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Title of thesis

Municipal solid waste incineration as a sustainable way of energy production

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Table of contents

Chapter 1: Introduction

Daily human activities are tightly linked to the flow of resources; as civilizations advanced, our usage of materials increased, and as a result, these resources were collected (Brunner, 2015), and it immediately raised people's worries. The necessity for cleanliness and waste quantity reduction arose due to waste amounts.

The non-hazardous, biodegradable or nonbiodegradable, carbonaceous or noncarbonaceous, reusable or unusable solid waste that we produce in our daily lives and during regulatory and commercial operations is known as municipal solid waste, MSW includes household, commercial, trade in goods, workplace, and street waste as well. (Ngusale, 2012). Construction and Debris from deconstruction, sewage sludges, and manufacturing waste and more are exempted. (Tonjes, 2012).

In the Indus Valley's ancient city of Harappa, an advanced system of wastewater drainage and solid waste disposal was one of the first incidences of human waste management that can be found, which was approximately 4,500 years ago (Rodda, 2004).

The background of municipal solid waste (MSW) burning in incineration in the EU extends back to the early twentieth century, when several member states developed the first waste burning plants (Smith, 2005). But that did not happen until the 1970s, that MSW incineration gained traction in the EU as a feasible waste-to-energy (WtE) replacement. The importance was made clear by the oil crisis of researching alternate energy sources during this time, waste-to-energy generated new interest in technologies such as incineration (Smith, 1978).

With the advances in emission control technologies have been achieved to address Environmental challenges. Flue gas cleaning utilization of equipment and advancements in combustion procedures considerably lowered MSW incineration emissions (White, 2000).

Additionally, the EU enforced strict emission criteria for waste incineration plants, encouraging the use of cleaner and more efficient technology (EU Commission, 2005). Considering the limitations, the EU progressively acknowledged MSW incineration as an integral component of integrated waste management techniques. nations like Germany and Scandinavia countries as well were early adopters of waste-to-energy incineration in the late twentieth century (Andersen, 2010).

These nations successfully integrated MSW burning into their waste management policies, viewing it as a complimentary strategy to recycling and waste reduction efforts.

The production of urban solid waste is rapidly increasing in developing nations like China as a result of rapid urbanization and consumerism driven by globalization. (Mian, 2016). Nevertheless, according to a World Bank assessment, a decrease in population growth and economic activity in 2020 due to the COVID-19 pandemic pandemic According to estimates, the amount of municipal solid waste (MSW) produced worldwide has grown by 2-3% from 2019 estimates(Kaza S. &., 2021)

This thesis examines how solid waste from municipalities is currently disposed of and shows how incineration may be a more environmentally beneficial choice than other using techniques already available, assess the data gathered, and make judgments about the current situation and in the last 20 years.

The following goals must be met in order to accomplish the main objective:

- Perform a comprehensive analysis of the waste that is currently being produced.
- Examine the classic sources side by side of energy production compared to WtE concept.
- Have an estimate of ways of development regarding sustainability.
- Examine municipal solid waste's potential for global generation of energy and its potential contribution to the world's energy balance.

Chapter 2: Literature review

By 2050, it is anticipated that there will be 9.7 billion people on the planet, increasing by about 2 billion in the next 30 years (United Nations, 2024). As seen in figure (1), there is a positive economic growth, which is resulting in the increase of merchandise purchases and needs for energy, increasing energy consumption per capita and waste generation, representing the biggest problems the world is facing in the last decades (Brunner, 2015). Nevertheless by 2050, it is anticipated that waste production in developing countries will be doubled. (Kaza S. Y., 2018).

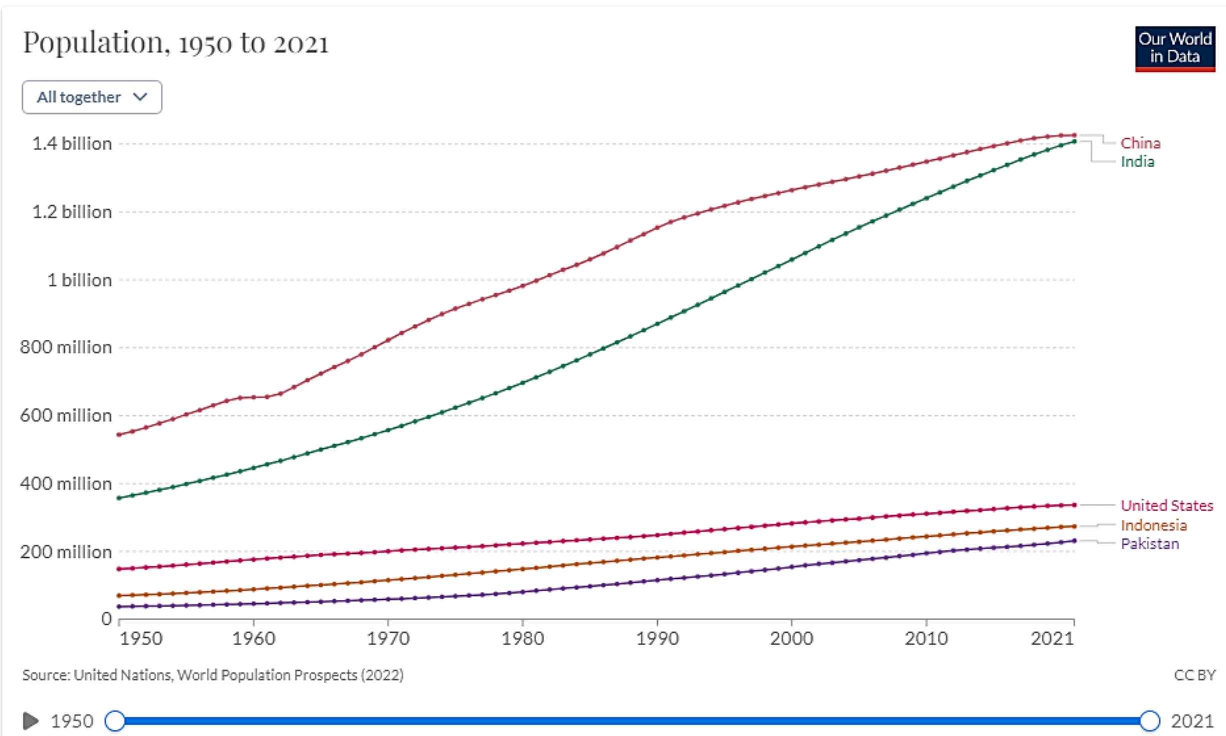

Figure 1: World population (Ritchie *et al.*, 2023)

Municipal waste definitions can vary from one country to another, which reflects different waste management methods. 'Municipal waste' is defined as for the purposes of national yearly reporting of municipal waste to Eurostat.

Households produce most of the municipal waste, while equivalent waste from workplaces, enterprises, and other groups is also included. The majority of the municipal waste supplied is waste that is collected by or on behalf of local authorities and disposed of via the waste management system. (Hoornweg, 2012).

In the past, disposing of MSW in landfills was the conventional approach for its low cost of construction and availability of land. Regardless of this, it is known that disposing of MSW in landfills has a significant detrimental effect on the environment due to things like ground water pollution, greenhouse gas emissions like methane (CH_4) alongside with carbon dioxide (CO_2), and the expansion of the area of land used for waste disposal (Siddiqua, 2022).

According to GMI (2021), MSW is one of the main sources of anthropogenic methane emissions, accounting for over 60% of waste that ends up in landfills and disposal sites worldwide. When organic waste, such as food scraps and yard debris, decomposes improperly, methane gas is created at these disposal locations. This gas contributes to global warming by polluting the atmosphere.

Lots of nations and local governments are putting into practice different waste management techniques to solve this problem, including composting, anaerobic digestion, and landfill gas collection systems. These techniques assist in capturing or converting the methane created by MSW, decreasing emissions, and utilizing it as an energy source. To counteract climate change and encourage sustainable development, waste management techniques, MSW methane emissions must be reduced.

Waste comes from two main sources, household-related activities and industrial hazardous waste. In the year 2012, Every year, more than four billion tons of waste are produced worldwide, of which 1.6 to 2 billion tons are MSW (Mavropoulos, 2015). Today, MSW produced in 2023 was 2.3 billion tons of the total waste and is expected to increase to 3.8 billion tons by 2050 (UNEP, 2024).

In the year 2008, more than 3.5 billion individuals were unable to access the most basic waste management services, such as organized waste disposal from their residential homes. Despite the global development, even after 10 years, 33% of the global waste produced is still mismanaged, over 2 billion people cannot access waste collection and waste recovery, and disposal facilities are unavailable for more than 3 billion people, according to the World Bank estimates in 2018 (UNDP, 2024).

The main issue is linked to urban areas and is anticipated to escalate even more due to the swift urbanization that will occur in the next 15 years. The absence of proper waste management services and the prevalence of open dumping are evident in the significant quantities of plastic waste that are deposited in our oceans each year, totaling over seven million tons each year (Mavropoulos, 2015). These numbers indicate the risks of neglecting having proper urban structure which secures basic elements of waste collection and treatment.

These increases of energy and waste requires a new development look on how humanity proceeds with waste management which requires a new shift, Waste-to-energy (WtE) concept.

Chapter 3: Research methodology

The methodologies employed in this study are described in this chapter, The methodology has 2 approaches. The first is to conduct a comprehensive review on Municipal Solid Waste Incineration (MSWI) as a sustainable method of energy production. The second is to conduct a survey to understand the general opinions regarding waste incineration and its impact on the environment. The aim is to determine the energy potential of MSW and also the potential risks associated with its use for energy production.

1. Research Design

The methodology used is to analyze and conduct a systematic review and collection of information obtained from existing literature, previous studies, research articles, and reviews related to MSW, waste-to-energy (WtE) technologies, sustainability, and WtE efficiency. In addition, a questionnaire (Annex 1) has been constructed to gather data that can be analyzed quantitatively to understand the distribution of attitudes and opinions regarding waste incineration among the surveyed population.

2. Data Collection

Two methods were used. The first method to collect data is to search and access relevant literature using academic databases such as PubMed, Scopus, Web of Science, Google Scholar, and institutional libraries. The second method is related to the survey, is to share the survey within social media groups, LinkedIn, and SurveyCircle to gather data about the public opinion and attitudes towards MSW.

3. Data Analysis

Related information regarding MSW is extracted from reliable sources and articles, evaluated and organized based on thematic areas like technological aspects, regulations and policies in the EU and economic feasibility.

The data gathered from the survey is assessed and analyzed using Excel to calculate arithmetic averages and standard deviations, in order to study the tendencies of every aspect researched in the survey.

4. Scope and Delimitations

This study specifically focuses on Municipal Solid Waste Incineration (MSWI) as a method of solid waste management and energy production. The other WtE methods are solely considered in the context of comparative analysis and are not the primary focus of this research. The survey considered the opinions and attitudes of the public, which includes students, researchers, and academics but also the general public and industry professionals.

5. Limitations

- Concerning the first part, this study is potentially limited by the availability of information that considered specific aspects of MSWI, and includes a certain bias towards publications in English thereby potentially ignoring research and articles specific to certain countries that are in other languages
- Regarding the second part, the study also depends on a public survey which is a valuable tool but can create biases in answers such as: not enough diversification in the population which means that the results do not reflect the broader public, social bias (socially acceptable but not necessarily truthful answers), public knowledge which means that the survey may contain complex questions that the general public isn't well-informed about.

Chapter 4: Results and Discussion

Results from the literature research

1. Municipal Solid Waste (MSW): The perspective on EU Regulation

The term municipal solid waste (MSW) refers to a wide range of waste products produced in urban and suburban areas from residential, commercial, and institutional sources. Managing MSW has emerged as a crucial component of environmental governance as populations increase and cities become more populated. MSW is defined and regulated in the European Union (EU) according to a thorough regulatory framework that aims to reduce the negative effects that waste generation and disposal have on the environment and human health.

Several legislative directives that create a unified framework for waste treatment, collection, disposal, and resource recovery incorporate the EU's approach to MSW management. In addition to providing member states with guidance on MSW management, these regulations seek to create consistent guidelines that support resource efficiency, public health, and environmental sustainability.

- According to Directive (2008/98/EC): the Waste Framework Directive: The Waste Framework Directive (WFD), which is at the heart of EU waste regulation, establishes fundamental guidelines for all waste management operations. The "waste hierarchy," which is introduced in this directive, places the greatest emphasis on waste prevention and is followed by recycling, reuse, and recovery, and disposal as a last choice. By favoring sustainable and preventive methods over simple disposal, this hierarchy strives to reduce the negative effects on the environment. (European Commission, 2008).
- EC Directive (1999/31/Landfill Directive): Another essential part of EU waste control is the Landfill Directive, which aims to lessen the environmental risks connected to landfills. As organic waste breaks down in landfills, large volumes of methane, a powerful greenhouse gas, can be released, endangering local health and accelerating climate change. In order to solve these problems, the Landfill Directive forbids the disposal of specific waste types, including liquid waste, infectious medical waste, and other hazardous

chemicals, and establishes stringent guidelines for landfill management (European Commission, 1999).

The directive's mandate that member states progressively cut back on the quantity of biodegradable municipal waste (BMW) discharged in landfills, with a target of 35% less than 1995 levels by 2020, is a crucial component. In order to manage the biodegradable components of MSW more sustainably, this reduction objective encourages member states to investigate alternate waste treatment techniques such composting, anaerobic digestion, and incineration (Scarlat et *al*., 2019).

- The Directive 94/62/EC, which addresses packaging and packaging waste. Packaging waste, which includes items like plastics, metals, papers, and glass, makes up a significant amount of MSW. Targeting this particular waste stream, the Packaging and Packaging Waste Directive establishes guidelines for the avoidance, repurposing, and recycling of packaging materials. It requires manufacturers to take into account the environmental impact of their packaging and sets recycling goals for various packaging materials, promoting the use of recyclable, reuse, and compostable materials. According to the directive, 65% of all packaging waste must be recycled by 2025, and by 2030, that percentage will rise to over 70 percent (European Commission, 1994).

The Palin Granit Case and the Meaning of Waste

The definition of "waste" under EU law is based on the ruling of the European Court of Justice (ECJ) in the Palin Granit case (Case C-9/00). The question in this case was whether leftover granite from quarrying activities could be considered "waste" under Directive 75/442/EEC of the EU Waste Framework Directive, which defines waste as any substance that the holder "discards or intends or is required to discard."

The European Court of Justice (ECJ) made it clear in its decision that items that are thrown away, even if they may have future economic worth, can be regarded as waste. The case demonstrated that the fundamental criteria is purpose to discard, which means that things that are kept forever without explicit intentions for their future use—even if they have an opportunity to be reused—are usually regarded as waste (European Court of Justice, 2002).

Since then, the Palin Granit ruling has shaped EU waste legislation by reaffirming that the concept of waste places a high priority on environmental preservation and necessitates the prudent handling of items whose future uses are unknown (European Environment Agency, 2019a).

2. MSW Management Challenges: Waste-to-Energy and EU Regulations

For a number of years, WtE power plants have been operational, However, Current technology utilized in Municipal Solid Waste Management (MSWM) is still facing many issues around the world and must be oversaw carefully. Aside from that, numerous studies have been undertaken to lower the amount of MSW while improving current WtE to increase the quantity of energy generated
as a type of technology. MSWM is essential for controlling modern WtE power plants in an environmentally friendly and effective method. Many studies on MSWM for local locations have been conducted, which included MSWM and strategies of current techniques, therefore offering the recent description and making additional thoughts for adjustments.

In 1975, the European Union passed the first waste Framework Directive, marking the beginning of its efforts to control garbage and waste flows (1975/442/EEC). The mandate has raised serious issues with harm to the health of humans and the environment as well as the unlawful transportation of both hazardous and non-hazardous waste. Since then, a number of other nations have attempted to control garbage and waste flows. According to the European Commission, the main document that outlines waste policy for EU Member States is the Waste Framework Directive (2008/98/EC). The 1975 Waste Directive has undergone several revisions.

The three documents that provide the foundation of a waste policy that is applicable throughout the EU are the Waste Framework, Waste Shipment Directive, and Hazardous Waste Directive, Even though the mentioned articles described all of the basic concepts, waste treatment principles, and detrimental effects of waste on the environment and the general population, the waste hierarchy was left out of the text. Additionally. Before their respective directives were put into effect at the start of the 2000s, common waste treatment activities such as incineration and landfilling did not have any environmental criteria to adhere to. These issues were finally overcome (European Union, 1975).

The management of waste is a prominent issue for most governments throughout the world, and the European Union is not an exception to this rule. Incineration of municipal solid waste (also known as MSW) is a frequent practice in the European Union (EU) for the management of waste, and it has been done for several decades. and it has been done for several decades. In 2018, According to the European Commission, 10% of the EU's total energy output from renewable sources came from the incineration of solid waste from municipalities (2020). Concerns have been raised however, regarding the effects that incineration of MSW may have on the environment and the general population health. Those effects include ash residues, greenhouse gas emissions, and pollution of the air, As a direct result of this, there has been an ongoing discussion in the EU over the viability of incinerating MSW as a source of renewable energy.

3. Viability of MSW Incineration for Renewable Energy in the EU

Studies have been conducted over the course of several years to investigate the viability of municipal solid waste incineration in the European Union (EU) as a source of renewable energy. At the beginning of the 2000s, A few studies examined how burning municipal solid waste (MSW) affected both the economics and the environment. For example, Lemieux (2003) conducted research that examined the effects of landfilling versus incinerating municipal solid waste (MSW) on the environment in the EU. According to the findings of the study, landfilling had greater negative effects on the environment than incineration did across the board, including in terms of climate change, human toxicity, and ecotoxicity. On the other hand, the study brought to light the fact that there are a number of unknowns about the influence that incineration has on some aspects of the ecosystem, such as acidification and eutrophication. In a similar vein, Tanguay-Rioux (2021) conducted an investigation that analyzed the economic and environmental performance of municipal solid waste incineration in the EU. According to the results, incineration of municipal solid waste is economically viable and has fewer negative effects on the environment than landfilling does in most categories. However, the study concluded that there was uncertainty regarding the impact on several environmental categories.

Determining whether or not municipal solid waste incineration can continue to be a sustainable source of renewable energy has received more attention over the past decade. As an illustration. Vehlow (1996) conducted research to examine the viability of municipal solid waste incineration in Germany. The findings imply that by providing a reliable source of renewable energy and reducing greenhouse gas emissions, municipal solid waste incineration has the potential to support the country's sustainable development. However, the study also revealed that there were issues linked to the sustainability of incinerating municipal solid waste (MSW), includes the requirement to improve the effectiveness of processes and reduce emissions of contaminants like furans and dioxins. These difficulties were revealed by the research.

Incineration of municipal solid waste was discussed in a study on the sustainability of biomass usage in the EU that was released in 2020 by the European Commission 2020 (European Union, 2000). The paper underlined the potential for incineration of municipal solid waste to contribute to the EU's objectives for renewable energy and reduce the amount of waste that is landfilled. However, the paper also found several sustainability difficulties related with incinerating municipal solid waste (MSW), including as concerns with air pollution, emissions of greenhouse gases, and waste management hierarchy. The study recommended assessing the feasibility of burning solid municipal waste on an individual basis, with consideration given to the unique circumstances surrounding each individual plant.

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4. Preventive Concept and Precautionary Principle in Waste Management

Growing concerns about emissions and the limited impact of technological advancements have led to the creation of the preventative concept. It came about because of these two factors. It has become abundantly clear that advancements in technology alone cannot ensure that there will be no emissions if there is not also effective waste management that begins with the production process.

The waste hierarchy is built on a few guiding concepts:

- In response to growing worries about emissions and the limited impact of technical breakthroughs, the preventive concept has evolved. It became evident that emissions free could not be achieved by technology developments alone without effective integrated waste management that starts with the production process (Hulpke, 1997).
- Taking safety precautions is something that is encouraged by the precautionary principle, even in circumstances when there is insufficient evidence to support the assumption that there would be a negative effect.

There are four primary aspects: first, the use of the prevention principle when uncertainty is involved; second, the provision of proofs by the activity's proponents; third, the investigation of all possible alternatives prior to the approval of potentially hazardous activities; and fourth, the public's knowledge of and involvement in the decision-making process. (Kriebel, 2001).

5. Waste Management Hierarchy

5.1. EU Waste Regulation and Waste Management Hierarchy

In 1975, the European Union approved the first waste Framework Directive (1975/442/EEC), marking the beginning of its efforts to regulate waste (European Union, 1975), It raised serious issues regarding the unlawful transportation of hazardous and non-hazardous waste, as well as damage to the environment and the general population. Although there have been several amendments to the 1975 Directive, the Waste Framework Directive (2008/98/EC) (European Environment Agency, 2008) is the main legislation that specifies the waste plans of EU Member States. EU-wide waste legislation is based on three documents: the hazardous substances Directive, Waste Shipment Directive, and Waste Framework. Even so, the literature described above covered all the essential concepts, waste management rules, and the harm waste does to the environment and the general population.

The Solid Waste Management Hierarchy, which is shown in figure (2), provides a systematic approach to waste management, with the aim of reducing the environmental impact of waste while promoting sustainability and resource conservation.

Reducing waste's detrimental effects on the environment and public health is the main goal of waste management. Managing trash production, encouraging waste reuse, assisting biological recovery, recycling, raising awareness of non-recyclable waste, and making sure that waste treatment and disposal do not harm individuals are all necessary to achieve this goal.

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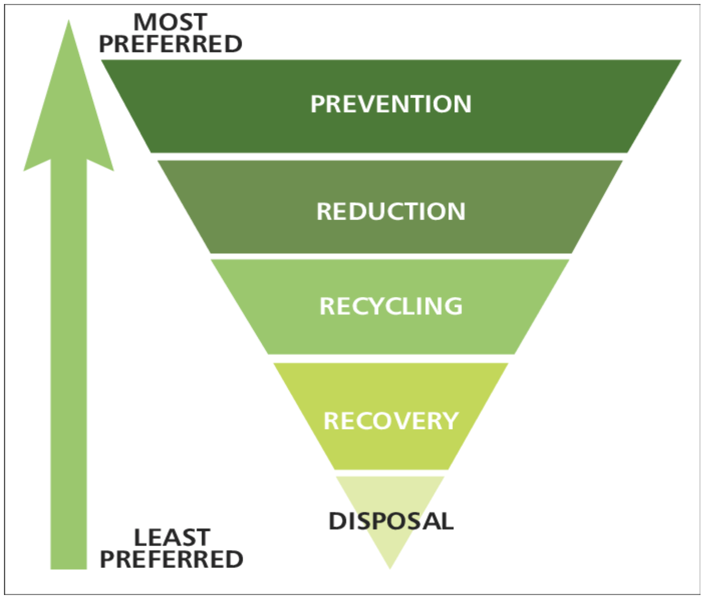

Figure 2 : waste management hierarchy (Komen, 2013)

According to the US Department of Energy (US DOE), MSW is comprised of 82% biomass and 18% petrochemical wastes, which are both combustible materials. This classification by the US DOE puts MSW in the category of biomass fuel as a renewable energy source (Psomopoulos, 2009). Recycling is a better choice than utilizing waste for energy recovery if it is financially possible and does not hurt the environment. However, even in nations with highly developed recycling facilities, a sizable quantity of municipal solid waste (MSW) is still left behind after recycling. Instead of dumping MSW in landfills under such circumstances, it becomes more ecologically and financially sensible to utilize it for energy recovery.

5.2. Waste management hierarchy limitations

The waste hierarchy took more than 40 years to develop and is used as a guideline in EU waste management. Yet, it might not be as effective as it could be at reducing waste output. The biggest obstacle is the basic idea of waste itself—how it is defined. In 1996's Communication on Community Strategy, the fuzziness of the waste/product line was acknowledged. To solve the problem, you must define "waste." The Strategy additionally calls for the identification of all waste, regardless of its monetary value, in compliance with a 1996 declaration by the Commission of the European Communities. Similarly, "any item or material that the holder discards or plans to discard, regardless of its worth. (Commission of the European Communities, EU, 1996), waste is anything that is being discarded, regardless of its material worth.

The criteria used to determine when an option has been exhausted are at the center of the dispute because they can significantly affect whether the hierarchy is successful in achieving the dematerialization of the hierarchy outlines. These factors include how the priority order is implemented specifically, when it is acceptable to move from a higher priority waste management method to a lower one, and which practices must be exhausted before lower-level alternatives become intriguing (Wolf, 1988). Therefore, implementing the priority order presents challenges.

6. MSW Generation

6.1. Worldwide

Worldwide, an estimated 2.01 billion tons of MSW are created each year, with one-third of that amount being disposed of in ways that are harmful to the environment. Moreover, it will increase to almost 3.40 billion tons by the year 2050. The most popular methods of disposing of MSW generated around the world are open dumps and landfills, as shown in the graph. Only around 11.1% of the total amount of MSW generated is incinerated (Wold Bank, 2022).

Waste collection is a crucial part of waste management, but the expense varies greatly depending on economic level. Nearly universal waste collection services are available in upper-middle- and high-income countries, while in low-income countries, about 47% of waste is collected in cities, but this percentage drops sharply to 26% outside of cities. About 44% of waste is collected in Africa below the Sahara, compared to at least 90% in Europe, Central Asia, and North America (Wold Bank, 2022).

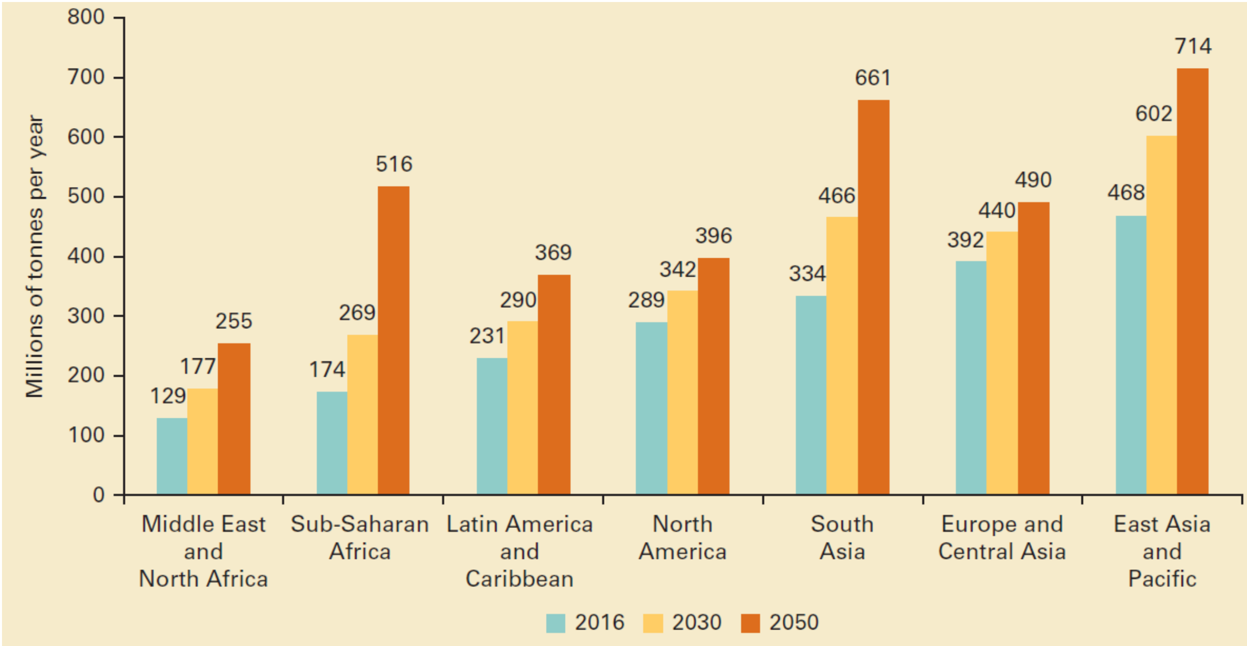

Figure 3: waste generation depending on region (millions of tons/years) (World Bank, 2022)

6.2. In the EU

Figure (4) examines the per capita production of municipal waste in 30 European nations from 2004 to 2022 while taking these limitations into consideration. Municipal waste produced in 2022 is used to rank countries in ascending order.

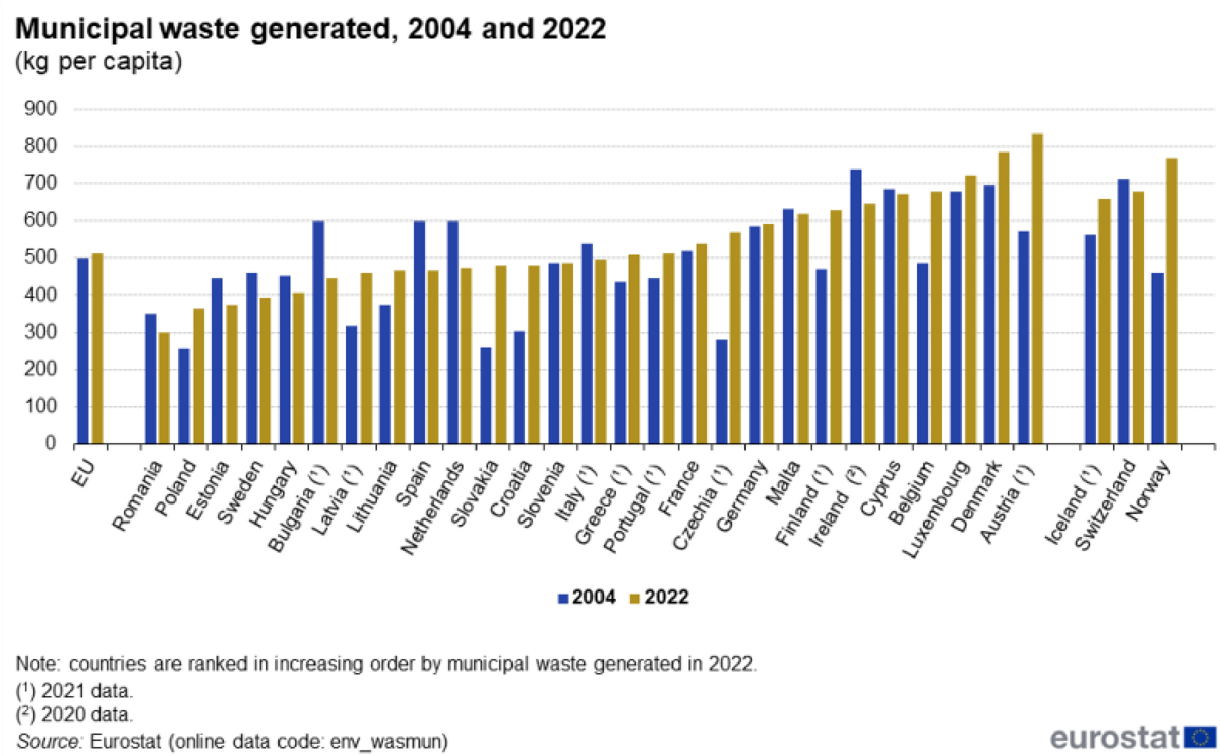

Figure 4: Municipal waste generated, 2004 and 2022 (Eurostat, 2024)

In 2022, the level of municipal solid waste generation varies completely from one country to another in the EU. The figures range from 301 kg per capita in Romania to 835 kg per capita in Austria. Compared to 2004, 17 countries increased their MSW production in 2022, and 13 countries have decreased it. Many variables, including varied consumption patterns, economic prosperity, and the effectiveness of municipal waste collection and management systems in each nation, are thought to be the cause of these disparities. Additionally, every nation has its own plans for collecting and managing waste, as well as how to combine household waste with commercial and industrial waste (Eurostat, 2024).

6.3. Municipal solid waste components

Discarded food, paper, wood, plastic, metals (both ferrous and nonferrous), glass, textiles, and rubber are the main constituents of municipal solid waste, as shown in Table 1. The place and season in which municipal solid waste (MSW) was generated has a significant impact on its composition.

Table 1: Average MSW composition in EU
Eurostat, 2024

Waste component	Percentage (%)
Organic materials	37
Paper and Cardboard	24
Plastics	11
Glass	7
Metals	4
Textiles	3
Other materials	14

The study made by Bidlingmaier (2004) incorporated a distinct collection and biological waste treatment program in the European Community, which provides an average breakdown of the components of municipal solid waste (MSW) in EU member states. The study's conclusions indicate that the most prevalent waste categories in the EU that are classified as municipal solid trash are paper and cardboard (24.1%), organic garbage (24.5%), plastic (12.4%), metals (7.5%), glass (5.8%), textiles (5.1%), wood (5.6%) and at the end other waste (15%).

Food scraps, grass clippings, and any other material capable of decomposition are included in the organic waste category. It is essential to understand that the composition of municipal solid waste (MSW) varies greatly among EU nations because of differences in waste management techniques, habits of consumption, and legal frameworks. However, these findings underscore the necessity of implementing efficient waste management methods, in order to decrease the environmental impact of MSW and transition to a circular economy that maximizes resource efficiency and reduces waste, such as source separation and biological treatment.

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7. MSW landfill or WtE

Figure (5) represents a comparison between the development in municipal solid waste landfill rate in 27 European countries and implementing the WtE concept from 2000 to 2020.

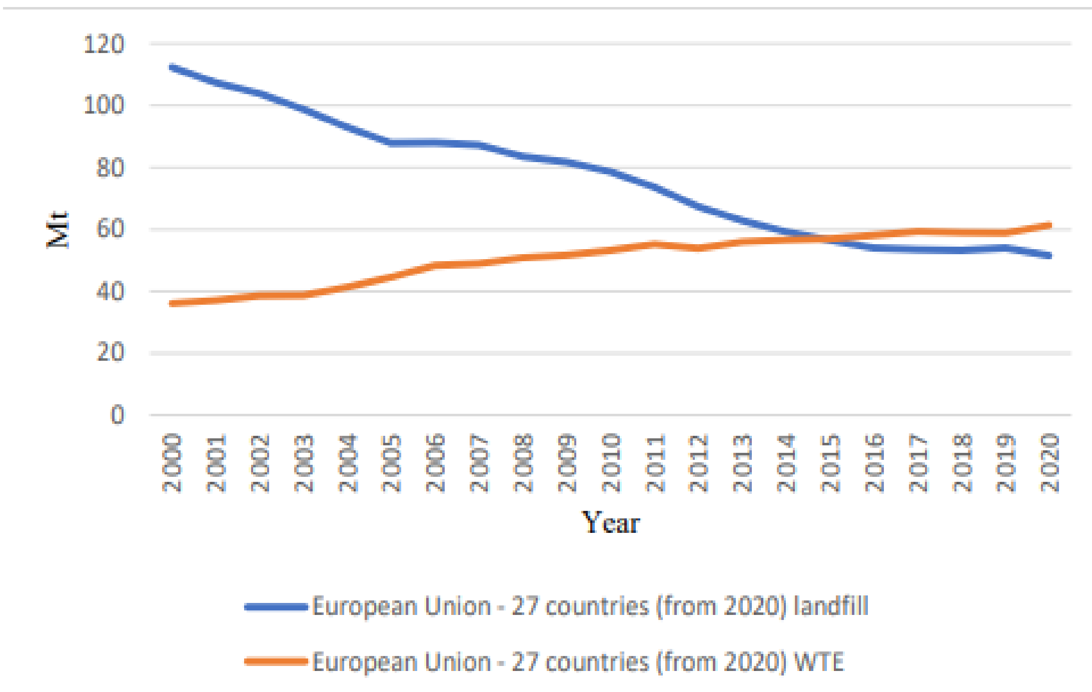

Figure 5 : Comparison of MSW Landfill and WTE in EU from 2000 to 2020 (in Mt) (European Environmental Agency, 2019b)

By looking at the data presented in Figure (5), it is indicating the positive trend occurring in these 27 European countries towards more WtE direction since the year of 2000. This positive trend has many reasons. The most important one is the increased need of energy and the continuous accumulation of waste.

The EU has gradually reduced its reliance on landfilling for the disposal of MSW from 2000 to 2020. The EU Landfill Directive (1999/31/EC), which established goals for lowering the quantity of biodegradable waste sent to landfills, is mostly what caused this drop. By promoting recycling, composting, and WtE as disposal alternatives, member states have been actively working toward achieving these targets (European Union, 1999).

In order to comply with the European Green Deal's "Striving to be the first climate-neutral continent" acts, these positive tendencies are anticipated to increase. The EU commission claims that over 75% of the country's greenhouse gas emissions are caused by the production and use of energy. Decarbonizing the EU's energy system is thus vital to meeting our 2030 climate targets and the EU's long-term goal of reaching carbon neutrality by 2050 (European Commission, 2023).

In one of the most recent trends, Germany had announced its intentions to shut down its final three reactors on the 15^{th} of April 2023, confident that its green transition would be successful without nuclear power, In spite of the energy crisis caused by the Ukrainian-Russian conflict in the past year (euronews, 2023).

A comparison of the trajectory of increases in WtE and landfills shows that the EU has been able to significantly decrease landfill volume over the last two decades while concurrently increasing WtE consumption and moving toward recycling and recovery. Waste management practices have evolved as well. Between 2008 and 2017, the rate of municipal solid waste (MSW) disposed of in landfills decreased by 43%, while the rate of MSW recovered for energy increased by 72%, the rate of MSW recycled increased by 22%, and the rate of MSW composted or digested increased by 18%. While in the United States Between 1960 and 2015, they experienced an increase in both landfill and WtE as shown in the Figure (6) below.

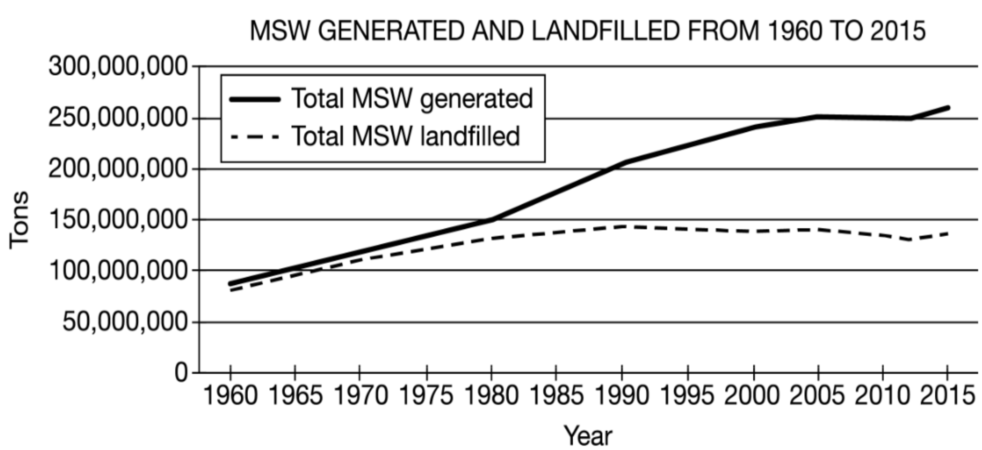

Figure 6 : MSW generated and Landfilled in the US from 1960-2015 (EPA, 2011)

8. MSW management in the EU

Figure (7) represents the percentage of the development of MSW management strategies from 2010 to 2020 in EU-27 countries. The considered strategies are landfilling, incineration, and recycling. The "Other" category represents the difference between the quantity of MSW generated and the quantity that is treated. The difference is caused by many factors during waste processing, such as losses during storage and also during mechanical-biological treatment of MSW.

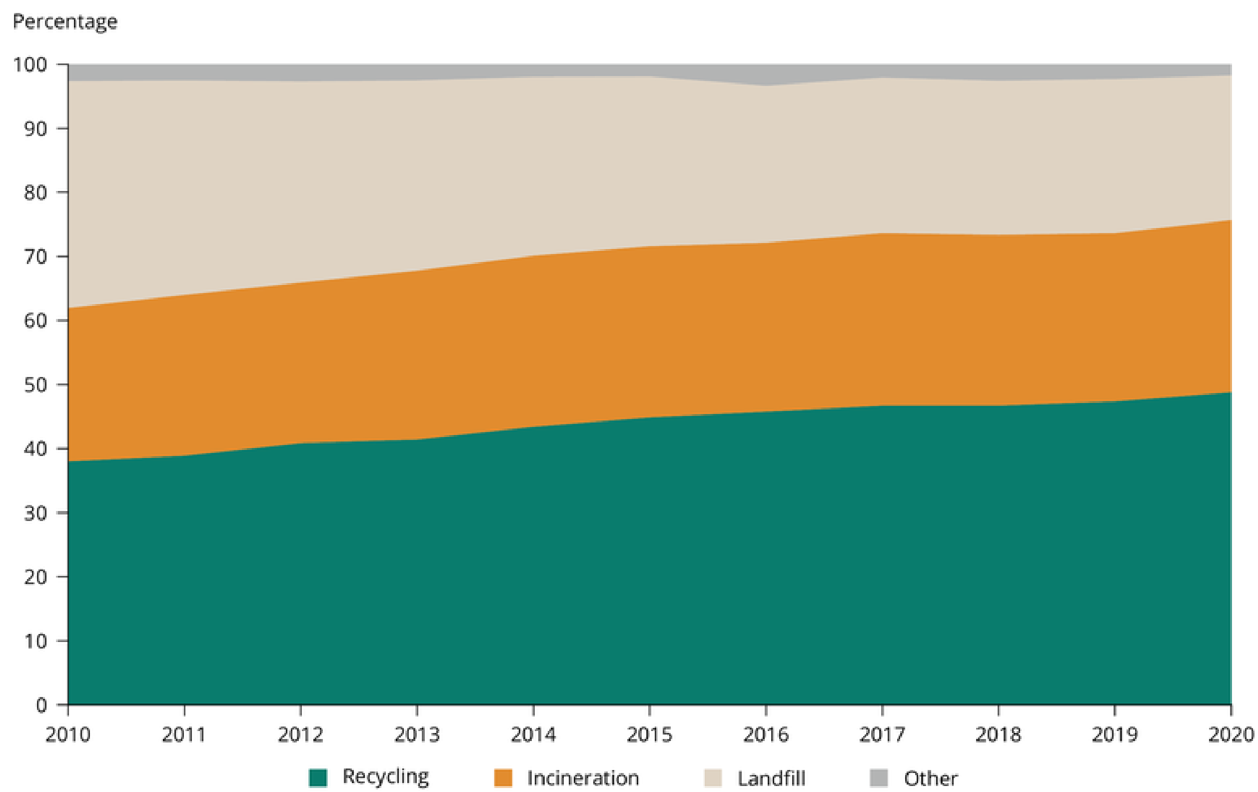

Figure 7: Development of municipal waste management in the EU-27, 2010 – 2020 (European Environment Agency, 2023)

According to Figure (7) above, While the amount burned increased by 2%, the amount recycled climbed by about 11%, and the overall amount of municipal waste buried in landfills reduced by roughly 13%.

Nevertheless, these numbers and the data in figure 8 reveal considerable differences in waste management performance across the continent, with France (121) and Germany (96) having the highest number of WtE operations in 2018, and Hungary (1), Luxembourg (1), and Estonia (1) having the least.

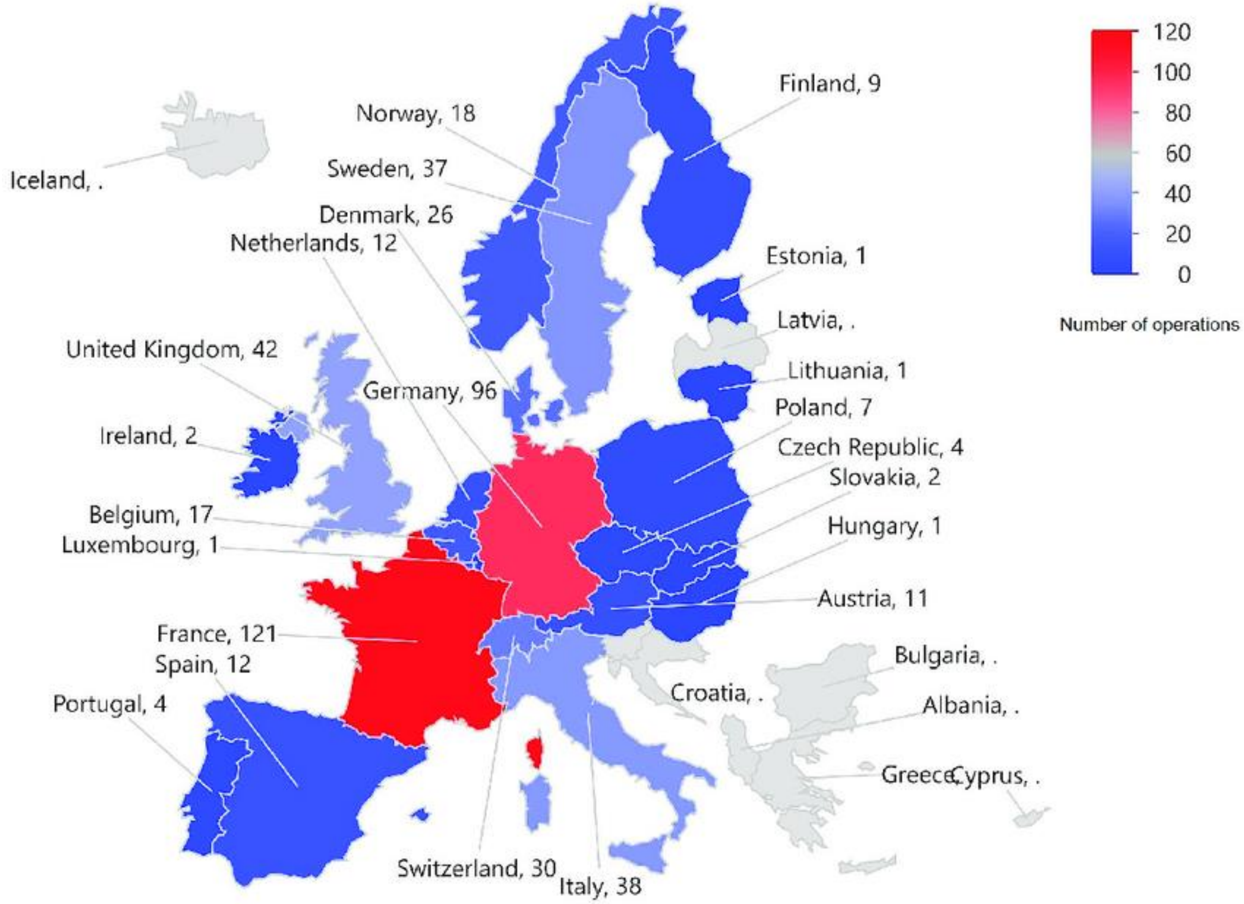

Figure 8: WtE operations in the EU in 2018 (Tauš, 2023)

9. WtE Operations in the EU

Despite its negative reputation, incineration has experienced a resurgence in recent years, emerging as a crucial solution in waste management and energy production, particularly in the European Union (EU). The EU has established ambitious targets for waste management and energy generation, leading to a significant increase in the use of incineration. According to Eurostat, approximately 26% of all municipal solid waste (MSW) in the EU was incinerated in 2019, and this percentage is projected to rise in the future. The Netherlands stands at the forefront of waste management, boasting facilities capable of processing over 600 000 tons of waste on average. On the other hand, Denmark has taken the lead in developing environmentally friendly waste-to-energy plants, exemplified by Imager Bakke, commonly known as Copen hill. When it comes to waste management, the Netherlands is at the forefront with their facilities being able to process more than 600 000 tons of waste on average. However, Denmark has taken the lead in clean waste-to-energy plants with Amager Bakke, also known as Copenhill. With its impressive capabilities, this plant has the capacity to oversee up to 400 000 tons of municipal waste annually. It not only efficiently manages waste but also generates a substantial amount of electricity, ranging from 0 to 63 MW, and provides heat output ranging from 157 to 247 MW, based on the energy consumption requirements. In 2020, the plant experienced a surge in demand for its services, enabling it to process a remarkable 599 000 tons of municipal waste. Additionally, it successfully supplied electricity to more than 80 000 households and delivered heat to over 90 000 apartments. What sets this facility apart even further is its exceptional flue gas cleaning technology. This advanced system ensures that all emissions produced during the processes are effectively addressed and responsibly managed (Tauš, 2023).

10. MSW energetic potential and a comparison with traditional fuel generated plants

Nearly 80% of the electricity produced worldwide comes from fossil fuels including coal, oil, and natural gas, with thermal power plants generating the higher majority of this energy (Ahmadi, 2016).

Since about a century ago, thermal power plants (TPPs) have been used in numerous industrial operations. The primary energy source for these devices is the heat extracted from the fuel. Water is boiled in a boiler at a steam power plant, where it is converted to high-pressure steam that travels through turbine blades. As a result of this spin, the generator starts to produce power. However, the use of fossil fuels in these facilities has negative effects on the environment, including ecological deterioration, air pollution, and direct health risks to people. Achieving sustainable development requires implementing long-term plans and acting swiftly to address the present environmental issues facing the world (Esen, 2006).

Traditional methods for disposing of urban waste include landfills, composting, and incineration. Some of the processes focus on producing power, while others prioritize waste disposal. Today, a proper management strategy grounded in the principles of sustainable development requires waste to be repaired or utilized as a potential source.

Different methods, including life cycle assessment (LCA), were used to compare various methods in order to select a suitable waste management system. And according to Muralikrishna and Manickam (2017), The objective of a life cycle assessment (LCA) is to determine the total environmental impact of a product over its entire lifespan by tracking its movement from the point of origin until disposal from the extraction of raw materials through their processing, manufacturing, distribution, and use, where decision-makers can identify areas for improvement and make informed choices to reduce a product's or process's overall environmental impact by using life cycle assessment (LCA) to look at the entire life cycle. Results from LCA can be used to inform sustainable design and policy decisions as well as to find opportunities for resource efficiency, waste reduction, and optimization.

Using the LCA method, it was discovered that MSW incineration is a suitable alternative due to its advantages over other waste disposal options, as it performs better environmentally. The process produces heat that TPPs can use as a source of energy. Numerous researchers have examined this method and mentioned some advantages of MSW incineration, such as requiring less land than a landfill, being weather-independent, producing clean ash, disposing of hazardous waste, lowering air pollution, and lowering the risk of surface water pollution (M.S, 2018).

The heat energy produced by burning municipal solid waste (MSW) can be measured as either the higher heating value (HHV, Qh) or the lower heating value (LHV, Ql).

Numerous researchers have examined this method and mentioned some advantages of MSW incineration, such as requiring less land than a landfill, being weather-independent, producing clean ash, disposing of hazardous waste, lowering air pollution, and lowering the risk of surface water pollution (explained in the next title).

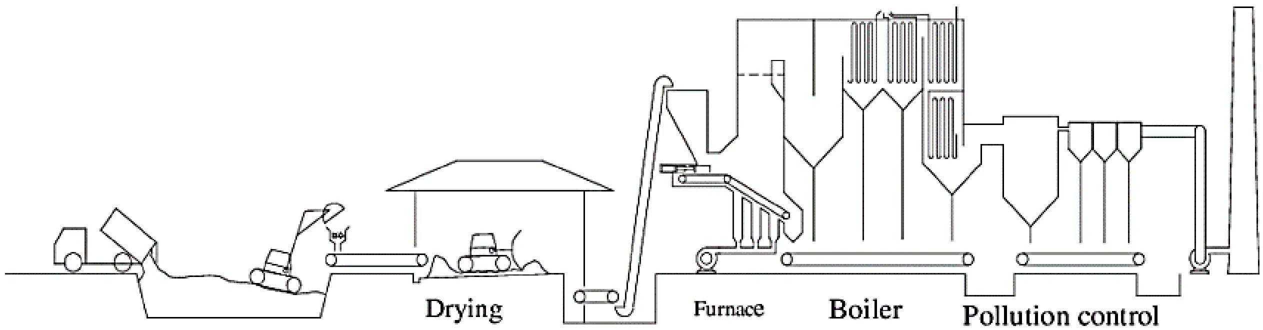

Figure 9 : A concept for a small-scale waste-to-energy facility (Pasek et al., 2013)

A casual collector might choose recyclable goods from waste that has been gathered from the city and put into a ditch. The residual waste is then chopped in a machine before being dispersed on the drying floor by a chopper, it is intended to put the WtE facility near to a TPA. Before being transported to the furnace using a belt conveyor system, To bring the waste's moisture level down to less than 40%, it is allowed to air dry for a few days. In the combustion chamber, the waste burns by itself at a temperature greater than 850°C. In a boiler, steam is produced from flue gas in order to produce electricity. Before being released through a stack to the surrounding air, the flue gas is cleaned and conditioned.

11. Tanner diagram for waste combustion

The sides of the Tanner diagram provide three axes that represent the amounts of ash (on a wet basis), organic matter (fixed carbon and volatile yield), and moisture (figure 10). As a result, two of the components are at 0% and each angle of the Tanner diagram indicates 100% of the entire amount of only one component (moisture, ash, or organic matter). Below the maximum moisture content of 50%, below the highest ash content of 60%, and above the minimum quantity of organic matter of 25% is the Tanner diagram region that represents the viable self-sustained combustion of MSW (without the addition of any extra high-quality fuels). This is because the combustion of MSW can be self-sustained if these three parameters are met. If the MSW composition does not fulfill these specifications, only the addition of a high-quality fuel can make the MSW burn (Vlaskin, 2018).

Therefore, depending on the components of the MSW, the efficiency and the environmental consequences of the incineration process can be determined.

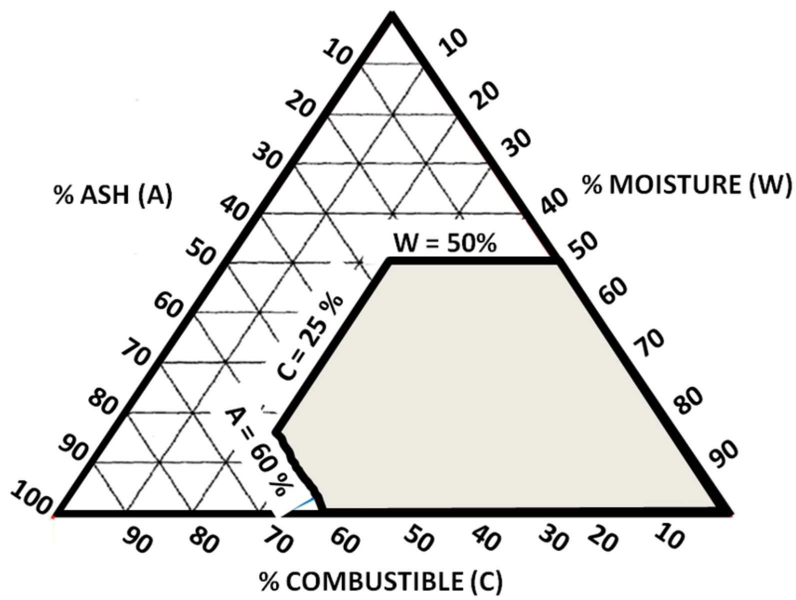

Figure 10: Tanner diagram for waste combustion (Pasek et al., 2013)

Materials with relatively high heating values include plastic, rubber, and cloth. When they are dry, both food waste and garden waste have reasonably High Heating Values (HHVs that may reach up to 20 MJ/kg).

However, when these types of waste have a high percentage of moisture content, they have the lowest calorific potential. Paper waste has such a tiny percentage of moisture, even if dried, it has the same HHV (about 17–18 MJ/kg). The HHV of wet wood is often the same as that of dry wood, but the HHV of dry wood typically climbs to 20 MJ/kg (Baud, 2004).

12. Role of policies and legislations in WtE

Much of the research that environmental scientists conduct is meant to eventually impact legislation, and they play a crucial part in how population responds to environmental concerns. The four main tenets of the precautionary principle are: taking preventive action in the face of uncertainty; increasing public participation in decision-making, investigating a variety of alternatives to potentially damaging acts, and transferring the burden of proof to the proponents of an activity (Kriebel, 2001).

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Many countries are focusing on effective resource use policies in order to reduce natural resource consumption and deal with the coming energy problem. (Ünal, 2019). The US Environmental Protection Agency (US EPA) considers power and heat produced from non-recyclable waste to be renewable energy generation. This approach minimizes carbon emissions by lowering landfill methane production and balancing energy needs from fossil sources (The U.S. Environmental Protection Agency, 2016). While in the EU, Energy conversion from MSW as a waste management method is growing, both in terms of the number of facilities and capacity and is backed by regulatory regulations. (Branchini, 2015).

Decision-makers can find opportunities for improvement and make wise decisions to lessen the total environmental effect of a product or process by using LCA to examine the full life cycle. Results from LCA can be used to inform sustainable design and policy decisions as well as to find opportunities for resource efficiency, waste reduction, and optimization.

The European Union (EU) has committed to achieving a sustainable circular economy that minimizes the development of waste, maximizes the efficiency with which resources are used, and lowers the impact on the environment, especially with the green deal initiative (European Parliament, 2009). These goals are ambitious. In order to accomplish them, the EU has enacted a wide variety of rules concerning the management of MSW, including policies about incineration. In spite of the fact that incineration has historically served as a means of waste disposal, the EU has recently adopted regulations that aim to reduce the amount of waste that is burned in power plants and boost the amount of waste that is recovered and recycled.

One of the most significant pieces of waste management law in the European Union is the Waste Framework Directive (2008/98/EC). This directive emphasizes the waste management hierarchy, which ranks recycling, reuse, and waste avoidance as the most crucial waste management practices, surpassing landfilling and incineration. Along with targets for reducing waste generation and improving recycling, the directive sets standards for the treatment of hazardous waste. The EU has also implemented a variety of additional policies that are relevant to waste management. These policies include the Packaging and Packaging Waste Directive, which attempts to decrease the impact that waste packaging has on the environment, as well as the disposal Directive, which establishes minimum requirements for disposal sites. Both directives are examples of EU policies (European Environment Agency, 2008).

Launched in 2020, the EU's Circular Economy Action Plan (European Commission, 2020) has as its primary objective the promotion of a more circular economy. This will be accomplished through the increased use of secondary raw materials, the reduction of waste, and the enhancement of resource efficiency in addition to increasing the use of more ecologically friendly waste management techniques including biological treatment and material recovery, the plan asks for a reduction in the quantity of waste that is burned and disposed of in landfills. In order to improve resource efficiency, the plan also includes initiatives to encourage the use of digital technologies, support the development of circular business models, and encourage the adoption of eco-design principles. Since the plan includes these projects, they are included.

In order to prolong the life cycle of materials and goods, the circular economy promotes sharing, leasing, reusing, repairing, restoring, and recycling them for as long as feasible. The circular economy seeks to reduce waste and retain materials in the economy by recycling, establishing an ongoing loop of value, in contrast to the conventional linear economic model of take-make-consume-throw away. Making the transition to a circular economy has several advantages.

First of all, it contributes to environmental protection by lowering biodiversity loss, avoiding disturbance of landscapes and habitats, and decreasing the use of natural resources. Additionally, because waste management, product use, and industrial operations are major contributors to emissions, it helps to reduce greenhouse gas emissions. Since more than 80% of a product's environmental impact is assessed during the design stage, designing products to be more sustainable and efficient from the start helps lower energy and resource usage (European Parliament, 2009). Adopting more reliable and repairable products also reduces waste generation, addressing the issue of excessive packaging and promoting reuse and recycling.

Additionally, the shift to a circular economy lowers reliance on raw commodities. Recycling raw materials reduces the concerns of price volatility, availability, and reliance on imports in light of an increasing population and finite supply. This is especially significant for vital raw materials that are utilized in technologies that are essential to reaching climate goals (European Parliament, 2009).

Adopting the circular economy can also boost competitiveness, encourage innovation, boost economic growth, and generate employment. By 2030, the adoption of a circular economy is predicted to create 700,000 jobs in the EU alone (European Commission, 2020). Consumers also benefit from durable and innovative products that improve quality of life and save money in the long run.

To transition to a circular economy, the European Union (EU) is taking action. With an emphasis on waste reduction, sustainable product design, and consumer empowerment—including the right to repair—the European Commission unveiled the circular economy action plan in 2020. In order to attain a carbon-neutral, environmentally sustainable, toxic-free, and fully circular economy by 2050, the Parliament has passed a resolution calling for additional measures, including legally obligatory goals for the use and consumption of materials. In 2022, the Commission unveiled a set of initiatives to hasten the shift to a circular economy, including consumer empowerment, sustainable products, a review of building product regulations, and a sustainable textile strategy. In the same year, the Commission also suggested new packaging regulations for the entire EU that would enhance packaging design, cut waste, and encourage the use of bio-based and biodegradable plastics by promoting recycling and reuse and providing clear labeling.

Certain rules for waste incineration facilities in the EU are established under the Waste Incineration Directive (2000/76/EC). It aims to stop or minimize waste incineration's detrimental effects on the environment and human health. The directive guarantees the environmental sustainability of waste-to-energy facilities by defining emission limit limits for a variety of pollutants. Waste-to-energy facilities that adhere to these guidelines promote the production of greener energy and minimize harmful emissions (European Union, 2000).

In order to reduce greenhouse gas emissions and enhance energy security, the Renewable Energy Directive (2009/28/EC) encourages the use of renewable energy sources. It recognizes how waste-to-energy technology can be used to convert non-recyclable garbage into renewable energy. The guideline states that if waste incineration energy satisfies specific sustainability requirements, it may be regarded as renewable. By reducing dependency on fossil fuels and carbon emissions, this accreditation promotes the use of waste-to-energy systems as a sustainable energy source (European Parliament, 2009).

The Circular Economy Package, which consists of many directives and laws, intends to convert Europe to a more effective sustainable and resource-efficient economy. Waste-to-energy technologies play an important part in this transformation by extracting energy from non-recyclable waste, so contributing to resource circularity and reducing waste disposal (European Commission, 2020).

In conclusion, the European Union (EU) is making significant strides toward a sustainable circular economy through the enforcement of regulations that encourage the use of more ecologically friendly waste management techniques and support the reduction of garbage incineration. By promoting the development of creative circular business models and the more efficient use of existing resources, these policies not only help to mitigate the adverse impacts on the environment but also create new opportunities for economic growth. Nonetheless, more needs to be done to achieve the challenging waste management goals established by the European Union. Furthermore, in order to advance toward a more sustainable future and keep improving waste management techniques, continuous research and innovation are essential.

Results from the questionnaire

The questionnaire was conducted by using an online google forms, which then have been distributed via Email and Facebook groups to various students Groups in Hungary, the questionnaire succeeded to receive 101 responses during the period between 2024 July – 2024 October.

1. Gender

This first figure shows the gender distribution of respondents. It highlights how many people from each gender group participated in the survey. This distribution can indicate the sample's diversity in terms of gender representation.

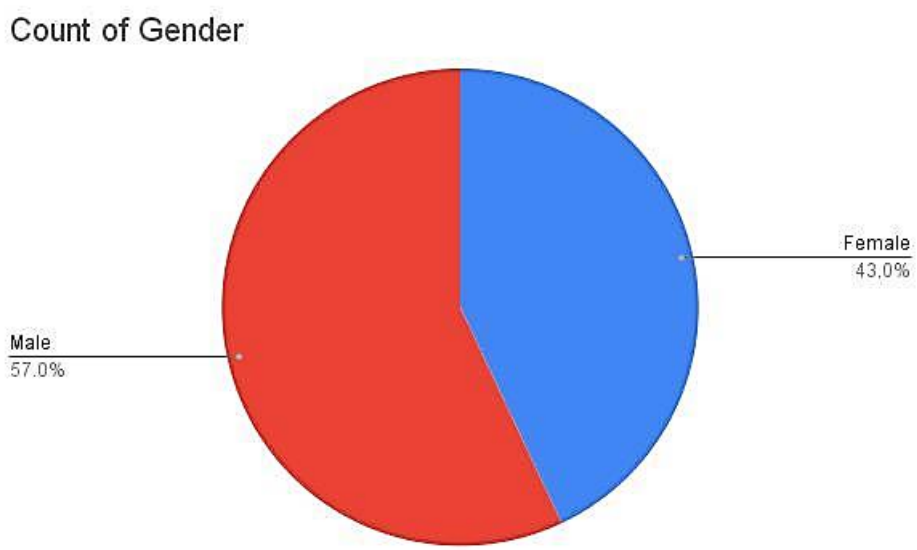

Figure 11: Participants gender statistics
Source: own editing based on survey results

According to Figure 11, the population of respondents can be considered homogeneous, although the male respondents (57%) are a slightly more than the female respondents (43%).

2. Age

Figure 12 shows the age distribution of respondents.

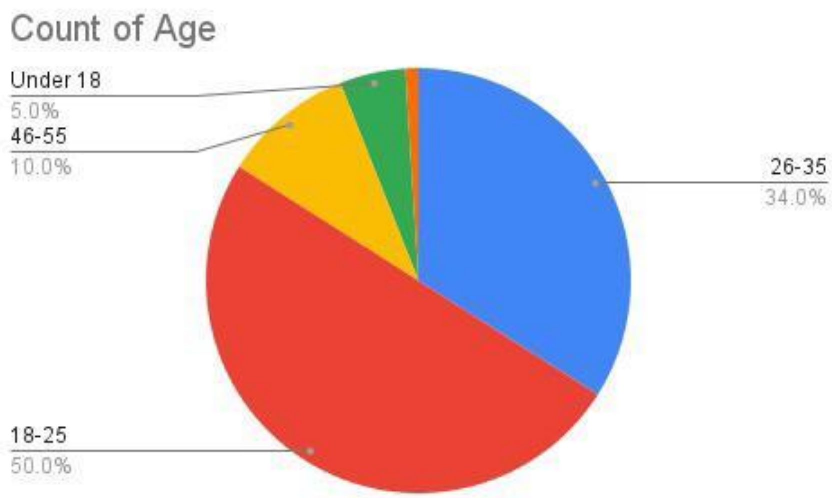

Figure 12: Age distribution of participants
Source: own editing based on survey results

The biggest group of respondents are between the age of 18-25, representing 50% of the respondents. This shows that the majority of survey respondents are young university students as will be shown in the next figure.

The second-largest age group is 26-35, representing 34% of respondents. A smaller number of responders about 10% are between the ages of 46 and 55, with only 5% under the age of 18.

This distribution demonstrates that the survey sample tends toward younger people, which may affect the overall opinions about waste incineration considering a generational opinion.

3. Education level

The graph in Figure 13 shows the respondents' education level.

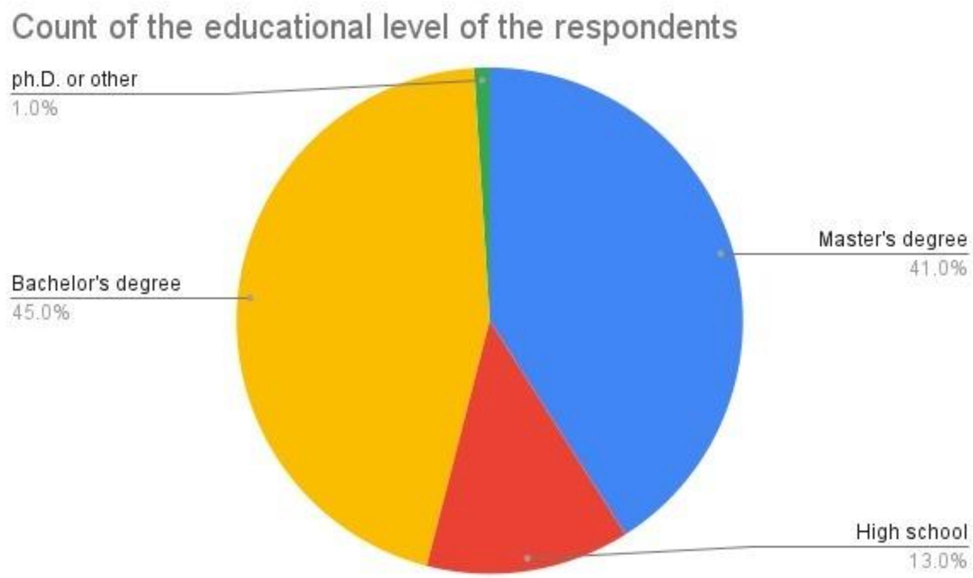

Figure 13: Education level of the survey participants
Source: own editing based on survey results

The largest category, at 45%, consists of the respondents who are in their or have a bachelor's degree, suggesting that nearly half of all respondents have higher education.

41% of respondents hold a master's degree, indicating a high percentage of representation of highly educated in the sample. The survey found that 13% of respondents completed high school, while only 1% obtained a Ph.D. or other higher qualifications, showing a low proportion of persons with doctoral-level education.

The survey was conducted on a random selection of universities and educational events, with the majority having at least a bachelor's degree. This suggests that the survey respondents are better aware of difficult environmental issues like it is discussed in the survey.

4. Living Near Waste Incinerators

Participants were if they ever resided in a locality where waste incinerators are operational. Results are presented in Figure 14.

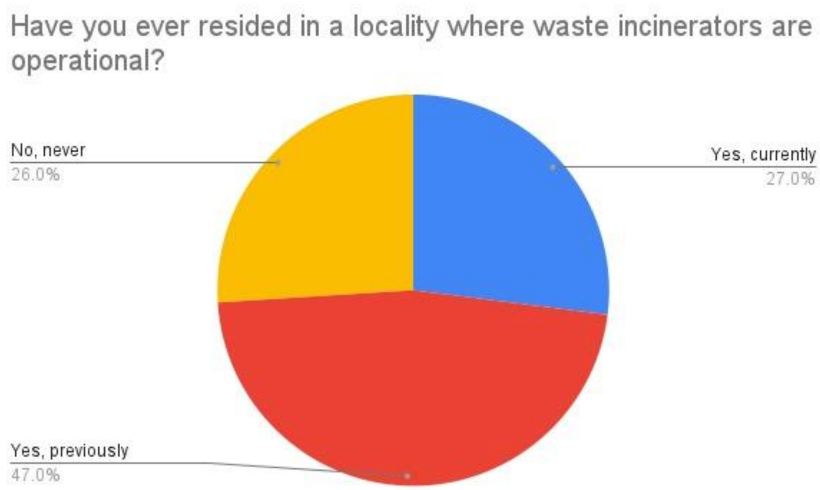

Figure 14: Living Near Waste Incinerators in the same city
Source: own editing based on survey results

Almost half of the respondents (47%) had previously lived in a city with an operational waste incinerator, and 27% continue to live in locations where incinerators are active. This simply means that most of the respondents (74%) have knowledge or some information about these facilities. This real-world experience most likely influences their perspectives, giving their comments more weight. On the other side, 26% of respondents had never lived near an incinerator, yet their perspectives nonetheless help to provide a comprehensive grasp of public opinion.

5. Familiarity with waste incineration

This chart in Figure 15 shows how familiar the respondents are with the concept of waste incineration.

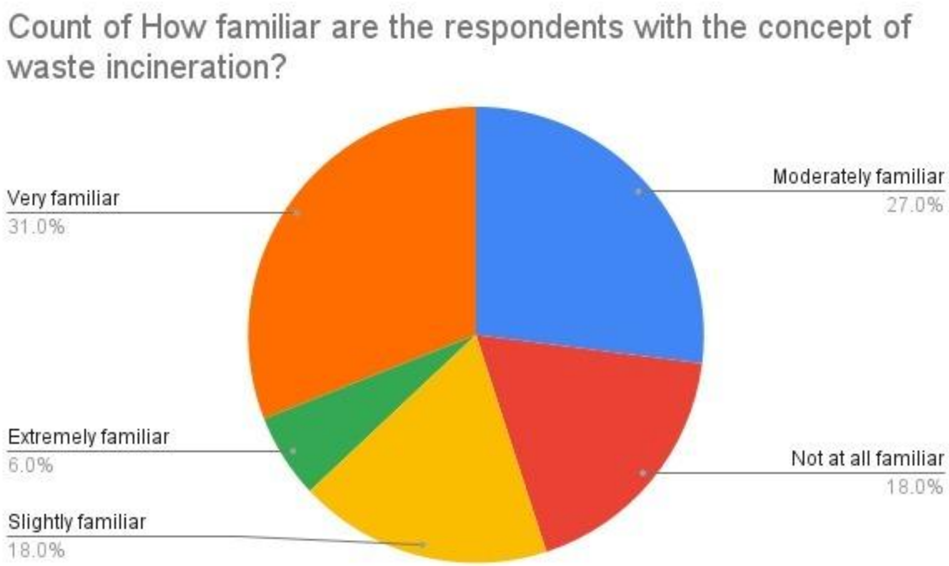

Figure 15: Familiarity of the survey participants with waste incineration
Source: own editing based on survey results

- The biggest group is about 31%, answered as very familiar, showing that nearly one-third of respondents have a strong understanding of waste incineration.
- The second biggest group is about 27% of respondents answered as moderately familiar, showing that they have an average understanding of the topic.
- 18% of respondents are slightly familiar, while another 18% are not at all familiar, indicating that about one-third of respondents have little or no knowledge of waste incineration topic.
- Only 6% are extremely familiar, suggesting that only a small portion of participants have a deeper understanding of the topic.

In summary, most respondents are at least somewhat familiar with waste incineration topic, but there is a significant range in how well they understand it, with a smaller portion being very knowledgeable. This diversity in familiarity could impact the overall opinions or attitudes toward waste incineration in the survey final results.

6. Waste incineration impact on the environment

In this section the respondents were asked to rate on a scale from 1 to 10 their agreement on different questions, where 1 means they do not agree at all, and 10 if they fully agree.

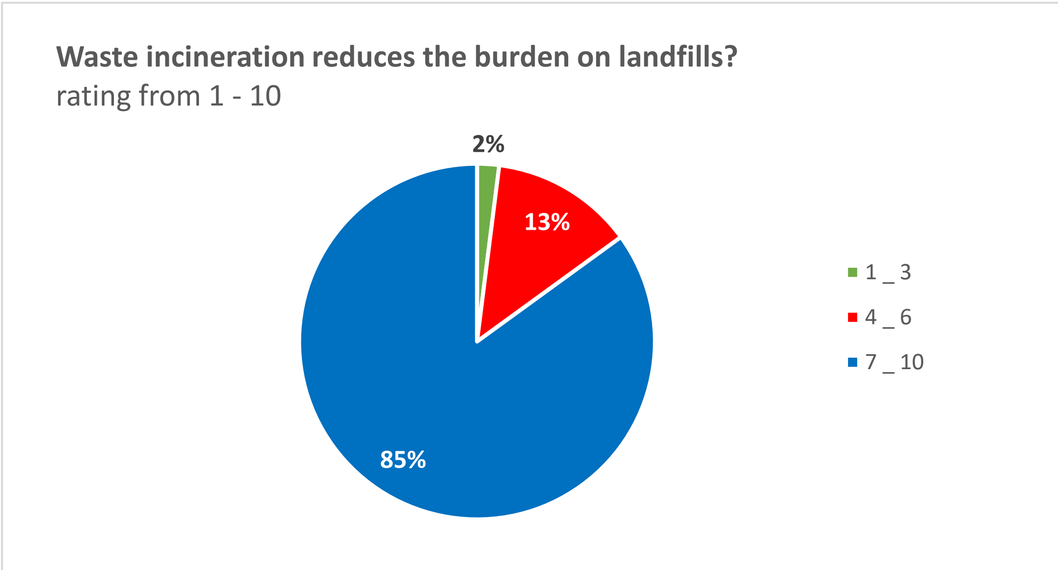

Figure 16: Opinions of respondents on waste incineration effect of landfills
Source: own editing based on survey results

In accordance with the graph data in Figure 16, the majority of respondents tend toward agreeing that waste incineration decreases landfill use, with the majority answering within the agreement range (7-10). Only a small fraction of the ratings is negative, showing that this idea is widely supported and accepted.

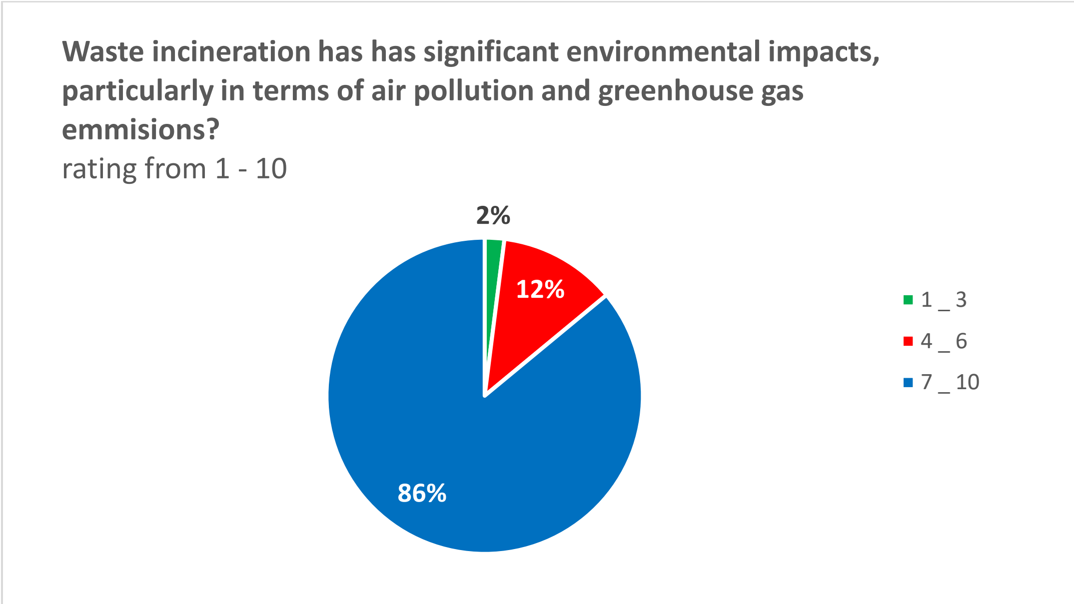

Figure 17: Opinions of respondents on waste incineration environmental impact
Source: own editing based on survey results

According to the graph on Figure 17, a large majority of respondents believe that waste incineration has serious environmental consequences, particularly in terms of air pollution and greenhouse gas emissions. The highest answers were from (7-10), showing strong concerns about the environmental impacts of waste incineration, indicating awareness in the possible effects of waste incineration in general.

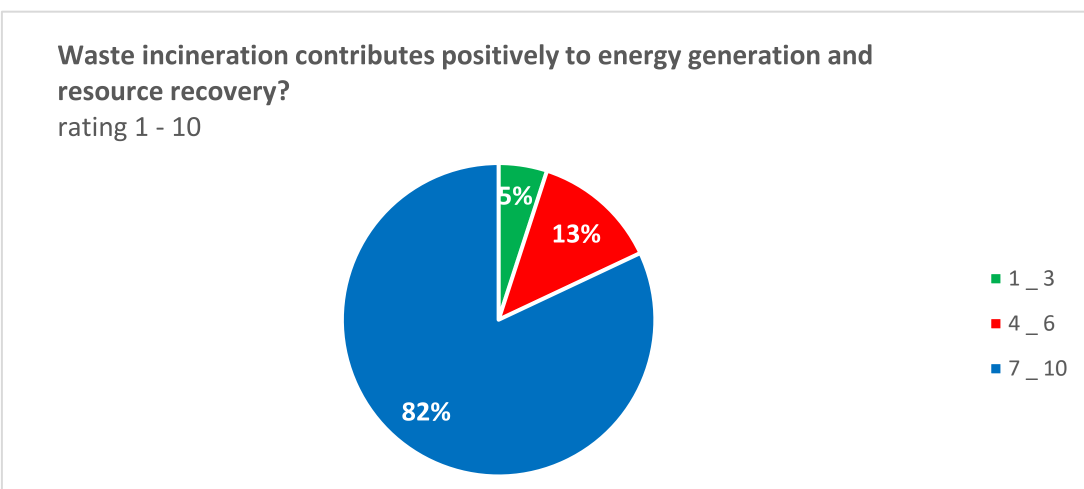

Figure 18: Opinions of respondents on waste incineration impact on energy and resources
Source: own editing based on survey results

According to Figure 18, the majority of the respondents (7-10) made up for more than 65% of the total answers; therefore, it indicates the agreement of the positivity of using waste incineration as source of energy production and resource recovery.

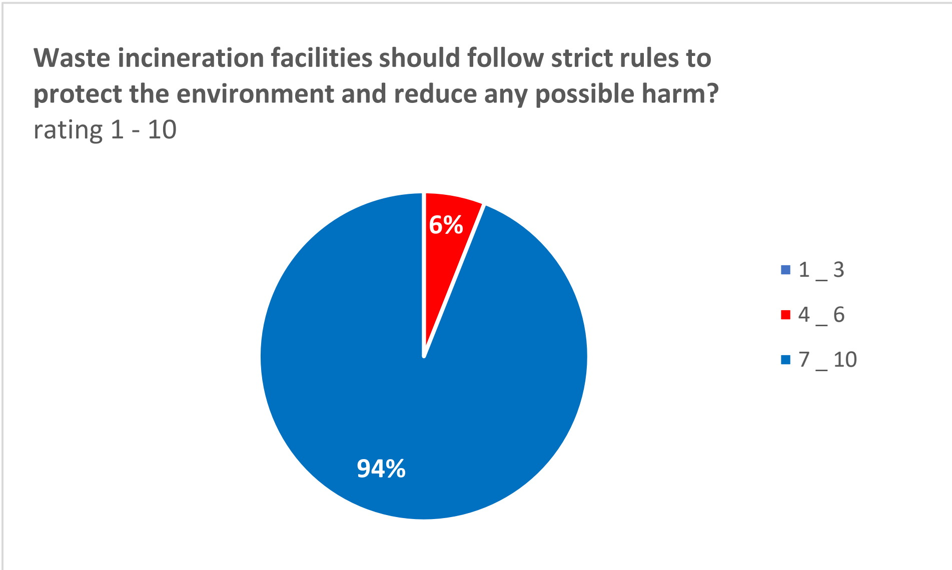

Figure 19: Opinions of respondents on waste facilities following regulations
Source: own editing based on survey results

In Figure 19, there was almost total agreement about the premises of the importance of having strict rules to protect the environment and reduce the possible harmful effects in the case of the operation of a waste incineration plant.

7. Community Priorities for Waste Incinerator Decision-Making

In this section of the survey, the respondents were asked what factors they believe should be prioritized in the decision-making process for the implementation of waste incinerators in a community, and to rank each factor from 1 to 5, with 5 being the most important and 1 being the least important.

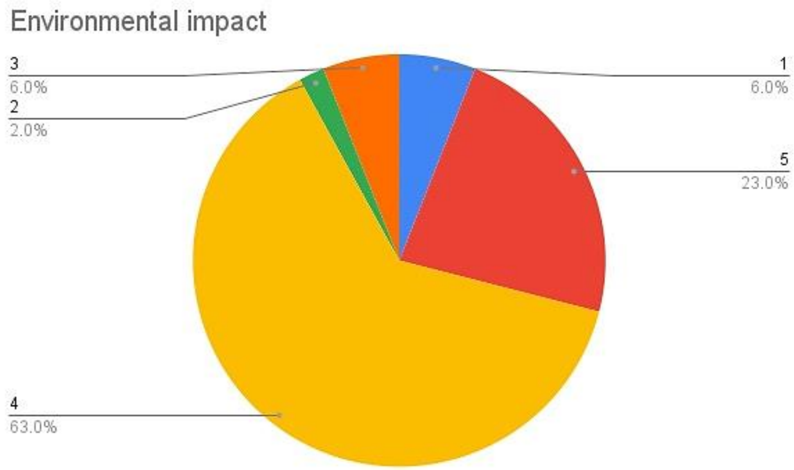

Figure 20: Ranking environmental impact priority in waste incinerator implementation
Source: own editing based on survey results

The graph distribution in Figure 20 shows that the majority of the respondents believe the that the environmental impact should be the priority (with ranks 4 and 5 accounting for the majority), indicating a total agreement on prioritizing such aspects of waste incineration implementation.

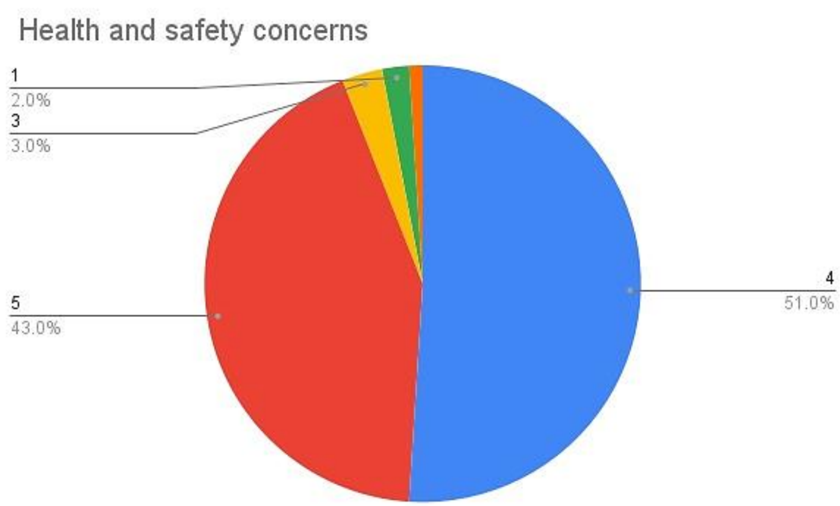

Figure 21: Community Emphasis on Health and Safety in Waste Management Decisions
Source: own editing based on survey results

This chart in Figure 21 shows the results for the question of whether health and safety concerns should be prioritized in the decision-making process for the implementation of waste incinerators in a community. And according to the results, health and safety concerns are considered important by respondents, showing that this factor is a top priority for most people when evaluating waste incineration initiatives or implantation

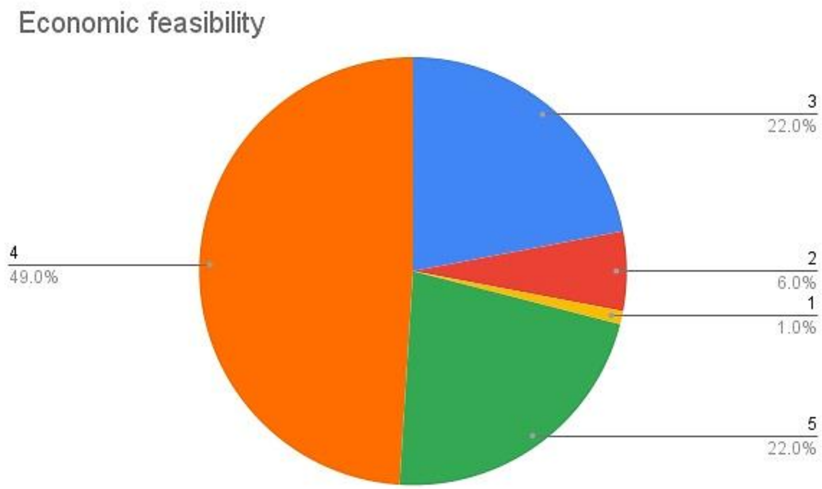

Figure 22: Ranking economic considerations in waste incinerator adoption
Source: own editing based on survey results

Economic feasibility is considered by many as a significant aspect (Figure 22), with most respondents giving it a high ranking (4 or 5). This shows that the financial viability of waste incineration plants is an important issue for the majority.

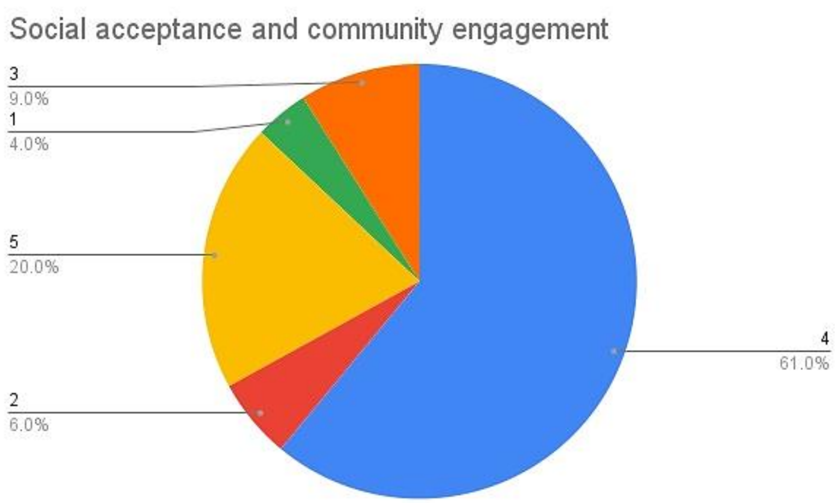

Figure 23: Ranking social acceptance's priority in implementing waste incineration
Source: own editing based on survey results

This chart in Figure 23 shows the answers whether social acceptance and community engagement is an important factor, the graph shows that the majority with over 80% (4;5) consider it as an important factor, but there is about 20% (3,2,1) consider it as medium to not an important factor which indicates how the population look differently on the importance of social acceptance of waste incineration future plans.

8. Waste incineration role in waste management and sustainability

This chart in Figure 24 shows the high agreement on how significant the contribution of waste incinerators to the current challenges of waste management and environmental sustainability is as a viable option, with more than 70% answering as very significant indicates that waste incineration is widely acceptable in the community which it was the survey conducted on them.

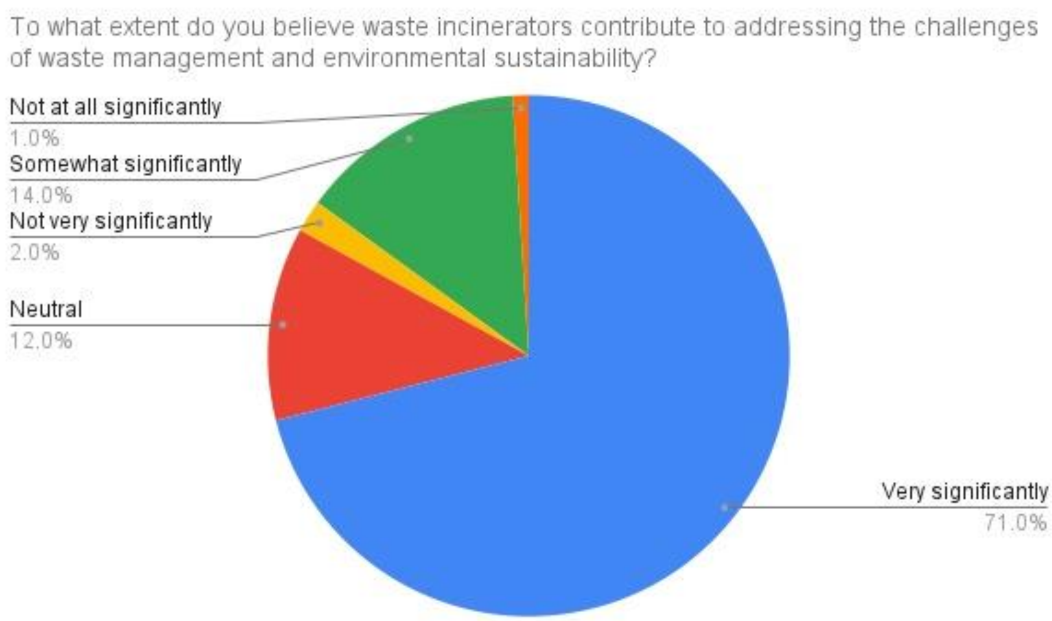

Figure 24: Participant's knowledge on waste incineration role in waste management and sustainability

Source: own editing based on survey results

9. Alternatives of waste incineration

The respondents answered when asked if they could name any alternatives to waste incineration for managing solid waste. The answers were categorized and presented in Figure 25.

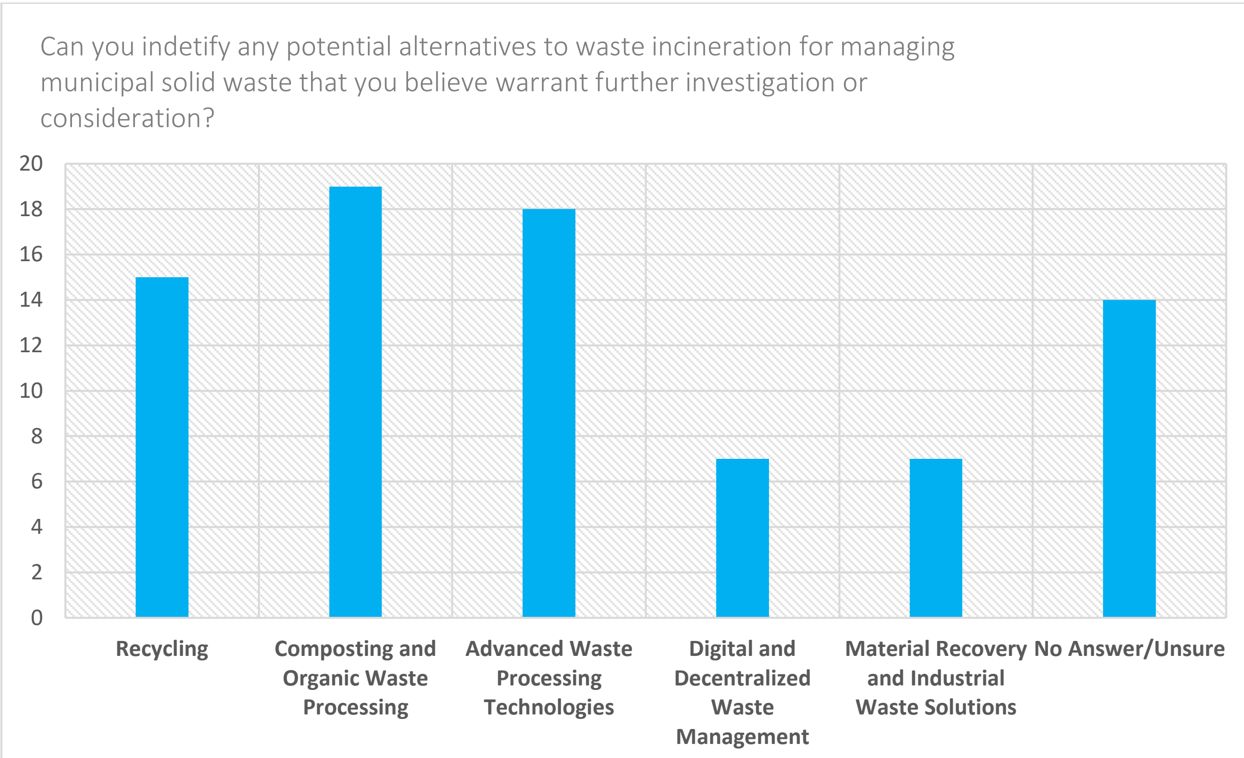

Figure 25: Participants' opinions on alternatives for waste incineration
Source: own editing based on survey results

The chart in Figure 25 indicates that the participants are quite knowledgeable about many alternatives that exist for managing municipal solid waste, which is reassuring. The most common answer was that of composting and organic waste processing (19 answers). The second most common answer is advanced waste processing technologies (18 answers) such as pyrolysis, gasification, and also thermal treatment of waste. Participants also suggested recycling (15 answers), which includes general recycling mentions and mechanical or chemical recycling. Other answers included digital and decentralized waste management (7 answers) like 'Vacuum waste collection', 'Decentralized anaerobic digestion', 'Carbon neutral waste management'…etc. Other people suggested material recovery and industrial waste solutions (7 answers). The results show the diversity of options that can be suggested but there is no agreement on a specific alternative.

10. Examination of the principal associations from the survey data

The correlation between some of the results was examined to have an overview of the principal associations that might be relevant to this study.

10.1. Knowledge of waste incineration and the correlation with concern for environmental impact

The following Figure 26 represents the correlation study between how familiar the responding population is with the technology of waste incineration and their level of concern of its environmental impact.

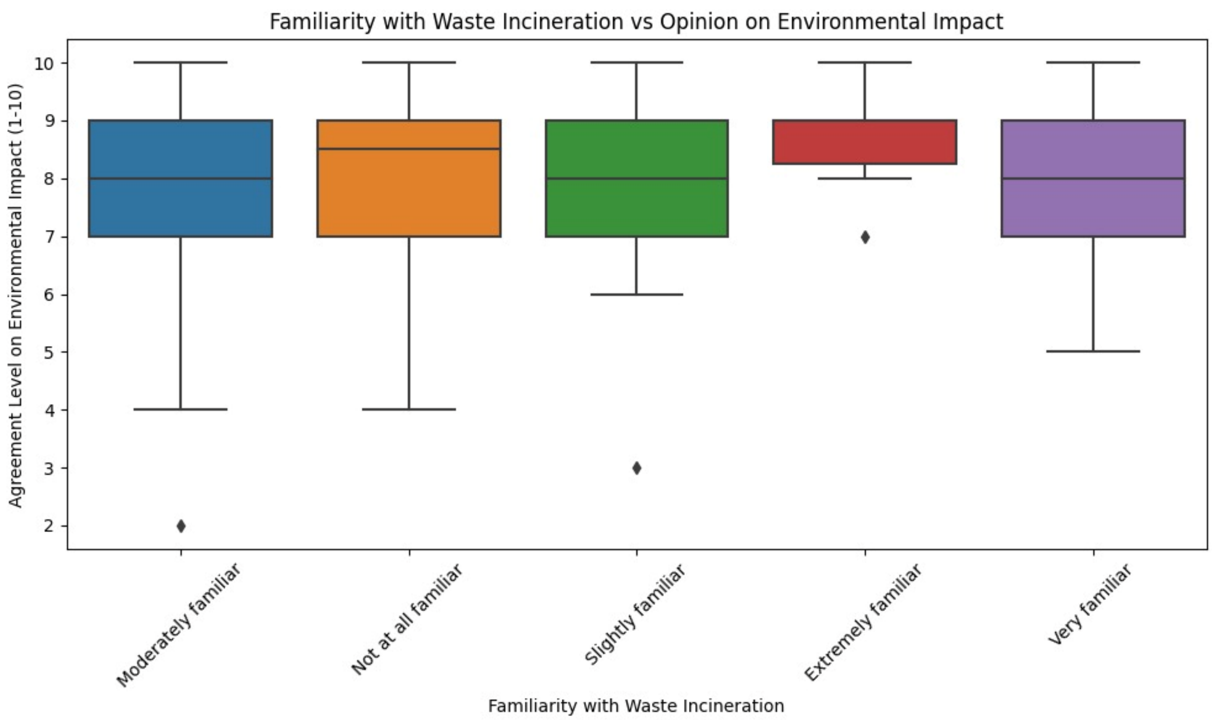

Figure 26: Familiarity with waste incineration Vs Opinion on environmental impact
Source: own editing based on survey results

More knowledgeable respondents are more likely to hold a wider variety of views on the environmental impact of trash incineration, with some being extremely worried and others not. This implies that familiarity may result in more complex viewpoints, revealing a range of viewpoints among better-informed people.

10.2. Opinions on Incineration as an Energy Source per Age Group

Figure 27 represents the results of examining the correlation between the age group and the opinion on using waste incineration as an energy source

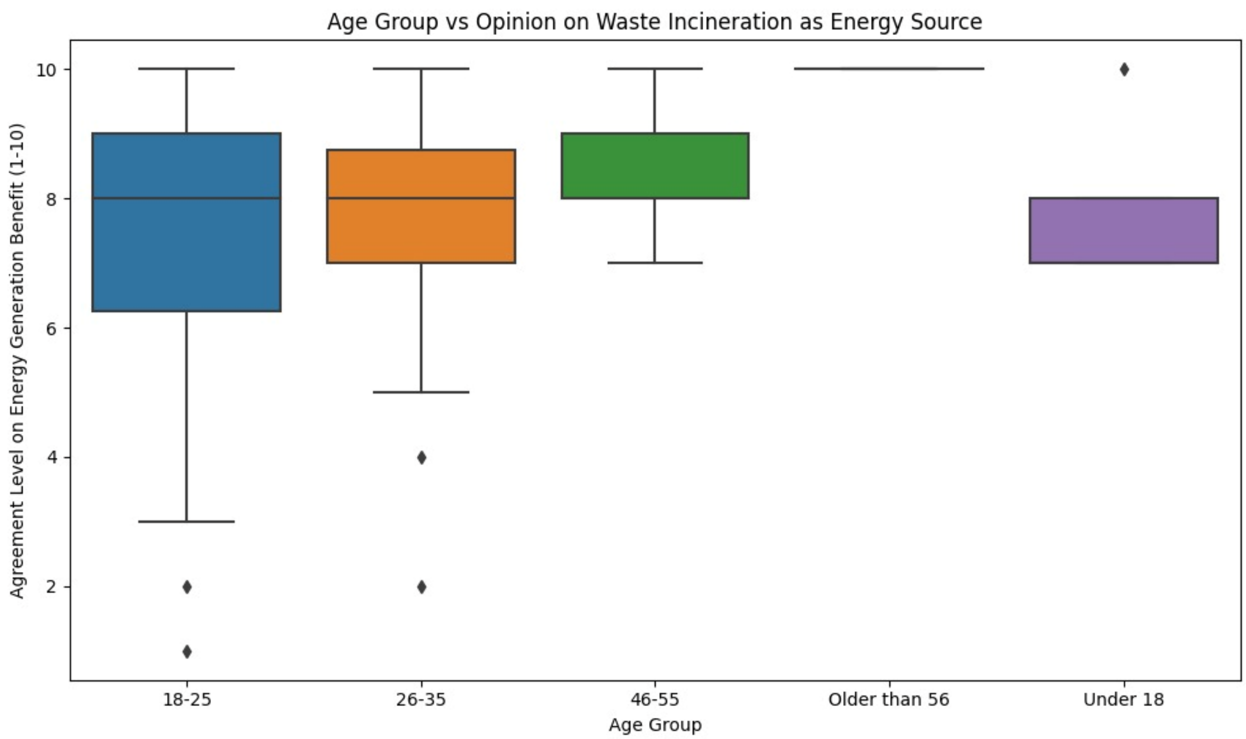

Figure 27: Age group Vs Opinion on waste incineration as energy source
Source: own editing based on survey results

While older groups (26–35) tend toward moderate agreement, younger groups (18–25) have a greater range of opinions about the advantages of incineration for energy generation. This may indicate that younger people's views on the energy advantages of garbage incineration are either more polarized or more strongly held.

10.3. Impact on the Environment versus Agreement on Environmental Concerns

The following graph in Figure 28 represents the correlation between the importance of environmental impact in the opinion of the respondents and their concern for the technology's environmental impact.

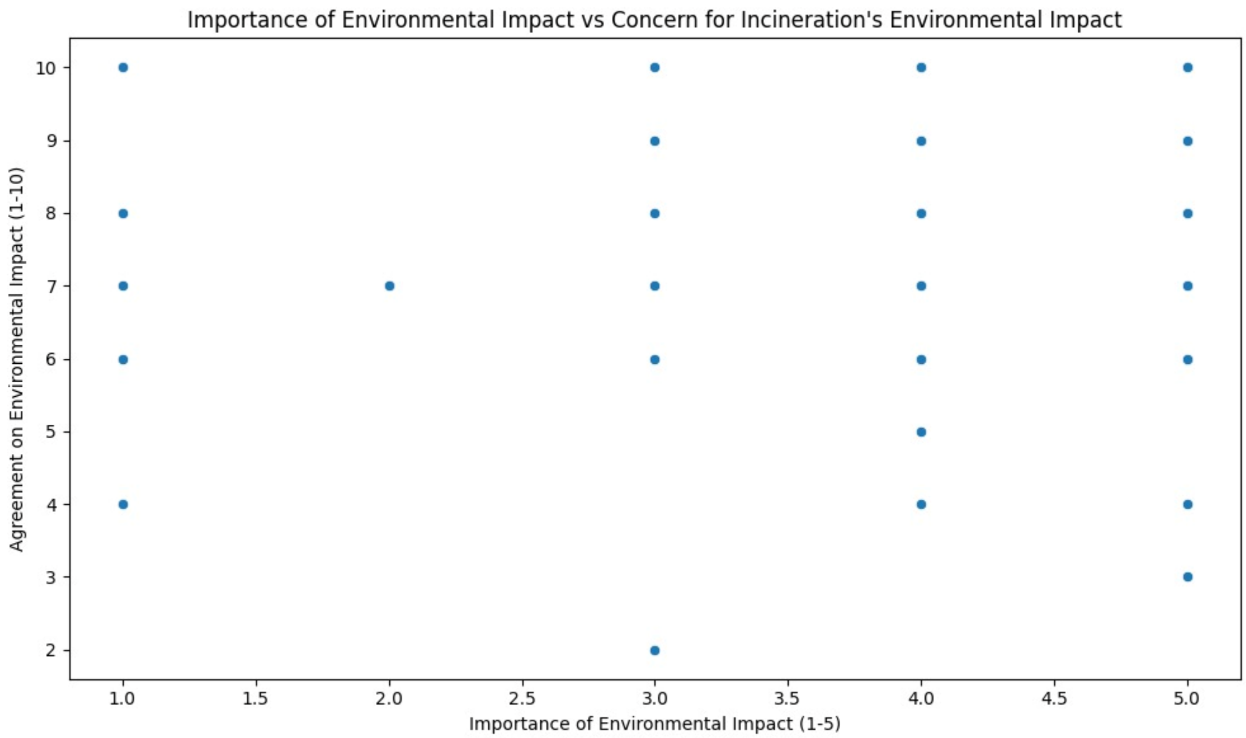

Figure 28: Importance of environmental impact Vs Concern for incineration's environmental impact

Source: own editing based on survey results

Positive trends indicate that respondents who place a high priority on environmental effect (ratings of 4 or 5) are also more concerned about how waste incineration affects the environment. This association highlights how critical opinions about incineration are probably influenced by environmental priorities.

Conclusion

According to the results of a quality examination of municipal solid waste, MSW from various places is largely composed of organic components (with a total composition of roughly 80%), and its carbon content ranges between 50 and 55%. Because of the presence of plastic in municipal solid waste, the atomic ratio of oxygen to carbon is lower than in traditional biomass. The percentage of sulfur in municipal solid waste is typically less than 1%, while some coals may contain a higher percentage of sulfur. The organic components of municipal solid waste (MSW) typically contain between 10 and 12% ash.

However, the presence of glass, metals, and a variety of other nonorganic materials in MSW (the quantity of ash found in MSW) causes the ash content of MSW to rise to between 20 and 35%, which is comparable to the amount of ash found in coals. MSW has a relatively high moisture content when compared to other forms of waste due to the involvement of food and garden waste. The LHV of municipal solid waste ranges between 6 and 11 MJ/kg.

This value can be increased to 15MJ/kg by conducting additional preparation steps as sorting, drying, and shredding. This value exceeds that of woody biomass, wood pellets, and low-grade brown coals for heating. Although data suggests that municipal solid waste (MSW) in general can be considered an organic fuel and can be successfully used to generate electricity using a waste-to-energy process, this concept remains controversial.

Energy recovery from municipal solid waste (MSW) is contributing to the mitigation of both global and local environmental impacts. It is expected that, given its potential benefits and low implementation costs, it will maintain a contribution equivalent to other renewable technologies now entering the market. Energy recovery from municipal solid waste should be implemented wherever it offers a feasible and attractive method of integrating with recycling and reuse initiatives, while minimizing the effects of waste disposal.

Overall, and according to the survey results, the study shows that most people are familiar with waste incineration and think it's a good idea, especially since it helps to reduce the quantity of waste that ends up in landfills. A considerable proportion of respondents have firsthand experience living near incinerators, which lends credence to their viewpoints. The survey also reveals a level of awareness about alternate waste management methods. Recycling is regarded as a realistic option, but there is still a need to educate the public about alternatives, such as composting or other innovative waste management strategies.

In conclusion, while waste incineration is considered as a realistic technique for managing municipal waste, there is an opportunity to widen the discussion about which alternatives can be also acceptable to the public view. We may achieve a more acceptable approach to waste management by increasing awareness and giving more information on sustainable waste management procedures. This could assist in balancing the benefits of incineration with alternative, potentially more sustainable long-term options.

Summary

Municipal solid waste incineration as a sustainable way of energy production

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Any type of development can only be considered sustainable if the waste created by it is not allowed to increase and is instead entirely reused/recycled/recovered. Attempts to recover energy from municipal solid waste (MSW) have been among the ways used to achieve this goal. The carbon content of MSW is roughly 60% consisting of elements that may be biodegraded into fuels such as or burned, producing usable energy. MSW also includes a lot of components, such as metallic waste and fragments of glass that can be recovered or used again in energy conservation. MSW looks to be a viable source of energy and resources based on these characteristics. In fact, the majority of us still produce far more MSW than is necessary, because we believe it is usable if we Effortfully enough. However, how plausible is the energy potential of MSW? What dangers await us if we truly try to use MSW as an energy supply? The present analysis addresses these crucial concerns. In addition, a survey was conducted to understand the general opinions regarding waste incineration and its impact on the environment

Keywords: waste management, Waste to energy, Sustainability, WtE efficiency.

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List of figures

List of tables

Annex: the survey questions

Public attitude toward waste incinerators

These questions are designed to gather data that can be analyzed quantitatively to understand the distribution of attitudes and opinions regarding waste incineration among the surveyed population.

Gender *

- ☐ Male
- ☐ Female
- ☐ Prefer not to say

Age *

- ☐ Under 18
- ☐ 18-25
- ☐ 26-35
- ☐ 46-55
- ☐ Older than 56

What is your Education level? *

- ○ High school
- ○ Bachelor's degree
- ○ Master's degree
- ○ ph.D. or other advanced degree
- ○ Autre : ____________

How familiar are you with the concept of waste incineration? *

- Not at all familiar
- Slightly familiar
- Moderately familiar
- Very familiar
- Extremely familiar

Have you ever resided in a locality where waste incinerators are operational? *

- Yes, currently
- Yes, previously
- No, never

On a scale from 1 to 10, please rate your level of agreement with the following statements regarding waste incineration: *
where
1 if you do not agree at all.
10 if you totally agree.

Waste incineration reduces the burden on landfills.

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

Waste incineration has significant environmental impacts, particularly in terms of air pollution and greenhouse gas emissions. *

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Waste incineration contributes positively to energy generation and resource recovery. *

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Waste incineration facilities should follow strict rules to protect the environment and reduce any possible harm. *

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

What factors do you believe should be prioritized in the decision-making process for the implementation of waste incinerators in a community? *
(Rank from 1 to 5, with 5 being the most important and 1 being the least important)

Environmental impact

1 2 3 4 5

○ ○ ○ ○ ○

Health and safety concerns *

1 2 3 4 5

○ ○ ○ ○ ○

Economic feasibility *

1 2 3 4 5

○ ○ ○ ○ ○

Social acceptance and community engagement *

1 2 3 4 5

○ ○ ○ ○ ○

To what extent do you believe waste incinerators contribute to addressing the challenges of waste management and environmental sustainability? *

- ◯ Very significantly
- ◯ Somewhat significantly
- ◯ Neutral
- ◯ Not very significantly
- ◯ Not at all significantly

Can you identify any potential alternatives to waste incineration for managing municipal solid waste that you believe warrants further investigation or consideration? *

Your answer

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STUDENT DECLARATION

Signed below _ **Abushawareb Ahmed Z.M.**__, student of the Hungarian University of Agricultural and Life Sciences, ____**Szent István**___ Campus, Environmental Engineering BSc Course <u>full time</u>/correspondence declare that the presented Thesis is my own work, and I have used the cited and quoted literature in accordance with the relevant legal and ethical rules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course, and my thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes <u>no</u>

Date: 10. November 2024.

____

Student

SUPERVISOR'S DECLARATION

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; the student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn to the importance of using literature data in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes <u>no</u>

Approval of thesis for oral defense on Final Examination: <u>approved</u> not approved

Date: Gödöllő, 11. November 2024

Dr. Csegődi Tibor László

Internal Supervisor