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Municipal Solid Waste Management. Types and Comparative Study Case: Finland and the Republic of Moldova

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ABSTRACT

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The scope of this research is to present to the public knowledge the types of municipal solid waste (MSW), as well as ways of management of each type. It reflects the analysis of management methods practiced nowadays, such as recycling, composting, landfilling and Waste-to-Energy method. A comparative study case is initiated on the present practices of MSW management in Finland and in the Republic of Moldova. The outcome of the comparison reflects the benefits of waste-to-energy incineration plants towards the landfilling which is the main MSW treatment in Moldova. Based on the specific example of Combined Heat and Power (CHP) incineration plant in Lahti, Finland - Kymijärvi II power plant – it is emphasized the importance for Moldova to switch from landfilling to waste-to-energy technology that benefits both the environment and the recovery of energy that can be used by the citizens. Since the non-recyclable waste is being combusted and taken advantage of, it helps to switch the focus from the utilization of natural resources and it contributes to building up circularity between waste and production of new energy. The comparative study between incineration plants and landfilling proves that waste-to-energy technology is superior to landfilling when referring to greenhouse gas emission reduction and landfill gas recovery, as higher emission reduction and landfill gas utilisation can be obtained with an incineration system.

Key words: municipal solid waste treatment, recycling, landfill, waste-to-energy incineration

CONTENTS

ABBREVIATIONS AND TERMS

AD	Anaerobic Digestion
CFB	Circulating Fluidised Bed
CHP	Combined Heat and Power
GHG	Greenhouse Gases
LFG	Landfill Gas
MSW	Municipal Solid Waste
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PV	Photovoltaics
PUR	Polyurethane
PVC	Polyvinyl Chloride
PW	Plastic Waste
SRF	Solid Recovered Fuel
TAMK	Tampere University of Applied Sciences
WTE	Waste-To-Energy

1 INTRODUCTION

On our planet waste has become a substantial environmental issue to address in earnest, since it is inevitably produced daily in every domain of human activity. This research focuses on presenting the type of waste each of the individuals contribute to equally and directly, referring to Municipal Solid Waste. The scope of this research is to present to the public knowledge the types of municipal solid waste, as well as ways of management of each type. It reflects the analysis of management methods practiced nowadays, such as recycling, composting, land-filling and Waste-to-Energy method. As a study case, it is initiated a comparative study case on the present practices of MSW management in Finland and in the Republic of Moldova. Whilst researching on both countries, conclusions are conducted on the improvement of the MSW management in Moldova through problem-solving proposals referring on applied methods in Finland, given the fact that the world’s goal is to switch to a green management of waste which would be beneficial for both humans in the economic sphere, as well as for the planet itself. There is an increasing amount of materials that can serve for the society longer than in one row, therefore ways of greener management should be applied in order to capitalize the energy potential from the waste. In this research, this aim is specifically referred to countries in development, when the Republic of Moldova is taken as an example under the analysis of a theoretical reconstruction of the MSW management system.

1.1 Municipal Solid Waste

Municipal Solid Waste (MSW), often referred to as trash or garbage, comprises the items which are regularly utilized and discarded, including product packaging, office used supplies, furniture, textiles, bottles, food residue, newspapers and more. It originates from residences, educational institutions, healthcare facilities, and commercial establishments. (U.S. Environmental Protection Agency 2016.)

A study from Avató & Mannheim, 2022, shows the distribution of solid waste in EU from 2021, which emphasizes the individual share of the most known types of municipal solid waste (MSW). Therefore, the biggest share of the waste out of all the MSW is depicted to be organic waste, with the share of 40%, followed by paper – 18%, plastic – 11%, glass – 5%, textiles – 4%, metal – 3% and the category of "others" – 19%, that most likely include mixed waste that cannot be safely put in the earlier-mentioned categories.

Another study report written by Hassan, Kasmuri & Basri, 2019, shows as well household waste composition in percentage, where it can be observed the share of each type of waste disposed from the humans' daily activities in the European Union from 2021. Organic waste is identified the one with the biggest share of 44,3 %, followed again by plastic – 11,7%, paper – 9,4 %, garden waste – 5,9 %, textile – 3,9 %, glass – 3,5 % and metal – 2,2%. In other words, it can be seen the volumes of each type of waste thrown away in a usual house from which the MSW is further composed of. Further analysis will be concentrated on these particular types and their ways of value restoration.

1.2 Organic Waste. Composting

Organic waste is the biodegradable material of plant or animal origin. It can present food waste, garden residues, timber waste and biosolids. (Australian Government, Department of Climate Change, Energy, the Environment and Water 2023.) From the first sight, it does not mention any issue regarding the pollution of the environment. This stereotype is wrongly understood by the public, since its accumulation on the landfills results in soil contamination and the release of greenhouse gas emissions. The organic waste, also referred to as biowaste, breaks down into carbon dioxide, water and methane with the help of the living organisms from the environment it is disposed on. If not valued properly, the biowaste still presents a danger.

There are two ways of recycling the organic waste: composting and anaerobic digestion.

Composting refers to the natural breakdown and stabilization of organic materials in an environment that promotes the generation of heat through biological processes, leading to thermophilic temperatures. The end result is a sufficiently stable product that can be stored and applied to land without causing negative environmental effects. Another definition refers to composting as a managed aerobic procedure involving successive microbial populations that engage in both mesophilic and thermophilic activities, resulting in the creation of carbon dioxide, water, minerals, and organic matter that has been stabilized. Two types of composting have been observed: aerobic and anaerobic. Aerobic composting is referred to the breakdown of organic waste in the presence of oxygen (air). The final outcomes of this biological process include carbon dioxide (CO_2), ammonia (NH_3), water and heat. It is also a type of oxidation, as the chemical equation of the aerobic composting is the following:

$$COHNS + O_2 + aerobic\ bacteria \rightarrow CO_2 + NH_3 + other\ end\ products + energy \quad (1)$$

Anaerobic composting involves the breakdown of organic waste without the presence of oxygen. The resulting byproducts include methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and small quantities of various gases and low-molecular-weight organic acids. The chemical equation for anaerobic composting is the following:

$$(COHNS) + O_2 + aerobic\ bacteria + energy \rightarrow C_5H_7O_2N \quad (2)$$

Advantages of composting can be seen in the waste stabilization, which confer putrescible organic waste and inorganic waste into a stable state, causing less environmental damage if disposed on land or water. Another reason for taking composting into consideration is the pathogen inactivation, as the highest temperature biologically generated during the chemical process is 60 degrees Celsius, meaning that the pathogens such as bacteria and viruses are inactivated and the byproducts from the initial waste can be securely arranged on land and/or as fertilizers on soil. (Polprasert 2007, 88-95.)

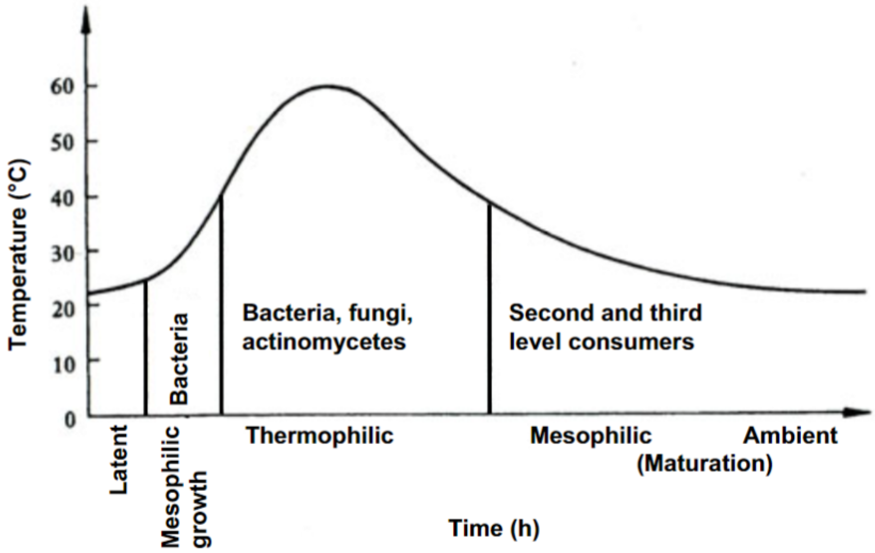


FIGURE 1. Temperature and microbial growth development (Polprasert 2007, 93, attached with the kind permission of IWA Publishing).

Figure 1 illustrates how temperature influences the life of bacteria during the composting process. It can be seen that the process has biological phases: latent, growth, thermophilic and maturation. It can also be broken down into mesophilic, thermophilic and maturation. During the mesophilic phase, the heat stabilizes, and under the activity of endogenous microorganisms (second and third level consumers), the compost pile transforms into nutrient-rich mass that can be later used as in the farming industry. (Papale, Romano, Finore, Lo Giudice, Piccolo, Cangemi, Di Meo, Nicolaus, & Poli 2021, 1-3.)

Moreover, the composting prevents soil erosion, as it improves soil quality, as well as it impacts the improvement of the plant quality and harvest. As a total, it is advantageous in reducing the impact of climate change, as it creates a circularity of natural biomaterial, and it can heavily combat the formation of the landfill waste. (US Composting Council 2023.)

The success of a composting process depends on the types of organisms that break down and stabilize the bio wastes. If there are imbalances in the chemical and physical outer conditions, the compost piles are subject to a failure in the right microbial growth. Because of this uncertainty and inability to control every aspect for the right chemical reaction to happen, composting can have a negative

side, since the mostly expected concentrations of nutrients and the destruction of pathogens have decent chances of not happening. Consequently, the crucial nutrient parameter is the carbon/nitrogen (C/N) ratio, which should be 20/1-40/1. Phosphorus (P), while sulphur (S), calcium (Ca), are the nutrients needed to form, as they are the fundament for cell metabolism development. (Polprasert 2007, 97-100.)

Anaerobic digestion (AD) is a process lead by bacteria, where organic matter, such as wastewater biosolids, and food wastes, is subject to decomposition in an environment without the presence of oxygen. The production of biogas during anaerobic digestion occurs within a closed container known as a reactor. (United States Environmental Protection Agency 2023.)

It has similarities with the earlier-mentioned anaerobic composting, yet they are different mainly because of the end-products of the chemical reaction. While anaerobic composting eliminates methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and other gases and organic acids, AD produces biogas, which is a compound formed between methane and carbon dioxide. The chemical reaction can be broken down into the following:

$$Organic\ matter \rightarrow CH_4 + CO_2 + H_2 + NH_3 + H_2S \qquad (3)$$

The advantages of AD stand for the biogas produced. Methane is captured and can be used as a renewable energy, which is supports carbon neutrality policy, as it generates energy without impacting the carbon dioxide emissions in the atmosphere. Together with electricity generation, it provides plant nutrition through the separation of the digestate, which can be later used as an organic soil fertilizer. It also goes along with 80% less odour from farm slurries, as the whole process is conducted in sealed digesters, and not in piles and pits as the anaerobic composting. (Agri-Food & Bioscience Institute 2016.)

1.3 Recycling

As a matter of fact, according to the Waste Framework Directive of the European Union, the definition of recycling is "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes". This thesis will report the general theoretical explanation of two types of waste recycling as examples: plastics and paper, in order to give an overall view to the public of what processes can be considered as recycling.

1.3.1 Plastics

The worldwide generation of plastic was observed to be consistently growing at an annual rate of 8.4% since 1950. In 2018, plastic production was calculated to be of 0.36 billion tons, and it is supposed to raise up to 0.50 billion tons by 2025. Around 60% of plastic waste (PW) is not recycled and ends up in the environment. The major types of plastics in high request are referred to polyvinyl chloride (PVC), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyurethane (PUR), and polystyrene (PS). PW is mainly composed from these leading plastic types. For instance, the packaging field represents the biggest consumer of plastics and assists as the primary contributor to PW due to the large-scale use of disposable items. PW produced by the packaging industry mainly includes PET, PS, PE, and PP. PW degrades in a slow pace and is capable of existing in the environment for hundreds of years, since it is listed under the label of nonbiodegradable waste. (Huang, Wang, Ahmad, Ahmad, Vatin, Mohamed, Deifalla & Mehmood 2022, 1-3.)

Recycling is defined as the process by which plastic waste (PW) is the subject of re-extrusion. Mechanical recycling is the most common method, because of its cost-effective advantages. The first stage of this type of recycling includes shredding or cutting, where PW is cut into tiny particles by utilizing saws or shears to alleviate easier handling. From the shredding phase, the plastic residues can go through a variety of processes.

Huang et al. 2022 describes the further processing of shredded plastic. It can be depicted that there are at least 5 ways to reinforce plastic material into human use again. There is pyrolysis and liquefaction that results in fuel oil, fuel gas and char carbon as the final products of the process. Moreover, other processes that can be applied onto shredded plastic are the mixing with tar-bitumen, which produces the road pavement that can be used further in road construction purposes. Another procedure is mixing shredded plastic with concrete, obtaining light weight aggregate used in structure development. As well there is the process of washing and agglutination of the plastic shred, which refers to another process of extrusion. This method breaks down into more processes, being palettization, granulation, moulding and wood-plastic composite. From extrusion to fuel oil production, plastic waste management can serve for prevention of landfill extension, as well as it can reduce the fossil fuel use through the implementation of the fuel oil and char created through pyrolysis and liquefaction.

APChemi 2022 describes the process of pyrolysis, which is a chemical reaction involving heat breakdown at 380°C to 650°C. The outcome of this reaction stays in the production of three aggregation states of plastic resulting products: 50% to 90% of pyrolysis oil (liquid product), 10% to 50% of pyrolysis gas (gaseous) and 5% to 10% of powder residue (solid product).

There is a well-based perspective for the end products of this chemical reaction, since the results stands in the production of gaseous and liquid fuels, from which renewable energy is produced in a sustainable way. Because pyrolysis and liquefaction reactions are oxygen-independent, it means that there are very low to no emissions of carbon dioxide as a byproduct.

1.3.2 Recycling of Paper

Paper recycling is one of the most commonly applied recycling methods practiced to waste materials. Recycled paper is a whole part of paper and pulp production, with estimated recycling rate in Europe of about 72% in 2012, including a growth of 20% from 2000). Recycled paper is considered to be a key raw material component in the paper industry. Together with that, it promotes considerable

environmental and resource recovery advantages in a circular perspective of paper waste management. (Pivnenko, Eriksson & Astrup, 134-135, 2015.)

Tutak 2019 describes the growth and the development of paper recycling in Europe between 1991 and 2012. A considerate growth is noticed between these years, from 40% of recycling rate in 1991, 47% in 1995, 52% in 2000, 62% in 2005, 69% in 2010, 70% in 2011 to the final of 71,7% in 2012.

The recycling of paper undergoes a variety of steps which are concluded in a study made by Petrova, Kochev & Karagyozova-Dilkova, 2021. The general process of paper recycling is resumed in the following steps described in the earlier-mentioned study: the wastepaper undergoes a variety of steps to be obtained as a final product of pulp, meaning that it needs to be taken through the processes of pulping, course screening, cleaning, brightening, fine cleaning, ink removal, decolorization and washing before it is dried and result in pulp.

While collecting the fibrous raw material in the first step, it is taken into consideration that there may be other materials than paper from the earlier use, such as printing ink, scraps and leftovers or mineral particles. Therefore, while starting the process of paper recovery and recycling, the pulp needs to be cleansed in order to achieve a paper-like final product. The goal of the treatment of recovered paper is to generate a homogenous mass that contains enough fibers to create further paper material. (Grossmann, Handke & Brenner, 165-169, 2014.)

Therefore, it can be concluded that the collection of utilized paper and board is the first step in the recycling process. Paper for recycling must be processed separately from other materials. It is substantial that it is treated separately from other waste as contaminated papers are not acceptable for recycling. It should be noted that the final generation process for paper recycling is identical as the process utilized for paper products created from virgin fibers. Nevertheless, the recovered paper should be treated with thorough cleaning and sorting. For papers that contain ink from printing, the ink must be removed through the process known as de-inking. After the paper waste is delivered to the paper mill, a slushing process is begun, as the paper needs to be transformed into pulp, a mass from which it is easier to extract and remove the non-fibrous materials considered

as contaminants. The fibers are deeply cleaned, and the obtained pulp is filtered and screened more times to turn it into an applicable material for papermaking. The ink is removed in the de-inking stage in order to be able to make the resulting paper whiter and purer. In this de-inking process, the ink is removed in a flotation process with the effect of the air that is blown into the solution. The ink sticks to the bubbles of air and it is delivered to the surface of the solution where it is divided. The next step after de-inking is when the fibers can be bleached, commonly with hydrogen peroxide. After bleaching, the pulp can be processed into paper. The pulp resulted from recycling can be mixed with virgin fibers, depending on the quality of the recycled pulp and the necessity to strengthen the further paper by adding more raw material. Nevertheless, some types of paper, for example newspapers, can be produced from 100% recycled pulp. (European Paper Recycling Council 2024.)

1.4 Landfilling

Sanitary landfilling and open dumping is one of the most popular technology of disposal of MSW treatment. It is used mainly because of the economic advantageous causes as low cost and low-technical requirement. The European Union (EU) Directive on waste landfills has outlined particular aims for diminishing the amount of disposed waste and regulating the landfill sites. Landfilling represents the disposal, constriction and embankment fill of waste on suitable landsites. Currently, landfill is considered affordable in terms of financial scopes, as it requires relatively low investment and simple technological equipment. It is the only method of disposal that can include every type of MSW. Even if lately, the landfills have been decreased in use and volume due to new MSW treatment methods, it still remains as a reliable way of waste management worldwide. The major causes of emissions and environmental problems from the landfills are: the waste materials themselves left on the site, the emissions from the waste transportation, the wind as a factor of spreading the waste, the toxic dust created on the landfill surface, landfill gas and leachate generated from the rain runoffs. (Vaverkova 2019, 1-10.)

The research of Vaverkova, 2019, shows data of European countries with the MSW generated in 1995 and 2016 as a measurement of kg/capita together with their share in percentage on the landfills. Therefore, some countries of interest have been selected for the purpose of this thesis in order to compare the values of the quantity of MSW from both of these years and to understand the dynamics of the amount of MSW generated throughout a period of 21 years. Therefore, the values of the kg/capita for Sweden are ones of the lowest one for both of the years, as in 1995 the value is 386 and in 442 in 2016. The following country leading the list of the lowest MSW volume is Romania, with the quantity of MSW of 254 kg/capita in 1995 and of 228 in 2016. Estonia has also comparatively low values of 370 kg/capita in 1995 and 327 in 2016. Finland had its values of 437 kg/capita in 1995 and 504 kg/capita in 2016.

Moreover, this research illustrates the amount of MSW expressed in kg/capita and how much of that waste is disposed on the landfills in several countries from Europe as to show which countries have the least and the most landfill share in percentage from all the methods of MSW management in those countries. Therefore, from the original source it has been the selected the numbers of landfill share of extremes, meaning that the information from this thesis shares data from the countries with the least (Sweden, Denmark, Germany, Austria, Finland – under 3%) and the most (Romania, Greece, Malta – above 80%) landfill share in Europe. Even if the disposal on the landfills is deemed to be a reasonable method of MSW treatment, it can be surely considered as the least rational towards environmental friendliness (Chakravarty & Kumar, 2018, 203-2019).

Landfilling can be relied on for a short period of time since the landfill recovery can take up to hundreds of years. The by-product of the landfills are biogas and leachate which is a serious concern for the sustainability of the environment. Together with biogas and leachate, it also creates unpleasant odours, unsanitary approach of unsorted waste and obviously, air pollution. Biogas or landfill gas (LFG) is the result of the decomposition process of organic matter. The production of biogas varies in the time period on the landfill, which can be seen on table 1. Table 1 represents the complex example of bacterial waste decomposition as a long-term effect from aged waste repositories. The process when the most active gases are formed is during the anaerobic decomposition of organic matter.

MSW is composed of about 150–250 kg of organic carbon per ton of waste, while the microorganisms turn a considerable part of the waste into landfill gas during anaerobic processes. (Białowiec 2011, 7-10; Vaverkova 2019, 4.)

Environment	**Aerobic**	**Anaerobic**			**References**
Time period	**Phase I**	**Phase II** *3-6 months*	**Phrase III**	**Phase IV**	Abedini 2014, Vaverkova 2019, Ziyang, Luochun, Nanwen & Youcai 2015
CO_2	0%-35%	35%-63%	64%-49%	40%-60%	
H_2	0%-10%	10%-20%	20%-0%	-	
CH_4	-	-	0%-50%	45%-6%	
O_2	20%-5%	5%-0%	-	-	
N_2	80%-50%	50%-30%	30%-2%	2%-5%	

TABLE 1. Composition of each stage of landfill degradation and the gas formation

The produced LFG with 40–60% methane contains an average heating value of 17,765 kJ/N m3. Since the efficiency of the energy conversion is 34%, the generated electric energy is around 2.5 kW h/N m^3. (Zappini, Cocca & Rossi 2010, 5066.) When the methane and carbon dioxide are combined together in the results, it can be considered that the total amount of greenhouse gas emissions on the landfill would be about 1.37 E+09 kg of equivalent carbon dioxide (Lombardi Carnevale & Corti 2006, 3212). As the LFG production starts one to two years after the waste disposal, its generation is influenced by the waste composition, moisture content, temperature, the landfill age (Scheutz & Kjeldsen 2019, 351). Even if the LFG is started to be produced 1-2 years later from the moment of its dumping, it continues to form during 15 to 25 years (Vaverkova 2019, 5). Additionally, according to Directive 31/1999/CE: “LFG shall be collected from all landfills receiving biodegradable waste and the LFG must be treated and used. If the collected LFG cannot be used to produce energy, it must be incinerated”.

1.5 Waste-to-energy

From the MSW treatment technologies it can be deducted that the landfill gas is deemed as a greenhouse gas, generating in a big part the gas methane. Nevertheless, the treatment of MSW from landfills can be transformed into a possibility of resource recovery as a sustainable production of energy, being referred as “waste-to-energy” (WTE) technology. There are three essential methods of WTE technology: thermal conversion (incineration, pyrolysis and gasification), biochemical conversion and landfill. Most often, the thermal conversion is referred to the incineration method, as it is the most utilized technology from this type. Incineration is meant as a thermal combustion of waste through eliminating its volume in a furnace by treating it with very high temperatures (750 to 1000°C) in order to use its energy value for heat/or electricity production. This method is a well-preferred one, as the total mass of the waste is reduced by 70% and the total volume is diminished by 90%. The incineration process can be seen in three stages: incineration, energy recovery and air pollution. As MSW is burned, a lot of toxic air pollutants are being released, such as SO_x, CO_x and NO_x compounds. Pyrolysis is another technology where the waste is thermally treated in the absence of oxygen. There are three types of pyrolysis methods which are conventional pyrolysis (550–900 K), fast pyrolysis (850–1250 K), and flash pyrolysis (1050–1300 K). The third type of thermal conversion technology is gasification, where MSW is transformed into CH_4, CO_2, CO, H_2 and H_2O and some inert gases with the presence of high temperature of 4700°C, where there is no combustion and a controlled amount of oxygen and/or steam. Because of the reactor design and operational parameters, this process produces methane and other hydrocarbons. The process also results in harmful contaminants such as small char particles, tars and ash. (Tolzu, Özahi & Abuşoğlu 2016, 809-810.)

The next classification of WTE technology is referred to biochemical conversion, where the waste reacts with microorganism enzymes. The two main types of this method are anaerobic digestion and composting, which were described previously in this report. Landfilling is also considered a technique of waste treatment that should use scientific-based principles of well-functioning in order to minimalize the damage the landfill is producing to the environment. Sanitary landfilling is referred to scientifically processed MSW treatment with the waste being dumped

on the soil, where detailed engineering planning was performed in order to facilitate a neat construction of the landfill with leachate and gas leaking control. (Vaverkova 2019, 1-10.) If referred to an engineering approach to a construction of a sanitary landfill, the study of Vaverkova 2019 represents a schematic display of how it should exist for temporary environmentally safe aims. Therefore, a sanitary landfill should contain a specially arranged place with an in-built landfill space construction underground, containing a groundwater monitoring system, leachate collection system at the bottom of the deposit, a landfill liner as well as a leachate treatment system together with gas control properties and a final top cover of the space.

Even though landfilling is the most common method of MSW treatment worldwide, recent technologies tend to rely on incineration, as it substantially reduces the waste mass by 70% and 90% of its volume. It serves as an efficient landfill space reduction, as it shortens the necessity to use large areas for waste disposal on the open spaces of ground. Nevertheless, is not treated according to environmental standards, thermal treatment of MSW can produce serious environmental issues regarding the discharge of the pollutants being a byproduct of the process. (Tolzu, Özahi & Abuşoğlu 2016, 809-810.)

1.6 Waste-to-Energy incineration plants and their environmental impact

The incineration plants are also referred as waste-to-energy (WTE) plants. The principle of the plant goes in the combustion that produces heat which enhance the huge amount of steam in boilers that transmit it to the turbogenerators in order to generate electricity. The procedure starts from the collection of waste which is transported by vehicles to the WTE plant sites. As there is a lot of waste mass operated, the vehicles are weighted before and after they discard the waste into the big refuse bunkers. The weighting is done in order to be able to track the amount of waste collected from every vehicle. For the purpose of controlling the release of waste odours into the environment, the air in the refuse bunkers is controlled to be under the atmospheric pressure. In the conference paper of Kaneko, Tsurumine, Poon, Onuki, Dai, Kawabata, & Matsubara from 2019 it can be found the path of the waste in an incineration plant. A grab cane is used to

pick the waste collectively from the bunker in order to be fed up into the combustion chamber. The incinerator operates at 850 to 1000°C, and therefore, the inside walls of the incinerator are being protected by a lining of refractory material so that the corrosion and the high heat do not destroy the plant from the inside out. The volume of the remaining waste, called ash, after the combustion is reduced to 10% of its initial volume. Even if the environmental pollution is still linked with the incineration system of waste treatment, it should be noted that the modern technology prevents the air contaminants from escaping the 100-150 m chimney, as an efficient flue gas cleaning system comprising electrostatic precipitators, lime powder dosing equipment and catalytic bag filters are installed to stop the dust and pollutants from the flue gas before it is released into the atmosphere. Also, the ferrous scrap metal which cannot be burned is selected from the ash with the help of its magnetic properties and it can be later recycled and used again. The ash can be also used as a mixing component in the construction industry, roads, pavement and road barriers. (National Environment Agency of Singapore 2023.) Moreover, if analysing the release of environmental pollutants, it should be noted that toxic fumes, such as dioxins, are by-products of the chemical reaction of waste combustion. They present environmental and health concern as threats. Nevertheless, for the sake of the public and natural safety, they are stopped from their release into the atmosphere in the incinerator's fabric filters, having them trapped in the filters and later disposed of on engineered landfill sites.

1.7 Waste management in Finland

In Finland, paper and cardboard, glass packaging, metal, plastic, mixed waste, hazardous waste, electrical equipment and batteries are sorted separately as a rule (infoFinland 2023). Finland is a country with a significant presence in extractive industries, as evidenced by the overall volume of generated waste.

The majority of this waste originates from activities such as mining, quarrying, construction, and manufacturing. Municipal waste constitutes a relatively small percentage, ranging from 2% to 3% of the total waste produced. Even though the share of MSW is small as a share, it should be still addressed as a waste

management issue, as it comes directly from the citizens and it is in the same power of influencing the state of the environment as the other types of waste. In 2020, municipal solid waste represents a percentage of 2.8% of all the waste generated in Finland, which in numbers it depicts approximately 3.3 million tons in total, meaning 596 kg of household waste per inhabitant.

EastCham Finland ry published an article in 2020 describing the share of the waste recovery methods applied in Finland. Therefore, the biggest share belongs to energy recovery – 58%, then material recovery (without aerobic and anaerobic digestion) – 28%, aerobic and anaerobic digestion – 13,5% and landfilling of 0,5%. As these values reflect the percentages that each of the used recycling methods are used to treat MSW in Finland and 58% represents the energy recovery method, it is referred to incineration. Incineration has been introduced in Finland from 2012, and since then, it has played the most important role in MSW addressing. This article also refers to a significant decrease of landfill applications from 2012 onwards. If by 2012, the percentage of landfill was about 45%, by 2020, after the appearance of incineration technology, it is continuously leading to only 0.5% of its share in 2020. Therefore, the main goal of MSW management in Finland is to permanently remove all the landfills.

The previously mentioned article also describes the evolution of MSW treatment in Finland from 1997 to 2020. It can be seen from the graph of the article that the energy recovery from landfilling started to skyrocket during the years around 2012, the incineration was introduced at that time in Finland. Therefore, it can be seen that if there were low values (close to 0) during 1997-2010, from 2011 it can be depicted in a raise of the energy recovery up to around 1500 thousand tons of treated waste. Moreover, the landfilling decreased in the same years, as the incineration started to be applied at full scale, having values of around 1300 thousand tons of treated MSW during the years of 1997 to 2010, and having it decreased to close to 0 thousand tons of treated MSW by landfilling by 2020. Material recovery with aerobic and anaerobic digestion stayed at higher values throughout the years and then raised during the years of 2012 to 2017 from a constant of around 800 thousand tons of treated MSW through this method from years of 1997 to 2012 to 2000 thousand tons beginning with 2017 onward.

Waste-to-energy approach is led by waste incineration plant with energy recovery, which are represented by plants with combined heat and power (CHP plants) that are aimed to produce electricity and heat to entire districts for a city. From the total waste directed to the CHP plants of 58% from the total MSW amount, in Finland, nearly 1% of Finland's electricity and around 8-10% of district heating is produced annually, in relevance with the heating demands and weather conditions in wintertime. From the data of 2021, there are already 10 CHP plants operating with a total capacity of 1.9 Mt/a. Incineration is regulated by the Waste Incineration Regulation, which is based on the EU Industrial Emissions standards, and it is a legal proof that incineration plants are not a danger for the environment and health, since their activity is controlled under environmental permits. To be noted, an important EU regulation accorded to the environmentally safe authorization of waste incinerations is the Waste Incineration Directive (Directive 2000/76/EC). BAT (best available technologies) conclusions have been adjusted to EU level for waste incineration which submit for example emission levels for airborne emissions and monitoring conditions. BAT conclusions for waste incineration are put forward for renewal around every 10 years. Therefore, municipality controls most of CHP plants. There are four of the municipal energy companies, which are named Kotkan Energia, Lahti Energia, Oulun Energia and Vantaan Energia (where the city of Vantaa owns 60% and the city of Helsinki owns 40% of the energetic capacity). Nevertheless, Fortum Plc. represents the biggest plant owner in Finland which is a government-controlled energy company. (EastCham Finland ry 2020).

CHP represents a technology that generates electricity and thermal energy at high performance while utilizing a variety of technologies and fuels. The losses of heat are diminished on an on-site power production, as the heat can be used in municipal facilities as process heating, steam, hot water, and even cold water. CHP can be built near an individual facility or it can supply thermal energy and power for an entire district. CHP can be a reliable energy supplying system for all day around, and also in the case of grid outages or technical errors, as it can be technologically connected with other types of energy supplier methods, such as solar photovoltaics (PV) and energy storage.

Nearly two thirds of energy is wasted generated during conventional separate power and heat production. Mostly, the waste is eliminated into the atmosphere during generation, transmission and distribution. CHP is a highly effective technology in heat preservation, as it captures it and perform on an 80 percent efficiency, compared to 50 percent for conventional types of technology (e.g. on-site boiler). This is why CHP systems offer less carbon emissions than separate heat and grid power, as it can maintain energy losses at a low level. (United States of Environmental Protection Agency 2023.)

1.8 Waste Management in Moldova

The main technology of waste management in the Republic of Moldova is the same as in most of developing countries - landfilling, with approximately 1158 landfills being operated with a total area of a 1,229 ha (Scorpan, Taranu, Comendant, Taranu, Druta, Trescilo & Renita 2018, 92-94; National Centre of Environment n.d.). Landfills are directed by local public authorities and normally do not follow environmental regulations. The statistical data announces that the amount of solid household waste is continuously increasing, from 2172,8 thousand m^3 in 2008 to 3043,1 thousand m^3 in 2018. (National Centre of Environment n.d.)

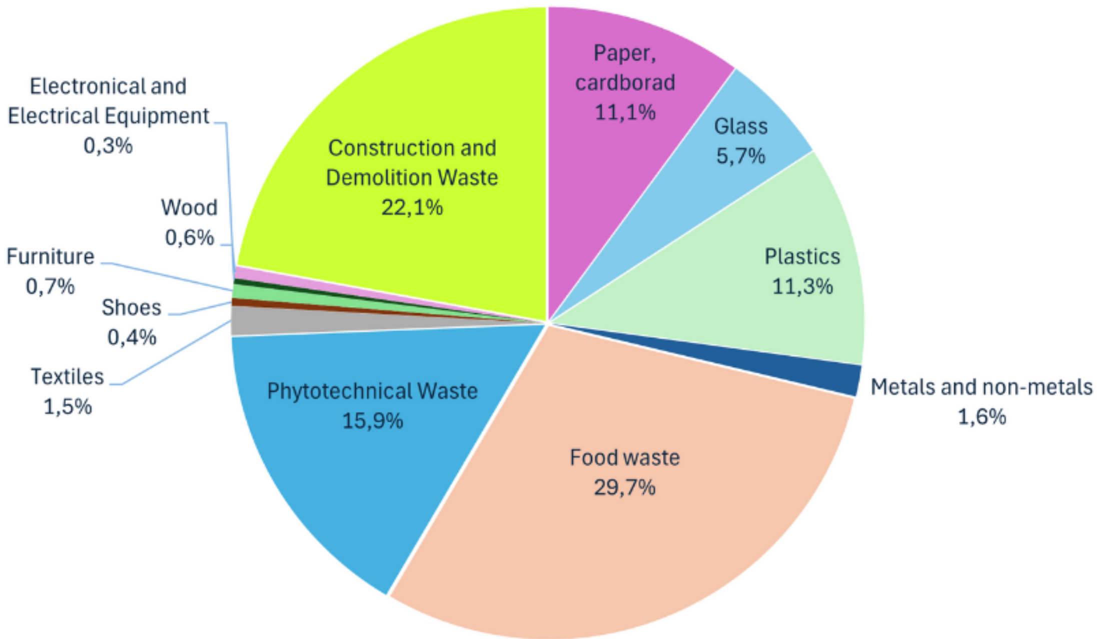


FIGURE 2. Morphological composition of MSW in Moldova (Government Decision of the Republic of Moldova 248/2013).

Figure 2 depicts the share of each type of MSW in percentage, one of the biggest shares representing the organic waste, followed by construction and demolition waste and phytotechnical waste. Nevertheless, the country is working on attracting foreign investments from European Union banks in order to help address the MSW management. Referring to the current situation, according to the Decision of the Government nr. 248 from 10-04-2013, it can be highlighted that waste management in the Republic of Moldova represents a harsh and unsolved issue, both from an organizational and legislative point of view. Although the field of environmental protection is regulated by around 35 legislative acts and over 50 Government Decisions, the legal aspect of waste management needs to be essentially improved, as both the review and modification of the legal and institutional framework, as well as the creation of an integrated system, are necessary of technical and ecological regulation in the areas of selective collection for recycling, valorisation, elimination and storage of waste. The current waste deposits are not exploited properly as they are not compacted and not periodically covered with inert materials for the purpose of preventing landfill fires and the spread of unpleasant odours. There is no strict control of the quality and quantity of waste that is evacuated from the warehouse and municipal solid waste collection points. There are no facilities for the recovery of the produced biogas or for the recovery/treatment of the filtrate. The access roads to the warehouses and inside them are not maintained, the means of transport are not washed when leaving the warehouses. The warehouses do not have fencing, with a proper entrance and warning signs. Another negative aspect of inadequate waste management is the fact that many recyclable and useful materials are stored together with non-recyclable ones, thus losing a large part of their useful energy potential (paper, glass, metals, plastics). Being mixed and contaminated from a chemical and biological point of view, their recovery represents a tough action. Nevertheless, the same Government Decision reflects the fact that waste management includes all the activities of collecting, transporting, treating, valorising and disposing of waste. The responsibility for waste management activities stays within their producers/citizens, in accordance with the "polluter pays" principle, as well as with producers/production companies, in accordance with the "producer's responsibility" principle.

2 SCOPE

The scope of the thesis is to propose the waste-to-energy technology as a solution for Moldova’s issue with MSW management. As the main way of waste management in Moldova is still landfilling, this thesis is underlining a comparative study case between the waste-to-energy practices in Finland and why this practice should be also considered in Moldova.

3 MATERIALS AND METHODS

The methodology used for this thesis is scientific research through scholarly sources such as articles, reviews, conference papers, legislation documents, books, reports concerning the MSW management in Finland and the Republic of Moldova. References were taken from the earlier-mentioned types of scientific materials and were included in the thesis information. The main scientific engines and official scientific publishers used for the research are ResearchGate; Elsevier Ltd. through ScienceDirect; IEEE Xplore; MDPI; Semantic Scholar; Open Access (OAPEN) that represents a platform coordinated with publishers with the scope of presenting a quality controlled collection of open access books; official governmental online websites as United States Environmental Protection Agency, National Environment Agency of Singapore, National Library of Medicine from the National Center for Biotechnology Information – PubMed Central as officially controlled by the United States government; documents supported by the Government of South Australia, the Republic of Moldova (Governmental Decisions); CRC Press, Taylor & Francis Group; Wikimedia Commons for certain images in order to be able to legally use the internet-accessible images for the purpose of a visual representation of the thesis written information as support material; National Center of Environment of the Republic of Moldova; MedCrave Online Publishing Group; InfoFinland published by the City of Helsinki; Journals of UTHM (Universiti Tun Hussein Onn Malaysia) Sage Global Academic Publisher; European Paper Recycling Council (EPRC); EastCham Finland, which is an international chamber of commerce; documents from EUR-Lex – Access to European Union Law; Springer; APChemi, which is a patented technology provider for cost-efficient pyrolysis and pyrolysis oil purification; Agri-Food and Biosciences Institute of the UK.

As a method, the strategy of a comparison was made through an in-depth literature review whilst taken into study purposes, as to highlight the MSW management practices in Finland and then in the Republic of Moldova based on the example of the Kymijärvi II Waste-to-Energy incineration power plant with Combined Heat and Power (CHP) principle located in Lahti, Finland. Additionally, a thorough analysis of another comparison between incineration and landfilling was made in order to build up reasons to support the overall aim of this thesis: the

Republic of Moldova needs to cease landfilling and start implementing an Waste-to-Energy incineration technology. The analysis of comparison between incineration technology and landfilling was done through various graphs adapted from the original sources that precisely explain the superiority of Waste-to-Energy technology towards landfilling. The two of the main studies were used to present the comparison between landfilling and incineration. The first one is written by Assamoi & Lawryshyn, 2012, where two scenarios were evaluated based on waste treatment resulted after diversion in the City of Toronto, Canada. The first scenario was taken as status quo, where all the residual waste was landfilled. The second scenario presents the process development in the case of the incineration of nearly 50% of the residual waste together with the remainder being landfilled. Electricity was counted in each scenario. The second study is conducted by Han, Long, Li, & Qian, 2010. This research emphasized electricity generation and greenhouse gas (GHG) reductions through comparing MSW landfill and incineration systems with three different electricity generation efficiencies — 10%, 21%, and 24.7% (3 scenarios).

These research sources were used in this thesis to stress the superiority of Waste-to-Energy incineration technologies towards landfilling proven through large-scale experiments, observations and studies from larger group of qualified scientists. Both studies analysed scenarios of the development of incineration and landfilling towards future years under different perspectives: energy efficiency, electricity generation, GHG emissions, cost efficiency.

4 RESULTS AND DISCUSSION

4.1 Waste-to-energy incineration CHP: The Kymijärvi II power plant

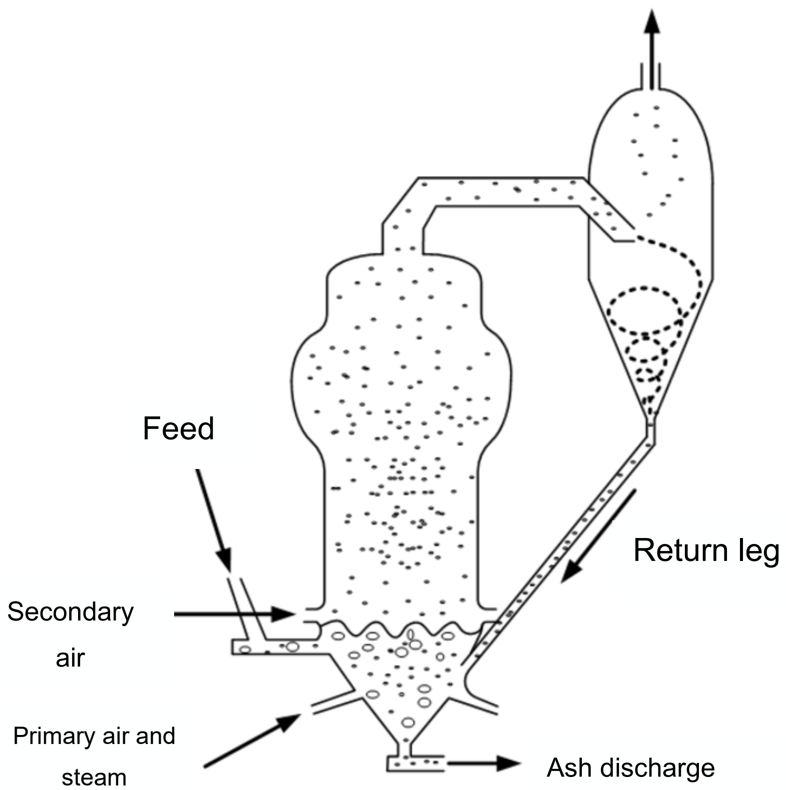
The Kymijärvi II power plant (picture 1) represents an individual facility that produces municipal and industrial waste-based solid recovered fuel (SRF) out of source-sorted household and industrial burnable energy waste to generate district heat and electricity in Lahti, Finland.

PICTURE 1. Kymijärvi II power plant (Ojp, CC BY 3.0).

It is owned by Lahti Energia Oy and it is one of the world’s first gasification plants that consumes SRF obtained from plastic, wood and paper waste that are not suitable for individual material recycling, combined altogether. The Kymijärvi II is transforming Lahti region into a zero-waste city, diminishing substantially the landfill MSW and its territory. The plant was launched in May 2012 and the new technology is supported by Finnish Valmet Technologies Oy. Based on gas purifying technology, it generates 90 MW of district heat and 50 MW of electricity for the entire region of Lahti, including neighboring cities. Kymijärvi II plant is in a new spotlight worldwide, as it is a relevant example for a sustainable and green management of waste. It illustrates a piece of future on how powerplants need to be constructed further. (Makron Oy 2024.)

4.2 Technology of Kymijärvi II powerplant

Once the truckloads with separated waste are disposed to the power plant location, it is necessary that plant suppliers do the shredding of the waste to a particle size of 6 cm together with its moisture reduction of below 20-30%. After the processing, the waste is delivered to the plant's fuel depot.



PICTURE 2. Principle of a Circulating Fluidized Bed (Mattern, CC BY 3.0).

Then, the SRF is transferred into two 7,500 m^3 silos where it is processed in order to be fed into one of the two Circulating Fluidized Bed (CFB) reactors, as shown in picture 2. These reactors, also referred to as gasifiers, include hot sand and limestone that are conveyed through a fluidization process with air that enters from the bottom of the CFB reactors. The fluidized bed together with the SRF are treated with a 900°C temperature while being mixed. The oxygen will not be enough to cover the burning of the fuel, and therefore, it will decompose into a gas. The gas going to the top of the reactor needs to be cooled down in a cooling system that will drop the temperature to 400°C. As the mixture in this tank was mixed with more components, it will contain impurities that are going to transform

into a solid ash after the cooling. The impurities are formed from metals, i.e. Pb, Zn and alkali chlorides. They fall down to the chamber floor with the support of a nitrogen injection once every minute to be further collected and removed from the tank. The plant contains 12 cooling chambers which include 300 high temperature ceramic fiber (candle) filters that are significant for the removal of metal particles, leaving the purified gas to go through them. The ash is then removed and it can be further used in the cement production and construction industry, i.e. road building.

The new gas has an equal value as the natural gas regarding its purity, and it can be safely fed into the power plant boiler. Even though the tank corrosion is a frequent problem related to the nature of the feedstock, the issue in Kymijärvi is managed by a high-quality gas purification system. Moreover, there is an efficient electricity production due to the high steam temperature and pressure. The efficiency goes up to 90% with the boiler temperature of 540°C that is operated on the condition of under 121 bar of pressure. (RICARDO-AEA Ltd 2013).

4.3 Advantages of CHP

The plant manages to provide power to 87.000 inhabitants. The local customers can benefit from lower heating and electricity bills compared to the conventional utilized fuel for the district provision. Since the non-recyclable waste is being burnt and taken advantage of, it helps to switch the focus from the natural resources and it helps to build up a circularity between waste and production of new energy. In this way, the full potential of the waste is being evaluated and taken into real value, without losing its benefits. CHP is a technology with a low environmental impact, because the gasification of biofuels and co-combustion of gases in the coal-fired boiler substantially reduces CO_2, SO_2 and NO_x emissions. (RICARDO-AEA Ltd 2013.)

One of the major benefits of this kind of plants is volume diminution. The potential of volume reduction could be considered on 75% and more, since the incineration helps to prevent more need of land use and it even reduces the space area. Moreover, the ash generated after the combustion can be recycled as an additive

in the construction industry in, for example, concrete or aggregate. (Wang, Shao, Matovic, Whalen 2014, 472)

WTE incineration is also considered one of the most environmentally sustainable ways of MSW disposal. WTE incineration plants diminish the requirement for energy from fossil-fuel fired power plants, which utilize important raw materials and generate nearly four times the particulate emissions as WTE incinerators. Moreover, if analyzing the release of environmental pollutants, it should be noted that for the environmental and health safety, dioxins and furans resulted from waste combustion and found in the exhaust fumes released into the atmosphere are caught in the incinerator's fabric filters where they are stopped from moving forward in the air and further are disposed of in landfills with a sustainable engineering approach, as mentioned earlier. (Porteous 2001, 157-167.)

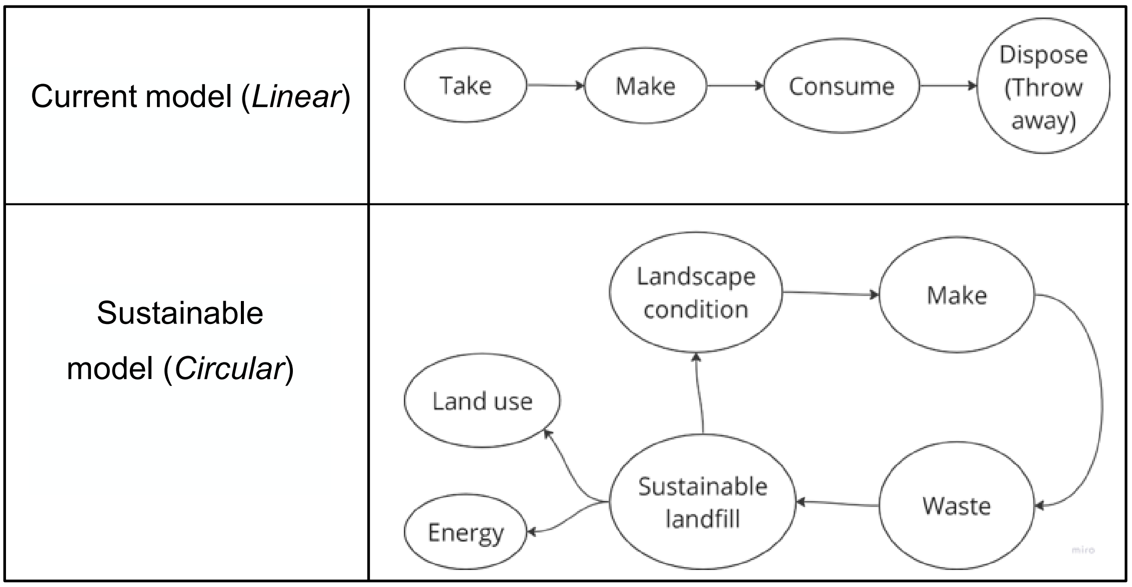
Even though the incineration power plants are used in a smaller quantity than the fossil fuel ones, they produce half of the CO_2 of a fossil fuel plant per MWh of electricity generated, as the study conducted by Muñoz, Vargas, Balmant, Arena, Ordonez & Mariano in 2017 demonstrate that a WTE plant releases approximately 0.4 mg of CO_2 per MWh of net electricity generated if analyzing it near the fossil fuel power plants which emit 0.84 mg of CO_2 per MWh of electricity produced. Therefore, in comparison, WTE plants emit fewer contaminants to produce electrical energy.

In relevance with the updated operating data analyzed by WTE industry of the USA, if 1 metric tonne of MSW is combusted in a contemporary WTE power plant produces a net of 600 kWh of electricity, meaning that it can exclude the necessity to mine a 1/4 tonne of high quality US coal or importing one barrel of oil. Therefore, WTE is the only option to avoid landfilling of non-recyclable wastes, where the waste decomposition releases carbon dioxide and methane. They represent greenhouse gases that are still escaping from the modern sanitary landfills in an approximate percentage of 25%, even if there is a gas collection network and biogas utilization engines or turbines. (Psomopoulos, Bourka, & Themelis 2009, 1719.)

One of the most highly valuable advantages of incineration consists of its chemical principle to destroy harmful bacteria that are characteristic to hazardous and medical waste. There are mobile incinerators that exist for the purpose of an improved control on illness pandemics. Even if hazardous and medical waste combustion normally does not substantially contribute to energy generation because of its relatively small amount of volume and weight, it is still worthy to note its contribution towards a more sanitary environment. (Karim & Corazzini 2019, 35-36.)

4.4 Reference to the Republic of Moldova's MSW treatment

Picture 3 depicts the difference between the linear and sustainable model of landfilling. It must be mentioned that the current model of MSW treatment in Moldova is a linear one, meaning that there is no circularity from the production of the goods consumed by the citizens and the disposal of the MSW produced in the country.



PICTURE 3. Current and future model of landfilling.

It can be noted that a way to treat disposed waste can be through energy, which means to apply the waste-to-energy method of waste treatment. From the earlier example of Kymijärvi plant, a parallel of comparison can be traced and deducted that the Republic of Moldova can uptake this example and follow the technology

as in Lahti, Finland. The application of this example can be also done for a district only. In other words, if an incineration power plant is to be built in Moldova, it could be situated in the center region of the country, near the capital, where the transportation of the waste throughout all the country could be convenient. It can be made in such a way that the powerplant could feed up with energy only a district of a city, from the outskirts of the capital, for instance. In this way, the new experiment of the country could be tested on a smaller area, which should be linked with a traditional power source in case of incineration plant failure.

4.5 Comparison between landfill and incineration

A study effectuated by Assamoi and Lawryshyn from 2012 reflects the proof of superiority of incineration towards landfilling that depicts the comparison the energy generation between incineration and landfilling.

The study reflects a representation of the potential energy produced from the landfilling and incineration, attributed for each of the years from 2011 to 2039. It can obviously be seen that the amount of energy generated from the incineration is considerably higher than from the landfill, according to the graph it is nearly as 3 times of more energy (expressed in MWh) that can be used from incineration already from our present year of 2024, regardless of the assumptions made for further years of 2039. Therefore, it is already efficient nowadays to recover energy from incineration, which has up to 4 times more potential than from the landfill (as analyzed from the graphs shown in the scientific report). If analyzing the energy generated from landfilling from 2023, there is nearly 55000 MWh recovered, whereas for incineration, there is the value of around 215000 MWh recovered. Also, the incineration offers a more constant energy production, as the landfill has a certain period of time (in the anaerobic process) when most of the gases are formed and can be extracted. Figure 1 can show it from a more complex view that after the anaerobic peak, the energy is starting to decrease and the energy recovery cannot be further processed.

This study also reflects the interdependence of waste management cost regarding the distance from the city core, as the study contained the relationship

between the costs of waste residues transportation from a theoretical city core to both a landfill facility and a possible situation of an incineration plant at 50, 100, 200 and 500 km. It can be seen that the landfills appear to be the most cost-efficient, since there is only one way to transport the residues and the landfill sites are the final destination, compared to the incineration plants that need further processing and therefore, transportation for the second waste residues after the combustion (ash and metal residues transportation). (Assamoi & Lawryshyn 2012, 1028-1029.)

Nevertheless, it should be noted that the cost-efficiency of the landfill option is an extremely short-term advantage that from the initial stage requires minimum investments and long-term environmental damage on a serious concern. On the other hand, incineration facilities are considered to perform better in terms of more electricity production, larger environmental offset and better consideration towards the environment and the circularity of waste, which the linear-purposed landfill cannot offer at this stage, especially in the Republic of Moldova. (Assamoi & Lawryshyn 2012, 1028-1029.)

The second study used for this thesis research is from 2010 from the Shanghai University from China by Han, Long, Li & Qian, 2010, compared through a research on the electrical generation and the total greenhouse gas (GHG) emission reduction for both MSW landfill systems and incineration plants. The results show that for the landfills, the total electricity generation is 198,747 MWh, and the total GHG emission reduction is 1,386,081 tons CO_2 during a 21-year operation period. For incineration systems, the total electricity generation is 611,801 MWh, and the total GHG emission reduction is 1,339,158 tons CO_2 during a 10-year operation period with the electricity generation efficiency being of only 10%. The research proves as well that electricity generation grows faster than the GHG emission reductions with the enhancement of electricity generation efficiency, which in this study was taken in three scenarios: 10%, 21% and 24.7% of electricity efficiency. The research also shows that the incineration systems prove superiority in LFG application and GHG emission reductions.

Starting from the 10% of electricity generation efficiency in an incineration, it can

already be mentioned that the incineration system produces from up to 9-10 times more energy expressed in MWh than the landfill system if the case of 2018 if analyzed between the landfill electricity generation potential and the incineration where the scenario of 24.7% efficiency is being compared. In other words, if around 18000 MWh of electricity can be generated from the landfill gas potential in 2018, for the incineration of 24,7% efficiency, nearly 170000 MWh of electricity can be produced. If the case of the incineration of 21% is taken, there is around 140000 MWh of electricity produced, which makes it 7 to 8 times more productive than the landfill potential. If the case of 10% efficiency of the incineration is compared to the landfill energy produced for the same year of 2018, it should be noted a difference of 3 to 4 times more electricity generated in the favor of incineration, with around 65000 MWh of electricity produced.

The three different scenarios of 10%, 21% and 24.7% electricity generation efficiency is deducted from the different temperature and pressure in the incineration systems. In other words, the more temperature and pressure is applied, the more electricity efficiency it will get. Nevertheless, it should be considered that the more these two factors are raised, the greater is the chance for boiler erosion and corrosion. Therefore, high-quality boilers and advanced equipment is required for more efficiency to be worked on.

If referred to GHG emission reductions, while the electricity generation efficiency raises from 10% to 21%, the GHG emission reductions only increase by 37%. Also, when the electricity generation efficiency grows from 21% to 24.7%, the GHG emission reductions only increase by 9%. Therefore, the increase of GHG emission reductions is less differential if comparing the electricity generation given the function of the electricity generation efficiency growth. As long as MSW disposal is the most important goal for environmental safety, it is considerable to meliorate the electricity generation efficiency for GHG emission reductions with proper advanced technology.

When referring to GHG emission reduction and LFG recovery, the incineration system is undeniably eminent to a landfill system, as higher emission reduction and LFG utilization can be obtained with an incineration system. As an example of an analysis of the same year of 2018, if the landfill can reduce around 120000

tCO_2, the 10% efficiency incineration can reduce up to 190000 tCO_2, the 21% efficiency – around 250000 tCO_2 and 24,7% - 265000 tCO_2.

Electricity generation is directly proportional to electricity generation efficiency. However, it should be considered at a greater scale the improvement of electricity generation efficiency in order to acquire more emission reduction. The growth of GHG emission reductions is not as proportional as that of electricity generation. It is primordial to restrain CH_4 emission from landfills because its emission reduction is on a considerable smaller proportion than that of incineration. It should be mentioned that methane emission from landfill is one of the most important influencers to adjust the potential of the global warming. (Han, Long, Li & Qian 2010, 315-321.)

4.6 Challenges of implementing WTE incineration technology in Moldova

The incineration method is considered to be an integral and complex technology that demands a large amount of investment both financially and technically, as specific specialists are needed to keep the plant's performance maintained. The operation costs are very high, as skilled professionals need to be involved in both building of the plant and then for the good running of the system. As there are high updated standards for environmental safety of this kind of plant's performance, there is a thorough request of skilled personnel in the engineering as well as in the environmental-legislative part of running such a plant. For the Republic of Moldova, it would be a case to attract foreign specialists from this domain of WTE incineration plant operation, and that would mean to invest in the labor market opportunities as well as the salaries that should be considerable enough for foreign workers. It should be also kept in mind that the working system needs to be adapted in the English language, as the foreign professionals would likely operate in English and not Romanian. Therefore, the Republic of Moldova needs to be prepared to open the labor market for English-speaking people that would agree to work for the incineration plant under a decent salary. Also, in order for the plant to be highly efficient, it requires specific equipment that can deal with the majority of the waste that is currently laying on the landfills and is obviously not separated. The plant needs to be able to cope with volatile metals such as

mercury, thallium and cadmium, as well as with PCB-included waste and radioactive waste that needs to be treated with uncommonly high destruction efficiency. Even if radioactive waste can be incinerated as all the other waste, the high amount of contaminants which are released after the combustion need to be treated with special dust and gas stopping filters and also the ash resulted after the process needs to be controlled for the immobilization of radionuclides. The incineration plant needs to ensure a complete consumption of the flue gas and residues, since the secondary waste resulted after the incineration process demand a further treatment/recycling. There is a considerable risk of heat loss which needs to be also preserved and kept under strict regulations, as from the corrosion, erosion and boiler fouling procedures, the heat recovery can be inefficient. The plant can still work under environmentally safe conditions, it is just needed to be operated under rigorous regulation and precise equipment so that there is minimal heat loss and dangerous vapors released in the atmosphere. (Buekens 2013.)

It is known that the Moldavian population has a huge gap in environmental knowledge, as the incineration process is believed to be extremely harmful for the society, when in fact, this belief should be considered as an outdated mentality that needs an urgent update. People should know more about the benefits of an incineration plant with CHP technology, as the society will only have to benefit from the low costs of electricity and/or heat, together with the elimination of the negative impacts on the landfill and leachate on the soil and underground water. Unfortunately, the society knows about the negative influence of the toxic fumes released in the atmosphere by a chimney of an incineration plant, without realizing that nowadays, the technology has advanced and follow up the environmental regulations and standards which allow only the toxic-free emissions from these incinerators through specially designed filters that remove the dust, toxic gases and particulate matters from the emissions that are released in the environment. The major changes in a state come primarily from the people themselves, and therefore, education could be a good motivation for people to open their mindset into accepting such a plant project.

5 CONCLUSIONS

Given the efficient practices in Finland, the Republic of Moldova needs to take into consideration the building of an incineration plant that would use the MSW disposed on the landfills as a current technology. As small as it can be, this kind of plant project would be extremely beneficial for the space reduction of the landfills in Moldova, since there is a heavy dependency and reliance on the only method of waste management here. The waste volume can be reduced by 75%, meaning that the Moldavian lands could have a new life of adequate utilization. WTE incineration is a note-worthy alternative for the current waste management in Moldova, at is includes a lot of benefits, i.e. greenhouse gas emission reduction compared to landfilling and energy production. However, the successful chances of its realization are challenged by the cost, investors, and the possible impacts to recycling practices. Even if the financial and technological investment is overwhelming in the initial stage, it should be still considered for the sake of long-term benefits that landfilling is incapable of offering. The comparative study case proves that starting from the 10% of electricity generation efficiency in an incineration power plant, it can be already noticed that the incineration system produces from up to 6 times more energy than the landfill system. Since the non-recyclable waste is being combusted and taken advantage of, it helps to switch the focus from the utilization of natural resources and it contributes to building up circularity between waste and production of new energy. It would be also advantageous for Moldova to adapt its waste management systems to innovative ones, as to support the transition to the European Union while integrating the European waste treatment standards locally. This thesis focused on proving that incineration plants do not represent a threat for the environment and public health, because their activity is regulated under environmental permits, as one of the most important legal documents that states a stringent control over the incineration plants' functions in the EU is the Waste Incineration Directive (Directive 2000/76/EC). Therefore, more academic involvement is needed to analyze the EU waste treatment standards for the purpose of helping Moldova present its potential waste incineration plant initiative projects to the EU financial funding systems that could grant financial resources to construct it, as, based on Moldova's small geographic surface area, 1 waste-to-energy incineration plant would be enough to address the landfill issue.

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