Urban Waste Management: The Case of the System in Lyon

An Interactive Qualifying Project

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Abstract:

This project aimed to create a case study of the waste management practices in Lyon, France, including its history, public policies, and other reasons for success. Data was collected through expert interviews and archival research. Cultural and thematic analyses were performed on the responses, with the aim of determining the most significant factors contributing to Lyon's success that could be applied to other locations. The study found successful, innovative policies with regard to waste reduction, collection, and treatment. These policies have led to a high performing system in Lyon through its recycling, composting, and incineration, with some improvements to be made. Information from this case study has been conveyed in the form of an interactive map of Lyon's waste collection sites and a guide to best waste management practices synthesized from the findings of the case study.

Executive Summary

Introduction:

Lyon's waste management system is much better than that of its peers. With a thorough sorting system and robust residential cooperation, the city does a great job managing waste and encouraging recycling. Dating back to the 1st century B.C.E. Lyon is an old city not designed with the needs of a contemporary waste management system in mind. Despite this, Lyon has still adapted to the needs of the modern world, including in the way in which it manages its waste. While Lyon continues to improve the state of their system, waste seems to be becoming nearly unmanageable worldwide. Between 1965 and 2015, global waste production has more than tripled (Chen et al., 2020) and is expected to further increase. In 2015, between 7 and 9 billion tons of waste were produced (Wilson & Velis, 2015). Urban waste management is a pressing issue ubiquitous around the world.

This project, based within Lyon, sought to determine what specifically made Lyon's urban waste management so effective, and how those tactics could be applied to improve other municipalities to curb the worsening waste crisis. Utilizing various research methods, we investigated the history, current practices, and future goals of Grand Lyon, to find which areas were ahead of their peers, and which areas could still use improvement.

Background:

Any urban waste management (UWM) system can be broken down into the following three most important steps: collection, treatment, and disposal. The first step brings all the waste together to one location. The second makes the waste more suitable for disposal. Finally, the third step, disposal, allows the waste to be placed in its final location. The most common method of waste treatment is incineration, where trash is burned to reduce its volume up to 90%, typically to collect energy as well (Chimenos et al., 1999). The most common method of disposal is landfilling, where waste is buried underground.

These most common methods of waste management are not sustainable. Incineration often releases harmful heavy metals as well as greenhouse gases, requiring careful processing of fumes and ash to avoid (Jobin et al., 2016; Di Maria et al., 2021). Similarly, landfilling can have harmful effects on the surrounding ecology, so suitable land must be carefully chosen (Tammemagi, 1999). Because of these harmful effects, recycling is an important step to reduce waste. A good waste management system would use the most sustainable methods available and encourage recycling as much as possible.

Methods:

With the goal of using research in Lyon to produce a framework of ideal UWM practices, we conducted expert interviews and site visits to some of Lyon's waste treatment facilities. Using ethnographic methods and cultural analysis, we painted a picture of Lyon and its UWM system in order to better inform our results. Data visualizations, including a heatmap of the city's drop off sites, were created, as well as quantitative comparisons between Lyon and other comparable cities.

Prior to conducting any interviews or gathering information from any individuals, informed consent was obtained. They were informed of the purpose of the research, the voluntary nature of their participation, and their right to withdraw from the study at any time without consequence. They were given the option to remain anonymous or to consent to the use of their name in published works. All data collection activities were conducted under an IRB-approved protocol, protecting participants' rights, privacy, and well-being.

Findings:

Lyon has a plethora of effective practices that could be applied to other locations. For one, they are the one of very few municipalities to emphasize reduction of waste through programs such as Extended Producer Responsibility, textile collection, and repair workshops. Lyon has robust collection infrastructure compared to similar municipalities. Lyon has a dual-stream sorting system, which separates glass from other recyclable materials. Residents are well-educated on this system and participate in it with high frequency. While their recycling system is effective, its handling of 31.2% of Lyon's waste by mass is still below the EU recycling rate targets for 2025 (Métropole de Lyon, 2020; European Environment Agency, 2023). Lyon has established composting as standard practice for managing the city's bio-waste as of 1 January 2024. While the Lyonnais process is effective, its infrastructure is new, and public awareness of the process is limited. 61.2% of Lyon's waste is incinerated with energy capture, a rate higher than EU targets (Métropole de Lyon, 2020; European Environment Agency, 2023).

Based on these findings, in conjunction with site visits and expert interviews, the group established a framework for urban waste management. This framework firstly emphasizes the waste reduction techniques. Lyon is a great example of proper waste reduction techniques. Ideally, waste management would be unnecessary because there would be no waste to manage. However, this is an impossibility, and waste management must be done. The framework emphasizes proper sorting, which can be achieved through convenient collection and sorting processes, as well as through education and awareness. Lyon performs well in these areas, though based on its low recycling rate, improvements can be made to improve the rate at which waste is properly sorted.

The framework emphasizes sorting because proper sorting must occur for the framework's preferred method of waste treatment: recycling. While recycling can best be increased through better initial sorting, French and Lyonnais policies such as modernization of recycling facilities, clear instructions for sorting, incentives, and Extended Producer Responsibility. Sorting must also occur to implement the framework's recommendations for bio-waste, wherein urban bio-waste should be composted and rural bio-waste methanized. These processes create beneficial byproducts and alleviate the energy cost of the preferred method of waste treatment for non-recyclable, inorganic waste: incineration with energy capture. This method is preferred for waste that cannot be recycled, composted, or methanized for its production of energy and heat, its reduced emissions, and its relatively little pollution when compared to the alternative: landfilling. Landfilling, according to our framework, should only be used for waste which cannot be recycled, composted or methanized, or incinerated. This waste is typically hazardous, radioactive, or toxic. This priority of techniques is followed by Lyon.

This project resulted in the creation of two deliverables, both of which can be found at site (URL?) and in the appendix (MAYBE?).

Conclusion:

Lyon, while still having plenty of room for improvement, shows much that can be taught to other municipalities. Namely their robust sorting system and strong resident participation. Their recycling rates can be improved, but as a whole, Lyon's UWM system outperforms any of its competitors. Creating a strong UWM system is difficult, and requires meticulous planning, but

Lyon shows that adapting a city for modern waste needs is possible, even for one built entirely without that infrastructure in mind.

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1. Introduction

As you walk the streets of Lyon, you will find recycling and waste bins everywhere. On nearly every street corner, you can find trash collection and recycling bins. They have grey bins for glass; green and yellow for bins plastic, metal, paper; brown bins for composting; and black bins for regular trash, often surrounded by more trash due to being filled. More than most places, the Lyonnaise seem to be very aware of how to properly dispose of waste and the importance of doing so. Every home has multiple bins for proper sorting and curbside collection occurs weekly. Flip over any packaging item and you'll find a label displaying how to sort the item. Despite being one of France's largest cities, with people walking up and down sidewalks at all hours of the day, finding trash in public places is very rare (other than cigarette butts). Dating back to the 1st century B.C.E., there are Roman Ruins scattered about the city; Lyon was clearly not designed with the needs of a contemporary waste management system in mind. Despite this, Lyon has still adapted to the needs of the modern world, including in the way in which it manages its waste.

While Lyon continues to improve the state of their system, waste seems to be becoming nearly unmanageable worldwide. Between 1965 and 2015, global waste production has more than tripled (Chen et al., 2020) and is expected to further increase. In 2015, between 7 and 9 billion tons of waste were produced (Wilson & Velis, 2015). This increase in waste has raised questions on how it affects the climate and how the waste can be properly managed to minimize its environmental impact as much as possible. While minimizing the total amount of waste produced is helpful, proper management techniques are vital to protect the environment and the health of local residents.

This project, based within Lyon, sought to determine what specifically made Lyon's urban waste management so effective, and how those tactics could be applied to improve other municipalities to curb the worsening waste crisis. Utilizing various research methods, we investigated the history, current practices, and future goals of Grand Lyon, to find which areas they were ahead of their peers, and which areas could still use improvement.

Chapter 2 will discuss the background research necessary to understand and frame the goals of this project and its significance. Chapter 3 will explore in depth the methods this project will implement and the deliverables it will produce. Chapter 4 will discuss the results and findings obtained by exercising the methodology previously outlined in Chapter 3. Chapter 5 will discuss other deliverables created in conjunction with this report, while Chapter 6 will cover the circumstances of the project, limitations thereof, and conclusions that have been drawn from it.

2. Background

This chapter will begin by exploring the history and importance of waste management and examining the most common practices currently used. It will then provide an in-depth look at recycling practices and the specific challenges associated with treating electronic and electrical equipment waste (e-waste). To showcase a successful example of innovative waste management strategies, the case of Curitiba, Brazil, will be presented. Finally, the current waste management systems in Lyon and France will be analyzed to provide context for the project's focus on Lyon as a case study.

2.1 Waste Management History and Practices

As the environmental climate crisis continues to worsen, waste production only exacerbates the issue. In the United States, municipal solid waste (MSW) landfills were the third-largest producer of methane, accounting for 14% of the nation's total production (US EPA, 2017a). Landfills cause habitat damage, air pollution, water pollution, and fire hazards (El-Fadel et al., 1997). In its current state, waste production has very negative impacts on the environment.

There are three main steps cities must follow regarding waste management. The first is the collection step. Waste must be gathered from individuals throughout the city; this can be done by either a collections system that travels around the city or by common drop-off points for residents to bring their trash to. Drop-off points are typically either small drop-off points spread throughout the city or one large central point for all trash to be disposed. The collected waste then undergoes treatment to make disposal easier. There are various treatments, each with its own pros and cons; the list includes, but is not limited to: sorting, recycling, incineration, and biological treatments, the most common of which is typically incineration or recycling (WASTE TREATMENT

METHODS, n.d.). After its treatment, the waste must then be disposed of, typically either in a landfill or a composting location (Hazlegreaves, 2019).

According to the U.S. Environmental Protection Agency (EPA), the most common method of waste disposal is landfills. Landfills are the final destination for household waste, where large amounts of trash accumulate to separate it from the local environment. Despite their widespread use, landfills have two significant flaws: environmental contamination and extensive space requirements. Landfill site selection is conducted very meticulously. Because contaminants from the trash may seep into the local environment, locations are chosen where the ecosystem can mitigate or "attenuate" their effects (Tammemagi, 1999). This significantly limits their potential locations and implies that landfills will eventually reach a maximum capacity where they can no longer safely receive more waste without causing environmental harm.

Landfills also occupy significantly more space than any other waste management method. The average landfill requires 600 acres (Vasarhelyi, 2021), making space limited. Due to the necessity of large locations with specific conditions, landfill space is highly restricted. Once landfills reach capacity, they must be closed or capped, requiring the search for a new location, rendering the old site unusable. Consequently, if suitable land is unavailable nearby, municipal solid waste (MSW) must be transported and processed at another facility, exacerbating its environmental impact, and shifting the issue elsewhere.

While a responsibly managed and maintained landfill can be an effective way to manage waste, it should only be seen as the last line of defense in protecting nature from trash. Space is limited and extremely valuable. Before waste is dumped in a landfill, other processing methods should be considered and applied where possible. Methods such as waste incineration and recycling, each with their own drawbacks, could help alleviate some of the strain on waste industries.

Waste incineration is the process of burning MSW to shrink its size and usually produce energy. Incineration is very effective at reducing the volume of waste by up to 90%, leading to much easier storage and lower land requirements (Chimenos et al., 1999). Among OECD nations, Japan, Sweden, and Finland have the highest incineration rates at 79.8%, 60.1%, and 57.9% respectively (Filipenco, 2024). Full data on incineration rates in OECD nations can be found below in Figure 1.

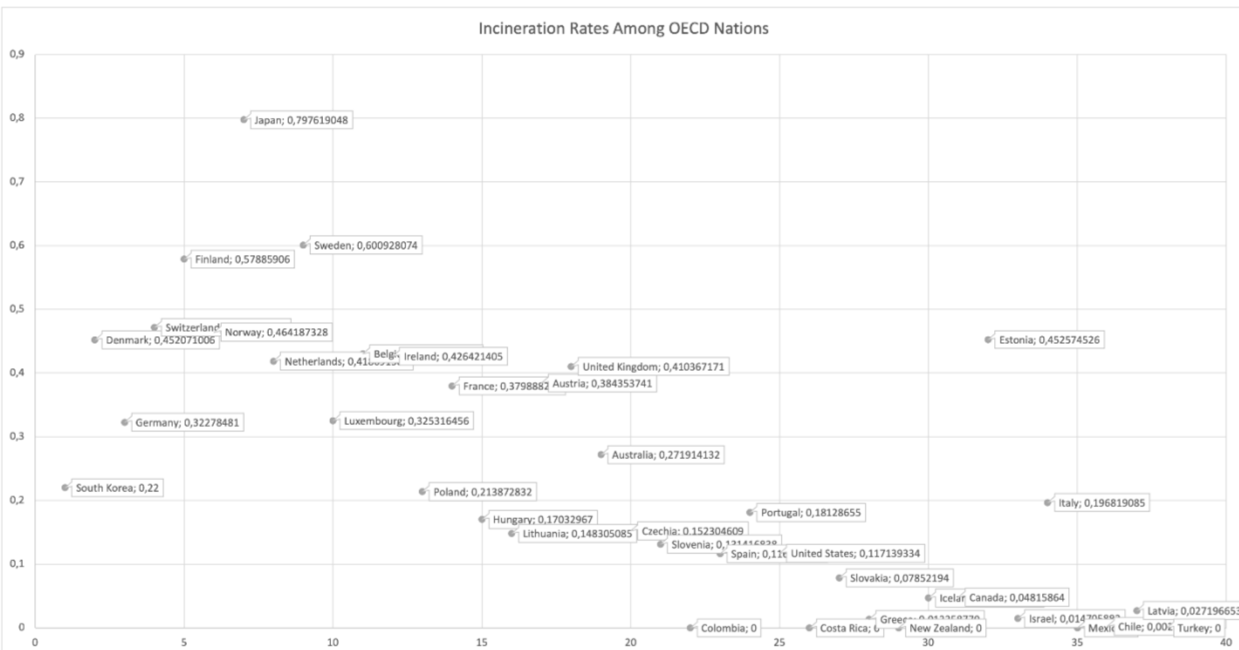


Figure 1. Incineration Rates Among OECD Nations (Filipenco, 2024; Willoughby, 2024)

One advantage of waste incineration is the potential of energy generation. Incineration facilities can produce both electricity, ranging from 37,900 MWh to 226,300 MWh, and heat, ranging from 20,500 MWh to 588,130 MWh (Di Maria et al., 2021). To put this into perspective, the electricity generated by these facilities could power between 7,962 and 47,550 French households for a year, based on the average annual electricity consumption of 4,760 kWh per household in France (*What Is an Average Energy Bill in France?*, 2016). This energy production should help offset the financial costs of creating and managing an incineration system. However, further studies show that non-combustible forms of waste, such as glass and metal, comprise an increasing percentage of global waste output. Aluminum production is a very energy-dense process. Recycling aluminum can save some of this energy, but subjecting aluminum to waste-to-energy combustion renders it non-recyclable due to mixture with too many toxic materials, squandering rather than generating energy (Abbasi, 2018).

While waste incineration may be useful in generating energy, it also has its drawbacks. Like landfills, incineration produces large amounts of greenhouse gases (Di Maria et al., 2021). The combustion of hydrocarbon compounds unavoidably produces methane and CO2. It also produces heavy metals, such as copper, lead, antimony, tin, zinc, arsenic, chromium, and aluminum, which require special processing and protective measures for the local environment (Jobin et al., 2016). To reduce harmful heavy metals and other toxic contaminants, waste processing companies, such as WM, have long lists of materials not allowed in typical household wastes including aerosols, batteries, and other dangerous waste (*WM*, n.d.). While safer for the environment, this complicates things for residents, leading to mistakes in sorting and materials slipping through where they should not.

Incineration also is linked with certain adverse effects. While it is difficult to precisely identify the health effects of incineration plants on surrounding communities due to confounding factors, a majority of papers sampled researching the topic report significant adverse health effects related to waste incineration (Tait et al., 2020). Common findings from these studies showed that increased risk of exposure to known pollutants such as those aforementioned, increased risk of developing neoplasia, correlation with reproductive complications, and links to diseases such as hypertension and decreased lung function (Tait et al., 2020). In addition, incineration plants such as these are disproportionately located in disadvantaged communities near historically marginalized groups. As a result, the adverse health effects of industrial sites such as incineration plants are disproportionately borne by economically and racially disadvantaged communities (Salas, 2021).

Waste incineration, like landfills, has its place in any comprehensive waste management plan, but it cannot be the only technique employed in a waste management system. Not all materials can be incinerated and decomposed completely. In addition, the management of the highly hazardous solid waste ash produced after incineration requires its own special set of treatments to be properly managed and disposed. It is important to remember that incineration is considered waste treatment, not waste disposal. It can be a very effective treatment since its product only takes up about 10% of the volume that MSW sent to landfills does (Chimenos et al., 1999).

Any effective urban waste treatment program will involve selection or application of all the common strategies presented, among other strategies such as composting. Some methods are suitable for specific materials, and all methods should be considered when determining the optimal treatment and disposal plan. Impacts on human health, the local environment, and the global climate must all be considered.

2.2 Recycling

Recycling plays a key role in a well-performing urban waste management system. The discussion around recycling typically falls under two categories: the internal methods by which recycling is conducted, and the external policies which encourage its use. This section will provide context on each of these areas.

2.2.1 Recycling Collection and Treatment

Recycling is potentially the most effective method of reducing waste and should be considered before any other method of waste treatment or disposal. Recycling is the process of taking used materials and processing them in such a way that they can be reused in the production of new goods. This benefit makes recycling the most sustainable method of waste treatment, as it reduces both the total amount of waste and the demand for the consumption of new materials.

According to the EPA, the most recycled common household material in the U.S. is paper and paperboard, comprising about two-thirds of all the materials recycled by mass, followed by metals, plastic, and glass (US EPA, 2017b). Further details can be found in Table 1.

Table 1. Material Composition by Mass of U.S. Recycling (US EPA, 2017b)

Material	Percentage Composition by Mass
Paper/Cardboard	66.54%
Metals	12.62%
Rubber, Leather, and Textiles	6.05%
Wood	4.49%
Plastics	4.47%
Glass	4.43%
Other	1.40%

However, recycling itself is not without drawbacks. The recyclability of materials varies significantly; some are very easy to recycle, while others are almost impossible. For instance, food waste, which constitutes an estimated 24% of municipal solid waste (MSW) by mass (US EPA, 2015), is entirely unrecyclable and is better suited for incineration or composting. Different materials require distinct recycling methods; for example, plastic and glass need completely different treatments and must be separated accordingly.

This difference makes the manner in which recyclables are collected one of the greatest challenges the waste recycling industry faces (*Challenges in Recycling*, 2022). Various methods for these collections have developed in various locations. In the U.S. most recycling processors use single-stream recycling (Hutman, 2022), which means each household puts all their recyclables together without separating them. The processors then separate the recyclables inside the recycling facilities (*Types of Collection - DSNY*, n.d.). This reduces complexity for the consumer, which, as discussed, likely leads to higher recycling rates (Knickmeyer, 2020), but raises the cost of recycling treatment. Cross-contamination is also a possibility, where trash or recyclables are mis-sorted and receive inappropriate treatment, and non-recyclables (such as food) might contaminate other recyclable material, which leads to delays within the recycling plant. As a result, recycling rates are lowered, and many things that could have been recycled end up as waste (Hutman, 2022).

Because it can be challenging to separate recyclables, household sorting and cooperation from the community are essential to facilitate recycling. Recyclables not only need to be separated from typical household waste, but some recyclables must also be separated from each other. Convenience was found to be a significant factor in an individual's likelihood of recycling (Knickmeyer, 2020). This finding implies that recycling should be made as easy, quick, and efficient as possible for individual households to maximize recycling rates. Knickmeyer also discovered that knowledge about recycling, such as how to contribute, increased urban residents' ability and willingness to participate in waste sorting.

Unlike the United States, Europe and Japan typically use double-stream recycling methods (Yolin, 2015). Both have laws that require consumers to separate recyclable materials before they are discarded. For example, cans must be washed before recycling, and placing them in normal trash bags is prohibited (Métropole de Lyon, 2024b). This has greatly improved the recycling rate. However, many places have experienced pushback against this method due to its complexity and the need for people to at times travel a distance to dispose of trash at specific times (Hutman, 2022). Some of the major factors to increase the recycling rate are the trash collection frequency and distance from home. There is a positive relationship between the distance from people's houses and the recycling center (The Recycling Partnership, 2020).

A 2015 study throughout Ontario found that while single stream recycling systems were able to recycle more materials by weight, they were almost 30% more expensive than dual stream systems. (Lakhan, 2015). This leaves cities with a question: do you prioritize cost or efficiency? Some cities may be able to afford the cost of separation in a single stream system, while others may be able to use a dual stream system while maintaining high participation. Both systems have pros and cons which much be weighed to decide which is appropriate for location.

2.2.2 Recycling Conducive Policies

In 2023, The European Union committed to both reduce the overall waste production and the recycling rate (*Waste Framework Directive - European Commission*, 2023). Currently, the E.U.'s average waste is about 4.8 tons per capita (Waste Statistics, 2023) in 2020, and the average recycling rate in the EE.U.is 48.73%. In France, the recycling rate is 43.8% (Municipal Waste Recycling Rates in Europe by Country — European Environment Agency, 2023). As shown in Figure 2, France ranks about average in per capita waste production among E.U. nations, however it still ranks much higher than the U.S.

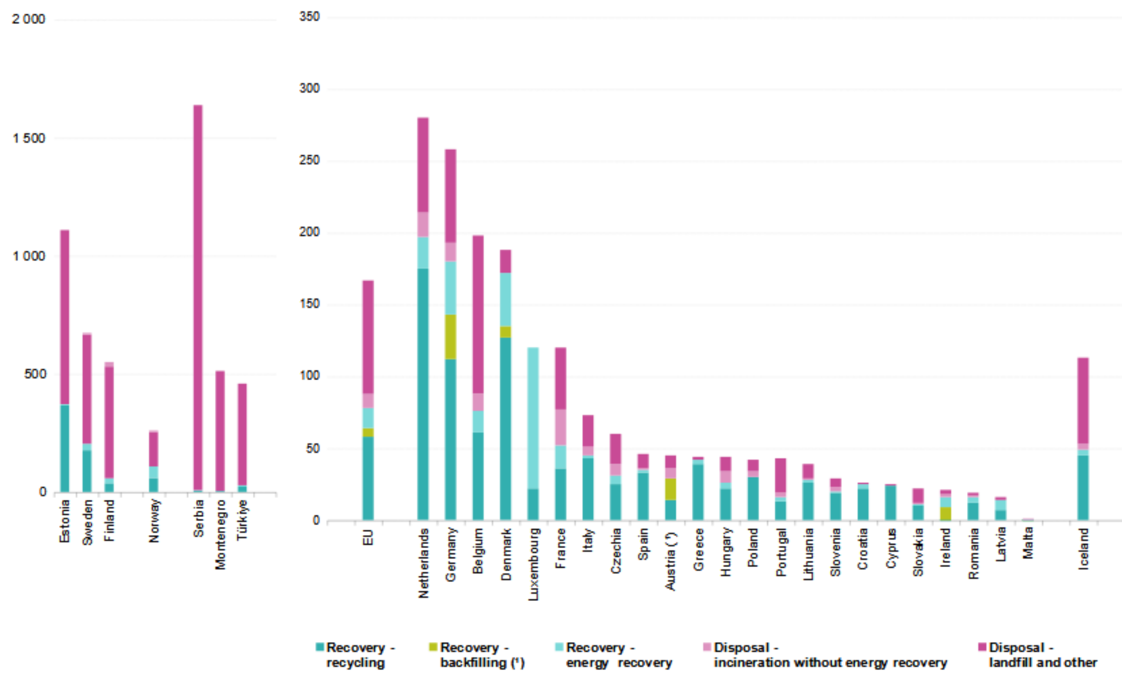


Figure 2. Waste production per capita in the E.U. Dark green is the percentage recycled, and dark pink is the percentage landfilled. (*Waste Statistics*, 2023)

This commitment makes finding ways to increase recycling participation of particular concern. Adding real money incentivization is one method that can help increase the recycling rate. In the United States, people in the state of New York can claim 5 cents for every plastic bottle sold within the state that they return to special machines which sends the bottle to be recycled (*NYS Department of Environmental Conservation*, n.d.). This program has led to the highest plastic bottle recycling rate in the U.S. (*Get Your Money Back - NYSDEC*, n.d.). It also highlights the importance of incentives in encouraging people to recycle. Some other states in the U.S. also have a plastic bottle tax, such as Massachusetts (*State Beverage Container Deposit Laws*, 2024). However, due to a lack of recycling machines, people may improperly dispose of bottles due to greater convenience (*Commonwealth of Massachusetts*, n.d.; *Get Your Money Back - NYSDEC*, n.d.). Massachusetts' plastic bottle recycling rate is lower than New York's, but still higher than the national average (LeMoult, 2024; US EPA, 2017b c).

Another effective policy to increase recycling rates is Extended Producer Responsibility. This policy ensures the packaging industry has certain obligations to cover the costs of recycling the waste they generate. In France, waste-producing industries pays fees to the Green Dot company Eco-Emballages based on the quantity and type of packaging they place in the market. Eco-Emballages then provides funding to local authorities to support the costs of collecting and processing packaging waste for recycling. Under France's Grenelle Act, Eco-Emballages is required to cover 80% of the optimized net costs of packaging waste recycling services (Cabral et al., 2013).

However, even with industry funding through Extended Producer Responsibility schemes like the Green Dot system, government subsidies are often still required to make recycling financially viable for local authorities. Efficient recycling systems impose additional costs compared to refuse collection and disposal. The financial burden is further increased by the volatility of recycled material commodity prices. Public policy and investment to support recycling may be justified though when considering the environmental and social benefits and avoided disposal costs.

Currently, recycling is not inherently profitable, and subsidies are needed to cover its inherent financial losses. A study examining the financial flows in the recycling of packaging waste in France found that the revenues generated from the sale of recycled materials and industry fees in 2010 only covered around 56% of the total costs incurred by local authorities for providing packaging waste recycling services (Cabral et al., 2013). The authors argue this raises important policy questions about whether the costs of recycling systems should be fully borne by the industries that manufacture this waste per the polluter-pays principle, or if public subsidies to recycling should be provided.

While the packaging industry has an obligation to fund a substantial portion of packaging waste recycling costs, government subsidies also play an important role in overcoming the financial losses that would otherwise make comprehensive recycling nonviable for local authorities to pursue. Determining the appropriate balance of shared costs between industry and the public sector is an important policy issue for government officials in establishing sustainable financing models for successful recycling programs.

2.3 E-Waste

A category of waste of particular interest is e-waste. E-waste, or electronic waste, is waste generated by electronic devices discarded by a previous owner. As electronic devices gain more widespread use, e-waste becomes an even greater portion of overall waste generation and has thus been a cause for concern. In fact, e-waste is one of the fastest-growing waste streams in the world (*Tackling Informality in E-Waste Management: The Potential of Cooperative Enterprises*, 2014). Despite this, in 2022, only 13.8 billion of the 62 billion kilograms of e-waste generated was documented as being collected and recycled in a responsible manner. A further 16 billion kilograms was estimated to have been handled in high and middle-income nations with adequate systems in place to handle the demands of e-waste, while an estimated 18 billion were handled by low-income nations without proper e-waste infrastructure, and the remaining 14 billion were believed to be landfilled with other waste streams (Baldé et al., 2024). This makes the management of such waste an essential consideration in modern waste management systems.

The consideration of e-waste in modern waste management systems is essential due to unique concerns about e-waste. E-waste involves highly polluting plastics and metals, including lead, gold, aluminum, and copper. These metals make up over 60.20% of the composition of e-waste by weight, while plastics, metal-plastic composites, and other pollutants make up a combined 22.88%. This combination of materials poses a dangerous environmental and health hazard when disposed of using inferior, uncontrolled techniques (Widmer et al., 2005). Given that over half of e-waste is estimated to be handled as part of the general waste stream or in nations with inferior infrastructure and practices in use, these health risks pose a serious threat to global health, especially for historically disadvantaged peoples (Baldé et al., 2024; Salas, 2021).

In addition to the health and environmental concerns associated with e-waste, there are also privacy concerns to be considered. Improperly disposed e-waste may also include sensitive user data from its previous owner, introducing a privacy risk that must be addressed to prevent violations of sensitive, private user information (*E-WASTE MANAGEMENT | Urban Agenda Platform*, n.d.).

2.4 Bio-waste

Another important consideration when managing urban waste is how to handle organic waste. Bio-waste accounted for about 34% of MSW in 2017, of which about 60% was food waste. The remainder of bio-waste's composition is primarily associated with garden and park maintenance (Linden & Reichel, 2020). The mismanagement of bio-waste has profound negative environmental effects. The methane produced by uncontrolled, anaerobic biodegradation of organic waste, especially in landfills, accounted for 3% of the E.U.'s total greenhouse gas emissions in 1995 (*Biodegradable Waste - European Commission*, n.d.). While the European Commission's definition of bio-waste does not include agricultural waste, the agricultural waste stream can be integrated with the two main, dedicated bio-waste treatment techniques due to its biodegradability (ADEME, 2023; *Biodegradable Waste - European Commission*, n.d.; Joulin, 2024).

There are two principal ways of managing bio-waste. The most recently introduced of these is methanization. This process traps and purifies the methane produced by anaerobic biodegradation. This process results in two final products. The methane captured can be integrated with the natural gas supply, which is typically used for heat and power as an alternative to electricity. Additionally, the digestate used in the biodegradation process can be used as fertilizer. This method is most effective for agricultural waste, as the methane yields associated with agricultural waste are much higher per mass than the same yields associated with food, garden, and park waste (LA MÉTHANISATION, 2023).

The more common approach to bio-waste management is composting. The composting process involves the natural, aerobic decomposition of bio-waste. This process principally yields compost, a fertilizing product. The process also yields heat, carbon dioxide, and moisture. The compost yielded by the process of composting can be made to serve a variety of specialized purposes depending on the application (Joulin, 2024).

These two processes exist in competition, as they cannot effectively coexist within a single UWM system. This makes analyzing the advantages and disadvantages of each of these practices essential when developing a framework for a city's UWM strategy.

2.5 Curitiba, Brazil: Lixo que Não é Lixo

In 1989, the city implemented an innovative waste management plan called "ixo que não é Lixo" (waste that isn't waste) with the goal of increasing recycling rates and reducing the amount of waste going to landfill (Silva & (ixo que não é Lixo). An innovative waste management program aimed at increasing recycling rates and reducing the amount of waste sent to landfill (Silva &

Bollmann, 2011). The program's objective is to enhance residents' access to waste sorting and collection services while underscoring the significance of recycling.

One of the program's pivotal elements is the utilization of door-to-door collection of recyclables. The city employs distinctive green trucks with easily recognizable banners to remind residents of collection times (Silva & Bollmann, 2011). This initiative eliminates the necessity for residents to make a trip to the landfill, thereby fostering community participation in recycling programs.

To promote the practice of waste sorting, the city has conducted educational campaigns featuring cartoon characters, particularly for children (Silva & Bollmann, 2011). These campaigns have successfully raised residents' awareness of the importance of recycling and encouraged them to adopt sustainable waste management habits.

In addition to educational initiatives, Curitiba has implemented incentive programs to further encourage recycling. The "Câmbio Verde" program allows residents to exchange recyclables for fresh produce, while the "Cambio Escola" program exchanges recyclables for school supplies (Silva & Bollmann, 2011). These programs not only encourage recycling, but also offer tangible benefits to participants, particularly those living in low-income communities.

The "Lixo que não é Lixo" program also aims to involve informal waste pickers and refuse collectors, who play a central role in the city's waste management system. The city has established waste sorting centers to provide employment opportunities for these individuals, thereby enabling them to work in safer and more hygienic conditions (Silva & Bollmann, 2011).

In its early years, the program was highly successful. The quantity of recyclables collected per day increased from 14 tonnes in 1989 to 35 tonnes in 1994. By 1998, 59 tonnes of recyclables were being collected daily in Curitiba, representing the program's greatest success (Silva & Bollmann, 2011).

Nevertheless, despite the initial success of the "Lixo que não é Lixo" program, recycling rates began to decline in the late 1990s and early 2000s. By 2005, the daily recycling rate had fallen to 25 tonnes (Silva & Bollmann, 2011). A number of factors contributed to the decline in recycling rates. These included a lack of investment and awareness on the part of municipalities, which led residents to lose their recycling habits. In addition, the arrival of a new group of residents unfamiliar with Curitiba's recycling culture also contributed to the program's declining effectiveness (Silva & Bollmann, 2011).

In response, Curitiba initiated a revitalization campaign in 2006 with the objective of reinvigorating the "Lixo que não é Lixo" program and increasing participation. The new campaign updated the brand and messaging, while retaining popular elements such as music collection vehicles (Silva & Bollmann, 2011). The city also invested in new educational activities and incentive programs to engage both long-time residents and newcomers.

More recent data shows that Curitiba continues to face challenges in its waste management efforts. In 2020, the city produced 3,423 tonnes of municipal solid waste (MSW) per day, with a recycling rate of just 23% (Devendran et al., 2023). This suggests that, despite the city's history of innovative waste management, recycling rates and waste reduction could be significantly improved.

In addition to the "Lixo que não é Lixo" program, Curitiba has implemented a number of other waste collection systems and programs to manage the various waste streams from households, commerce, and industry. These include the Estações de Sustentabilidade (Sustainable

Development Stations) and Ecocidadão (Ecological Citizenship) programs, which serve to complement existing recycling efforts (Devendran et al., 2023).

By 2020, the city of Curitiba will have a total of 39 solid waste collection points and one waste disposal point, where collected waste will be treated before going to landfill. The city faces a significant challenge in that it currently depends on a landfill located 30 km from the city center, which is projected to have a remaining lifespan of less than 10 years (until 2030) (Devendran et al., 2023).

Curitiba allocates 6% of its municipal budget to the collection and transportation of MSW, underscoring the financial significance of waste management in the city's comprehensive planning (Devendran et al., 2023). Despite this investment, the city continues to confront challenges, including suboptimal logistical arrangements for collection and transfer, elevated levels of contamination of recyclables, and the relatively low recycling rate of 23% previously mentioned.

Furthermore, the city's geographical and demographic characteristics contribute to the complexity of its waste management system. Curitiba covers an area of 434.9 square kilometers and has a population density of 4,062 people per square kilometer. A study by Devendran et al. (2023) revealed that there are 6,443 residential buildings in the study area, generating waste on a daily basis.

To enhance the efficacy of the waste management system, the municipality of Curitiba plans to construct waste transfer stations. These facilities will serve as an intermediary between waste collection and final disposal, reducing transportation costs and enhancing the efficiency of waste sorting. The study identified six potential sites for transfer stations in Curitiba, which could result in savings of approximately 1.5 million Brazilian reais (BRL) per year in fuel costs for transporting solid waste (Devendran et al., 2023).

The implementation of the TS would also address one of the primary challenges currently facing Curitiba in the field of waste management: the lack of waste segregation at source. Currently, waste from different sectors (notably residential, industrial, and commercial) is mixed at collection points. The TS promotes more efficient waste segregation, increases recycling rates, and reduces the overall cost of waste disposal (Devendran et al., 2023).

The City of Curitiba has set an ambitious goal of collecting 100% of municipal solid waste (MSW) within the city limits. This target, when achieved, will significantly extend the life of the existing landfill and bring the city closer to its goal of zero waste to landfill. The city aims to recycle 85% of its waste and send only 15% to landfill. (Devendran et al., 2023).

The study by Devendran et al. (2023) also conducted a sensitivity analysis based on different waste management options. The results indicate that if Curitiba achieves the 85% recycling target while maintaining the current per capita waste production of 1.09 kg/capita/day, the lifespan of the existing landfill could potentially be extended from 2030 to 2058. This underscores the profound impact that elevated recycling rates can have on municipal waste management systems.

The Curitiba case study illustrates that fostering sustainable waste management practices necessitates sustained effort, commitment, and investment over time. Initial outcomes must be actively reinforced by ongoing education, accessibility, and incentives (Silva & Bollmann, 2011). As populations expand and evolve, it is crucial to proactively integrate new residents into existing waste management cultures to guarantee sustainable project success.

2.6 Lyon

The Lyon metropolitan area is the second largest by population in France, with 1.416 million residents as of 2020 (*Comparateur de Territoires*, n.d.). The area is governed by a single metropolitan government, which has jurisdiction over the city and 58 other suburban communal 2areas. The city itself is broken into nine arrondissements (neighborhoods). Each of these has its own local government with some authority over local policies, though waste collection and management is not one of these (*Grand Lyon Métropole*, n.d.). It is the prefecture of both the Auvergne-Rhône Alpes region and the 69th department. As a result, Lyon is a particularly interesting case to consider with respect to urban waste management. Its size and political significance in central-southeastern France make it a leader in the region: where Lyon goes, the rest of Auvergne-Rhône Alpes follows. Resultingly, examining the urban waste management system and practices in Lyon is essential to understanding the current and future state of waste management in the region, which in turn significantly influences the performance of France as a whole in relation to European standards on waste management.

The metropolitan area of Lyon covers 500 km^2, however the city covers only 48 of these. The city is trisected by its two rivers, the Rhône and the Saône. The city lies in the foothills of the northern French Alps (*Lyon | History, Population, Map, & Facts | Britannica*, 2024). Lyon has a good public transportation system, with clean stops and low average wait times (Boutin et al, *unpublished*). The city is served by the A6, A7, and A43 Highways, which go to Paris, Marseille, and Grenoble respectively, as well as high-speed rail lines to Paris, Marseille, and Montpelier. In conducting this project, it was discovered that Lyon hosts the most comprehensive municipal website in France for public data, and in so doing makes finding information on the city and its operations easy and convenient for the general public.

This research project was sponsored by WPI's Lyon Project center and its site director Professor Drew Brodeur. The focus is to use Lyon, France as an example of strong waste management techniques. Our goal was to conglomerate the important lessons related to waste reduction, collection, and treatment in the areas of recyclables, bio-waste, and other solid waste categories from the Lyon case study and use it as a jumping off point for designing a framework of best practices for UWM. This framework could be applied to other cities in future projects.

3. Methods

The goal of this project was to create a case study on Lyon's waste management practices, determine how they achieved their current system, and describe how their practices can be applied in other similar cities. This goal was achieved using multiple research methods intentionally employed to gain the greatest and most diverse information on the system possible. By using different methods, the biases of each form can be better mitigated, allowing for a more accurate view of the system.

In order to assess the effectiveness and sustainability of Lyon’s waste management system, we had five main objectives:

1. Archival research to determine the specific policies, infrastructure, and historical development of Lyon's waste management system.
2. Interviews with key stakeholders, such as city officials and waste management professionals, to gain expert insights into the decision-making processes, challenges, and successes behind Lyon's UWM system.
3. Ethnographical research and field observations to observe firsthand the system at work
4. Data Visualizations of data related to Lyon’s UWM system
5. Quantitative comparison of the relevant performance metrics of Lyon’s UWM system and similar municipal systems

The following sections will provide a detailed description of each research method, including their strengths, limitations, and specific application within the context of this case study.

3.1 Method 1: Archival Research

Archival research is essential to synthesize information from relevant research already conducted on a topic. The pros of archival research are its relative ease and cost-effectiveness, as well as a deep and comprehensive overview of a topic that archival research can provide (Burrier, 2024). In the age of the internet, countless databases and publications on a variety of topics are available from anywhere in the world at no or little cost to the user. This information can be synthesized to establish the full academic consensus on a topic and situate a case study.

There are several drawbacks to archival research, namely its propensity to be out of date, cost, language barriers, missing data, and selection bias. Due to the extensive time investment required of proper research in conjunction with the rapidly changing nature of the world, published research can quickly become out of date (Burrier, 2024). Additionally, while the internet provides a great wealth of resources, the full extent of research on a topic is often in multiple languages, kept behind paywalls, and updated with relatively little frequency. These barriers make it difficult to amass a comprehensive understanding of a given topic and can also contribute to the final drawback of archival research: selection bias. Because of the vastness of available literature, it is impossible to review all the relevant research on a given topic, meaning a selection of literature will be chosen according to potentially arbitrary, flawed human criteria. Thus, great care must be taken to ensure that the research that is selected will be a representative sample.

In order to address these flaws, the most recent research possible was prioritized. Data was acquired from a variety of sources and compared to minimize selection bias where possible. Research was also conducted in both English and French so large swaths of information were not ignored. Literature was chosen according to the credibility of its publisher(s), author(s), and methodology, as well as according to the credibility afforded it by peer researchers.

Researching the current state and historical development of Lyon's waste management system through archival research is critical for understanding what makes the system effective and how it evolved over time. Some key aspects investigated include:

- What types of waste are collected, and how often are collections made?
- What are the steps people need to take before going through the trash into garbage collection point?
- Where are waste collection points located, and where do the collected materials go for processing?
- What are the recycling rates for different waste streams?
- What policies, infrastructure investments, and public campaigns were implemented to achieve the current system?

We conducted extensive archival research to gather secondary data on Lyon's waste management policies, practices, and infrastructure (Mohr & Ventresca, 2002), including reviewing government reports, policy documents, waste management agency publications, and academic literature related to Lyon's waste management system. We will analyze data obtained from Lyon's waste management agencies. This data provided insights into both the current system's performance, effectiveness and the context in which that system operates. Archival research will provide a foundation for understanding the technical aspects and historical development of Lyon's approach to waste management.

3.2 Method 2: Local expert interviews

Conducting interviews with experts allowed the project to gain experts' understanding of a subject. This includes, but is not limited to, city officials and waste processing employees. Engaging with professionals and policymakers is crucial for understanding the decision-making processes, challenges, and successes behind Lyon's waste management system. These individuals possess valuable insights into the strategic planning, implementation, and ongoing management of the city's waste practices. By conducting semi-structured interviews (interviews consisting of a pre-written list of questions and flexibility to ask follow-up questions) with influential stakeholders, we are able to gain a comprehensive understanding of the factors that have contributed to Lyon's effective waste management and identify potential areas for improvement.

Semi-structured interviews were conducted with a diverse range of stakeholders, including:

- Researchers with extensive background in the field
- Executives and employees at Lyon's waste collection and processing companies
- Local advocates who campaigned for waste management improvements

Interviews explored stakeholders' roles, experiences, and perspectives on the development, implementation, and challenges of Lyon's waste management practices. Broad interview questions include:

- What data and best practices informed the decision to make specific changes to Lyon's system?
- In hindsight, is there anything you would have done differently to implement the changes?
- What tradeoffs or sacrifices were required to achieve the current system?
- Does Lyon have any distinct characteristics that make it well-suited for strong waste management?
- What areas of Lyon's current system still need improvement?

Interviews were be conducted in person and via video conferencing, where needed, and were audio-recorded on an iPhone with participants' consent using iOS's built-in Voice Memo software. Any necessary transcriptions were made through a locally run software, and the original recordings were deleted upon completion of the study to protect the privacy of respondents.

Transcriptions were inductively coded to identify common themes and unique insights through qualitative thematic analysis.

Expert interviews have certain disadvantages. Specifically, individuals may have their own financial or political motivations that may be unstated or may bias their responses. This drawback can be mitigated by performing interviews with multiple individuals with varying stakes and positions within the subject of interest and triangulating their observations. Interviews also high time commitment required great effort to coordinate and conduct (Burrier, 2024). A final challenge is that of the language barrier, specifically between the group of researchers (mostly native anglophones) and the group's interview targets (mostly native francophones).

3.3 Method 3: Ethnography

Ethnography, or field observations, provide an intimate understanding of a given topic relative to the location of the given researchers. Ethnography is advantageous due to its intensity of observation and intimacy with the case being studied. This allows for better-informed insights into the topic of study, which in turn allows for more meaningful conclusions to be concluded (G. Burrier, personal communication, 2024). Ethnography is limited by its time-intensiveness and lack of generalizability and scalability. Conducting an ethnography requires a significant amount of time and effort dedicated to a niche aspect of the given topic. While this results in an intimate understanding of a subject, it is unable to adequately contextualize a case study in the universe of cases. Developing such an understanding using this methodology requires incredible investment of time, which introduces an opportunity cost: ethnography requires high time investment, and that time may often be better invested in other methodologies which require less time investment and produce greater amounts of more workable data (G. Burrier, personal communication, 2024).

We conducted field observations of waste collection and processing infrastructure and practices (Kawulich, 2005). This involved visiting facilities, public spaces, and residential areas to gain first-hand insights. Observations were documented through field notes, photographs, and videos, focusing on aspects such as waste sorting systems, collection schedules, and public engagement with waste management initiatives. These field observations allowed the group to develop a personal, intimate understanding of the UWM system in Lyon and the way in which residents interact with it. This enabled the group to deduce better-informed conclusions on the way the UWM system in Lyon functions and provide better-informed recommendations on ways in which it can be improved and adapted in other municipalities.

In addition, the study incorporated cultural analysis to explore the social and cultural dimensions of Lyon's waste management system. This involved examining how cultural values, norms, and practices related to waste and environmental stewardship shape residents' attitudes and behaviors toward waste sorting and recycling. Cultural analysis draws upon qualitative data from interviews and observations and relevant literature on French and Lyonnais culture. This analysis was susceptible to the biases of the observers conducting the analysis, which was mitigated through the reservation of judgement when confronted with unfamiliar practices and norms, as well as through careful attention to the opinions of local residents.

3.4 Method 4: Data Visualizations

Using data gathered from Lyon’s data portal (Métropole de Lyon, 2024a), we created an interactive map of waste management sites in Lyon. This includes the locations of:

- garbage bins
- compost bins

- glass bins
- bottle drop-off sites
- recycling drop-off sites
- household waste drop-off sites
- waste collection centers.

The map is hosted on lyonwastemap.org and was created using SvelteKit with Typescript, making use of the Leaflet library to create the interactive map (*Leaflet — an Open-Source JavaScript Library for Interactive Maps*, n.d.; *SvelteKit • Web Development, Streamlined*, n.d.). A heatmap overlay was also developed using the Leaflet.Heat plugin to visualize the geographic distribution and concentration of the different collection site types across the city (*Leaflet/Leaflet.Heat*, 2014/2024).

The heatmap uses a color gradient from green to red to indicate the proximity and density of collection points in different areas. Green areas have good coverage, with collection sites within one street block based on the average distance between streets in Lyon. The color progresses to red in areas further than three blocks from any collection site. Areas not covered by the heatmap have no collection sites within three blocks' distance. The street metric was used as a baseline as having a collection point within one street allows a direct line of sight of a disposal site from the sidewalk, as any disposal site on the same street would be easily locatable. Whereas sites multiple streets away require active searching for a disposal site.

In preparing this report, more general-purpose visualizations were determined to be necessary in order to convey important points the group interpreted from various datasets. Utilizing the data we gathered throughout our research in Lyon, we created various data visualizations to better convey the information contained within the datasets. These visualizations were created in

Microsoft Excel and are featured throughout this report in the form of figures (*Microsoft Excel*, n.d.).

3.5 Method 5: Quantitative Comparison

In order to provide a reference point against which Lyon waste management statistics can be compared, we searched for comparable data portals in other cities. While various waste statistics are available on the scale of entire nations, we chose to compare to another city in France in order to compare the performance of Lyon's UWM system to a peer city, as the scale of UWM across a nation is starkly different to that of a city. We decided on Paris as it is the capital of France and has a long-established, well-documented waste management system (Villeneuve et al., 2009). However, Paris is divided into twelve territories with their own local waste management initiatives, so we sought a region with a publicly documented focus on waste management (La Métropole du Grand Paris, 2024). Grand Paris Seine Ouest is a territory of 320,000 residents that describes itself as "the creative, digital, and sustainable territory" and has an active effort to improve its waste management practices through initiatives similar to those in Lyon (Grand Paris Seine Ouest, 2024h). These initiatives include a public composting initiative and a public data portal providing relevant statistics (Grand Paris Seine Ouest, 2024e, 2024a). Thus, Grand Paris Seine Ouest was chosen for comparison, being a region of the French capital known for its sustained commitment to sustainable waste management practices.

3.6 Other Considerations

Some obstacles for this research include language barriers, as only one team member, Nolan Willoughby, is fluent in French. There was a limited timeframe of approximately six weeks in which to conduct interviews and research, and waste management agencies may have been hesitant to share candid opinions or internal data. Navigating the bureaucratic steps to obtain permission for interviews or facility visits is time-consuming, with dozens of hours spent reaching out to a carefully maintained tracking sheet of potential contacts, but our time in Lyon to conduct this research was limiting. Of the twenty experts we reached out to via email, only one agreed to do an interview. Further, although handheld camera reports in public places may take place without prior approval, employees of the first public waste drop off site we visited told us we were not allowed to film (French Ministry for Europe and Foreign Affairs, 2024). To overcome these challenges, we collaborated closely with local partners to ensure accurate translation of materials, build trust with stakeholders, and effectively manage the research timeline. This allowed us a accurate translation of an interview conducted in French, an additional interview through the referral of our local advisor, and two site visits with full filming permission.

Informed consent was obtained from all individuals prior to their participation in the study. Participants were informed about the purpose of the research, the voluntary nature of their participation, and their right to withdraw from the study at any time without consequence. They were also assured of the confidentiality of their responses and that no personally identifying information will be reported, unless otherwise agreed upon.

This study received Institutional Review Board approval, and all precautions were taken to protect the interviewees' names and identities, unless otherwise explicitly agreed upon. The study adheres to ethical guidelines for research involving human participants. All data collection activities were conducted under an IRB-approved protocol, protecting participants' rights, privacy, and well-being.

3.7 Deliverables

The primary deliverable is a written report presenting a detailed case study of Lyon's urban waste management strategies and policies. This report identifies the strengths and weaknesses of Lyon's current system. It focuses on identifying successful initiatives and the underlying factors that have contributed to their effectiveness, and providing an analysis of how these successful strategies and policies were implemented. The report concludes with a set of actionable recommendations that outline specific policies and strategies that other municipalities can adapt and implement to enhance the efficiency, performance, and environmental sustainability of their own urban waste management systems.

In addition to the case study, the project has also developed a framework for urban waste management that synthesizes best practices and guiding principles for effective waste management in cities. The framework draws upon the lessons learned from the Lyon case study, and literature review to provide a structured approach to designing and implementing successful urban waste management systems covering aspects such as collection, sorting, recycling, and disposal. By offering an actionable, evidence-based roadmap, the framework aims to support other cities in their efforts to build successful waste management systems.

4. Findings

Having conducted the previously discussed methodology, the group developed several findings related both to best practices of waste management and to the specific situation in Lyon, France. This chapter will discuss these findings, starting with practices beyond waste collection and treatment in Lyon found during archival research. Following this brief overview, discussion and data on the collection system in Lyon will be presented. Findings about the treatment of waste will then be discussed according to the category of waste to which the findings pertain. These findings will be presented in the order of general solid waste, followed by recyclable materials, and finally bio-waste.

4.1 Lyon Employs Creative Solutions to Mitigate Waste Generation

Beyond implementations of established treatment techniques, Lyon employs innovative solutions to make good waste management practices easier and more convenient for residents. One of these methods is seen throughout France in the form of Extended Producer Responsibility (EPR). EPR places additional responsibility on producers and manufacturers for the ways in which their products and their packaging are disposed of at the end of their product life. EPR also requires on-site sorting of waste for construction and demolition professionals, and manufacturers (European Environment Agency, 2023). In so doing, responsibility for proper treatment of waste is shifted from households, by making more products more easily recyclable, further boosting recycling rates.

Another such technique is promoting the reuse of items in usable or reparable condition rather than treating them as waste. This is accomplished through the repurposing of waste deposit sites into "donneries," or donation sites. These sites collected 264 tonnes of "donations" in 2020, of which 45.7 were sent to second-hand shops to be sold and 124.2 were sent to manufacturers to be repaired and repurposed (Métropole de Lyon, 2020). The city has also proposed municipal workshops dedicated to repairing bicycles, clothing, and electronics with the purpose of giving these products second lives and raising citizen awareness of their potential second lives (Métropole de Lyon, 2020). These programs aim to reduce the volume of waste entering the waste treatment system both through the elimination of the reused items themselves and the packaging, production, and new product these reused items replace. If well implemented and adopted, these programs offer promise in the reduction of waste, reducing the negative health and environmental effects inherent to waste treatment techniques and bolstering the effectiveness of the entire waste management system.

The group also found in its observations that Lyon is unique in its dedicated collection of textiles. Items such as used clothing, shoes, and other fabrics make up a significant portion of the waste stream and are particularly viable for repair and reuse. Despite this, the group has found in most cases throughout Europe, Asia, and the United States that dedicated textile collection and treatment does not exist. The sole exception to this is the case of Lyon, which collects textiles in a separate waste stream. This separation can help to reduce textile waste through repair and reuse, leading to a reduction in overall waste and a more robust waste management system. However, textiles still compose a significant share of waste that is managed through the city's generalized solid waste management techniques, implying that Lyon should invest more into public awareness of its dedicated textile collection system (Suez, personal communication, 2024).

Overall, Lyon's urban waste management system is strong in the ways in which it works to reduce the amount of waste it must treat. This goal of reduction is oft overlooked by other municipalities, and this is shown in the uniqueness of Lyon's waste reduction policies. Other locations should look to adopt these techniques.

4.2 Lyon has robust collection infrastructure

The Lyon Metropolitan Area, which serves 1.2 million residents (Métropole de Lyon, 2024c), has implemented a large network of collection facilities to manage various types of waste. To provide a basis for Lyon's system, we will compare to Grand Paris Seine Ouest (GPSO), a region of Paris with 320,000 inhabitants (Grand Paris Seine Ouest, 2024h), Figure 3 presents the number of collection points per 100,000 residents in both Lyon and GPSO.

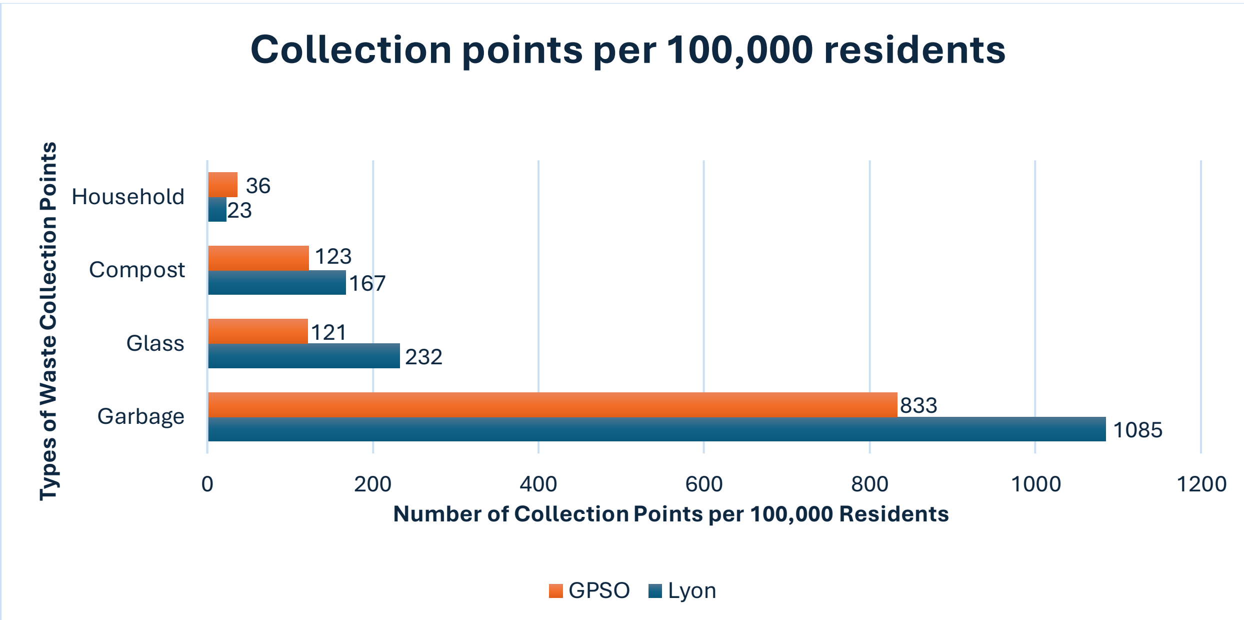


Figure 3. Collection points per 100,000 residents in Lyon and GPSO

As illustrated in Figure 3, the waste management infrastructure of Lyon includes 13,017 garbage bins or 1,085 bins per 100,000 residents (Métropole de Lyon, 2012). GPSO, by contrast, has a total of 2,666 bins or 833 bins per 100,000 residents (Grand Paris Seine Ouest, 2024c). This is a 30% higher availability of garbage bins in Lyon per capita, thus providing easier access to general waste disposal for the community.

For glass recycling, Lyon has 232 collection points per 100,000 inhabitants, with 2,786 total points (Métropole de Lyon, 2023), while GPSO has 121 points per 100,000 residents, with 388 total collection points (Grand Paris Seine Ouest, 2024g). Thus, Lyon has 91% more collection points per capita than GPSO, which provides more accessibility and is more convenient for residents.

In recent years, Lyon has increased efforts in composting its organic and food waste by providing more convenient public access points (UrbaLyon, 2023). Now, Lyon has 2,008 public compost bins, amounting to 167 per 100,000 people (Métropole de Lyon, 2022a). GPSO, with its 392 collection points, amounts to 123 bins per 100,000 people (Grand Paris Seine Ouest, 2024b). With 36% more composting bins than GPSO, Lyon has made composting much more convenient for residents through their efforts.

For general household waste disposal, Lyon provides 278 sites or 23 household waste drop-off sites per 100,000 residents (Métropole de Lyon, 2022c). This is the only category where GPSO outperforms Lyon, with 116 sites or 36 sites per 100,000 residents (Grand Paris Seine Ouest, 2024f). This could be because Lyon has identified that more numerous smaller sites, through their added convenience, encourage greater usage over a smaller number of large, concentrated sites (UrbaLyon, 2023). However, Lyon may offset this with more numerous larger general collection sites, where they operate 30 centers, for 2.5 large multi-waste collection centers per 100,000 inhabitants (Métropole de Lyon, 2022b). In contrast, GPSO has only 0.625 centers per 100,000 inhabitants, with two centers in total (Grand Paris Seine Ouest, 2024d), with Lyon having 400% more centers per 100,000 residents.

Overall while GPSO provides a greater number of sites for the disposal of general household waste, Lyon provides widespread accessible collection points for everyday waste and recyclables, complemented by the presence of larger, multi-waste facilities, which provides greater ease of access to waste disposal for most common items such as garbage, glass, and composting.

The high number of disposal locations likely made it much more convenient for residents, and therefore a large contributor to Lyon's success. The complex nature of Lyon's sorting system would have been thought to make it much harder for residents, as discussed in the background, yet the convenience and ease of access seems to have offset this to a degree.

4.3 Lyon Relies Heavily on Incineration

General waste is the largest fraction of waste produced and collected in Lyon (Métropole de Lyon, 2020). This waste consists of all the trash that can be neither recycled nor composted. As discussed in the background, the two main options for this kind of waste are landfilling and incineration.

The landfilling rates in Lyon, and France as a whole, are low. France saw a national landfilling rate of 18.1% in 2020, a rate far below the 26.2% target for E.U. members. Additionally, of the waste disposed of in landfills in France, 15% was biodegradable and consequently suitable for composting, well below the target of 35% for E.U. members (European Environment Agency, 2023). Lyon has a much lower rate of landfilling, where only 7.3% of municipal waste was landfilled (Métropole de Lyon, 2020).

As mentioned in the background, landfilling has very deleterious effects on both the health of surrounding residents and the environment, making the low rates of landfilling in France and especially Lyon an indication of good practices.

Instead of employing landfills, most of Lyon’s waste is incinerated, with the energy from the process then being captured. This technique treats 61.2% of collected waste (recyclable and otherwise) in the municipality (Métropole de Lyon, 2020). Grand Lyon has two large incineration facilities operating in the area: one in the north, in Rillieux-La-Pape, and a larger one in the south, in Gerland. A visit to the northern site informed much of these results.

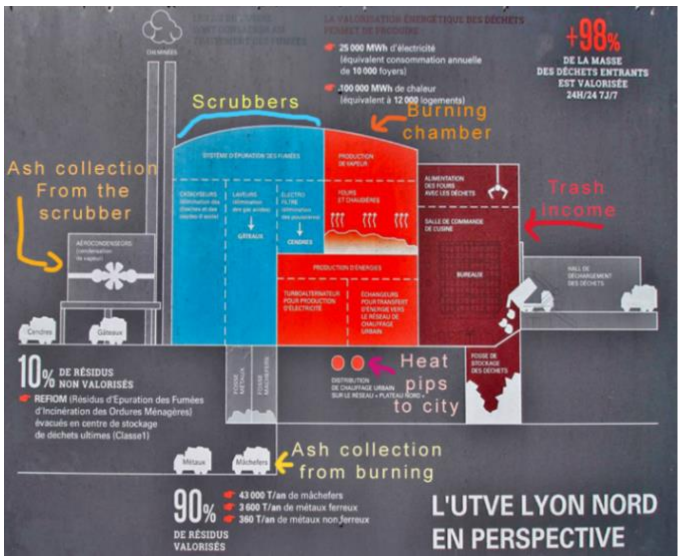
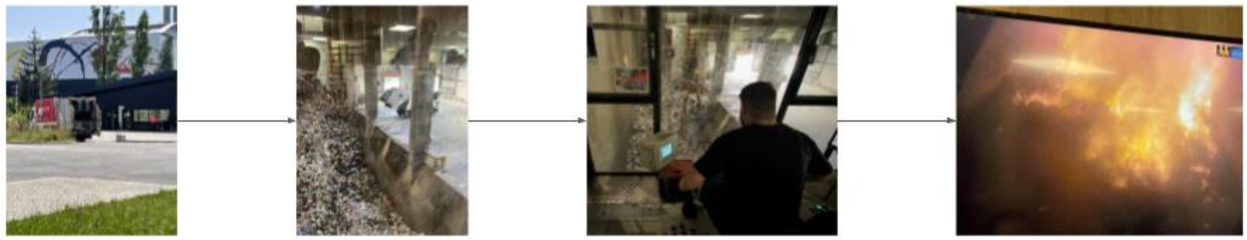


Figure 4. Diagram of Suez’s Northen Incineration Site

Garbage trucks carrying municipal waste (referred to as “reapers” by locals) arrive early in the morning, and are immediately weighed, and then scanned for especially hazardous waste. The hazardous waste will be disposed of separately and landfilled in a safe location. Some radioactive waste may be brought from hospitals, for example, which must be sealed in a safe container, and then buried. The rest of the reaper’s waste is dumped into a large pit. Site technicians then operate a crane which removes 3 tons of waste at a time and carries it to one of two chimneys for burning. The incinerators continuously run at approximately 850-1000°C without pause year-round, leading to a total of 400,000 tons of waste processed per year.



Collection Trucks are weighed upon arrival

Trucks then empty their contents into the trash pit

Crane operator lifts trash from the pit to dump into the chimney

Fire can then be monitored from a screen in the operators room

Figure 5. General Process of Waste Treatment at the Suez Plant

The energy generated from incineration is a huge factor in its dominance over landfills in the region. While incineration was initially developed as a way to reduce the volume of waste, recovery of the energy from the combustion proved extremely valuable. This energy is able to be collected and distributed as both electricity and heat for the surrounding metropolitan area. According to the northern incineration facility, operated by Suez, their facility can produce 2.4 megawatt-hours per ton of waste, for a total of 30 megawatt-hours per hour, according to site spokemen. This facility on its own produces energy for 24,000 homes, and heat for 40,000 homes. Additionally, the installation of solid waste incineration plants without energy capture is to be entirely phased out by 2025 according to France's 2015 Loi n^{o} 2015-992 in an effort to increase energy efficiency across French UWM systems (European Environment Agency, 2023).

While incineration is an effective method of waste treatment, like any other method, it is not without flaws. For one, many kinds of waste cannot be incinerated. This includes items like large pieces of metal, gas tanks, and e-waste. Despite being banned from usual household waste collections, this does not stop them from ending up at incineration facilities. Large pieces of metal can be filtered out by the system automatically, but some items, site technicians told us, cannot be easily removed. Once in the "trash pool," as they referred to it, these items will not be removed unless burning them would be extremely dangerous. These mistakes are a more than daily occurrence that must be taken into account when designing an incineration facility.

Once burned, the ash still must be dealt with as well. While Suez told us that 1 ton of waste can be turned into 50 kg of waste, a reduction of 95% of the volume, this ash still must be dealt with on its own. Incinerator ash is significantly more toxic than typical landfilled waste (*Incinerator Ash Concerns | Wilderness Committee*, n.d.), but must be buried all the same. Suez claimed that their ash is dealt with in a sustainable manner but did not elaborate on their precautions other than stating that they were buried at an “ultimate waste facility.” This “ultimate waste facility” would be a landfill, which, according to French law, may not be implemented on untreated waste and is only permitted for residues from other forms of waste treatment or toxic and hazardous wastes which may not be treated in another manner (European Environment Agency, 2023).

Toxic fume emissions are also a large concern for incineration facilities. Given that the incinerator was located near a local school, and with plenty of commercial and residential buildings within viewing distance, these concerns were even more important. Upon viewing, there was only a faint plume that was barely visible, but we were informed by site workers that this was highly dependent on the weather. According to Suez they are well within EU emissions regulations and so should not be dangerous to surrounding inhabitants. The incinerator was equipped with acid and base washes, as well as a NOx scrubber system to keep the fumes safe, as well as an analysis device to continuously determine the output composition.

Waste incineration produces fewer greenhouse gas emissions than landfilling, with 424 kg CO2 equivalent emissions per unit MWh of electricity generation, compared to 746 kg CO2 equivalent emissions produced by landfilling. This represents a reduction of 320 kg, or a 43% decrease. Furthermore, if the energy output from waste incineration replaces that of a equivalent fossil fuel plant, it results in a savings of 1,300 kg of CO_2 equivalent emissions over landfilling (Kumar & Samadder, 2017), a 75% decrease.

The financial viability of the facility is also important to note. Suez is a private contractor who is paid for two services: the first is accepting the trash, which the city collects, and the second is selling the energy they produce to the region's energy providers. Incineration is also taxed by the French government, which has also mandated the immediate cessation of capacity increases to incineration, the quartering of such capacities by 2020, and the halving of those same capacities by 2025.

Incineration has some significant drawbacks that must be considered, but Lyon's decision to prioritize it over landfilling seems to be their best option. Given the extensive land requirements of landfills, and the lack of energy production, incineration seems like the most suitable option for the region, that can likely be extended to similar regions.

We concluded that incineration is likely to aid most cities but cannot be the only solution. For one, incineration should not be seen as the primary generator of waste for a region, since they may incentive the creation of more waste (C40 Cities Climate Leadership Group, 2019). The primary function of incinerators is to reduce the volume of waste so that they don't take up as much landfill space. Energy collection is only a positive externality of this goal. A good sorting system may also be an important prerequisite. Food waste often makes up a significant portion of trash, and so if it is not sorted, the high water content means that it will take significantly more energy to burn (C40 Cities Climate Leadership Group, 2019).

Because of this, we recommend that a city first create a sophisticated waste sorting system, and then educate the population on then sorting. By having a breakdown of the types and proportions of the waste being collected, the city can then make an educated decision about whether incineration will be beneficial for them.

4.4 Recyclables

The group found several points related to the treatment of recyclables in Lyon. This section details findings related to the quantitative performance of the system, followed by specific points related to the collection of recyclables.

4.4.1 The Recycling System in Lyon Performs Well

Lyon has established a relatively convenient and easy recycling system. With the exception of glass, household recyclables are commingled at collection and sorted at treatment in a dual-stream system (Métropole de Lyon, 2020). This makes for a relatively convenient process for households, a factor associated with higher participation rates. Additionally, in conjunction with collection points, door-to-door collection takes place in frequencies ranging from twice a week to every other week (Métropole de Lyon, 2020). Door-to-door collection especially adds to the convenience of participation enjoyed by households in Lyon.

This system can be evaluated by various performance metrics. Notably, the overall recycling rate of Lyon's UWM system when accounting only for ultimate treatment techniques was 28.2% in 2020, while the equivalent packaging rate was 60.72% or 52.85%, depending on the method used to calculate the rate. These rates indicated a slight decrease from 2019 levels, while the growth in recycling, which would be further augmented by increased investment and attention to recycling in the future. Additionally, this decrease can be explained by several factors including strikes and the renovation of Lyon Nord (Métropole de Lyon, 2020). That said, this performance and the performance of France at large indicates a potential failure. Specifically, the target of a 55% recycle rate by the year 2025 seems out of reach both for the nation and the city, while the target 75% rate for packaging materials is a similarly distant target for Lyon (European Environment Agency, 2023; Métropole de Lyon, 2020)

Lyon places liability on the recycling companies it subcontracts, with contracts with recycling companies being renegotiated every 6-7 years. During negotiations, the government sets targets and requests these companies achieve goals such as reducing rejection rates (the amount of waste rejected from the recycling facilities into non-recycling waste treatment facilities) and determining their ability recycle certain materials/packages. If the current companies are unable to reach these goals, they are not awarded a contract (Françoise Sigot, 2020). This practice encourages recycling companies to improve technology and recycling rates to meet the continuously updated requirements (Métropole de Lyon, 2020).

4.4.2 National Regulations Help Standardize Cities' Systems

In France, national laws require the products sold in France have symbols explaining how to sort the waste generated by the product. These logos, called the "TRIMAN" logo (see Fig. 2 as an example), are required to appear on most of retail products sold in France, with few exceptions (FAQ relative à la signalétique TRIMAN et l'information précisant les modalités de tri, 2023).

Figure 6. TRIMAN Logo Including Sorting Instructions (*FAQ relative à la signalétique TRIMAN et l'information précisant les modalités de tri*, 2023)

All cities follow national regulations made by France Ministère de la Transition écologique et de la Cohésion des territoires (Ministère de la Transition écologique et de la Cohésion des territoires, 2021), expect for in the case of plastic films, which are regulated by local laws (Citeo, n.d.; Ministère de la Transition écologique et de la Cohésion des territoires, 2021). In Lyon, as in all French cities, the simplification of the sorting process has been mandated since 2023, with packaging materials required to be recyclable with the rest of the recyclable stream without requiring extra cleaning or separation (Citeo, 2023; CAPSO, n.d.). Because of this mandate, plastic bottle caps in France have been redesigned to avoid detachment and loss during transportation, allowing for separation to occur in the recycling factory. Additionally, contaminated paper (e.g. pizza boxes), envelopes with plastic windows, and other items that commonly cannot be processed by facilities in the United States can be recycled properly at French facilities (La Métropole de Lyon, 2024). The only limitations on the facilities' abilities to process recyclables are recyclables bagged or stacked within each other, as these cannot be separated upon treatment at the recycling facility. It is also encouraged but not required to crush recyclables in order to increase available space at collection (Élus, adhérents et agents au service des citoyens, n.d.).

4.4.3 Collection of Recyclables is Convenient and Well-Utilized

Our group has observed that Lyon has many mislaid trash items, and many items of trash have been placed outside the trash cans, near the trash bins that are not suitable for such trash. This phenomenon is more obvious in high-traffic, high-density residential areas, such as the park near the Rhône River. Also, many collection sites only serve a single type of collection (i.e. glass, recyclables, bio-waste, textiles, or solid waste), meaning that if one has waste belonging to multiple streams or to a stream not immediately within the vicinity of a site, disposal can be inconvenient. This inconvenience can lead to greater rates of missorted waste.

(Fig 3 in progress… I am waiting to pull this out from my cellphone)

While there is no punishment for people who improperly sort their waste, this does not seem to be an issue. According to the group's field observations, residents will at bring large bags of glass bottles to glass collection bins on the street, as glass collection is not a mandatory service within residences as is the case with other recyclables and solid waste collection. Similarly, textile collection is not mandatory within residences, however street collection sites tend to serve this need for residents, albeit at a lower capture rate than glass. Under this condition, the recycling rate is up to 40%.

Our group summarized all the materials and gave the following assumptions. First of all, a good education makes people willing to recycle. The data shows that people inside France are very concerned about the environment (BFM TV, 2020). Also, the simplicity of Lyon's dual-stream recycling system has increased the recycling rate, likely due to the relative convenience associated with such a system (Citeo, 2023). Finally, the Lyon government actively monitors the condition of collection sites and will occasionally send workers to ameliorate the condition of the sites (WHICH VISIT???, personal communication, 2024).

4.5 Bio-waste

One final area in which there are significant findings is the area of bio-waste management. This section will detail the specifics of findings related to this area both in terms of a general framework for best practices related to bio-waste, and in the context of the practices the case subject of Lyon has chosen to implement for its bio-waste management system.

4.5.1 Composting is Best for Urban Settings, Methanization for Rural Ones

In the course of this project, an interview was conducted with Badia Lahlou, a lobbyist with the Gaz Réseau Distribution France (GRDF) on the subject of methanization as a way to treat biowaste. This interview in conjunction with related archival research helps to examine the advantages and disadvantages of the methanization process as a way of managing organic waste. The advantages of this approach are linked almost exclusively with the methane it produces. Unlike conventional methods of methane extraction, biomethane is a renewable source of methane energy. It is also one of the only ways to produce methane within France's borders. This makes methanization a potential boon for a nation seeking energy independence, especially as sanctions on Russia cut off one of the largest producers of natural gas (including methane) from the European market (Badia Lahlou, personal communication, 2024). This makes a strong case for methanization in a nation seeking both energy independence and for all of its natural gas consumption to come from renewable sources by 2050.

By contrast, methanization's main competitor, composting, does not produce any energy. Composting does, however, produce a fertilizing product in the same way as methanization. It is a similarly low emissions method for bio-waste management, producing an equivalent of 13 kg of CO_2 (kg CO_2 eq) per tonne of bio-waste managed (Joulin, 2024).

The biomethane process also emits a much lower amount of carbon than traditional methane processes. Specifically, the production of an amount of biomethane equivalent to one kWh is linked to 44 kg CO2 eq, compared with the corresponding figure of 200 kg CO2 eq per kWh generated by traditional methane production. Additionally, the digestate used for and resultant from methanization can be used as a fertilizer, meaning that both of the final products of the process have ultimate uses (B. Lahlou, personal communication, 2024). This fertilizing byproduct can help to reduce reliance on chemical fertilizers, whose negative environmental effects are well-documented (Pradhan, 2020).

Unfortunately, methanization is not without its drawbacks. Methanization has differing yield rates across different types of biowaste. It is most efficient with agricultural waste and is much less so with the food waste most common in the urban waste management context. For this reason, farmers have begun growing crops such as corn specifically for the process of methanization, meaning that farmers are deliberately creating bio-waste in order to exercise this bio-waste management method (LA MÉTHANISATION, 2023). Additionally, as seen in America, the growth of corn specifically can have massive negative consequences on the environment (Foley, 2023).

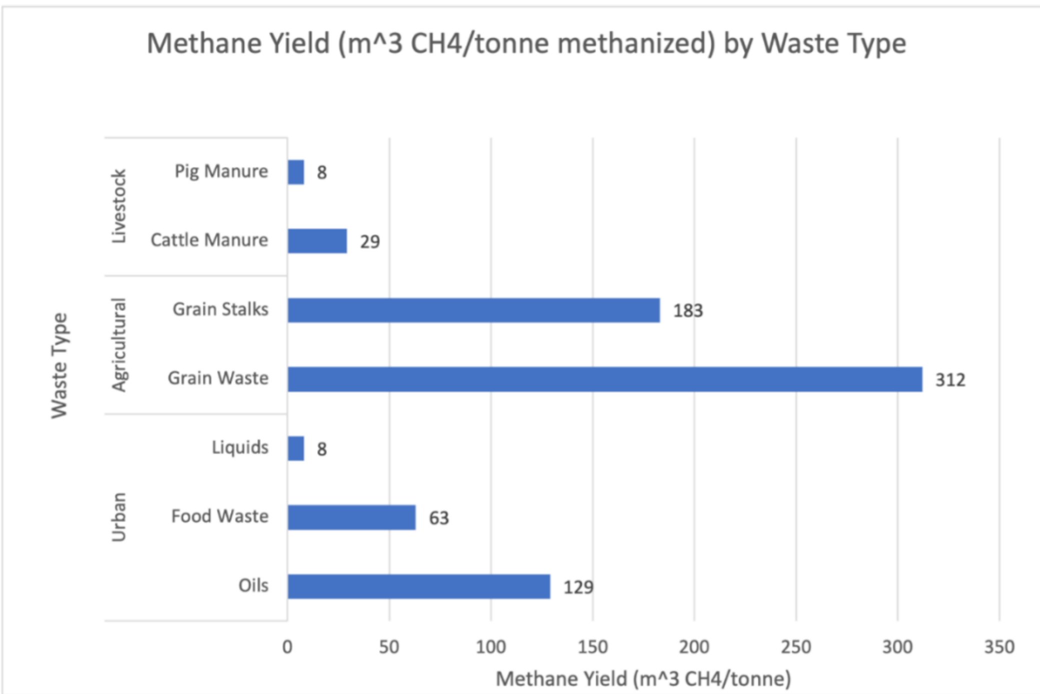


Figure 7. Methane yields by tonnage of various bio-wastes (Joulin, 2024; Willoughby, 2024)

Beyond the detriment of creating additional waste for the purpose of methanization, methanization also underperforms in the way in which it treats bio-waste when compared to its main competitor, composting. The methanization process emits 33 kg CO_2 eq per tonne of bio-waste treated, compared to the 13 kg CO_2 eq emitted per tonne of bio-waste composted (Joulin, 2024). Methanization installations must also be consistently stocked with large amounts of bio-waste in order to run efficiently. This means that the installations must be large and have a consistent flow of large amounts of organic material, hence the aforementioned growth of crops dedicated specifically for the purpose of methanization (Joulin, 2024). This makes methanization a much less flexible means of bio-waste management than its competitor, as well as a greater nuisance for local residents.

Methanization is also inferior in the fertilizing product it produces. While compost is consistently a non-toxic product which can be adapted in composition according to specific needs, the end digestate of methanization can have serious negative environmental effects. This is likely in part due to the relative lack of regulation pertaining to methanization. Regulation of methanization depends on the size of the installation and local regulations (Joulin, 2024). By contrast, composting is regulated by the EU to ensure that the resultant product has been rid of any potential pollutants (Racine, personal communication, 2024). Ultimately, this means that methanization digestate can result in the acidification of soil and the contamination of nearby water sources when used as fertilizer (Lallouët-Geffroy, 2019).

Economically, the installation, waste collection, and running/maintenance costs of a methanization system are greater than those of a composting system, even when scaled up to comprehensively compost an entire metropolitan area’s bio-waste. These methanization costs must be borne by farmers, though they are in part offset by reduced energy and heating costs thanks to the methane produced (Joulin, 2024). This is because natural gas distributors in France such as GRDF are forbidden from involvement with the production of biomethane and are only allowed to distribute the methane produces and to connect farmers and waste producers with engineers and others who produce the equipment for methanization (B. Lahlou, personal communication, 2024).

While it is easy to look at this information and decide that bio-waste should be handled in its entirety by composting, the benefits of methanization should not be ignored. Methanization presents great potential as a renewable energy source independent of foreign interests, especially as France aims to meet 100% of its natural gas needs through renewable, local sources by 2050.

An effective waste management system will thus seek to maximize the benefits of both composting and methanization while minimizing their negative effects, especially those of methanization. Given this objective, a good waste management system will involve composting in urban areas, where the composition of bio-waste is especially poorly suited for methanization. Composting would also be beneficial in rural areas, where food and other low-yield waste could be managed in the method most suitable to their composition. Methanization could thus be performed in conjunction with composting using the waste best suited to the process: agricultural waste. In order to best facilitate this combination, the responsibility for methanization would best be shifted from individual farmers to governments. This shift in scale would reduce both the need for crop growth dedicated to methanization and the burden of cost borne by individual farmers.

4.5.2 Lyon Subcontracts Composters to Manage its Bio-Waste

Because of Grand Lyon's urban context, composting is the best management practice for bio-waste. Composting practices have been standardized in the Grand Lyon since 1 January 2024, meaning Lyon adheres to our framework of best practices in terms of its bio-waste management. 2020 saw a significant investment in increasing the rate of composting in Lyon. The number of collection sites for compostable waste doubled from around 80 in 2019 to 179 in 2020. This increase was accompanied by a campaign aimed at informing residents about the advantages and process of composting. It resulted in a notable decrease in total composting tonnage from 28,841 tonnes in 2019 to 23,115 in 2020 (Métropole de Lyon, 2020). This investment in composting is crucial both for strengthening the infrastructure supporting a sustainable waste treatment method and for meeting E.U. goals for composting, where France as a whole is currently falling behind. Specifically, France's capacity for the composting of bio-waste is estimated to be 60%, while E.U. targets are set at 80% (European Environment Agency, 2023). To establish a greater sense of composting practices in Lyon, a site visit to the largest composting site in the area was conducted.

This site is managed by the subcontractor Racine, who shares the site with other companies performing other forms of waste management, and it is the largest of six in the Lyon Metropole. It handles about one quarter of the metropole's annual bio-waste, or 5000 tonnes of the annual 20000 tonnes generated, 70% of which comes from décheteries, or waste drop-off centers. The remainder comes from local farmers, who are able to drop off their bio-waste directly on site. Racine then mixes the bio-waste with recycled water into a relatively homogenous mixture. This waste is then fermented at 65°C for 50-60 days. This temperature is maintained by air pumps, which pump hot air into the fermentation piles from below. This practice eliminates the need for mixing the composting bio-waste during the fermentation process and provides the oxygen necessary for the aerobic digestion required for the composting process. The temperature and duration of fermentation is dictated by EU regulations, and ensures that all microbes, seeds, and bacteria are killed before moving on to the maturation process.

The compost is then moved to maturation, which takes at least six months, though it can take longer depending on the desired end product. For this reason, maturing piles of compost are marked with the month and year in which maturation began. The process can handle biodegradable plastics, however, in the case of large quantities of missorted material, the entire lot of bio-waste must be returned to its source (Racine, personal communication, 2024).

Figure 8. Lyonnais Compost in the Maturation Process

Aside from composting, this Racine site is involved in two other processes. Specifically, it also deals with wood waste, producing mulch and woodchips for the municipalities within Grand Lyon, as well as energy and heat through wood burning. This wood waste comes in part from another on-site subcontractor, Ecolia, which repairs and produces wood pallets. Racine also produces fertilizers on site using the compost it generates. These fertilizers are made for wide-ranging applications using specific additives according to the desired application. This process takes place in an on-site factory that, depending on the product, can run almost completely autonomously. These products are then sold to farmers. Farmers can also trade for these compost products in exchange for bio-waste (Racine, personal communication, 2024).

While Lyon has good composting practices in place, it is in its infancy. Composting access only became mandatory on 1 January 2024, and as such public education, awareness, and infrastructure related to compost is immature. This means that the Metropole should continue to develop infrastructure, education, and awareness related to composting. Such investments would help with the low composting rate in the city by increasing the rate at which households sort their bio-waste for compost and reducing the rate at which improper sorting occurs. Additionally, while the Metropole is largely an urban area, its rural areas and farms present some opportunity for methanization, which could be considered given the benefits of methanization.

While it a growing filed, the fact that it has been adopted so quickly should be encouraging to similar urban locations. The fast growth of composting in the region should give hope that creating a more effective waste management system is within reach.

5. Deliverables

The primary deliverables from this project are an interactive map of Lyon's waste management infrastructure and a guide synthesizing best practices for urban waste management systems.

5.1 Interactive Map of Lyon's Waste Management Infrastructure

An interactive online map was created showing the locations of various waste management sites across Lyon, including:

- Garbage bins
- Glass recycling bins
- Plastic/paper recycling bins
- Composting bins
- Household waste drop-off sites
- Recycling drop-off sites
- Waste collection centers

The map allows users to visualize the distribution of these different waste management points across the city. It also includes a heatmap overlay indicating the density and proximity of collection points in different areas using a color gradient from green (good coverage) to red (lacking nearby options).

The map aims to provide insights into the accessibility and convenience of Lyon’s waste disposal options for residents. It was created using Leaflet for the interactive map interface and SvelteKit for overall site development. The map is hosted at lyonwastemap.org and the source code is available on GitHub at github.com/ARealConner/lyon-waste-management.

5.2 Urban Waste Management Best Practices Guide

The group has created a stylized guide summarizing the key takeaways from the project. This guide uses findings from the Lyon case study to describe generalized best practices for the reduction, collection, and treatment of waste. This guide was created with the intent of serving as a potential framework by which other cities with weaker UWM systems might improve their practices.

6. Conclusion

This chapter will provide the group's concluding thoughts. These will begin with discussion of the limitations the group encountered, followed by a discussion of the significance of the project experience, and final concluding remarks regarding the project results and their significance.

6.1 Limitations

Some of the most important limitations of this study include the language barrier, as well as our response rate for interview requests. Only a single member of our team was fluent in French, which posed challenges for communication with native French speakers. Having a translator on our team remedied this problem somewhat but bottlenecked communication. We also reached out to a total of 20 different academic experts, municipal officials, waste management companies, and non-profit organizations and interest groups for potential interviews, with most not responding at all. Even of those who did respond, most were unable to meet with us, or directed us towards another contact. All but one of our initial contacts were written in French. In the end, we were only able to conduct two expert interviews outside of experts who were spoken to on facility tours.

One organization we reached out to also offered a facility tour that was outside of our project timeline. Since our group was only present in France and capable of working on this project from 20 May 2024 until the 12 July 2024, anything offered outside of that timeframe was not possible.

Given a broader time frame, many more things would have been possible. The group would have been able to perform an additional site visit at a recycling processing facility, which would have provided greater insight into the specifics of the practice as implemented in Lyon. Additionally, a broader time frame would have enabled the conduction of an interview with a local researcher whose recent work included a project dedicated to modeling the transportation of waste in Lyon. This interview could have offered insight into the practices associated with transportation of waste and site selection; a topic relatively unexplored in the context of this report. Finally, a broader timeframe would have also allowed for the conduction of resident surveys, which would have provided ethnographical context into the lived experience of Lyonnaise and their experiences with the local UWM system.

6.2 Reflection on the IQP Experience

In conducting this project, the members of the group benefited from several learning experiences not often found in traditional coursework. The purpose of the IQP is to conduct an interdisciplinary research project that examines the confluence of technology and society. All group members came from differing areas of academic expertise, and as such were able to bring diverse perspectives and approaches to the tasks at hand. The project also succeeded in its objective of providing context for the intersection of society and technology, as frequently in the research process the group found technical solutions and approaches being applied to the societal concern of waste management.

Due to the collaborative nature of this IQP, it was necessary to communicate frequently with all members of the team, as well as the project advisors. The team communicated mainly by email, but also used Discord and WhatsApp and had regularly scheduled meeting times to work through more in-depth challenges. With our sponsor Professor Brodeur and our IQP advisors, the team primarily communicated through email and meetings. This communication was critical to ensure that the team was on track and the work aligned with our sponsor's vision.

The team also shared responsibility throughout the project in various ways. Team members took ownership of various aspects that catered to each member's unique skillset. All members had opportunities to lead meetings and interviews. This team member would send the agenda to attendees prior to the meeting as well as keep the meeting on track. In the event that a question was asked and the lead was unable to answer it, they would direct the question to the team member who had ownership over that aspect of the project.

Through team meetings, deadlines, and feedback sessions, the team was able produce high quality work and remain on track. Team meetings occurred at least twice per week, but up to five times per week. These meetings were used to independently work, set deadlines, and review ideas and work. Deadlines were used to ensure that the team was on track to complete the project and receive feedback from the advisors and Professor Brodeur. Feedback sessions were also critical to ensure the team was able to provide the highest quality work.

These experiences helped to broaden the academic experience for all members involved in ways traditional coursework cannot. The experiences of working within a group on a project with broad social implications in a foreign country with the objective of producing a detailed, technical report on the subject are impossible to replicate in the traditional academic setting and will likely have implications extending beyond the hard skills taught in classrooms to the soft skills necessary for future success.

6.3 Future Work

Given the limitations of this project discussed previously, this group recommends the following future work.

TO-DO

- Conduct further interviews/Gather further information
- Recycling Facility Visit

- Survey local residents?
- Discuss economic costs more thoroughly
- Future Lyon IQP/Further Investigation on improving sorting?
- Future Lyon IQP/Further Investigation on waste reduction strategies?

6.4 Summary

Lyon has an effective waste management system when compared with similar systems around the world; however, it has improvements to make to its recycling, incineration, and composting rates when evaluated against EU targets. This can be accomplished in part through the continued rollout of public education and awareness campaigns on waste management, as well as the continued modernization of the system, especially with regard to bio-waste management.

There is much that other cities could learn from this model, produced using Lyon's data. For one, having a wide system of collections with accessible drop-off points is very important for the efficiency of a city's urban waste management. The complexity of the system, while detrimental, was not as detrimental as it could have been. Lyon's residents separate their waste into four main categories: waste, recycling, glass, and composting. Though this takes a significant amount of education to properly learn what goes where, it ultimately proved very successful for Lyon. This is not to say that mistakes weren't common. Suez told us that 1/3 of all items in the recycling system weren't supposed to be there. Though these mistakes are common, it was still more favorable to have waste processors manually separate each type of waste and recycling from each other.

The process of separating waste and subsequently training the populace to sort accordingly may be one of the most important first steps for cities to take when designing a waste management system. Having properly sorted waste allows cities to determine the proportions of each type of waste they are collecting. A city that collects a low proportion of bio-waste, for example, may not need large investments in composting, while a city that collects a large amount of bio-waste that is not separated may not be suitable for incineration.

Incineration, followed by the landfilling of ash, as seen in Lyon, was also likely a large contributing factor to the city's success. Incineration allows for the recovery of energy that would likely have been wasted if the trash were immediately landfilled. While incinerators may not be ideal in situations where the fumes cannot be properly cleaned, in cases where they can be monitored and filtered, and in locations where there is not a large amount of land suitable for landfills, incineration seems to be far and away the better option.

While still a fairly new endeavor, composting has been a very successful initiative in France. This proves that making improvements to the UWM system may not be as difficult as it seems, especially for a population already primed for good waste sorting practices.

Overall, Lyon's successes in waste management show much that can be learned from other municipalities. Despite being one of the largest cities in France, they are able to process waste more efficiently than comparable regions. Lyon has shown that, given the political will, participation of residents, and a sophisticated sorting system, making improvements to a city's UWM system is not as difficult as previously thought and can be implemented in other cities.

7. References

8. Appendices

Appendix 1: Interview Guides

Preamble (to be adapted for each stakeholder group):

You are being invited to participate in a research study on Lyon's waste management system. This study is being conducted by Casey LaMarca, Conner Olsen, Ming Tang, and Nolan Willoughby from Worcester Polytechnic Institute (WPI) as part of a research project. The purpose of this interview is to gather information about [specific stakeholder group's] perspectives on the development, implementation, and challenges of Lyon's waste management practices. Your participation in this interview is voluntary, and you may choose to stop at any time. Your responses will be kept confidential, and no personally identifiable information will be disclosed in any publications resulting from this study. The interview should take approximately 30-45 minutes. If you have any questions about this study, please contact gr-cleanlyon@wpi.edu. By proceeding with the interview, you give your consent to participate in this research.

Interview Guide for Municipal Officials:

1. What is your role in Lyon's waste management system, and how long have you been involved?

2. What data and best practices informed the decision to make specific changes to Lyon's waste management system?

3. In hindsight, is there anything you would have done differently to implement the changes?

4. What tradeoffs or sacrifices were required to achieve the current system?

5. Does Lyon have any distinct characteristics that make it well-suited for strong waste management?

6. What areas of Lyon's current waste management system still need improvement?

7. How do you engage with the public to promote proper waste sorting and recycling behaviors?

8. What challenges have you faced in implementing and maintaining Lyon's waste management system?

Interview Guide for Waste Collection and Processing Company Employees:

1. What is your role in Lyon's waste management system, and how long have you been involved?

2. How has your company adapted to changes in Lyon's waste management policies and practices over time?

3. What are the biggest challenges your company faces in collecting and processing waste in Lyon?

4. How do you collaborate with the city government and other stakeholders to improve waste management in Lyon?

5. What innovations or best practices has your company implemented to enhance waste collection and processing efficiency?

6. How do you ensure worker safety and well-being in your waste management operations?

7. What areas of Lyon's current waste management system do you think need improvement?

Interview Guide for Local Advocates:

1. What motivated you to become involved in advocating for waste management improvements in Lyon?

2. What were the key issues or challenges in Lyon's waste management system that you sought to address?

3. How did you engage with the community and other stakeholders to build support for waste management improvements?

4. What resistance or obstacles did you face in your advocacy efforts, and how did you overcome them?

5. What do you consider the most significant achievements or successes in improving Lyon's waste management system?

6. In what areas do you think Lyon's waste management system still needs improvement?

7. How do you continue to engage with the community and promote sustainable waste management practices?