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CAN WE BAG IT BETTER?

What institutional design approaches can be adopted to improve the efficiency of waste collection systems?

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1. Introduction

1.1 Background

Every day we create waste. Our food, and basically any product we consume, comes in some sort of packaging that we get rid of after we have opened it and used it. This uses up a lot of raw materials we are slowly running out of. (UNEP, 2019) It is essential to rethink the way we dispose of our waste, and therefore this thesis focuses on the research topic of examining the institutional frameworks that shape waste management practices worldwide. In some cities, plastic is collected together with organic and metallic waste; there are only separate collection bins for paper and glass. Once the garbage is collected, it is transported to waste management facilities, where they sort out the plastic and metal from the rest. In some other cities, however, they take a different approach; there, the recyclables are collected separately in dedicated bins, and their collection happens at a different time. This research will investigate the methods of recyclable waste collection from an institutional design point of view. Which regulation leads to a better result: processing the waste in waste management centres or leaving it up to the citizens to sort their rubbish?

Research on the topic of waste management is needed now more than ever. According to a report by the World Bank, the total municipal solid waste generated annually will grow to 3,4 billion tons by 2050. (World Bank, 2023)

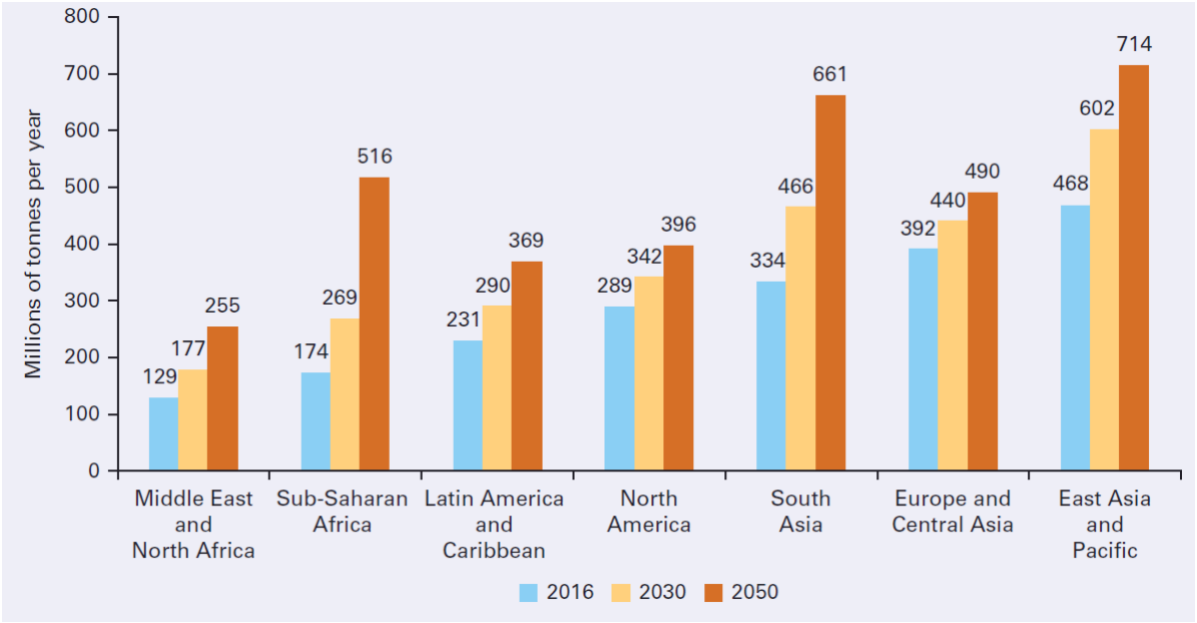


Figure 1: Prediction of the trends of total solid waste generation in the future (World Bank, 2023)

As shown in Figure 1, the expected growth is the highest in the developing countries of Sub-Saharan Africa and South Asia, where growing populations and economic development lead to a more populous consumer market. Reports have found that, overall, there is a positive correlation between waste generation and income level. (World Bank, 2023) However, high-income countries have better waste management systems regarding collection and recycling rates. (World Bank, 2023) The countries from the fastest-growing regions of Sub-Saharan Africa and South Asia do not have such waste management systems in place yet; here, more than half of the waste is currently openly dumped (World Bank, 2023), severely affecting the environment and health of citizens.

1.2 Research problem

This research will study the existing waste management systems of some cities around the world. It considers policy initiatives, collection techniques, separation methods, and examples of sustainable waste management policies to compare and draw conclusions from to determine how proper institutional design can shape the systems' effectiveness and how people dispose of their waste. It will also explore the challenges and opportunities of designing such frameworks that promote recycling and sustainability. Investigating the topic of comparison between waste management systems from around the world quickly leads to a dead end, with most studies and reports only investigating the local situation or just a specific part of our globe. There is research on the topic of integrated sustainable waste management in developing countries altogether (Wilson et al., 2013) and research on specific countries like a case study of Malaysia (Moh & Abd Manaf, 2017) or South Africa (Viljoen et al., 2012). However, a more comprehensive comparison of different systems from different settings is needed to truly understand the best way to organise a city's waste management system. This research is set to fill in the research gap found on the matter in a more international across-the-board manner.

1.3 Research aim

The goal of this research is to aid these developing countries with insight to be able to implement the kind of waste management system that was proven to yield the highest recycling rates in present-day scenarios. As the effects of irresponsible waste management do not stay on a local level, (WHO, 2021) it is in every human’s interest to take a step towards more effective and sustainable waste disposal.

1.4 Research questions

To examine the effects of different institutional design approaches on the recycling rates of existing systems from around the world and investigate the possibility of room for improvement for them, the following research questions were asked:

What institutional design approaches can be adopted to improve the recycling rates of waste collection systems?

1. How do the existing waste collection systems work around the world?
2. How efficient are the current waste collection systems regarding recycling rates?
3. What approaches can be implemented in the future to make the existing systems more efficient?

1.5 Methodologies

To gather and analyse data, this thesis uses multiple sources and methods. To collect the necessary information, literature review and statistical analysis were carried out. Based on the patterns found in the literature and relevant databases, hypothesises were formulated. These hypothesises were then tested statistically to find the relevance of the different organisational variables of a waste collection system on their recycling rates. The findings were then put back into context to answer the formulated research questions.

1.6 Structure of the thesis

The dependent variable, recycling rate, is first defined in the theoretical framework, and then the different independent variables that affect it in different kinds of institutional organisation methods are showcased. Three hypothesises are formulated based on the suspected effects of the independent variables on the dependent variable.
The methodology explains the research approach, mentioning that it was conducted for a bachelor's thesis and that quantitative methods were used to carry out its analysis. Additionally, it includes a comprehensive overview of the data collection process. It also provides detailed information about the dataset and literature utilised. Moreover, information on the ethical considerations taken into account during the thesis writing process can be found here.
In the statistical analysis part, the actual steps of the quantitative analysis are shown, aided with some explanation and conclusions based on the tests.
In the discussion, the results of the analysis are disputed in comparison to the existing literature on the topic. Here, the possible effects of other factors not included in the statistical analysis are also mentioned.
Finally, in the conclusion, the research questions are answered based on the findings of the thesis.

2. Theoretical framework

2.1 Dependent variable

According to a policy report on the matter, the recycling rate and target are often presented as a proportional value in percentage and reflects the proportion of materials recycled or recovered from waste. (Hotta et al., 2013) In the statistical analysis carried out in this research, it will serve as the dependent variable so the effects of the independent variables on the recycling rates of different cities on average can be observed. The goal is to find out which institutional design approaches yield the higher recycling rates to be able to determine which policies should be implemented when designing a new waste management system. It is a universal variable as it is a ratio of the recycled material and the total waste collected; therefore, a comparison of different-sized cities from around the world is possible.

2.2 Independent variables

Identification of the different types of waste collection methods is needed to make comparisons clear between them. The categorisation was taken from an academic journal called Plastic Waste Management: Current Status and Weaknesses (Horodytska et al., 2019). They identify the following four main types of waste collection methods:

- Curbside collection:

  This method refers to the type of waste collection when buildings and individual houses collect their own waste (often separating types of waste) into different bins or trash bags that the local municipality or a private company collects on specific days according to the regulations. Curbside collection of garbage is more costly compared to other methods because the collectors have to travel longer distances and take longer to complete their route. According to a study on the matter, the inherent costs of curbside collection are high because amounts collected per residence are small compared to the total waste stream. (Everett et al., 1998) Another issue can be if multiple private companies handle the collection. In this case, the trucks collecting often have to skip houses that belong to another company adding to the length of their route. Curbside collection mixed with multi-fraction separation (defined later) further increases the collection costs since either multiple single-section trucks have to do the routes or multi-section trucks have to be sent out that can cover smaller areas due to their smaller individual compartments. But according to previous research, curbside collection can reach the highest possible recycling rates. (Ferronato et al., 2019)

- Drop-off or bring point collection

  This method refers to the type of waste collection when instead of each building having its own bin, larger containers are placed near residential areas where residents living nearby can drop off their waste. These locations often include containers dedicated to a single type of waste, e.g., plastic, metal, glass, etc. These large containers are emptied regularly by their operators, who have to visit fewer locations compared to the curbside collection method. This method is also suitable for public areas such as schools, workplaces, and parks, so people don’t have to bring their trash far, lowering the likelihood of littering. However, an optimisation scheme to decide the appropriate

location and size of recycling drop-off stations is essential in solid waste management systems analysis. (Chang & Wei, 1999)

- Buy-back containers

  This method refers to the type of waste collection when the containers pay people for returning specific recyclable items that the container operator can sell in bulk. These containers are usually operated by private companies, sometimes next to existing public waste collection. They play an important role in waste collection, especially in lower-income countries, where people make a living out of collecting and delivering trash to buy-back containers. For example, a study investigating the South African recycling industry found that buy-back containers play a crucial role in facilitating the recycling potential of these informal sector participants. (Viljoen et al., 2012) They collect the trash that the official collection system would not, increasing the recycling rates of their region.

- Deposit programmes

  This method refers to the type of waste collection when people have to pay a fee in advance when purchasing a product containing plastic or other materials like glass or metal that they can get back upon returning the packaging. This initiative encourages people to recycle more through financial incentives. According to a study investigating the success of recycling rates, out of 98.1% households respondents who were aware of the deposit refund scheme, 76.3% returned their bottles to obtain the deposit. This high level of participation could be a result of the monetary gain attached to returning the beverage bottles. In the absence of financial gain, the level of participation could be reduced. (Bolaane, 2006) This method usually requires public-private partnerships where the government makes a central system for collection and private companies buy back their own containers.

Curbside collection and drop-off collection methods can be further categorised into subcategories based on the approach they take on the separation of recyclables and other types of waste. This research will also take into account the comparison of these subcategories and their effects on recycling rates.

- Single fraction – mixed solid waste

  With this approach, all solid waste is collected into a single bin, and recyclables are separated after collection at waste-processing facilities. This approach requires less citizen involvement. However, a study on the matter found that a single-fraction collection system is decidedly more inefficient in terms of materials recovery and, therefore, yields a lower recycling ratio of plastic packaging due to the increase of contaminants attached to the material. (Horodytska et al., 2019)

- Two fractions – dry waste and organic

  With this approach, biodegradable organic waste is separated from the rest of the trash. This method still requires separation after collection but lowers the number of contaminants on the recyclable materials.

- Three fractions – organic, paper and cardboard and the rest of the dry waste

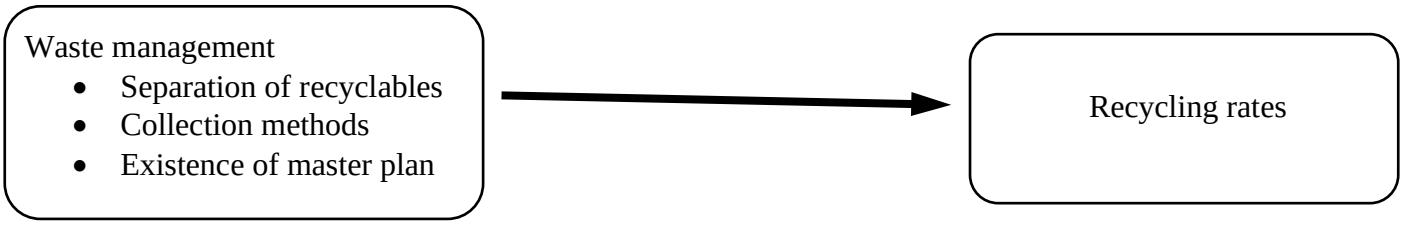
  With this approach, paper and cardboard are collected separately, making them easier to recycle due to lower levels of contaminants. It also makes the separation process easier as there are fewer categories to sort into. However, this method requires higher levels of citizen involvement as well as the need to operate selective collection.

- Multi-material collection systems

  With this approach, all recyclables are collected separately, including paper, glass, and aluminium, from the rest of the waste. This requires the highest levels of citizen involvement, but no waste processing facility is needed after collection.

According to the World Bank, a master plan is a 'dynamic long-term planning document that provides a conceptual layout to guide future growth and development.' (World Bank, 2015) In the case of waste management systems, it is essential to integrate them with the rest of the city as they are needed by homes and the industry equally. Master plans make the required connection between the different departments of governance responsible for the built environment, societal needs, and the environment. Their goals are reaching over the different levels of government, making them work together for a common target.

2.3 Conceptual model



2.4 Hypothesises

This thesis utilises statistical hypothesis testing to investigate the effect of the independent variables defined in the theoretical framework on recycling rates. The hypothesises were formulated based on the findings of the existing literature. According to previous research, curbside collection has a higher recycling rate compared to drop-off collection. (Morawski & Wilcox, 2017) Research papers on the topic also claim that a single-fraction collection system is decidedly more inefficient in terms of materials recovery, and it yields a lower recycling ratio due to the increase of contaminants attached to the material. (Horodytska et al., 2019) And according to a report on master plans, they are set out to guide growth and development in their field. (World Bank, 2015) To determine whether this analysis comes to the same results and conclusion as existing literature did, the following hypothesises were formulated:

- In the population, the average recycling rate between curbside, drop-off and mixed collection methods are the same.
- In the population, the average recycling rate is equal between single- and multi-fraction waste collection systems.
- In the population, the average recycling rate is equal between cities having a master plan for solid waste management and cities that have no such plans.

3. Methodology

3.1 Research approach

This research was conducted as a bachelor's thesis, so it had to meet the corresponding requirements. Therefore, the secondary data used was only collected from trustworthy official and academic sources, and the statistical analysis was carried out with the standards taught at the Statistics course of the Faculty of Spatial Planning. According to a study on the matter, 'Quantitative research encompasses a range of methods concerned with the systematic investigation of social phenomena, using statistical or numerical data.' (Watson, 2015) The quantitative research approach was chosen because the investigated dependent variable, the recycling rate, was a ratio variable; therefore, the research was easy to quantify. Due to the size of the available data, meaningful statistical analysis was possible. The quantitative research design consists of the following steps: first, a theory based on the current literature is developed, and then hypothesises are created based on the findings. The next step is to operationalise the concepts, including deciding on the dependent and independent variables and how to measure them. This is followed by the data collection that results in a database that will be the subject of the statistical analysis. Once the analysis is conducted, the results are interpreted, discussed, and linked back to the existing literature. (Watson, 2015)

3.2 Data collection

As a basis for the statistical analysis, the World Bank's 'What a Waste – Global Database' (World Bank, 2023) was used, which contains extensive data on solid waste management from around the world, covering over 360 cities. The data includes information on waste collection, composition, disposal, and institutional backgrounds of waste management. Using the regularly updated, largest aggregated dataset as the basis of the analysis ensured high-quality data and helped it be relevant and up-to-date to answer the research question as thoroughly as possible. The literature was searched through Google Scholar, with keywords such as 'waste management', 'sustainability', 'recycling', etc. The articles were then examined and only used if they were from a reliable source and up to date.

3.3 Data analysis

- Statistical analysis for hypothesis testing

To make sense of the vast dataset of the waste management systems of many cities, this research uses inferential statistics. Inferential statistics make inferences about populations by analysing data gathered from samples and dealing with methods that enable a conclusion to be drawn. (Brown & Saunders, 2008) This happens through hypothesis testing. To set them, the null hypothesises of the tests conducted were used. These tests are the one-way analysis of variance test and the two-sample t-test. They both test the means of groups, just for different numbers of them. Where the cases were divided into two by the grouping variable, (single- and multi-fraction collection systems, existence of a waste management master plan yes/no), the two-sample t-test was used to investigate if the variable makes a significant difference in their average recycling rates. The separation of waste was coded as a binary variable, 'Yes' meaning either two or three faction or multi-material collection systems, 'No' meaning single fraction waste collection. The existence of a master plan was also coded as a binary variable, 'Yes' meaning if there is a plan already in effect and 'No' meaning there is no plan in effect in the

city (yet). Where the independent variable had three categories, (curbside, drop-off, and mixed collection methods), the one-way analysis of variance test was used to test whether the different collection methods make a statistically significant difference in the average recycling rates of cities.

- Literature review

Data and inspiration were taken from numerous academic sources and reports of organisations regarding institutional design, statistics, and waste collection. Primarily, articles about previous research on the institutional background of waste collection systems and articles on recycling rates were studied. Finally, the collected data was analysed to determine which collection method has the best recycling rates.

3.3 Ethics

According to a book exploring the social, ethical, and legal issues scientists face today, their obligations include honesty, objectivity, transparency, protection of intellectual property, respect for colleagues, social responsibility, and non-discrimination, among others. (Shamoo & Resnik, 2022) While conducting this research, all of the relevant values were respected. The data was treated with honesty: it was not fabricated, falsified, or misinterpreted, was taken from reliable sources and the reporting on the outcomes was objective. Objectivity was kept by avoiding bias in the research design, the data analysis, and the reporting. This paper also aimed for transparency by disclosing its sources, analysis and methods for the reader and leaving it up to them to decide whether they agree with the way the research was carried out. Intellectual property was protected during the writing of this thesis; others' research was used as inspiration indeed, but always with reference to the original author(s). Respect for colleagues was shown in the form of providing peer reviews for their bachelor projects'. The social responsibility was explained in the introduction part of this paper, this research being needed for the future of our cities' sustainable growth and transformation. There was no discrimination in effect when dealing with the analysis of this paper: the dataset used included cities from all around the world, giving them a fair representation.

4. Statistical analysis: Hypothesis testing

4.1 **1st Hypothesis**: In the population, the average recycling rate between curbside, drop-off and mixed collection methods are the same.

A one-way ANOVA was performed on the dataset used for the analysis to determine whether the average recycling rate between curbside, drop-off, and mixed collection methods is the same.

Descriptives

waste_treatment_recycling_percent

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
Centralized drop-off point	33	11,45242	11,782800	2,051122	7,27442	15,63042	,000	46,400
Curbside collection	65	16,37257	15,375572	1,907105	12,56269	20,18245	,300	70,000
Mixed	30	17,47710	18,029719	3,291761	10,74469	24,20951	,600	72,000
Total	128	15,36297	15,293678	1,351783	12,68803	18,03790	,000	72,000

Table 1: Descriptive statistics for the three kinds of waste collection methods tested for the 1st Hypothesis

As Table 1 shows, the three groups have 128 cases in total, 33 representing waste collection systems with Centralized drop-off points, 65 with Curbside collection, and 30 with mixed approaches. Since all groups have a number of cases of at least 30, we can assume their values are normally distributed due to the Central Limit Theorem. The cases are cities; therefore, they are independent, and the dependent variable being tested is a percentage, consequently a ratio variable.

Tests of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
waste_treatment_recycling_percent	Based on Mean	1,207	2	125	,302
	Based on Median	,769	2	125	,466
	Based on Median and with adjusted df	,769	2	110,139	,466
	Based on trimmed mean	1,001	2	125	,371

Table 2: The outcome of Levene's test to check the homogeneity of variances for the ANOVA needed to test the 1st Hypothesis

To assess the homogeneity of variances, a rule of thumb could be applied. According to Table 1, two times the lowest standard deviation (2*11,78 = 23,56) is higher than the highest standard deviation (18,03). However, to test the variances professionally, Levene's test was conducted. As depicted in Table 2, its p-value is above 0,05, namely 0,302 which means the test is not significant. Consequently, the null-hypothesis cannot be rejected, meaning the variances of the groups are equal. Since the assumption of homoscedasticity is met, the ANOVA can proceed.

ANOVA

waste_treatment_recycling_percent

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	704,988	2	352,494	1,519	,223
Within Groups	28999,878	125	231,999		
Total	29704,866	127			

Table 3: The outcomes of the ANOVA carried out to test the 1st Hypothesis

As indicated in Table 3, the value of F is 1,519, which is not significant, with a p-value of 0,223, which is higher than the required 0,05. Consequently, the null hypothesis cannot be rejected.

We have no evidence to state that: In the population, the average recycling rate between curbside, drop-off and mixed collection methods are the same.

4.2 **2nd Hypothesis**: In the population, the average recycling rate is equal between single- and multi-fraction waste collection systems.

To determine whether the average recycling rate is equal among the single- and multi-fraction waste collection systems, an Independent Samples Test (Two-Sample t-test) was conducted on the dataset used for the analysis.

Group Statistics

	Separation existence	N	Mean	Std. Deviation	Std. Error Mean
waste_treatment_recyclin	No	33	8,59000	7,461933	1,298956
g_percent	Yes	95	17,71568	16,593843	1,702492

Table 4: Descriptive statistics of the two groups being compared in the Two-Sample t-test needed to test the 2nd Hypothesis

As illustrated by Table 4, the two groups have 128 cases in total, 33 representing waste collection systems where there is no separation of recyclables and 95 where sorting happens at the source. Since both groups have a higher number of cases than 30, we can assume their values are normally distributed due to the Central Limit Theorem. The variable tested for (average recycling rate) is a ratio variable, and as the cases represent separate cities, they are independent of each other. Therefore, all of the requirements of the two-sample t-test are met.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
waste_treatment_recycling_per cent	Equal variances assumed	13,421	<,001	-3,048	126	,001	,003	-9,125684	2,994111	-15,050941	-3,200427
	Equal variances not assumed			-4,261	117,916	<,001	<,001	-9,125684	2,141440	-13,366350	-4,885018

Table 5: The outcome of the Two-Sample t-test carried out to test the 2nd Hypothesis

The results of Levene's test help to evaluate the equality of variance. As indicated in Table 5, the p-value for the test is below 0,001; thus, it is significant. Therefore, the null hypothesis of Levene's test: "Variances for the two populations are equal" can be rejected, indicating that the variances are significantly different between the two groups. Consequently, the 'Equal variances not assumed' row of the Independent Samples table is relevant to the analysis.

In accordance with Table 5, the p-value for the 'equal variances not assumed' t-test is below 0,001, therefore, the test is significant, and the null hypothesis can be rejected. This gives enough evidence to state that:

In the population, the average recycling rate is not equal between single and multi-fraction waste collection systems.

In light of Table 5, the mean recycling rate of cities using single fraction collection equals 8,59%, while the mean rate in cities using multi-fraction collection is 17,72%, over two times more.

A 95% confidence interval on the difference between the two population means using a t-distribution with 118 degrees of freedom is (-13,366 , -4,885) according to Table 5, which indicates that there is significant evidence that the existence of source separation produces different mean recycling rates.

4.3 **3rd Hypothesis**: In the population, the average recycling rate is equal between cities having a master plan for solid waste management and cities that have no such plans.

To determine whether the average recycling rate is equal, between cities having a master plan for solid waste management and cities that have no such plans an Independent Samples Test (Two-Sample t-test) was conducted on the dataset used for the analysis.

Group Statistics

	Master plan	N	Mean	Std. Deviation	Std. Error Mean
waste_treatment_recycling_ percent	No	52	10,59885	12,390228	1,718216
	Yes	77	18,94208	16,417604	1,870960

Table 6: Descriptive statistics of the two groups being compared in the Two-Sample t-test needed to test the 3rd Hypothesis

As illustrated by Table 6, the two groups have 129 cases in total, 52 representing cities with no master plans for solid waste management and 77 representing cities with master plans for solid waste management. Since both groups have a higher number of cases than 30, we can assume their values are normally distributed due to the Central Limit Theorem. The variable tested for (average recycling rate) is a ratio variable, and as the cases represent separate cities, they are independent of each other. All of the requirements of the two-sample t-test are met.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
						Significance				95% Confidence Interval of the Difference
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
waste_treatment_recycling_percent	Equal variances assumed	8,904	,003	-3,113	127	,001	,002	-8,343232	2,680086	-13,646637	-3,039826
	Equal variances not assumed			-3,284	125,367	<,001	,001	-8,343232	2,540227	-13,370513	-3,315951

Table 7: The outcome of the Two-Sample t-test carried out to test the 3rd Hypothesis

The results of Levene's test help to evaluate the equality of variance. According to Table 7, the p-value for the test is 0,003, thus, it is significant. Therefore, the null hypothesis of Levene's test: "Variances for the two populations are equal" can be rejected, indicating that the variances are significantly different between the two groups. Consequently, the Independent Samples table's 'Equal variances not assumed' row is relevant to the analysis.

Based on Table 7, the p-value for the 'equal variances not assumed' t-test is below 0,001, therefore, the test is significant, and the null hypothesis can be rejected. This gives enough evidence to state that:

In the population, the average recycling rate is not equal between cities having a master plan for solid waste management and cities that have no such plans.

As indicated in Table 7, the mean recycling rate of cities not having a master plan for solid waste management equals 10,598%, while the mean rate in cities with a master plan is 18,94%, almost twice more.

A 95% confidence interval on the difference between the two population means using a t-distribution with 126 degrees of freedom is (-13,37 , -3,316) as evidenced by Table 7, which indicates that there is significant evidence that the existence of a master plan for solid waste management produces different mean recycling rates.

5. Discussion

One of the most important institutional decisions to make when organising a city's waste collection system is deciding on the collection method. This will influence the infrastructure needed to be built and the number of trucks required. But to investigate whether it effectively changes the outcome of recycling rates, the first hypothesis had to be tested: "In the population, the average recycling rate between curbside, drop-off and mixed collection methods are the same." The statistical analysis ran on the matter found that the type of collection method makes no statistically significant difference between the mean recycling rates of the different collection methods. However, this does not mean that the right choice of the waste collection system is negligible. Other cities have different needs for a well-working system, but most importantly, they have different resources, societal awareness, and willingness to participate. A study researching integrated approaches for assessing municipal solid waste collection and treatment scenarios found that introducing curbside collection could achieve the highest recycling rate. (Ferronato et al., 2019) However, in the case study on La Paz, Bolivia, the findings regarding selective collection differed. Applying the curbside collection could be a challenge with high expenses and bad results since the geographical area and the social awareness represent a barrier to developing an effective selective curbside collection. (Ferronato et al., 2019) The right institutional design approach towards the collection system's design must take these factors into account.

Another critical decision that needs to be made while planning the institutional background of a city's waste collection system is whether the recyclables should be sorted separately from the rest of the garbage or will they be sorted after collection in a sorting facility. To inspect if there is a statistically significant difference between single- and multi-fraction systems, a statistical analysis was carried out to compare the mean recycling rates between cities that apply source separation and those that do not. The analysis found that the average recycling rate in the population is not equal between single and multi-fraction waste collection systems. The mean recycling rate of cities using single fraction collection equals 8,59%, while the mean rate in cities using multi-fraction collection is 17,72%, over two times more. While source separation seems to be the obviously better option on paper, real-life situations often differ. A report investigating the implementation of source separation in Malaysia found that physical barriers to source separation and recycling practice, such as lack of space, inconvenience, and nuisance, besides misconceptions about the practice, are common issues (Moh & Abd Manaf, 2017), resulting in lower recycling rates. Source separation and recycling among households requires their willingness to separate waste for recycling and supporting infrastructure for them to do so, with consideration of their socio-economic conditions as well as it is not possible to develop a recycling system that fits all. Despite the possible intention to separate waste and recycling, barriers to recycling or reasons to non-recycling among households should be further identified. (Moh & Abd Manaf, 2017)

This leads to the last investigated institutional decision a city must make when developing its waste management system: should it have an integrated master plan for its development? To explore whether having a master plan for solid waste management changes a city's recycling rate, the third hypothesis was tested: In the population, the average recycling rate is equal between cities having a master plan for solid waste management and cities that have no such plans. However, during the analysis, the mean recycling rates of the two groups turned out to be statistically significantly different, for cities not having a master plan for solid waste management equalling 10,598% while cities having a master plan resulting in 18,94% of materials being recycled, almost two times more. As a study conducted on multi-objective optimisation models for strategic waste management master plans found, optimising the selection of systems that are part of a hybrid waste management master plan can potentially achieve maximum benefits and minimise negative impacts. (Abdallah et al., 2021) Therefore having a master plan for a city's waste management is crucial to help it become better implemented and more thorough.

6. Conclusion

In light of the results of the statistical analysis and their discussion, enough knowledge is gathered to respond thoroughly to the research questions asked.

6.1 How do the existing waste collection systems work around the world?

The existing waste collection systems work very differently worldwide. The only thing they have in common is that they all collect garbage from citizens and recycle some parts of it. But they can differ in their way of collecting the waste: they can collect it through curbside collection, drop-off collection or take a mixed approach combining multiple methods. (Horodytska et al., 2019) The systems can differ in the way they separate the recyclables in the waste, either using single- or multi-fraction collection. (Horodytska et al., 2019) Implementing various policy approaches towards the system's organisation is also a major factor resulting in differences: for example, having a master plan can greatly increase the efficiency.

6.2 How efficient are the current waste collection systems regarding recycling rates?

The different waste management systems examined yielded very different results ranging from barely any recycling (~1%) to very high rates (>70%). (World Bank, 2023) To find which variables lead to higher recycling rates on average, hypothesises were tested statistically. The averages of all groups were quite low (below 20% as a group). This tells us that, generally, around the world, current waste collection systems are relatively inefficient regarding recycling rates.

6.3 What approaches can be implemented in the future to make the existing systems more efficient?

The future of solid waste management depends on every human on this planet. While municipalities and governments can adapt better strategies and stimulate better waste collection, conscious and sustainable consumption is a key responsibility all must consider. Developing countries have a newly growing middle class with access to more and more

products thanks to their country's rapid economic development. (World Bank, 2023) However, the increasing consumption has to be followed by evolving waste management systems as well to cope with the increasing stress on them. New methods of waste treatment, like recycling, have to replace the old ways of open dumping. Even though consumption is high in developed countries like Sweden and Germany, they have the highest recycling rates because recycling practices are deeply embedded in society. (World Bank, 2023) Children learn to separate waste based on colour codes from an early age, and society acts as a whole to recycle as much as possible. Educating the people of developing countries on these forms of behaviour is of utmost importance.

6.4 What institutional design approaches can be adopted to improve the efficiency of waste collection systems?

Testing for different approaches' results on recycling rates, the analysis found that the mode of the collection has no significant influence whether curbside collection, centralised drop-off points or a mixed approach is utilised. This means that no matter which collection type a city chooses to implement, it won't significantly affect the recycling rates. However, when investigating whether the waste was sorted before or after collection, the analysis found that there is a significant difference between cities that utilise source separation and cities that do not, with the cities using this method having a higher average (8.59% vs 17,72%). When analysing whether the existence of a solid waste management master plan influences the recycling rates, a significant difference was found between cities that implemented a master plan and cities that did not, the cities with master plans averaging higher at 18,94% compared to 10,6%. Based on these findings, the best advice on institutional design for cities developing their solid waste management systems is to implement a master plan, sort the waste with source separation and collect it in a manner that fits their geographical characteristics.

6.5 Future research

While the findings of this thesis help to get an idea of which combination of existing waste management techniques yields the highest recycling rates based on a worldwide analysis, future research is needed to experiment with new types of waste management that could result in a more efficient system overall. Moreover, future research could investigate the effects of the geographical characteristics of cities on the types of collections that work best for them. In addition, further research is also required on the topic of how developing countries can educate their citizens more on recycling habits.

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