW as a source for future materials or energy (Turcott Cervantes 2018).

Waste management is in hands of municipalities, it is their obligation to take proper care, to provide an effective and efficient system for inhabitants. Primarily in developing countries it is a problem for municipalities due to financial resources, lack of organisation and complexity (Abdel-Shafy 2018). On the other hand, there are studies that in many causes MSWM is one of the main costs incurred by local authorities in developing countries. The cost can account up to 50 % of the city government budgets, it is also connected with understanding and planning (Aleluia 2017).

2.1.2.1. Life cycle assessment of municipal solid waste

Life cycle assessment (LCA) is an instrument to evaluate the environmental impacts associated with all stages of products life cycle, from its generation till disposal. It provides useful insight into improving the whole process from an environmental perspective (Yang 2014).

LCA was initially developed for the purpose of analysing products, but it has also been applied to the treatment of waste. LCA models simplify the real situation and could help with computer modulations to show pros and cons of individual methods and technologies in different situations and circumstances (Assamoi 2012).

However, in LCA studies, mainly the environmental impacts of chemical substances in land or air are analysed while the impacts of natural disasters and social activities are very difficult to be reflected in LCA results. In case of landfill, there are so many wide indicators differ in each place, so follow-up research is recommended and needed (Weng 2015).

2.2. Municipal solid waste treatment methods

Basically, municipal solid waste management represents the way of waste from hands of citizens till the last step of treatment processes. Main steps before final treatment methods and technologies are collecting, storage and transportation. Also, these steps need good infrastructure, technological background and financing. There are strong connections between location of collecting of waste and final treatment facility, labour force and economic situation (Erfani 2018). Although in developed countries waste is used as a resource to produce energy, heat, fuel and compost, in developing countries the current issues are these pre-treatment steps as collecting, storage and transportation (Moya 2017a).

Very important methods of MSW management are **reduction** and **prevention.** Well known method for people participation become rule of 3R's (Reduce, Reuse, Recycle) used in education and awareness among the people, nowadays modified to rule of 5R's (Refuse, Reduce, Reuse, Recycle, Rot) (Almasi 2019). These methods precede treatment methods and technologies for MSW (Aleluia 2017):

1) **Dispose methods**
    - Landfills
    - Open dumping
2) **Waste-to-Energy (WtE) methods**
    - Anaerobic digestion
    - Pyrolysis
    - Gasification
    - Incineration
3) **Material recovery**
    - Composting
    - Recycling

Figure 2 represents ideal steps in the waste hierarchy. We can see that **disposal methods** which include landfills and open dumping, are on the top of the pyramid with the smallest part, because ideally, disposal methods are the last steps as the worst handling with the waste. On the other hand, on the bottom of pyramid, there are steps focused on people's behaviour before even production of waste as **prevention** and **reduction**. After preventing and reducing the waste stream there is **recycling** in the waste hierarchy of preference. Recycling is the most environmentally friendly waste treatment method due to waste management of already produced waste. After recycling, there is step of recovery, including **energy recovery,** which covers utilization of materials that cannot be recycled. Potential of Waste-to-Energy to recover energy from unrecyclable components of waste made it an indispensable part of circular economy, which is a concept developed to achieve a closed-loop economy in which industrial and economic growth are decoupled from environmental degradation (AlQattan 2018).

Figure 2.: *Ideal waste treatment hierarchy (Malinauskaite 2017), adjusted by author.*

Unfortunately, **landfill** as a waste treatment method is the most widespread method across the world nowadays. On **Figure 3** could be seen today's situation of waste treatment methods. Prevention and reduction are on the bottom, with the lowest representation in the world. In developed countries this trend is slowly transforming into ideal, but in developing countries it is on the very beginning (Malinauskaite 2017).

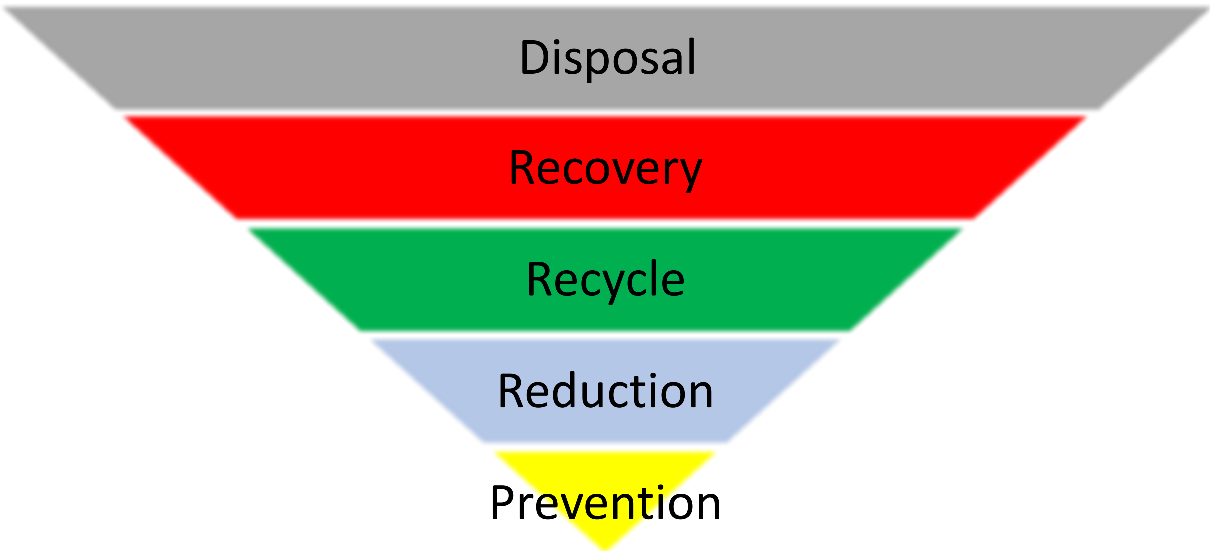


Figure 3.: *Current waste treatment hierarchy (AlQattan 2018), adjusted by author.*

2.2.1. Rule of 3R's

Present waste generation situation is very high around the world, and predictions are to grow more. Participation of population in MSW management is necessity to face this situation. In West European countries there are common a good **awareness** about MSW and the basic recommended procedures as recycling and even reducing and reusing (3R's) among the population. Hand in hand with governmental issues and restrictions, the system is particularly working. 3R's (5R's) are crucial in developing countries. Awareness is the necessary major step in developing countries in terms of local population and participation. Education of people could help to follow concept of 3R's (5R's) rules. Principal is to decrease amount of produced waste and to use already produced waste in the best environmentally friendly way either as a source of new materials (glass, metal, plastic) or fertilizers in the terms of organic waste (Huang 2016).

2.2.2. Dispose methods

Landfill is the least environmentally friendly waste disposal method in the terms of sanitary landfill. Many studies showed that landfilling causes the highest environmental impact compared to other waste management options (Kumar 2017). It is very insufficient method due to loss of material resources and energy recovery sources, but also the most economic valuable method (Aleluia 2017). Unfortunately, the most used waste treatment method worldwide is **landfilling** in both developing and developed countries. In developed countries MSW is particularly carried out in a systematic way, in the terms of sanitary landfilling. These days, sanitary landfills represent a viable and typically used method for MSW disposal all over the world, because it may achieve the reclamation of derelict land. Properly designed and operated sanitary landfills eliminated some adverse environmental impacts that result from other solid waste disposal methods such as burning in open-air burning sites and open-pit dumping. This technology has particular procedures, which must be fulfilled to meet international standards for sanitary landfill (Kumar 2017).

On **Figure 4** is documented properly carried sanitary landfill with impermeable subfloors, leachate and waste water draining to following treatment, there is also gas control and ventilation to prevent explosions and collapse of landfill, with possibility to subsequent treatment and utilization for waste-to-energy. Sanitary landfills must be carried after closing with stabilisation of coverage and control of runoff. Unfortunately, with not well controlled site, inappropriate impact could occur: fires and explosions, vegetation damage, unpleasant odours, landfill settlements, groundwater pollution, air pollution and global warming (Abd El-Salam 2015).

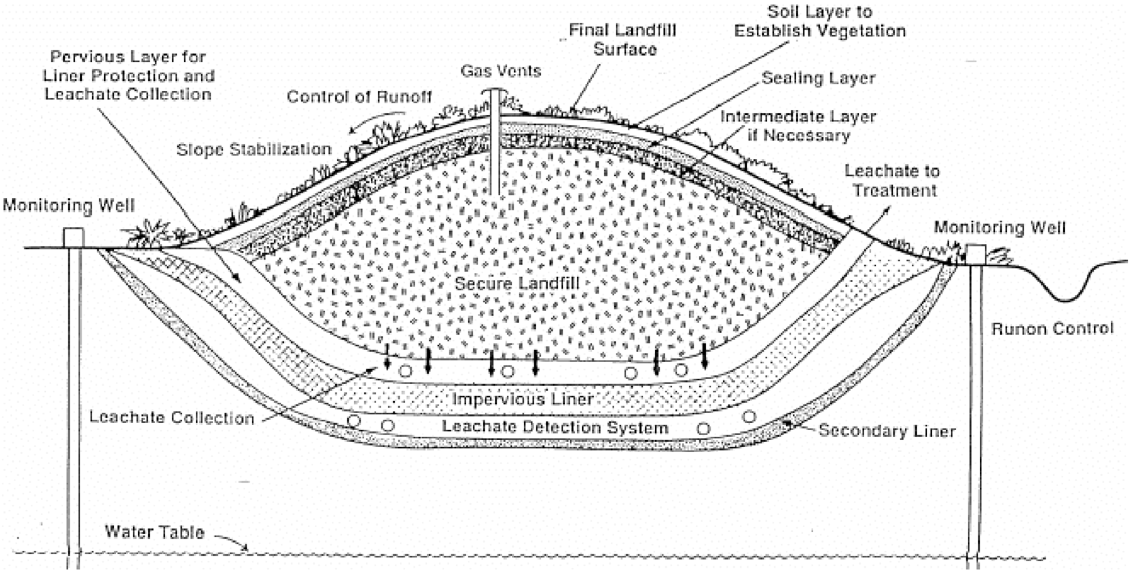


Figure 4.: Schematic cross section of a sanitary landfill (Qrenawi 2006).

There are many reasons for proper handling with sanitary landfill. Very important is to take care of concentrated effluent, landfill leachate. Landfill leachate is generated as a mixture of rainwater flowing through wastes, water produced from the biological and chemical processes of organic wastes and the inherent water of the wastes themselves (Zhang 2013). In general, for treating of sanitary landfill leachates, biological and physical-chemical treatment is not good. One of **appropriate technologies** as a complement to the other treatment of landfill leachate is reverse osmosis. However, this technology is not final, there are connected other steps due to the large volume of concentrates. Thus, alternative technology for treating the reverse osmosis's concentrate of the sanitary landfill leachate is required (Labiadh 2016).

Another issue, according to estimates, 30-70 million ton of **methane** gas is emitted per year from waste landfills around the globe. Because of high amount of organic waste in landfills, there are biological and chemical decomposition processes that produce landfill gas. The landfill gas production rate inside a landfill depends on various factors such as type of landfill, waste composition, climatic condition, moisture content and waste age. Landfill gas contains approximately 50-60 % of methane and it is considered as one of the major sources of anthropogenic methane emissions. There are numbers of models for **gas generation** from landfill, diverse in amount of methane production and economic profitability. Hence, recovery of methane from a landfill for electricity or heat generation is necessary to reduce the emission. On the other hand, economic profit could help with better handling the waste on specific landfill (Kumar 2017). It is mentioned that nowadays there is used about 3 % of worldwide potential of landfill gas. Landfill gas can use different innovative energy system technologies to produce electricity. Technologies such as gas turbine in Brayton cycle, Organic Rankine cycle, Stirling cycle engine or Solid oxide fuel cells. The appropriate treatment of landfills could result in land space remediation and reduction of emissions caused by landfill gas (Moya 2017b).

Sanitary landfills are constructed also in developing countries, but there is the problem with inappropriate handling and controlling, this leads to insufficient situation with sanitary of waste at all. Problems could be caused by low infrastructure and poor financial investments. Big influencing factor is proper knowledge and awareness of workers and public. On the other hand, developing countries in many cases called **open dumping** as a landfilling. With no systematic progress throw out MSW in open dumbs, in better circumstances open dumping is carried out with basic rules of landfills as waste water treatment and basic impermeable natural subfloors (Karak 2012).

Waste management situation in developing countries is alarming due to many reasons. Environmental impact is visible among the waste management practices, most common are open dumping, open-fire dumping and disposal sites (open dumping with governmental agreement). Other problems are related to population growth, less space for opening new sites as well as collapsing and closing of old overcrowded disposal sites/open dumps (Yadav 2018). Also, management of disposal sites/open dumps could have very dangerous consequences if it is not properly carried. There are many examples of collapsed landfills due to insufficient conditions of these localities, poor construction of landfills itself and overcrowding of sites although it is prohibited (Damanhuri 2009).

Examples of collapsed sites are all over the world: Spain 1996, Athens 2003 or the deadliest event of this kind, which killed 278 people in 2000 in Manila, Philippines. Most recent example of collapsed disposal site and the second deadliest in history is from Indonesia, Bandung district, in the year 2005. Leuwigajah disposal site was opened in 1987, but already in the year 1992 there were detected poor conditions for continue as a disposal site. In next years in average 4,500 tons of MSW per day was delivered to this disposal site, and in February 2005 many factors caused disaster: heavy rain for many days, insufficient management of site from the beginning, accumulation of landfill gas causing exploding and overcrowded mountain of waste. In one moment, huge landslide of about 3 million cubic meters of waste spread in valley. On **Figure 5** is documented that waste covered about 200 m wide stripe on a length about 1,000 m. This disaster killed at least 147 people. But there are estimates for more deaths due to impossibility of rescue activities in the whole area (Lavigne 2014).

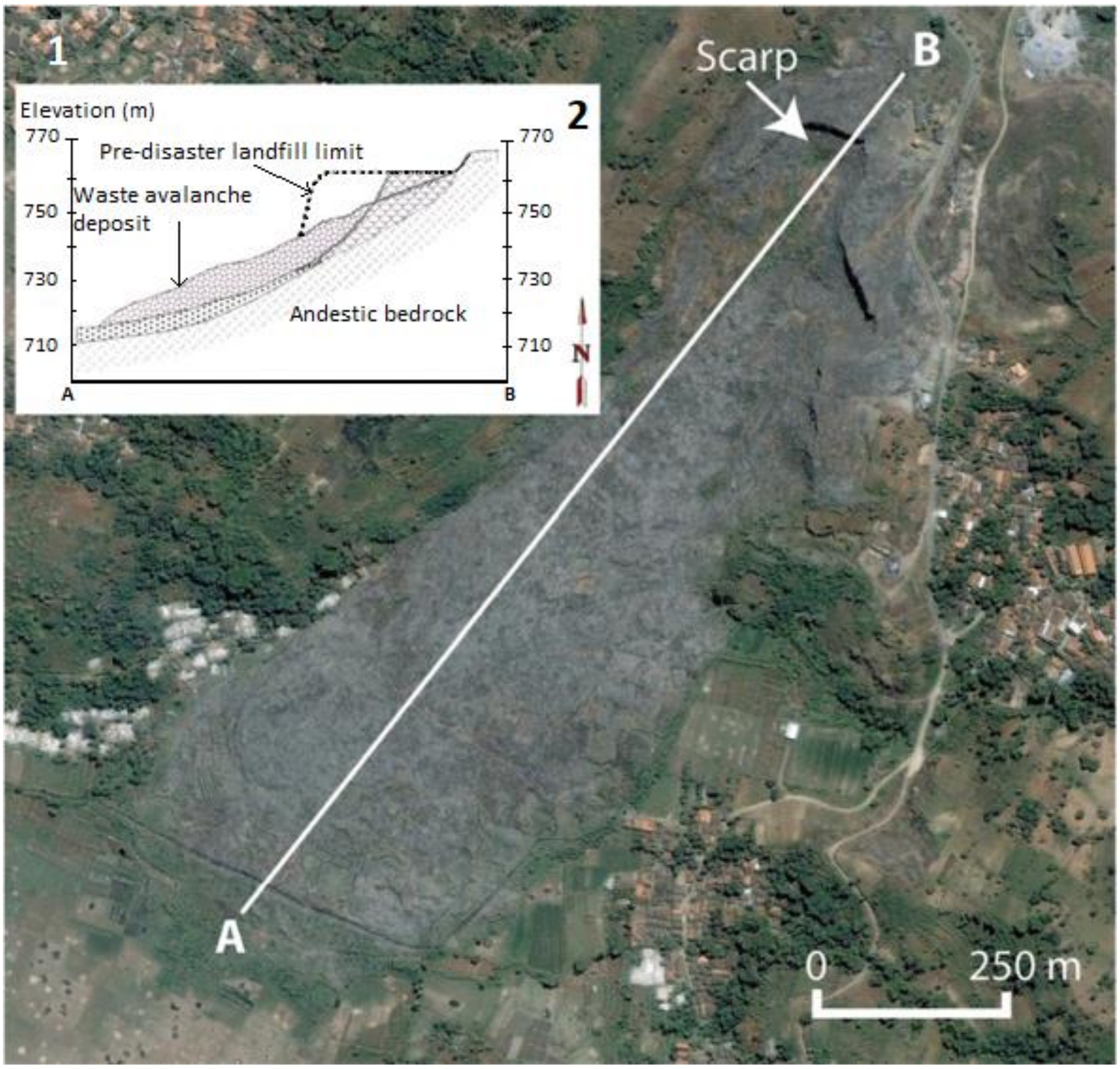


__Figure 5__.: Leuwigajah disposal site 1) Aerial view August 2006 2) Longitudinal profile (Lavigne 2014).

2.2.3. Waste-to-Energy methods

As a result of population growth and economic development it is predicted that energy demand will increase rapidly in next years. Major increase is presumed in developing countries. Numerously in excess of 50 % of energy consumption is expected to increase till 2030 in developing countries. It is said that **fossil fuels** will provide the bulk of the increase. Amount of gas, coal and oil consumption will show greatest increases of 65, 75 and 40 percent, respectively. On the other hand, renewables growth is expected up to 60 % starting from much lower baseline that fossil fuels. Nowadays, global energy demand is covered by renewable sources in just 20 %. Major of this energy (10 %) comes from combustible renewables and renewable municipal waste (UNEP 2018).

Municipal solid waste is classified under the broad umbrella of **biomass**, it normally contains significant proportions of materials such as food waste, wood and yard trimming, paper and others. MSW is also classified as a **renewable resource** because it is constantly producing biogenic material that would be destined in landfill, if not channelled towards energy generation purposes. WtE technologies are viewed as potential **alternatives** to the traditional fossil fuel production. There are three main paths through which energy is recovered from waste: biochemical, thermochemical and physicochemical (AlQattan 2018).

In biochemical route, biological treatment technologies are designed for natural biological process working with the organic part of MSW. This treatment is divided into two main groups: aerobic process of composting which is also used as a material recovery technology and anaerobic processes as are **anaerobic digestion** or biomethanation as a source of energy outputs. Organic waste is converted to liquid or gaseous form of fuel, then the biogas is burned to produce heat or electricity (Moya 2017a). In thermochemical way, through processes as **incineration, gasification and pyrolysis**, waste is converted to energy in the form of electricity and heat by applying high temperatures. Physicochemical way is about usage of chemical agents to transform waste into energy (AlQattan 2018).

2.2.3.1. Anaerobic digestion

Anaerobic digestion (AD) is good **alternative** of MSW treatment and represents potential solution to improve energy supply security. It provides multiple environmental benefits as are green energy production, organic waste disposal and environmental protection (Fan 2018).

AD is a process of microbial degradation of organic **biodegradable** matter in absence of oxygen that produces biogas and stabilises the sludge. Up on the process parameters and substrate composition depend the quality of generated biogas. Typical composition of biogas is 50-75 % methane, 25-50 % carbon dioxide and 1-15 % other gases. Produced slurry can serve as a soil fertilizer. It is necessity to have quality control of fertilizers from anaerobic digestion due to presence of undesirable materials (Bedoić 2019; Kumar 2017).

Anaerobic digestion technology is classified as wet (10-15 % of dry matter) or dry (24-40 % of dry matter) technique, depend on incoming material. Wet technology processes liquid material generally and it is used in wastewater treatment. Dry technology processes dry materials, it operates with higher solid content and produces greater heat. The production of biogas reduces the amount of waste and is used as a source of energy mainly in two ways: to produce heat and/or generate electricity (Moya 2017a). AD is operated under two main conditions; mesophilic digestion under low temperature conditions and longer retention time or thermophilic digestion under higher temperature conditions and shorter retention time (AlQattan 2018).

In numbers, it is calculated that anaerobic digestion can produced 2-4 times more methane per ton of MSW in 3 weeks than landfill in 6-7 years. 1 m^3 of biogas produced by AD can generate up to 2.04 kWh of electricity taking conversion efficiency of 35 %. From 1 ton of MSW it is possible to generate up to 150 kg of biogas. Major problem of AD is long time of processing, typically 20-40 days (Kumar 2017).

There are four stages of processing in anaerobic digestion. First, **hydrolysis** in which complex organic materials in the form of proteins, fat and carbohydrates are converted into soluble organic materials such as sugars and amino and fatty acids. In second stage of **acidogenesis**, products of first stage are broken down into acetate, hydrogen and higher molecular-weight volatile fatty acids. The third stage is **acetogenesis**, where products are further processed into acetic acid, CO_2 and hydrogen. Last stage, and the most important **methanogenesis** processes matter into methane and CO_2 from acetic acid and H_2. Biogas with main component of methane could be used for different purposes such as cooking, lightening, electricity generation and application in internal combustion engines (AlQattan 2018).

2.2.3.2. Pyrolysis

Pyrolysis is thermal degradation of solid waste with no oxygen. It takes place in temperature range of 300-800 ^oC and it produces **pyrolysis gas, oil and char**. In this process it is necessary to maintenance some pre-treatment steps. It requires mechanical separation of glass, metals and inert materials. In lower temperatures (around 300 ^{o}C) decomposition of organic materials starts and major products here are pyrolysis oil, wax and tar. Than in higher temperatures above 700 ^{o}C an inorganic material decomposes, and the major product is pyrolysis gases. **Syngas**, gas produced during this process, is mainly composed of CH_4, H_2, CO and CO_2. The net calorific value of syngas is in average 15-20 MJ/Nm^3. For good quality of pyrolysis products, the feedstock should be of specific composition of waste, i.e. plastic, tyre, electronic equipment and electric waste. In addition, studies found that after distillation of liquid hydrocarbons from pyrolysis processes, the resulting synthetic product has the same properties as the petro-diesel fuels (Kumar 2017; Moya 2017a).

Produced syngas could be used in different energy applications such as engines, boilers, fuel cells, turbines and heat pumps. **Solid char** can be pelletized and directly combusted in gasifiers, fluidized incinerators and pulverised coal boilers (Moya 2017a). Advantages of pyrolysis process are: the equipment for process is flexible for installation, it is a cleaner way in the terms of emissions production in comparison with incineration; various product used in various devices. On the other hand, effective pyrolysis requires homogenous waste stream, in term of very heterogenous wastes it needs costly pre-treatment. It could make the process economically undesirable (AlQattan 2018; Chen 2015).

2.2.3.3. Gasification

Gasification is another thermochemical conversion technology. Organic matter is converted into syngas in controlled atmosphere of oxygen with high temperature 700-900 ^{o}C. Gasification can reduce the waste mass up to 90 % of the volume of waste. **Syngas** is a main product of gasification (compounds are: CH_4, CO_2 and H_2) and could be combusted as a source of energy. Gasification is mainly used for homogenous types of solid fuel as coal or wood. In recent years, research is focused in MSW as a source (Kumar 2017; Moya 2017).

In general, MSW gasification process mainly includes drying, pyrolysis and char gasification. In contrast to pyrolysis, gasification needs with high temperatures also additional reagent. Typical gaseous reagents are steam, oxygen enriched air and carbon dioxide. Gasification temperature and agents are two important factors in the isothermal gasification process (Gurgul 2018; Xu 2018).

2.2.3.4. Incineration

In general, waste incineration is oxidation of combustible matter of waste, which is the most integrated technology across the globe in the terms of **Waste-to-Energy** technologies. It is high temperature waste treatment process (above 850 °C) (Moya 2017a). During last 20 years, incineration as an alternative for landfilling greatly increased. It is an attractive alternation due to significant **benefits** such as reducing of MSW volume up to 90 %, mass reduction up to 70 %. Possibility of energy recovery used in last decades is one of the biggest advantages of incineration due to economic profitability. In compare with other WtE technologies, the waste reduction is immediate and not dependent on long biological breakdown reaction time. Another benefit is opportunity of construction of a facility near the MSW generation points, which decrease transportation cost, directly connect the energy and heat supply with local sites and the air emission are controlled and cleaned to meet environmental legislative limit values (Karak 2012).

Firstly, incineration technologies were projected only for volume and **mass reduction** of municipal solid waste. Energy recovery started with waste heat recovery incineration. Early waste-heat technologies were low-pressure boilers than high-pressure boilers and water wall furnaces. Low-pressure boilers were first developed, their disadvantage was cooling of the furnace and lowering of combustion efficiency by locating boiler in combustion chamber. High-pressure boilers were invented later with advantages against low-pressure boilers in refractory linings which prevent excessive cooling of the furnace and additional effective cooling of flue gases to the required range of 250-300 °C. Water wall furnaces had higher heat recovery efficiency than both, low and high-pressure boilers. Main usage of recovered heat was to provide hot water for public and industrial heating, sewage slut drying and last but not least desalinization of seawater to supply potable water for coastal areas (Makarichi 2018).

Heat recovery for electricity production started in the middle of 20th century. In the end of 20th century, incineration started to be more complex as a complete waste treatment method (Makarichi 2018). Emphasis was placed on improved combustion efficiency, more sophisticated air emissions control systems and more efficient materials handling system (Silva 2019).

In classic incineration, waste is **directly burned** in the combustion chamber at an adequate temperature around 900 ^{o}C using flue gas and pre-heated air (Moya 2017a).In pre-processing steps are important: removing of bulky and hazardous materials as well as non-combustible, screening and sorting of MSW due to size, removing ferrous and non-ferrous but electrically conductive metals due to magnetic separators and eddy current separators (Makarichi 2018). In the term of combustion, there are **three main incinerators' types** used, namely grate incinerators (moving grates), rotary kilns and fluidized bed. In grate incinerator, the grate moves the waste in the combustion chamber through different zones. Wastes are well mixed, which helps in combustion of less combustible materials. Grate incineration is the most common type all over the world. Rotary kilns are similar, but the incineration occurs in a rotating chamber. In fluidized bed, there is bed of inert material that is fluidized with at the lower section of the combustion chamber into which waste is constantly fed. Constant air flowing under the bed allows the waste to move continuously to ensure better combustion (AlQattan 2018).

Currently, after combustion process, superheated steam is produced and then used within a cogeneration system to produce energy and heat. Electric energy is produced by generator, which is connected to turbine. Heat is produced by a district heating system. In Europe, the heat energy is used for heating in public and industrial buildings near to incineration facility, because for close objects the efficiency is high and transportation costs are low. Produced electricity is transported to power lines (Moya 2017a).

In terms of developed incinerations, combustion and energy recovery from waste, the system share only small part of a whole facility, roughly one forth. Rest of the facility is necessary for emissions cleaning. **Biggest challenge** with incineration is the emissions of **greenhouse gases** (GHG) and other pollutants that is contrary to the environmental benefits being some of the primary reasons for which is pursued. In comparison with other technologies, incineration perform better in CO and particulate matter emissions. On the other hand, it was found that incineration performs worse in SO_x, CO_2 and N_2O emissions, which can have significant negative impact on climate (AlQattan 2018).

As it could be seen in **Figure 6**, after combustion follows numbers of emissions cleaning processes/technologies as electrostatic precipitator, wet/dry scrubber, bag-house filtration and very crucial upgraded method for pollutant remove, selective catalytic reduction (SCR) with efficiency up to 90 % of NO_x pollutants cleaning (Setyan 2017). SCR is discussed technology due to comparison with older technology: selective non-catalytic reduction. Older technology has lower efficiency of pollutant cleaning (up to 50 %), but SCR has more indirect impact on environment. There are studies comparing and upgrading these technologies to achieve better results in pollutants remove (Van Caneghem 2016).

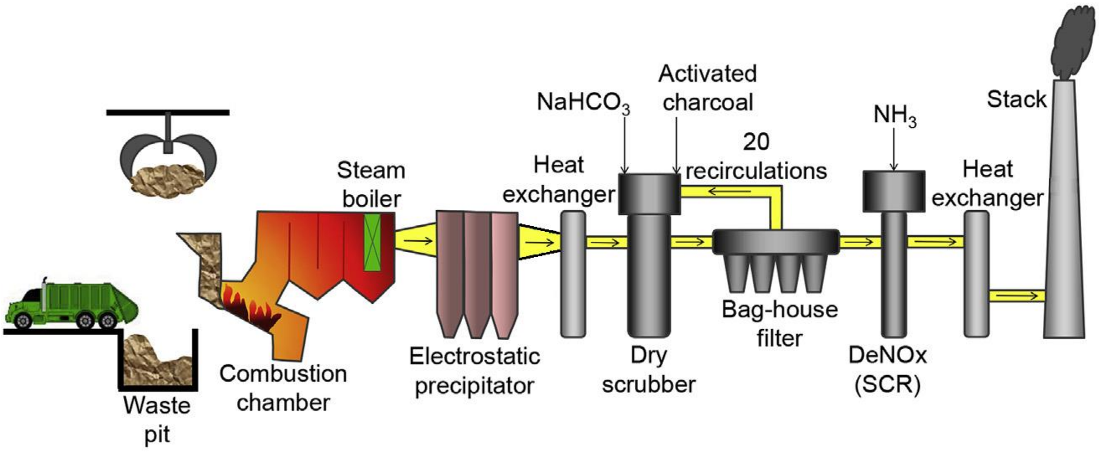


***Figure 6**.: Incineration plant schema with emission cleaning system (Setyan 2017).*

In the term of efficiency of waste incineration is hard to evaluate incineration in general. In the term of energy, it depends on design of incineration; whether it is only boiler, generates only electricity, or a combined heat and power plant. Very important is high electricity efficiency (Eriksson 2017). Important energy production approach has been assumed that other (fossil) fuels could be saved on a 1:1 basis, i.e. 1 GJ of waste heat delivered substitutes for 1 GJ of coal-based heat (Fruergaard 2010).

Comparison of emission production and environmental impact is much more complicated. If waste incineration replaces landfill, incineration represents much greener technology than landfill in terms of emission, resource and energy recovery, also land occupation. In the case of replacing incineration by another incineration, it is more complexity due to many conditions. On the other hand, substitution of good recycling technologies by incineration will deterioration the condition in terms of environmental impact, emission production and energy consumption (Eriksson 2017).

2.2.4. Material recovery methods

Worldwide, landfilling is the most common way of treating of municipal solid waste. However, the big part of this waste is organic matter in both developed and developing countries. These organic residues of MSW should be recovered and used as alternative manner. Only percentages of MSW organic matter are composted and reused. On the other hand, it is necessary to be focused on separating at all, because recycling of materials save raw material and energy to produce new one. Quite common recycled materials are paper, glass, metal, plastic and particularly in developed countries textile, toners and batteries (Castillo-Giménez 2019; Karak 2012).

2.2.4.1. Composting

Composting is a waste management process that allows transformation of organic residues into a stabilised product. In general, it is the most common process among the nature, which provide decomposition of **biodegradable matter** and as a product generates valuable materials such as compost. Composting is the best option in terms of limited resources due to cheap investments and low technological backgrounds (Lima 2018). In average, organic residues are represented in MSW up to 45 % in Europe and 55 % in average in developing countries. It is very important to change treatment of this material from landfilling and incineration to independent treatment such is composting. Although few of developed countries already started, many countries have to follow (Cerda 2018).

Source separated collection, mainly in urban areas is crucial for good management of organic part of MSW. Composting, which has clear benefits from both ecological and economic perspectives is very important simple technology which has to promote organic waste recycling (Wei 2017). It was found that composting and compost application can reduce some of the negative consequences that urbanization has upon soil properties and processes. Composting improves environmental services of green infrastructure in cities, like of the soil, as well as biocontrol of pathogenic microorganisms (Milinković 2019).

Composting of organic part of MSW has significant benefit against landfilling and incineration of this matter. It does not produce as much GHG emissions as other methods and does not occupy valuable agricultural land as in the case of landfills. Composting of organic wastes is sustainable process which helps to decompose relatively persistent organic compounds. **Compost** as a product represent valuable material. It provides better quality than commercial inorganic fertilizers (Onwosi 2017).

Composting is a **biochemical process** which is carried out by diverse groups of different microorganisms. It is solid-state fermentation process, which is affected by many factors. Important factors are temperature, aeration, moisture content, pH, C/N ratio and particle size (Onwosi 2017). Production of high-quality compost requires proper controlled and managed process. Bad pH condition or wrong C/N ratio which have to be under constant control could cause odour emissions, which can increase the environmental impact of the process, and low-quality compost (Cerda 2018).

2.2.4.2. Recycling

Recycling is one of the treatment processes, which is dependent firstly on selective collection of MSW at homes and then up on industry, where the waste as a paper, glass, plastic and metals is properly treated, recycled and transformed into secondary material (Ayodele 2018). Important thing is, that recycling is multi-disciplinary problem, which needs to be discussed on different levels. On one hand, the **environmental impact** is clear: material could be reused, it saves raw material, it saves energy of producing new material. On the other hand, it must fulfil economic requirements. The success of materials recycling depends upon its ability to consistently transform material wastes into high quality and marketable products, ensuring a stable market for the end products, and cost-effective manufacturing manner (Lino 2018).

Municipal solid waste recycling is the most common waste treatment option that has potential for further improvement in the world's municipal solid waste management. Expanding of recycling as a treatment method leads to lower environmental impact and lower economic costs. On **Figure 7** could be seen example of cycle of waste through recycling process. There are mentioned all main steps of plastic processing. These steps variates depending on used material. Linear economy should transform into circular economy at least in term of waste management. Recycling is a part of the field of reverse logistic, no longer required used products are processed to get again usable products for the market. It includes strategic and tactical decisions such as logistics network design and collection design. Recycling practices are varying in each country and have to fulfil adequate requirements in specific region (Bing 2016).

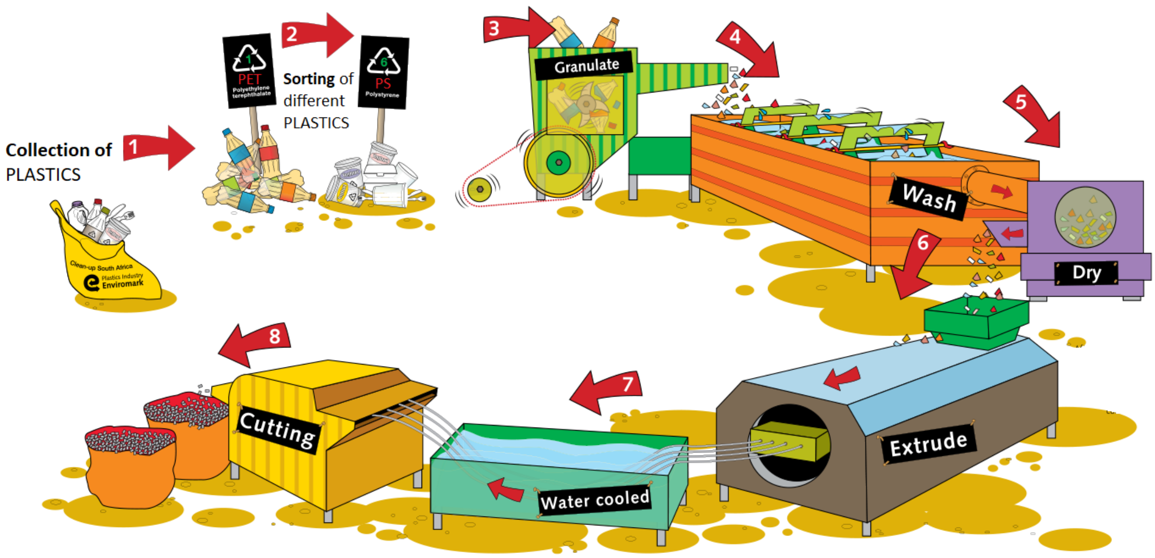


Figure 7.: Simplified diagram of plastic material recycle (Abdel-Shafy 2018).

2.3. Municipal solid waste management in Bandung, Indonesia

Waste management as a whole is one of the largest environmental problems in Indonesia. Due to huge increase of population, this problem affects mainly cities as Bandung and others. There are several **important factors** which influence municipal solid waste management in Indonesia, such as regulations, capacity and treatment technology, low public awareness, lack of infrastructure and low priority for local governments (Alberdi 2018).

2.3.1. Waste management under the Indonesian law

From the governmental point of view, in 2008 was enacted Act 18 on Waste Management. This Act includes **landfilling** as the main treatment method of MSW, although this act requires authorities to implement integrated waste management by considering the waste hierarchy of reduce, reuse and recycle. This Act was first of this type on national level, which shows that MSWM was not significantly developed in Indonesia, both in terms of infrastructure and coverage area. Also, aid for MSWM development from developed countries suffered from numerous distinct regulations. There is no exact number of operating landfills in Indonesia, the State Ministry of Environment estimated that all districts and municipalities have at least one landfill. It is said that in Indonesia is approximately 530 open landfill sites. Formally, there are two types of landfills operated by municipality: **Controlled landfill** and **Sanitary landfill**; officially based on the population number. Finally, there are only two established sanitary landfills in Indonesia. For controlled landfills there are simpler conditions for establishing and even operating of landfill. Real situation does not meet the formal regulation at all. None of any Indonesian landfill fulfils all required conditions, the most crucial are protection layers, leachate collection and treatment, landfill gas ventilation and treatment (Munawar 2018).

On the other hand, Indonesia is facing large growth of energy demand, which could become a treat for energy security of Indonesia. This country also has ambitious target of 23 % of energy achieved by renewable energy sources by 2025. The utilization of **new sources of energy** as waste is, could be effective and efficient solution for both problems. Waste will serve as a source of renewable energy and not as a fulfilling of land and proper technology will generate this energy in environmentally suitable way and with economic value (Alberdi 2018).

2.3.2. Bandung city

Bandung is a typical city in developing country with all advantages and disadvantages. On one hand, there is strong economic grow, huge industrial investments and population increase. Especially Bandung city had rapid economic growth till 2012, highest in West Java province and in long average very high in comparison with national average. Driving force of the city are the clothing factory outlets and boutique businesses but also industries as electronics, furniture and textiles. On the other hand, typical developing city's processes have their neglected parties. In the term of waste management: poor infrastructure, bad services, impropriate treatment technologies, underfunding of waste management, beside these issues, there is a problem with public awareness of waste handling and improper waste treatment methods used as the main treatment methods. Environmental impacts are not well discussed among the population (Tarigan 2016).

In 2013, Bandung's production of solid waste was estimated to be **1,600 tons per day** by more than 2.5 million of inhabitant. Only about 60 % of total waste was handled or collected by the services provided by municipality. Municipality are employing trucks which directly collect municipal solid waste from households on an irregular basis. On **Figure 8** is documented typical waste small-scale transportation vehicle used in Bandung metropolitan area. Waste is transported mainly into temporary solid waste collection facilities (TPA) that are more than 200 all over various locations of Bandung city. Temporary waste station represents small scale disposal site in the middle of the city with very bad sanitary conditions. In TPA waste is stored, waste pickers, so called *Pemulung* take very low amount of waste for their own personal benefit. Mainly they are collecting plastic, glass, paper and metals, valuable materials, which they could sell on a market (Tarigan 2016).

Figure 8.: *Typical transportation of waste to temporary waste station (Author 2018).*

On **Figure 9** is documented one of temporary waste station, which is under the municipality administration. Waste from household is transported there every day, somehow is the waste handled and again transported to the final disposal site. Until 2005, waste was disposed in Leuwigajah disposal site. After the **deadly landslide** of Leuwigajah landfill because of bad construction and operational conditions described above (Chapter 2.2.2), **Sarimukti** disposal site was constructed (Tarigan 2016; Lavigne 2014; Damanhuri 2009).

Bandung city is in **urgent situation** and needs new strategies and solutions to solve MSWM problem. With the waste production growth an increase of waste collection services is important. These strategies should improve the existing way of collecting, handling, transportation and disposal of MSW and also reduce the amount of waste production (Tarigan 2016). Actually, Bandung residents are **willing to pay** more to have better collection services, because people generally place higher priority to waste management problem than other environmental issues (Siyaranamual 2013).

Present situation is untenable in the terms of fees, in Bandung city is average fee for MSWM about 2.5 US$/year/household. But cost of MSWM per capita per year is about 4 US$ (Munawar 2018).

***Figure 9**.: Temporary waste disposal site in the middle of Bandung city (Author 2018).*

2.3.3. Sarimukti landfill

Sarimukti landfill was open as an emergency solution after Leuwigajah disaster. Unfortunately, from emergency solution became a regular disposal site used till nowadays, although the planned closing year was 2012. Sarimukti landfill represent typical Indonesian landfill. It covers treatment of waste of more than **8 million inhabitants**. In numbers, from more than 6,300 tons/day of generated MSW, 5,600 tons of MSW is collected and transported to the landfill daily. Rest of waste is mainly uncollected, open burned or dumped in rivers. Landfill officially cover the **area of 25 ha** of land (Munawar 2018).

Sarimukti landfill was opened as a **controlled landfill**, which means in accordance with the Indonesian law, lower quality than sanitary landfill. On **Table 1** can be seen differences in basic infrastructure requirements and landfill operational procedures in between two official groups of landfills: controlled and sanitary. The most important are **leachate treatment, landfill gas (LFG) collection and final cover application**, which in comparison with sanitary landfill are very insufficient (Munawar 2018). On the other hand, even these low standards are not sufficiently met. Although the equipment for leachate treatment and LFG collection is originally installed in very beginning in most of landfills, during the time it is unattended, and lost its function (Supriyadi 2016).

Table 1.: *Criteria for controlled and sanitary landfill (Munawar 2018).*

	Controlled landfill	**Sanitary landfill**
Basic infrastructure		
Base grade	Compacted on-site soil	Compacted on-site soil
Bottom liners	Compacted clay 2x30 cm	Compacted clay 3x30 cm
Drainage layers for leachate collection	Recommended	Min. 20 cm
Protection layer	Recommended	Min. 20 cm
Leachate collection	Min. gravel layer	Gravel layer and 300 mm PVC/HDPE perforated pipe
Leachate treatment	Stabilization ponds	Biological, chemical and physical treatments
Groundwater monitoring	Min. 1 each upstream and downstream	Min. 1 at upstream, 2 downstream and 1 at surrounding site
Landfill gas (LFG) collection layers	Gravel layer	Vertical 400 mm PVC/HDPE 50-70 m spacing, gravel layer every 5 waste layers
Surface runoff drainage systems	Required	Required
Buffer zone	5 m of wide	5 m of wide
Landfill operational		
Waste compact	Every 0.5 m of thick waste layer	Every 0.5 m of thick waste layer
Soil cover application	Weekly	Daily
Intermediate cover application	Required if no waste landfilled for at least 1 month	Every 5 m of waste and if no waste landfilled for at least 1 month
Final cover application	Min. 20 cm soil, drainage layer, vegetation layer	Impermeable, sub-drainage, protection and LFG collection layers
Leachate recirculation	Recommended	Required

In comparison, Sarimukti final disposal site fulfils the requirements for sanitary/controlled landfill much better than Leuwigajah site before the disaster. Unfortunately, there are still very insufficient conditions **negatively affecting**

environment through subterranean water and gas emissions on local and even national level. In **Figure 10** could be seen **leachate collection system** in Sarimukti final disposal site. This drainage is supposed to collect as much leachate as possible but did not collect all of the amount. On the other hand, there is not adequate leachate treatment technology and leachate recirculation is not introduced at all. Very similar problem is with **LFG monitoring**, collecting and treatment, open fires are common in this place. There is no **soil cover application**, surface is eroding, and waste is transported by wind to close neighbourhood. For a whole day, there is high number of waste pickers. In numbers, it is said that about 400 – 500 waste pickers are collecting waste to their purpose on site daily. Near neighbourhood and also site itself is home of whole families making money from collecting of waste (Munawar 2018; Supriyadi 2016).

Figure 10.: *Leachate collection drainage on Sarimukti disposal site (Author 2018).*

3. Aims of the Thesis

This Master Thesis's was focused on present situation in Bandung's MSW treatment facilities and deals with future possibilities of MSW handling. The **main aim** of the Thesis was to evaluate and recommend appropriate technologies for municipal solid waste treatment in Bandung.

Specific objectives:

- Assessment if the public demands that the government takes care of waste management services
- Description and evaluation of municipal solid waste management and treatment methods in Bandung
- Analysis of public perception of available municipal solid waste treatment methods and technologies in Bandung and its consequences for public

4. Methodology

4.1. Description of study area

Research was managed in Bandung city, the major city of West Java province, Indonesia (see **Figure 11**). During the research were visited all districts of Bandung city: Timur, Utara, Selatan, Barat and metropolitan area of Bandung. According to (Tarigan 2016) Island Java is the most populated island in the world and with more than 140 million of inhabitants is presence about 56 % of all Indonesian population. Bandung as a major city of West Java province is the third most populous city in Indonesia with more than 2.5 million inhabitants on area of 168 km^2. Metropolitan area of Bandung was home of 8.5 million inhabitants in 2014 on the area of 3,280 km^2 and the population is predicted to grow continuously in next years.

City is located 150 km southeast from the major city of Indonesia, Jakarta and because of high altitude (768 metres above the sea level) it has cooler year-round temperatures than other Indonesian cities. The basin's main river is the Citarum river, nowadays the most polluted river all over the world (Tarigan 2016).

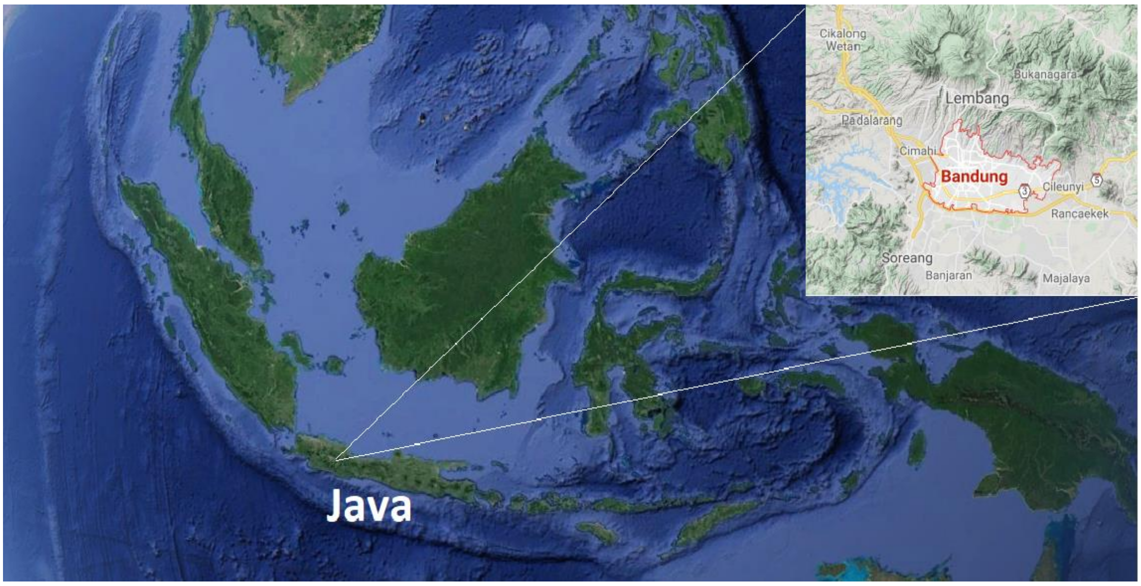


***Figure 11**.: Map of Indonesia with the sector of Bandung city on the island Java (Google Earth 2019), adjusted by author.*

In Bandung, as one of the most populated cities in Indonesia, population growth has created poor environmental living conditions that significantly influence sanitary conditions. One of the biggest problem that are those cities facing is improper management of municipal solid waste. It was estimated that only 60-70 % of MSW in Indonesia is transported to the final disposal sites by the institutions in charge of waste and sanitary affairs. Rest of waste is mainly handled through improper ways as are burning, open dumping or dumping in the rivers and streams. Only small amount of waste is recovered by waste pickers for their own profit (Damanhuri 2009).

4.2. Timeframe

Total time period for pilot testing, data collection, interviews and observation in Bandung, Indonesia, took almost two months, from 22th August until 3nd October 2018. Theoretical preparation for local environment, secondary data collection and questionnaire design started in March 2018.

Pilot testing was held in first few days to proper adjust of the final questionnaire. Data collection was ongoing through whole time period in Bandung city. Interviews conducted with governmental officers, landfill officers and workers, Bandung's services workers and local people were always agreed in advance. Observation across the city was mainly done by author, but visits of disposal sites, Bandung recycle centres and waste banks were agreed in advance and supervised by the Thesis's consultant Dr. Yayan Satiakti.

Data processing, coding and analysis were held in January, February and March 2018. The main used softwares were Statistical Package for the Social Sciences (SPSS) and STATA econometric software.

4.3. Data and data sources

For this Thesis were used two types of data collection through secondary and primary data sources. Secondary data were used for describing and better understanding of the issue before the very beginning of survey and observation in selected area. Primary data collection represents new source of data.

4.3.1. Secondary data sources

The principal scientific journals used as a source of adequate information were obtained from the databases like **ScienceDirect**, **Web of Knowledge** and **Scopus**. Journals as: Waste Management; Journal of Cleaner Production; Journal of Environmental Management; Energy Procedia; Resources, Conservation and Recycling and Energy. There were also used data from UNEP reports and Eurostat data overviews.

-Main used key words for searching were: municipal solid waste, waste treatment technologies, landfill, incineration, recycling, Waste-to-Energy. The major language of sources was English, minority of literature was originally in Indonesian (Bahasa) language.

4.3.2. Primary data sources

For primary data were used numbers of data collection methods including **structured questionnaire** for inhabitants of Bandung city as well as **interviews** with government officers, Bandung Resik (official city services) employees and landfill operators. Important sources of primary data were also **observation** and photo **documentation** for better understanding. Photo documentation from questionnaire investigation and study area is included in **Annexes.**

4.3.2.1. Structured questionnaire

As a main primary data source was chosen structured questionnaire. It represents the most appropriate instrument for data collection within short period of time from a target group with possibility of high number of respondents.

Questionnaire was elaborated in Indonesian (Bahasa) language and included demographic information and 26 main questions. Questions were divided to 5 sections:

Section 0) **Demographic questions** – gender, age, locality, education level and average monthly income

Section 1) **Waste management indicators** – satisfaction with waste management services, availability of waste management services, sufficiency of waste management services

Section 2) **Public perception and approach to MSWM** – awareness of 3R concept, interest in waste management, willingness to take part in workshops, importance of education, sufficient awareness of waste management

Section 3) **Municipal feasibility of WM services** – duty to pay taxes, willingness to pay for services, waste management by government

Section 4) **Municipal solid waste treatment** – usage of waste, knowledge of different method and technologies, acceptance of different method and technologies

Inconvenient **sampling method** and **snowball method** were used to select respondents. More than half of questionnaires (180) were collected face to face, rest of questionnaires were collected through social media. The questionnaire was shared with my colleague. Questionnaire in English language and photo documentation of questionnaire survey is in annexes.

4.3.2.2. Pilot testing

In the very beginning, there was conducted pilot testing among respondents (number of respondents n=10) from Padjadjaran University (UNPAD) in Bandung and inhabitants of municipality. Results were discussed with students and consultant Dr. Yayan Satiakti from UNPAD, Centre for Economic and Development Studies. Questionnaire was examined on practicability and viability of questions used in following survey. Consequently, there were applied small changes of questionnaire as a result of pilot testing and observation of the study area, then the final questionnaire was elaborated.

4.3.2.3. Interviews

As an important source of primary data were involved interviews with three groups of respondents depending on their knowledge of waste management. Every interview contained four main questions with sub questions, leaded in Indonesian (Bahasa) language and translated by Dr. Yayan Satiakti to English (photo documentation of interviews in annexes). Groups of respondents: officers from local government (n=2); officers of TPS, TPA Sarimukti, waste banks and Bandung Resik (n=5); inhabitants of Bandung (n=5). Interviews for first two groups were focused on professional knowledge.

- **First group** - questions about services of WM provided to inhabitants, arising of awareness, barriers for implementation of different waste treatment method and technologies, priorities in MSWM planning.

- **Second group** - questions about function of their services, sufficient awareness about operations, place adequation, opinion of changes

- **Third group** – description of MSW services in their place, sufficiency of MSW services, suitability of provided MSW services, opinion of changes

4.4. Observations

Due to the lack of information, observation of local conditions and habits, in the terms of waste handling and waste management services, was very important. For understanding problems and designing of more complete picture of situation in the Bandung city, there were undertaken observations of MSWM facilities such as temporary waste stations, Bandung Resik centre and Sarimukti as well as Leuwigajah final disposal sites.

4.5. Target groups

Survey was conducted with adult Bandung's residents living in Timur, Utara, Selatan or Barat district and metropolitan area. The respondents for **questionnaire** were chosen based on certain criteria:

- To have Indonesian citizenship;
- Living in the city of Bandung;
- To be adult (older than 18);
- Not working in government sector.

The respondents for **interviews** were chosen based on same criteria except last one, government officers were very important for this data collection. The total number of respondents of questionnaires was 334. The total number of respondents of interview was 12.

4.6. Data analysis

Primary data gained through qualitative and quantitative methods and observations were subjected to four types of analyses. First specific objective of the Thesis: Assessment if the public demands, that the government takes care of waste management services, was used descriptive statistic. For the second specific objective: Description and evaluation of municipal solid waste treatment methods in Bandung was provided by qualitative data: interviews and observations and by quantitative data: descriptive statistics was used to analyse Waste Management indicators. To achieve the third specific objective: Analysis of public perception of usage and outputs of available municipal solid waste treatment methods and technologies in Bandung, was implemented Multivariate probit model (MVP). Multivariate probit model is appropriate instrument to analyse factors likely to influence adoptions of different waste treatments methods and its consequences on inhabitants.

4.6.1. Multivariate probit model

Multivariate probit model was applied for modelling the multivariate adoption decision in the presence of adoption interdependence. MVP recognizes the correlation in the error terms of utilization equations and estimates a set of binary probit models simultaneously (in this case five probit models). MVP model for multivariate choice decision problems can be presented by two systems of equations (Greene 2007). First, system of equations with latent (unobservable) dependent variables are described by linear function of a set of observed variables and a multivariate normally distributed stochastic term. Equation for each type of dependent variable can be written as:

$$Y_{ik} = \beta_1 X_i + \varepsilon_i$$

where Xi represents a set of all explanatory variables **(Table 2)** $\beta 1$ is a vector of estimated parameters and εi is an error term. Yik is a dependent variable with k which indicates if respondent is willing to use waste as a source of new materials, to use waste as an energy source, to take part in community-based waste management solution, to use toilet sewage as a source of biogas in biodigester, to use landfill gas as an energy source.

The system of equitation describing the binary choices of respondents of the questionnaire is following:

$$Y_i^* = \begin{cases} 1 if Y_i^* > 0 \\ 0 if Y_i^* \leq 0 \end{cases}$$

Bandung's inhabitants are more likely to know and take in more waste treatment technologies due to many kinds of waste than individual technology. This is the reason for implementing multivariate probit model instead of binary probit model for each research. Multivariate model was used in several studies (Padilla 2018; Meng 2016; Ferreira 2010) in terms of waste management issues.

4.6.1.1. Multicollinearity

Presence of multicollinearity in regression model was tested by variance inflation factor (VIF). Since the empirical model includes a large number of independent explanatory variables, multicollinearity is a potential issue. Although the collinearity does not bias parameter estimates, it can influence the standard errors. Furthermore, the model becomes sensitive to changes in the sample size or in model structure (Greene 2007).

Wide divergence is described in literature, regarding the right VIF value to be used as threshold for collinearity. Commonly recommended values are maximum 10 (Sheth 2010), 5 or 3.3 (Mansfield 1982). Also, minimum value of tolerance is varying in the literature from maximum to 0.10 (Yu 2015) up to 0.20-0.25 (O'brien 2007).

VIF was estimated using the equation stated below:

$$VIF_k = \frac{1}{1 - R_k^2}$$

where R_k^2 is the R^2 - value obtained by regressing the k^{th} predictor on the other specified explanatory variables. Variance inflation factor is calculated for each of the *k* predictors included in a multiple regression model.

4.6.2. Explanatory variables

Variables expected to influence respondent's knowledge and relationship with waste treatment methods and their outputs. These variables included demographic characteristics of respondents (gender, age, education), variables from waste management indicators (satisfaction), variables from public perception and approach to MSWM (3R knowledge). Variables are described below, with theoretical justification for their inclusion in the model. In **Table 2** below there are described all variables included in Multivariate probit model.

Gender:

Variable that shows basic division of respondents. Number 1 indicated female, number 0 indicated male respondent. It was included for the possibility of different approach to usage of different types of waste treatments technologies based on gender. It is mentioned in many studies (Xiao 2012; Hadler 2011; Tindall 2011; Xiao 2007) that gender has low or no influence on respondent's approach to application of different types of waste treatments technologies. In opposite is study of Oztekin (2017) which said that there is significant difference between male and female approach to the usage of different types of waste treatments technologies.

Age:

Nominal variable, defined as an age of respondent in three categories. Number 1 indicated age of 18-24, number 2 indicated age of 25-39, number 3 indicated age of 40+. According to Mukama (2016) age had no significant influence on usage of different types of waste treatments technologies. On the other hand, the study results of Babaei (2015), showed that middle aged and elder people have more willingness to use different types of waste treatment technologies.

Education:

Nominal variable describing level of educational attainment. There are three categories of answer: 1 is for elementary school, 2 is for high school and 3 is for University. It is said that higher level of education (Pakpour 2014) was directly influencing the decision making in terms of usage of different types of waste treatments technologies.

Income:

Nominal variable describing monthly income of respondents, there were three main categories: up 2 mil. IDR, 2-5 mil. IDR and above 5 mil. IDR (1 mil IDR approx. 62 €). In some studies, people with lower income are more connected with waste management, their willingness to use variate treatment technologies with its benefits is higher (Matter 2013) On the other hand, there are studies, where people with higher income are more likely to pay for waste management services and also consider variable treatment technologies as a solution for waste management (Rahji 2009).

Satisfaction:

Nominal (binary) variable focused on public satisfaction with waste management system in Bandung city, where 1 indicate Satisfied, 2 indicate Unsatisfied. According to (Regaliza 2018) there are many important aspects influencing public satisfaction. On one hand, there are economic issues as costs and reliability of the collection services. On the other hand, there are more social issues as housing-related needs, waste separation, noise and accessibility, least but not last is environmental load by waste and waste handling. With satisfaction is also connected decision making of municipality about waste handling with direct impact for inhabitants in affected locality.

3R knowledge:

Nominal (binary) variable indicating knowledge of 3R (Reduce, Reuse, Recycle) 1 signified Yes, 2 signified No. Public awareness in municipal solid waste management and waste handling is really important. In the study of Chi (2011) it was published that 3R's are very beginning of successful MSWM. Knowledge of this problematic issue of waste indicates basic awareness among population and could influence decision making in terms of usage of different types of waste treatments technologies and their outputs.

***Table 2.**: Variables included in the Multivariate probit model estimation (Author 2019).*

Variables	**Definition**	**Type of variable**
	Dependent variables	
Waste to material	Willingness to use waste as a source of new material	Binary variable (1 = Yes, 0 = No)
Waste to energy	Willingness to use waste as a source of energy	Binary variable (1 = Yes, 0 = No)
Community-based WM solution	Willingness to act in community-based WM solution	Binary variable (1 = Yes, 0 = No)
Toilet savage as a source of biogas	Acceptance of usage of toilet savages for biodigester feeding, gaining gas for cooking	Binary variable (1 = Yes, 0 = No)
Landfill gas as a source of energy	Acceptance of usage of landfill gas for energy production	Binary variable (1 = Yes, 0 = No)
	Explanatory variables	
Gender	Gender of respondent	Binary variable (1 = Female, 0 = Male)
Age	Age of respondent	Nominal variable (1 = 18-24, 2 = 25-39, 3 = 40+)
Education	Level of completed educational attainment	Nominal variable (1 = elementary school, 2 = high school, 3 = University)
Income	Monthly income of respondent	Nominal variable (1 = <2 mil IDR, 2 = 2-5 mil IDR, 3 = >5 mil IDR)
Satisfaction	Satisfaction with local WM system	Binary variable (1 = Satisfied, 0 = Unsatisfied)
3R knowledge	Knowledge of 3R (Reduce, Reuse, Recycle) principles	Binary variable (1 = Yes, 0 = No)

5. Results and discussion

5.1. Descriptive statistics results

5.1.1. Demographic characteristics

Demographic characteristics of respondents are summarized in **Table 3**. Distribution of respondent is quite good. In terms of gender, it was almost half to half. Distribution in age categories shows that 50 % were in the age of 25-39, big group were respondents of 18-24 with almost 40 %, the smallest group were respondents of 40 and older. We can see that in location distribution, all categories are represented adequate percentage of respondents. Just minimum of respondents had elementary education (up to 5 %) and most of them (more than 50 %) had University education. High school is represented with 40 % of respondents. In the terms of monthly income, more than 50 % had 2-5 mil IDR per month, about 20 % had less than 2 mil IDR per month which is really low budget and considered as a minimum for living in Bandung. More than 25 % of respondents had more than 5 mil IDR per month.

***Table 3**.: Demographic characteristics of respondents (Author 2019).*

Variable	Description	Percentage [%]
Gender	Female	52.9
	Male	47.1
Age	18-24	38.3
	25-39	49.4
	40+	12.3
Location	Timur	23.1
	Utara	27.8
	Selatan	20.1
	Barat	14.3
	Metropolitan area	14.7
Education	Primary school	4.5
	High school	41.9
	University	53.6
Income	< 2 mil. IDR	21.9
	2-5 mil. IDR	51.8
	> 5 mil. IDR	26.3

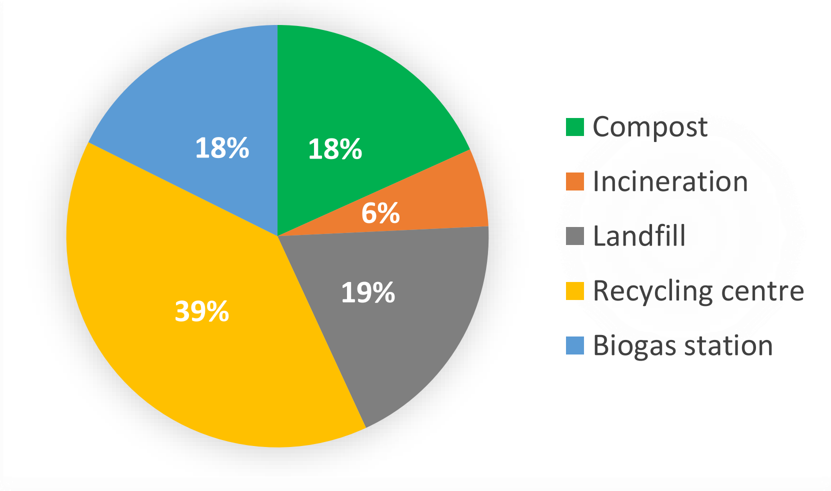
5.1.2. Municipal solid waste treatment indicators

Knowledge of waste treatment technologies differs quite significantly across the respondents. Composting as a waste treatment technology know almost 90 % of respondents and landfilling as the main waste treatment technology in Indonesia knows 84 %. Recycling as a treatment technology know 82 %. On the other hand, 36.5 % of respondents never heard about biogas plants and 21 % do not know incineration facility as a waste treatment technology. There were not used any more specific findings about knowledge of each waste treatment technology. Interviews spoke about low awareness of waste treatment technology knowledge.

''People are not well aware of waste treatment technologies. Separation could help to better implementation. Otherwise there is necessity of incineration which could help decrease overweighting of infrastructure by heavy transportation and reduce of waste amount sent to landfills.'' (officer of Waste Bank in Bandung).

On **Figure 12** could be seen preferences of respondents for implementing of new waste treatment technologies in their location. The most favourite technology among respondents is Recycling centre with around 40 %. Landfilling as a treatment method took 1/5 of preferences (second most popular opinion), nowadays it is practically the only official treatment method provided in Indonesia and it could be the reason for such a support. Third place is divided between compost and biogas station, both took almost the same share as landfilling. Least favourite technology for implementing is incineration with just 6 % which could be caused by low knowledge of this technology. Similar opinions about waste treatment technologies implementation were found in interviews, on the other hand more specific implementation reasons were mentioned during the interviews.

***Figure 12.**: Preference of technology for MSW treatment among respondents (Author 2019).*



''We want to separate the waste because we know the bad situation in our rivers and also on the beaches. Consumption is huge and just a very few people here take care about their waste. We are trying to reduce our production of waste, because it is the only way how to take care of it here.'' (resident of Bandung).

''Here in Bandung Resik we are able to process all kind of waste, plastic, glass, metals, organic materials. We have biodigester producing biogas. From plastic waste, we can produce our own ware, or we can produce pellets and sell them to big companies. Problem is that waste comes here untreated, so we cannot process it. At the end of the day, we process maximum of 10 % of incoming waste. Rest is going to disposal site.'' (officer of Bandung Resik facility).

''Government of West Java is focused on opening new sanitary landfills to improve the situation in Bandung district, another solution is not planned. Present situation is not good because our landfills are overloaded and does not fulfil all requirements that sanitary landfill must. Present waste management is based on two disposal methods, landfill with sanitary elements and worse, open dumping. It is very hard to implement new technology for waste treatment because it is very expensive, and those technologies are not suitable for our conditions.'' (government officer).

''Definitely, one of best solution would be incineration to avoid contamination of surface and ground water. Moreover, opened landfill does not fulfil any of requirements of

sanitary landfill. The pollution is devastating. Also, there are many of smaller open dumbs, you can see open fire all the time and the smell is bad.'' (officer of Bandung Resik facility).

On **Figure 13** is illustrated that in general level, residents of Bandung are not sure if they want to use waste as a resource of new materials or source of energy, in both cases more than 40% do not want it. Similar result is for using toilet savages as a feeding for biodigester for producing biogas. It could be caused by low aware and misunderstanding. On the other hand, there are clearly strong results of usage waste as a new source, namely organic waste as an input of composting (acceptance around 98 %) and usage of landfill gas as a source of energy (acceptance around 90 %).

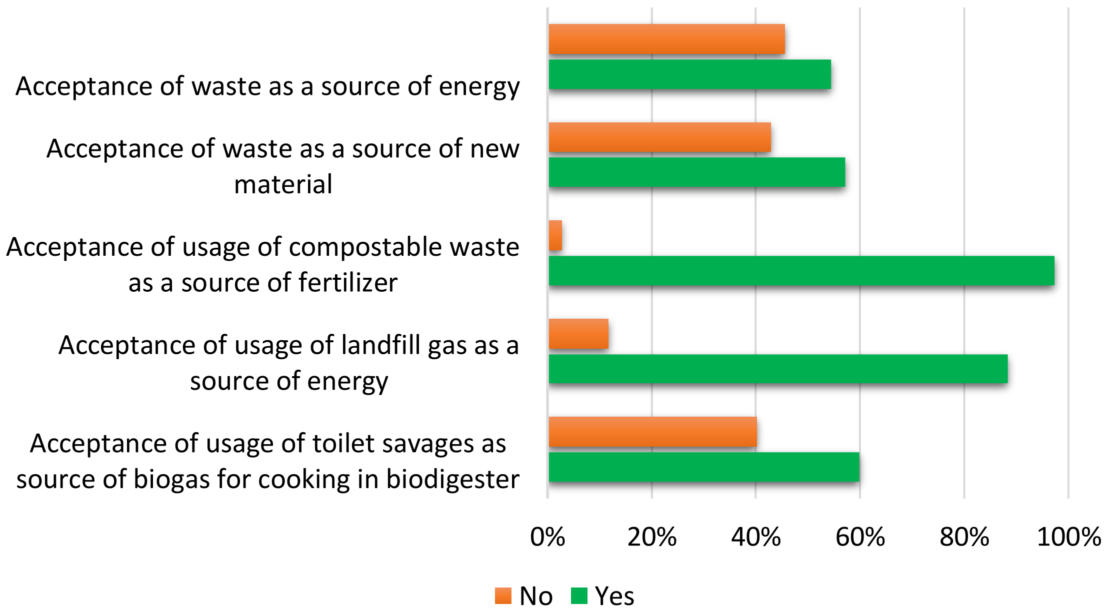


Figure 13.: *Data analysis results of acceptance of waste as a source (Author 2019).*

5.1.3. Municipal feasibility of WM services

Although MSWM services in Bandung are insufficient in 88 % residents were currently paying the taxes for MSW services. Majority (94 %) of respondents want government to take care of municipal solid waste management. Here is no possibility of statistical testing of influencing factors, because it is such high percentage of positive answer thus, in this study we are not able to find specific variables of respondents influencing decision. Although Indonesian law permit and support cooperation of formal sector with informal sector in the terms of waste management, from interview it is seen that there is no procedure within the cooperation of these two sectors and government want to take care of this issue independently.

''We are not planning any cooperation with informal sector, we do not think, it bring any benefits to us. Although there is no example of cooperation with informal sector, so there are not any experiences'' (government officer).

In terms of money, 59 % of respondents were willing to pay up to 30 000 IDR monthly, 33 % were willing to pay 30-50 000 IDR and 8 % were willing to pay more than 50 000 IDR per month.

Several studies (Babaei 2015; Al-Khatib 2015; Yoada 2014; Soares 2011) showed that people assume government to take care for MSWM, but there is various opinions about paying fees for MSWM services. In some countries there is problem that people do not want to take responsibility for waste treatment and just rely on government to take care of it (Yoada 2014). In Iran, study shows that people want government to not just take care but also pay for MSWM at all. They do not want to act in MSWM and majority of them do not want to pay for services (Babaei 2015). In Indonesia, East Timor people also want government to take proper care of waste management and the opinion is that MSWM is government 's responsibility, paying for services is adequate for satisfying services in terms of waste transportations and treatment itself (Soares 2011). On the other hand, in China, people do not trust government in implementing technologies for waste treatment. They do not want government to take care of waste management, because population do not think, government takes proper care of waste (Ren 2016).

5.2. Description and evaluation of municipal solid waste management and treatment methods in Bandung

Waste management services for households

Based on interviews with residents of Bandung, there are places where the services fulfil basic requirements, workers are collecting waste and transporting it away. On the other hand, people also face problems with irregular services or no services at all. From questionnaire is clear, that people are unsatisfied with waste management system in Bandung. There were about 98 % of unsatisfied respondents. Almost 79 % of respondents answered that, there is no available MSW service in their location. Also, more than 83 % of respondents said that waste management services in their location are insufficient. Interviews with residents of Bandung and government officers supported this opinion of public about insufficient services.

''We left the trash bag beside our home and somebody will take care of it. They took all the plastic and metals and rest they took somewhere.'' (resident of Bandung).

''In our street there is waste service. We left our trash in front of house and the guy goes once per day to collect it and take care of it.'' (resident of Bandung).

''There is no possibility how to handle the waste but throw it away. There are no bins or containers in the streets. Huge amount of waste is going down through the streams. People just throw it there and don't care.'' (resident of Bandung).

''We know about bad conditions of our waste management, infrastructure and services are in bad conditions, but we want to improve this situation.'' (government officer).

Situation about waste handling of households is inappropriate because if there is bad or no service at all, waste is not collected and transported, pollution of rivers and streams is common, open burning is usual practice to avoid big amounts of waste. From the observation, all these practices were recorded. In study of Mariani (2017) was shown that although knowledge of open burning and its consequences are spread among population in Malaysia, limited possibilities of waste handling leads to practices as open burning. Situation in Bandung is similar.

Bins and containers

In past years there were implemented some of MSWM services in Bandung. Firstly, on main streets there were bins for organic and inorganic waste (example on **Figure 14**). In interviews with government officers was said that majority of them were stolen or devastated. On the other hand, from interviews with residents, waste bank's workers and government officers, services were not fulfilled to satisfy basic steps like collecting waste from bins and cleaning the streets. Result is that in streets of Bandung there is not enough bins and containers for collecting the waste. As a consequence, there are problems with polluting rivers and forests with the waste.

''In city were installed bins for organic and nonorganic waste, but all the time we controlled the contain, in both were mixed wastes, organic and nonorganic together. People are not able to separate it. Also, there is not enough bins and services are irregular, all is caused by underfunding of this sector.'' (government officer).

''Yes, there are bins, you can find some of them in the streets, but there is not any services, bins are full and broken.'' (resident of Bandung).

''Because of no bins and containers in the streets, there is problem with polluting of small rivers and streams in the city. Many people do not have access to WM services. People just throw their waste to the river to handle it.'' (officer of Waste Bank in Bandung).

Figure 14.: *Bins for organic and inorganic waste on the main street of Bandung city (Author 2018).*

City services and Waste Banks

In Bandung are operating public services: Bandung Resik, well equipped facility with all kind of machines and transportation vehicles. On **Figure 15** are documented few of machines used for cleaning of streets, other examples are showed in annexes. This centre represents almost every crucial waste treatment method needed in the city, there are bins for separated waste, which is processed after collecting. Plastic material, glass and metals are sold out. In case of organic waste, there is functional biodigester used as a source of biogas for cooking. Beside there are containers for organic waste used as a composter. New fertilisers are sold or used for cultivation in the area.

Unfortunately, majority of waste is mixed and possibility to separate each group is minimal. Majority of waste goes to final disposal site untreated. As centre workers said in interviews, crucial step for treatment is separation of waste at very beginning.

''If the waste is separated, our services would be much more efficient. Now we are able to recycle only a few percent of organic waste, most of it goes to disposal site because it is mixed. The same problem with plastic and other, we take out the biggest and least contaminated parts and rest is going to landfill.'' (officer of Bandung Resik facility).

Bandung Resik is great showroom centre, but with its size and equipment it is not enough for MSW services even for ¼ of the city. Major problem is lack of money.

***Figure 15**.: Cleaning machines in Bandung Resik centre (Author 2018).*

Beside of public services as Bandung Resik, there are Waste Banks located across the city. They focus on purchasing of separated waste (plastic, glass, paper, metals) after processing, they sell it to companies. This money are the main source of funding for the whole Waste Bank operations. Waste Banks are able to collect separated waste from streets, but this is a paid service, not supported by government. Waste Banks are focusing on awareness campaigns for public, but with the lack of money, their impact is very low. Majority of people visiting Waste Banks are so called Waste pickers, who's source of money is selling separated waste.

''At this waste bank, we are promoting awareness, mainly about waste handling, but we are not able to expand this awareness through the town. Main reason is lack of finances and the government actually prefer awareness about negative impact of corruption.'' (officer of Waste Bank in Bandung).

''Government provided us awareness about 3R concept in past few years, nowadays there is a problem with waste separation. I know principle of this concept, but we don't have the opportunity to separate plastics, except to pay waste bank to collect it or bring it by ourselves to this organisation.'' (resident of Bandung).

Disposal Sites

In Bandung there is number of places so called Temporary Waste Stations (TPS), which seems like regular disposal site in the city. Collected waste is transported here by smaller vehicles and stored. Unwritten rules allow waste pickers to separate waste they want to sell, but majority of waste is stored, and latter transported by big vehicles to Final Disposal Site (TPA). On **Figure 16** could be seen very bad conditions on one of TPS. Because of location in the middle of city, consequences of improper handling and storing of waste influence all surrounding including houses, schools and shops. Smell and leachate is spreading among the city. People do not want to live and work near this place, but there is no other option.

''Government does not care about the situation of WM in the city. Since the Leuwigajah disaster, the only thing they did is new landfill in different place. But services in the city are still very bad.'' (resident of Bandung).

''The smell is bad, and waste is everywhere. We want somebody to take care of it.'' (resident of Bandung).

***Figure 16**.: Temporary waste station in Bandung (Author 2018).*

Former TPA Leuwigajah formally ended its operation after the disaster in 2005. Unfortunately, care about the site ended right after its closing. Current situation is documented on **Figure 17**, there is no ventilation of gases, no proper cover of waste and no collecting and treatment of leachate from landfill. Consequently, there are open fires and explosions of methane, waste is spreading with weather conditions, colourful and smelly leachate is polluting sources of water and all irrigation ditches in surrounding area. Some of these inappropriate handling consequences were observed in Leuwigajah location. From interviews is clear that government know about bad situation and want to improve, but there is not planning yet. One of excuses is lack of money.

''We want to improve conditions of our landfills and WM services but there is lack of money. Since 2008, our budget is still the same, beside with population growth and waste generation growth. Even in that time, it was not enough.'' (government officer).

***Figure 17**.: Area of former disposals site Leuwigajah with open fires (Author 2018).*

Since 2005, there was opened Sarimukti TPA as an emergency solution. Despite the fact that disposal site filled its capacity in 2012 and is currently operating in 2019. Sarimukti landfill does not fulfil requirements for sanitary landfill, there is no impermeable layer, only natural clay bedrock. Cover layers are not applicated, waste is spreading among surrounding, there is no landfill gas control, no ventilation and open fires and explosions are common in this place. On **Figure 18** is documented leachate collection pond. Firstly, it was established here for leachate treatment but nowadays, because of lack of money, pond is just collecting part of leachate, but there is no treatment or recirculation at all. Probably, leachate interferes surrounding of disposal site and pollute the soil. Ground water used for irrigation is most likely contaminated. Pollutants from leachate are most likely present in drinkable water. In study of Abd El-Salam (2015) were described numbers of pollutants, which contaminate groundwater sources and wells, if leachate is not well treated.

Daily, there is delivered more than 5,600 tons of waste, around 1,500 tons originate from Bandung city. Huge problem is the amount of waste, infrastructure is collapsing due to heavy trucks delivering waste and capacity is limited. Separation and other waste treatment methods could help to solve this problem. From interviews there are more opinions about solution of the situation. It is planned to build new disposal sites satisfying requirements of sanitary landfill, on the other hand there are opinions about different solutions as are incineration as Waste-to-Energy treatment method. Incineration seems as suitable solution for such amount of waste with high calorific value due to high amount of plastic materials. One of the biggest limitations based on interviews is underfunding of waste management sector.

''Definitely, one of best solution would be incineration to avoid contamination of surface and ground water. Moreover, opened landfill does not fulfil any of requirements of sanitary landfill. The pollution is devastating. Also, there are many of smaller open dumps, you can see open fire all the time and the smell is bad.'' (officer of Waste Bank in Bandung).

''People are not well aware of waste treatment technologies. Separation could help to better implementation. Otherwise there is necessity of incineration which could help decrease overweighting of infrastructure by heavy transportation and reduce of waste amount sent to landfills.'' (officer of Bandung Resik facility).

''Government of West Java is focused on opening new sanitary landfills to improve the situation in Bandung district, another solution is not planned. Present situation is not good because our landfills are overloaded and does not fulfil all requirements that sanitary landfill must.'' (government officer).

According to interviews, on Sarimukti disposal site live more than 700 people, majority of them are working as waste pickers. In comparison with Munawar (2018) who described 400 – 500 people, it is big difference. They collect waste and sell it to the companies, waste pickers are able to make more money by this job instead of average paid jobs in Bandung city. There is economic value of waste disposed in Sarimukti landfill. Documentation of the situation at TPA Sarimukti is included in annexes.

Figure 18.: Leachate collection pond in Sarimukti disposal site (Author 2018).

5.3. Analysis of public perception of available municipal solid waste treatment methods and technologies in Bandung and its consequences for public

Multivariate probit model

Model was used to analyse public perception of available municipal solid waste treatment methods and technologies in Bandung and its consequences for public. Multivariate probit model $\chi^2 = 151.52$ and was significant at 1 % ($p > \chi^2 = 0.000$) therefore model has a strong explanatory power. Presence of multicollinearity in regression model was tested by variance inflation factor. VIF of explanatory variable is 1.83 which fits in all mentioned criteria (10, 5 and 3.3) and multicollinearity issue is omitted.

In the first part of this section are presented results of important and statistically significant coefficients of explanatory variables. The regression results from multivariate probit model are presented in **Table 4**. These results suggested that gender of respondents, educational level and income played an important role in respondent's decision on each variable (willingness to use toilet savage as a source of biogas, willingness to use landfill gas as an energy, willingness to act in community-based WM solution, willingness to use waste as a source of new materials and energy).

Willingness to use toilet sewage in biodigester as a source of biogas for cooking

Coefficient of gender indicated that female respondents tended less likely to use this source of waste to energy technology. This coefficient was statistically significant at 1 % level. The coefficient of respondents with primary and higher education was negative, which indicate that people with university education tended more likely to use toilet savage in biodigester. This coefficient was statistically significant at 10 % level. The rest of variables had no statistically significant influence on dependent variable.

Result of study of Uhunamure (2019) showed, that female are more likely to accept this waste to energy technology than men, result is totally opposite of our research. One of significant differences is location of respondents, in a city it is more difficult to establish such a facility for producing biogas, and female are more likely to take care for more activities than just cooking. In our case, result should be probably influence by living in the city, where cooking is not the priority number one. In number of studies our result with educational level was confirmed, Jan (2018) and Mwirigi (2009) said that higher educational level had positive statistically significant influence on acceptance of biodigester sourcing gas from toilet sewage, the same result as in our research. According to Mwirigi (2009) higher education level make people much more adaptable to new ideas and new social reforms required by technology. Higher level of education is not just about knowledge of specific technology, but the way of thinking as well. Generally, willingness to use this technology was low, up to 40 % respondents do not want to accept this technology and its outputs.

Willingness to use landfill gas as a source of energy

From the set of explanatory variables, two were significant. Coefficient of gender indicated that female respondents tended less likely to use this source of waste to energy. This coefficient was statistically significant at 5 % level. The coefficient of respondents with primary and higher education was negative, which means that these people in comparison with university educated people are less likely tended to accept this way of usage of waste. This coefficient was statistically significant at 5 % level. Coefficient of satisfaction with WM services was negative, it indicates that unsatisfied people are more likely to use landfill gas as source of energy, coefficient was not statistically significant, but approaching to 10 % level. Coefficient of people educated with concept of 3R is positive, it means that these people are more likely to accept this Waste-to-Energy method. Coefficient of 3R knowledge was not significant but near of 10 % level.

Result of acceptance of landfill gas as a source of energy was much more positive than acceptance of biogas produced partly from toilet sewage, but again showed that female are tended less likely to accept that. Thus, landfilling is well known in Bandung, it is not unknown technology for residents and its products could be more easily accepted. Education is very important element to understand and accept this method of WtE technology.

Willingness to act in community-based WM solution (collecting and sorting of waste, composting)

Coefficient of low and middle income were negative, which indicates that people with higher income are more likely to act in community-based solutions. Also, coefficient of middle income was statistically significant at 1 % level. 3R concept knowledge coefficient was positive, which means that people who know this concept are more tended to act in community-based WM solution. Coefficient of 3R knowledge was statistically significant at 5 % level.

In study of Saphores (2014) there were similar results of positive statistically significant impact with increasing of income on community-based solution such as sorting and recycling of waste. Also, study of Zhang (2019) resulted that income is positively significantly influencing participation in community-based solutions. With higher level of income, also demand for environmental quality will increase. Our result could be conditional with more time for active participation in environmental activities due to greater independence on working time. But in study of Permana (2015), low income was the reason for higher involvement and acting in community-based WM solution as recycling and waste sorting. One of main reason could be the possibility of selling sorted waste, which could be another source of money. 3R knowledge and overall knowledge of waste management issues leads to higher involvement of public in sorting and recycling of waste activities. The same result as in our research was founded in study of Dhokhikah (2015), people involved in 3R knowledge are significantly more tended to act in community-based WM solutions such as sorting and recycling of waste. Community-based solutions are not just about waste management issues, often it is connected with all environmental issues.

Willingness to use waste as a source of new materials

From whole set of explanatory variables there was one significant variable. Coefficient of middle-income people was at 10 % level of significance. Coefficient was positive, it indicate that people with middle income are more likely to use waste as a source of new materials in comparison with high income people. Low income coefficient was not significant, but coefficient shows that trend of acceptance of this technology is similar as in middle income category.

Study of Zhou (2018) showed the opposite, people with lower income are less likely to adopt this waste usage, in the case of composting of organic waste income showed strong negative on the probability of adoption of these technologies. Another study (Palatnik 2005) confirmed that people with higher income are more likely to use waste as a source of new material, but study also showed that production of waste in households with higher income is higher and the correlation is clear. In our case, result could be caused by willingness of respondents to bring waste to some place under the condition of financial or material compensation which could attach in financial terms.

Willingness to use waste as a source of energy

Coefficients of low and middle income were both statistically significant, low income coefficient was significant at 10 % level and middle income coefficient was significant at 1 % level. It presents that people with low income and even more with middle income are more likely to use waste as a source of energy in comparison with people with high income. Coefficient of people aged 18-24 was not significant but close to 10 % level and shows that younger people are likely to use waste as a source of energy.

Study of Liu (2018) concluded that characteristics as age and education had significant influence on public acceptance WtE technologies in China, people aged up to 35 were more willing to accept WtE technologies than were older. Liu also said that people with higher educational level were more willing to accept WtE technology than those with lower educational level. Both characteristics are connected, because younger people are more educated and older people had lower educational level. Our results were similar in terms of age, but with no significant influence. Significance influence of income could be caused by different way of thinking about sources of energy. Those who have enough money do not think about basic needs as electricity is.

Table 4.: *Results of Multivariate probit model (Author 2019).*

	Coef.	Std. Err.	Z	P>z	95% Conf. Interval	
Toilet to Biodigester						
Gender	**-0.477**	**0.144**	**-3.330**	**0.001**	**-0.759**	**-0.196**
Aged 18-24	0.046	0.271	0.170	0.865	-0.485	0.577
Aged 25-40	-0.129	0.233	-0.550	0.579	-0.587	0.328
Higher Education	**-0.276**	**0.159**	**-1.730**	**0.084**	**-0.588**	**0.037**
Low income	0.086	0.256	0.340	0.735	-0.414	0.587
Middle income	0.080	0.188	0.420	0.672	-0.289	0.449
Satisfaction	-0.575	0.485	-1.190	0.236	-1.526	0.375
3R Knowledge	-0.065	0.182	-0.360	0.722	-0.422	0.292
Constant	**0.687**	**0.265**	**2.590**	**0.009**	**0.168**	**1.205**
Landfill gas as a source of energy						
Gender	**-0.511**	**0.195**	**-2.620**	**0.009**	**-0.893**	**-0.130**
Aged 18-24	-0.041	0.379	-0.110	0.915	-0.783	0.702
Aged 25-40	-0.257	0.334	-0.770	0.441	-0.910	0.397
Higher Education	**-0.446**	**0.206**	**-2.160**	**0.031**	**-0.851**	**-0.041**
Low income	-0.324	0.324	-1.000	0.317	-0.959	0.311
Middle income	-0.035	0.248	-0.140	0.887	-0.521	0.451
Satisfaction	-0.679	0.479	-1.420	0.156*	-1.618	0.260
3R Knowledge	0.336	0.224	1.500	0.134*	-0.103	0.775
Constant	**1.753**	**0.386**	**4.540**	**0.000**	**0.996**	**2.510**
Community based participation in recycling and composting						
Gender	-0.134	0.159	-0.850	0.397	-0.445	0.177
Aged 18-24	0.008	0.302	0.030	0.978	-0.583	0.599
Aged 25-40	0.146	0.271	0.540	0.589	-0.384	0.677
Higher Education	-0.150	0.172	-0.870	0.382	-0.488	0.187
Low income	-0.413	0.296	-1.400	0.163*	-0.994	0.167

Middle income	**-0.593**	**0.229**	**-2.590**	**0.010**	**-1.041**	**-0.145**
Satisfaction	0.022	0.511	0.040	0.965	-0.979	1.024
3R Knowledge	**0.450**	**0.196**	**2.300**	**0.021**	**0.067**	**0.834**
Constant	**0.908**	**0.300**	**3.030**	**0.002**	**0.320**	**1.496**
Waste as a source of material						
Gender	-0.137	0.142	-0.970	0.334	-0.415	0.141
Aged 18-24	-0.064	0.265	-0.240	0.810	-0.583	0.456
Aged 25-40	-0.006	0.231	-0.020	0.980	-0.459	0.448
Higher Education	0.148	0.157	0.940	0.346	-0.160	0.456
Low income	0.244	0.254	0.960	0.336	-0.253	0.742
Middle income	**0.343**	**0.188**	**1.830**	**0.068**	**-0.025**	**0.710**
Satisfaction	-0.517	0.478	-1.080	0.280	-1.453	0.420
3R Knowledge	0.005	0.183	0.030	0.978	-0.354	0.364
Constant	-0.018	0.263	-0.070	0.945	-0.534	0.497
Waste as a source of energy						
Gender	-0.075	0.138	-0.540	0.588	-0.345	0.196
Aged 18-24	-0.355	0.267	-1.330	0.184*	-0.880	0.169
Aged 25-40	-0.245	0.234	-1.050	0.294	-0.704	0.213
Higher Education	0.042	0.154	0.270	0.785	-0.260	0.344
Low income	**0.469**	**0.252**	**1.860**	**0.063**	**-0.025**	**0.963**
Middle income	**0.513**	**0.187**	**2.750**	**0.006**	**0.147**	**0.878**
Satisfaction	0.190	0.463	0.410	0.681	-0.717	1.097
3R Knowledge	-0.148	0.181	-0.820	0.412	-0.503	0.206
Constant	0.136	0.262	0.520	0.604	-0.378	0.649
Number of observations		334				
Wald χ^2		151.52				
Prob > χ^2		**0.000**				

* mentioned variables with no significant influence

In **Table 5** is shown pairwise correlations between the error terms. Number of them were statistically significant, which proved the interdependence between the adoption of usage different methods and technologies for municipal solid waste treatment. The reason could be usage of these technologies or awareness about those technologies, knowledge of one technology or method leads to knowledge of other technologies and methods for MSW treatment. As a consequence, respondents do not decide to adopt only one waste treatment method, instead respondents decided to accept group of similar technologies/methods or decided to choose these technologies/methods they know better and were familiar with them. It shows that waste management has not one side solution, even in residents view. Waste should be treated by origin, and by best utilization.

***Table 5**.: Conditional correlation between opinion about waste treatment technologies /methods and its consequences for Bandung's residents (Author 2019).*

	Toilet to Biodigester	**Landfill gas – energy**	**Community participation**	**Waste - material**	**Waste – energy**
Toilet to Biodigester	1				
Landfill gas – energy	**0.646***** (0.079)	1			
Community participation	0.043 (0.094)	0.140 (0.110)	1		
Waste – material	-0.012 (0.083)	0.018 (0.099)	-0.023 (0.091)	1	
Waste – energy	**0.158**** (0.082)	0.043 (0.109)	-0.016 (0.094)	**0.755***** (0.045)	1

Note: Standard errors in parentheses

*** significant at 1%

** significant at 5 %

6. Conclusion and Recommendation

6.1. Conclusion

Municipal solid waste management situation in Bandung city, Indonesia is in inappropriate conditions. Almost all residents (respondents of the questionnaire survey and interviews) are unsatisfied with MSW services. The main problems are not adequate services or missing services at all as about 80 % of respondents confirmed that, there is no waste services in their locality. Description of present WM situation is varying depends on the testimonies from interviews and observations. Although government sector described effort to implement awareness among population, installation of bins and containers through the city, residents highlighted lack of interest of authorities in waste management at all. Also, observation proved that bins and containers for waste are located in city streets sporadically and services are irregular. City services under the control of government proof that there is possibility to implement adequate services, e.g. Bandung Resik has well equipped mechanisation for MSWM services and waste handling. But more than regular services, Bandung Resik represents demonstration devices with very low impact on waste management situation in Bandung. Also, implementation of waste cycle is not adequate, collected mixed waste is hardly treated in different way than disposal. Waste banks mediate redemption of recyclable wastes and awareness campaign, but with limited financing sources had very limited influence.

The main treatment method for the whole Bandung district is landfilling in operational disposal site Sarimukti, this site do not meet international standards of sanitary landfills, with inappropriate leachate collection and treatment, no covering layers, no emission control and treatment. Sarimukti landfill is since 2012 overloaded but still used as the main disposal site. Although Waste Bank and Services employees recommended different treatment methods and technologies in front with composting and incineration, government has still the same access to waste management highly influenced by low financing of this sector. Future planning count with opening of new disposal sites, with no technical improvement.

Although greater part of respondents is not satisfied with MSWM in Bandung nowadays, majority of them wants government to take care of MSWM. People want proper services for fees they are paying and also people are nowadays thinking about environmental impacts of inappropriate waste management. From the point of view of respondents, the most preferred technology for waste treatment in Bandung was recycling centre, which showed that people are already thinking about waste production consequences. On the other hand, up the day, landfilling is most common treatment method in Indonesia and Bandung, which has significant influence on residents. It is well known practice here thus people also prefer this method among other, it is second most preferred waste treatment technology.

Multivariate probit model shoved that respondents' opinion about each treatment technology is linked with other technologies, the most influencing factors for decision were education, gender and level of income. Education is very important for learning of waste treatment technologies due to the fact that in Bandung, there is almost no other possibility to see different treatment technology than disposal site. For people with this knowledge it is more acceptable to adapt new technologies and methods.

6.2. Recommendations

The very beginning for better municipal solid waste management in Bandung is sorting of waste from the source in households. On the other hand, very important is position of municipality which has to ensure appropriate conditions for possibility of adequate waste services and waste sorting. It is the first step of transformation of waste management, which opens new ways of waste treatment methods.

It is necessary to engage companies and factories in financing of municipal solid waste management in Bandung. Government will have access to higher foundations and could implement more sophisticated technologies for waste treatment. Taxes and fees could also decrease the amount of waste produced by companies, as a result reduce of all produced waste in Bandung city.

Although, the most required treatment method from public responses is recycling centre, it should begin with new awareness campaign about 3R concept.

Transformation of waste handling among population take in general long time. Change of behaviour of residents of Bandung city in terms of waste is necessary, but it is very long procedure. As a very beginning there is a necessity of waste sorting and waste awareness. City infrastructure has to face changes in the terms of waste collecting services, waste transportation services and waste treatment facilities.

Waste management is complex system with many important parts and divisions, basic distribution to organic and inorganic waste needs its proper handling. Due to high percentage of organic waste it is very important to implement composting technologies to proper organic waste treatment. Sorting and processing of organic waste should dramatically decrease amount of waste disposed in landfills, simultaneously organic waste could serve as a source of fertilisers or energy.

In terms of Bandung city and national requirements, one of best solution for present situation seems to be incineration facility as Waste-to-Energy technology. In comparison with other possible technologies, one of prominent advantages of incineration is fast reduction of waste quantities by burning. Amount of generated waste in Bandung is enormous and space for dispose is not enough. Unsanitary landfill Sarimukti do not meet environmental requirements, city infrastructure is overloaded, energy demand is increasing, and the city is facing massive blackouts.

This solution could help from overloading of running landfills and slow down new opening. Present incineration technologies met high environmentally friendly standards, in comparison with landfill it is much better solution in the terms of emissions and has perceptible lower negative impacts on environment. Location near city centre could help with less overloading of city infrastructure by heavy transports and save money. Calorific value of MSW in Bandung should be high due to high share of plastic waste and production of electricity from waste combustion could help to cover energy demand which is increasing rapidly in urban areas.

There is not only one solution in municipal solid waste management in Bandung. Different treatment methods have to be implemented, awareness campaigns have to be spread among population. People have to be tended that proper waste management has positive impacts for their lives. Position of waste should be changed in view of

Bandung's inhabitants, i.e. from material without any economic value to valuable source of new materials or energy and in case of organic waste – fertilisers, from useless material with no impact on their lives, environmental issue in everybody's interest. Authorities should change their attitude quickly and start to look for new solutions in a way of waste treatment methods and services for their own residents. New solutions for Bandung's waste management situation could be inspired from other countries, which do not use anymore landfilling as a main waste treatment method.

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Annexes

List of annexes

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Annex 2: List of question in interviews

Annex 3: Photo documentation during questionnaire survey

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Annex 5: Photo documentation of Bandung Resik Centre

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Annex 1: Structured questionnaire

For Master's Thesis were used questions 1, 5, 7, 9 (sections 1 and 2) and the whole sections 3 and 4

Czech University of Life Sciences Prague
Faculty of Tropical AgriSciences

Declaration:

Dear respondent, this questionnaire is anonymous, and results will be used to Diploma Thesis data collection and writing at Czech University of Life Science (CULS), Faculty of Tropical AgriSciences, Kamýcká 129, 165 00 Prague, Czech Republic, Europe. Also, questionnaire will serve both to CULS and Universitas Padjadjaran, Center for Economic and Development Studies, Jl. Raya Bandung KM.21, Indonesia as base for further research.

Thank you for your time!

Denisa Beňová, denisa.beno@gmail.com
Kryštof Mareš, krystofmares@seznam.cz

Demographic information

Gender:	Male	Female
Age:		
18 – 24	25 – 39	40+

Location:

- Bandung Timur (Margahayu Raya, Riung Bandung, Ujung Berung, Antapani)
- Bandung Utara (Setiabudi, Dago, Pasteur, Cihampelas)
- Bandung Selatan (Kopo, Soreang, M. Toha, Baleendah, Cibaduyut)
- Bandung Barat (Kab. Bandung Barat dan Sekitarnya)
- Metropolitan area of Bandung

How long have you been living in the city of Bandung?

Education level:

- None
- Higher education
- University education

Average monthly income:

< 2 mil. IDR 2-5 mil. IDR >5 mil. IDR

<u>Section 1</u>

1) **Are you satisfied with waste management system in your location?**
   Satisfied Unsatisfied
2) **How do you handle waste on daily basis? (please select one option)**
   - Bins, Containers, etc.
   - Put the waste in plastics bags in front of house
   - Burning
   - Other: (specify)
3) **a) Do you have the possibility to separate the waste you dispose of, based on paper, plastic, glass, biology, organic, and non-organic?**
   - Yes
   - Only part of waste
   - No

   b) If there is no possibility to separate waste, would you appreciate the possibility to separate waste to different bins according to its origin?

   Yes No

4) **Which type of waste do you separate? (please select one option)**
   Whole waste
   Partly: Paper Plastic Glass Bio
   No separation at all
5) **Is in your location available service for waste management?**
   Yes No
6) **Please describe waste management services in your location:**
7) **Does WM services sufficient?**
   Yes No
8) **Percentage division of daily produced waste:**
   Biological Plastic Paper Glass Others

<u>Section 2:</u>

9) **Do you know 3R (Reduce, Reuse, Recycle) concept?**
   Yes No (If no, please continue to Q11)
10) **Do you act according to this concept?**
    Yes No

11) **Are you interested in WM and its solution in terms of decreasing negative impact to environment?**
Yes No

12) **Would you be willing to take part in workshop/campaign/demonstration field about waste management handling?**
Definitely yes Rather yes Rather no Definitely no

13) **Do you consider education of WM important from your point of view?**
Definitely yes Rather yes Rather no Definitely no

14) **Do you agree with integration of WM education at primary schools?**
Definitely yes Rather yes Rather no Definitely no

15) **Do you think there is sufficient awareness in your location of waste handling?**
Definitely yes Rather yes Rather no Definitely no

16) **Do you think there is sufficient awareness in your location of waste recycling?**
Definitely yes Rather yes Rather no Definitely no

<u>Section 3:</u>

17) **Do you currently have to pay certain taxes or fees for waste management services at your place?**
Yes No

18) **Do you want waste management to be carried out by the government?**
Yes No

19) **How much is your willingness to pay for waste management per month?**
30,000 IDR 30,000-50,000 IDR more than 50,000 IDR

<u>Section 4:</u>

20) **Would you like to use waste as source of:**
    a) Material Yes No
    b) Energy Yes No

21) **Do you know following technologies of waste management treatment?**

Technology	**Yes**	**No**
Composting		
Incineration		
Landfills		
Recycling		
Biogas station		

22) **Which technology would you prefer in your locality? (please select one option)**
Composting Incineration Landfills Recycling Centre Biogas station

23) **Would you be willing to take action in community-based waste management solution?**
(for example: Separate waste, collect biological waste at one place to composting for benefit of whole community etc.)
Definitely yes Rather yes Rather no Definitely no

24) **It is acceptable for you to use toilet savages for biodigester feeding and obtain gas for cooking?**
Definitely yes Rather yes Rather no Definitely no

25) **Is it acceptable for you to use landfill gas for energy production?**
Definitely yes Rather yes Rather no Definitely no

26) **Is it acceptable for you to use compostable waste as source of fertilizer?**
Definitely yes Rather yes Rather no Definitely no

Annex 2: List of question in interviews

Interview questions for citizens	**Interview questions for organization officers**	**Interview questions for government officers**
How the MSWM services work here?	How is this organization running?	How do you provide/handle MSWM services and who is responsible for it?
Do government arise any kind of awareness about MSWM?	From you point of view, do you obtain sufficient awareness about waste handling/recycling?	Do you arise any type of awareness campaign?
Does the government provide MSWM services in accordance to your vision?	Is this place adequate (in terms of location, waste amount…) to operate?	What are the main barriers to implement other final disposal solution than open dumping?
What should be done differently from your point of view?	Is there something that should be done differently to make operations smoother?	What are the set-up priorities in MSWM in Bandung?

Annex 3: Photo documentation of questionnaire survey

Annex 4: Photo documentation of interviews

Annex 5: Photo documentation of Bandung Resik centre

Annex 6: Photo documentation of Sarimukti disposal site