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Comparative Assessment of Municipal Solid Waste Management plans in European and Brazilian Cities

AC Medina Jimenez[1*], R Palacios-Bereche[1] and S Nebra[1,2]

[1]*Centre of Engineering, Modelling and Social Sciences, Federal University of ABC (CECS/UFABC), Avenida dos Estados, 5001; Santo André, SP, 09210580, Brazil.*

[2]*Interdisciplinary Centre of Energy Planning, University of Campinas (NIPE/UNICAMP), Hall University City "Zeferino Vaz" (Prefeitura Universitária - UNICAMP) Cora Coralina 330, Campinas, SP, 13083896, Brazil.*

[*]**Corresponding author:** Ana Carolina MJ, Centre of Engineering, Modelling and Social Sciences, Federal University of ABC (CECS/UFABC), Avenida dos Estados, 5001; Santo André, SP, 09210580, Brazil, Tel: +55(11) 97109-2413, E-mail: ana.medina@ufabc.edu.br

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Abstract

Municipal solid waste (MSW) management is one of the main problems faced by city authorities around the world, since this topic encompasses different objectives, application areas, and policies. Seeing as all these issues are relevant, they need to be correctly studied, analysed and executed to find intelligent solutions for each city. In order to develop an appropriate waste management plan for the cities' reality, a common used strategy is to support these plans, considering the experiences of cities that presented relevant results and that are leaders in the area. Thus, this work aims at presenting a summary of the waste management practices applied by leading European cities in the field, showing relevant information regarding efficient strategies and good practices, which can assist in the development of management plans for Brazilian cities, where no significant progress has been made in recent years. Helsinki is the city with the highest *recycling* rate (48.1%), and also the city with the highest waste fee (89.88 US$ monthly per house). The European standards require the citizens to separate the waste into at least five fractions, ensuring an efficient collection system, cities that separate the waste into different fractions present the best recycling rates. In the same way, cities with less collection frequency present the best results, demonstrating that a high-frequency waste collection does not guarantee an efficient performance.

Keywords: Waste Management; MSW; Recycling Rate; Selective Collection; Frequency Waste Collection; Waste Fee

Introduction

In the last centuries, the constant and accelerated human development has increased the consumption of products and services, thus increasing the waste generation. By 2050, per capita waste generation in high-income countries is projected to increase by 19%, while in low and middle-income countries this percentage may be more than 40% [1]. The increase of the population is an important factor in the uncontrolled waste generation, however it cannot be leave aside: the accelerated consumption pattern; the lack of environmental education and commitment of the population; furthermore there is the lack of engagement of the authorities in the development of policies that strengthen the model of circular economy, involving the product manufacturers in the search for a joint solution to the social and environmental problem of the traditional "take-make-consume-dispose" system [2]. Many of the waste generated do not have natural cycles of degradation, or contain several components that makes difficult to return them to the production chain, affecting the whole system, being necessary to obtain more raw materials [3, 4].

Waste management (WM) is one of the biggest problems that governments have had to face worldwide, because these are complex systems, which require planning, investment, reliable management, public policies and cultural factors; involving all sectors and economic levels of society. Since it is such a sensitive system to be dealt with, managers and authorities model their WM plans according to practices adopted in other places, which have shown positive environmental and social results, adapting these practices to their local realities [5, 6].

The present work studied the WM plans of eight European cities that presented the best results in the "Green cities Index" developed by [7] the city of Curitiba, Brazil, which presented the best results in the "Latin-American Green Cities" developed by [8], and seven (7) cities of the great ABC region in the state of São Paulo. The objective of this work is to study the main characteristics of the WM system of European cities such as: the good practices applied, the types of waste collection systems, waste fee adapted, waste treatment system, and the different educational actions that these cities promote. Thus, this analysis can be used as a practical guide to improve WM plans in Brazilian cities.

Materials and Methods

A literature review of the WM plans of eight European cities and eight Brazilian cities was accomplished; the study focused on the information reported by the governments, analysing annual reports, statistics and official documents published in their native languages.

For all the cities the fractions collected have the same definition, mixed waste (MX) are the waste that cannot be recycled, the organic fraction (ORG) is garden and food waste. The recyclable fraction (RCY) is all the waste that can be recycled such as *plastic, metal, paper, cardboard and glass.*

Copenhagen, Denmark

The WM is performed by the City Hall and the selective collection is done door-to-door for all waste fractions. Usually, the collection of MX and ORG fractions is done once a week in residential properties (houses), while for residential apartments this collection can have a higher frequency, depending on the amount generated; in these cases, the additional collection must be contracted with the City Hall. Collection of RCY fractions depends on the type of residence; for residential apartments the frequency of collection must be planned together with the City Hall, and depends on the amount of waste that is generated. For residential properties, collection ranges from 1 month for plastic and metal to 2 months for paper Additionally, the city has door-to-door collection of hazardous and electronic fractions, which occurs every 13 weeks for houses. The entire collection system is managed using the "Easy Waste (No Affalds service)" application, in which, residents can find all the information regarding collection days, fees, schedule, calendar, etc. The system also has an informative guide named "ABC of the waste", where it is possible to search the correct place of disposal, according to the product to be discarded. Waste Collection and treatment fee is charged annually, for MX,

ORG and RCY fractions [9]. Waste refuse from the sorting process is treated at the waste-to-energy (WtE) incineration plant ARC's Amager Bakke, located in the city centre; in 2018, this plant processed 443,000 t of waste [10]. The city has a return program for glass and plastic bottles and aluminium cans. Citizens deposit these packages in authorized places or return machines, they receive a reward ranging from 1 to 3 DKK (0.15 to 0.46 US$) that depends on the capacity of the bottle or can [11].

Stockholm, Sweden

The WM is performed by Stockholm Water and Waste department (Stockholm Vatten Och Avfall). The collection is done door-to-door for two fractions, MX and ORG; for residential properties and apartments the collection is carried out once a week for both fractions [12]. Depending on the amount generated, it is possible to hire a higher collection frequency. RCY, hazardous and electronics fractions must to be taken to one of the 254 recycling centres in the city [13]. Part of the collection and treatment of waste is financed by the residents; the waste fee is applied to the MX fraction and is charged quarterly. The ORG fraction collection is free for residential properties up to 140 L every two weeks; for apartments this service has an extra cost. The waste fee is formed by a basic and a variable fee, that depends on the weight of waste collected, or depends on the contracted volume [14]. MX fraction and waste refuse from sorting processes is treated at the Högdalenverket WtE plant, managed by Stockholm Exergi, located inside the city [15]. The ORG fraction is treated at Himmerfjärdsverket biodigestion plant, where biogas is produced with 2/3 of sewage sludge and 1/3 of external material such as food waste. The plant can produce about 5.3 Nm^3 of vehicular gas per 100 kg of food waste [16].

Oslo, Norway

The WM is public and performed by Oslo sanitation department (Renovasjonsetaten – RNE). The selective collection is done door-to-door for 4 fractions, which must be separated in different plastic bags [17]. In the green one, the ORG fraction must be disposed; in the blue one, plastic fraction; and in the supermarket bag (different colour from green and blue), the MX fraction. These three bags can be deposited in the same container that is collected once a week. Paper fraction must be disposed in a different container, specially designed, it is collected every 14 days. Depending on the amount generated, it is possible to hire a higher collection frequency. Other fractions such as metal, glass, hazardous and electronic must be disposed in the recycling centres or in the waste collection points, located in different places in the city. Part of the WM system is financed by the residents; the waste fee is applied for all collected fractions and is charged quarterly. The waste fee is formed by different taxes: a volume and an overload (if the distance between the street and the container is more than 10 meters), a locked door (if the collector needs a special key to open the waste storage room) and an extra bag collected (if the container is full and there are extra bags in the floor of the waste storage room) [18].

The MSW collected is taken to the Haraldrud and Klemetsrud waste treatment plants, both plants are operated by the Energy recovery agency – EGE (Energigjenvinningsetaten in Norwegian). The Klemetsrud plant is located on the city outskirts and Haraldrud is located inside the city. The waste sorting process consists of separating bags by colour. For this purpose, optical sensors are used to identify the bags colour; being identified, the bags are separated and sent for the appropriate treatments. The sorting process is mechanized and operated remotely, Haraldrud and Klemetsrud plants have an optical separation process with a capacity of 100,000 and 50,000 t $year^{-1}$, respectively. Additionally, the plants have optical sensors that identify loose, bulky waste and black bags; these wastes and the MX fraction (supermarket bags) are sent to the combustion with energy recovery process. The incineration process at the Klemetsrud and Haraldrud plants have a capacity of 103,000 and 346,000 t $year^{-1}$, respectively. Thermal energy produced in these plants is used in the city's district heating network, which represents approximately 20 percent of the city's heating demand [19]. The plastic fraction is exported to treatment plants in Germany and Sweden, where it is processed for further use as raw material [20].

The Romerike biodigestion plant (RBA) treats the ORG. This plant also treats fluid waste from industry and ORG fraction from commercial activities. In 2016, all the waste collection trucks and 12.5% of public buses, used the biogas generated in the RBA as fuel [19]. The residual product of biogas production is offered as bio-fertilizer to farmers in the region, due to the high nutrient content. In 2017, 43,000 m^3 of liquid and 2,000 t of solid Bio-fertilizers were produced [21]. Garden fraction disposed in the waste collection points is used to produce fertilizer of different qualities, all of them approved by the Norwegian Food Safety Authority. The price of one m^3 of fertilizer varies between 189 to 550 NOK (20.39 to 59.35 US$), depending on its quality [17].

Norway has a return program for plastic bottles and aluminium cans. Infinitum is the company in charge of management and operation of approximately 3500 return machines installed in several markets around Oslo, this system allows the collection of approximately 93% of these packages. When bottles or cans are deposited in these machines the citizen receive a reward ranging from 1 to 3 NOK (0.11 to 0.32 US$), depending on the package capacity.

Vienna, Austria

The WM is public and performed by Department 48: WM, street cleaning and vehicle fleet (MA 48). The collection is done door-to-door for 3 fractions: ORG, MX and paper, this collection is made once a week. Depending on the amount generated, it is possible to hire a higher collection frequency. RCY, hazardous and electronic fractions have to be taken to MA48 recycling centres or in the waste collection points. Since 2002, the responsibility for the correct separation of all collected fractions lies with the citizens (currently the waste is separated into six fractions) [22]. Waste Collection and treatment fee is charged annually, just for the MX fraction, promoting waste separation. The waste fee is formed by a volume tax. In addition to the selective collection, there are several recycling centres and waste collection points around the city. There are 223,000 containers for MX fraction; 94,000 for paper and cardboard; 6,000 for metal; 6,700 for glass (light and dark); 13,000 for plastic; 2,000 for kitchen waste and 83,000 for garden waste. Furthermore, the city has 16 hazardous waste collection stations. MX and bulky wastes are treated at the four WtE plants: MVA Flötzersteig, MVA Spittelau, MVA Pfaffenau and WSO 4, all located inside the city. The four plants have a combined capacity of 780,000 t $year^{-1}$, thermal energy produced is used in the city's district heating network [23].

Amsterdam, The Netherlands

WM is carried out by the city hall, in which the citizen is required to separate the waste into six fractions. Glass, plastic, drink cartons, textile and ORG fractions must be deposited separately in the correct container at the several waste collection points located around the city. For the paper and MX fractions the collection depends on the district and/or neighbourhood, there are two ways to collection; these fractions must be deposited separately in the correct container at the waste collection points or they can be collected through the door-to-door system using bags or plastic containers, this must be done on a fixed day and hour at week. If the citizen puts the waste outside on the wrong day or at the wrong time, he could be fined. There are about 12,940 containers around the city: 1,424 for glass; 1,078 for plastic; 346 for textiles; 1,995 for paper and 7,997 for metals and MX. Waste Collection and treatment fee is charged annually and it is a fixed fee, independent of the collected volume [24, 25].

The Afval Energie Bedrijf treatment plant (AEB) has a sorting plant, where the RCY fractions from the waste collection points containers are separated, packaged and sent to the correct treatment. In addition, AEB have a WtE plant where MX fraction is treated; this plant is located inside the city. The WtE plant has a processing capacity of 1,385,488 t $year^{-1}$ of waste and 81,464 t of concentrated sewage, the electricity produced is sold to the national grid and the heat produced is used in the city's district heating network [24, 26].

Amsterdam has a deposit and return program in which the citizen must pay a deposit fee at the moment they buy a product packaged in a plastic or glass bottles; the deposit fee varies from 0.25 to 1.5 € (0.28 and 1.69 US$). When the packaging is placed in the return machine (located in the supermarket), the machine prints a refund receipt that can be used to pay for the next purchase [27].

Zurich, Switzerland

The WM is performed by Entsorgung + Recycling Zürich – ERZ (Disposal and recycling municipal department). RCY fractions must be deposited separately in the correct container at the waste collection points located around the city, the collection and treatment service of these fractions are free, since the citizen disposes them correctly [28, 29].

For the ORG and MX fractions the collection depends on the district and/or neighbourhood, there are two ways to collection; these fractions can be collected through the door-to-door system using official plastic containers for each fraction; or the fractions must be placed in the Zurich bags (Züri Sacke "S-Z") and disposed of in S-Z containers; both collection service are done once a week. Since "polluter-pays" program was created, MSW sent to WtE plant has been reduced by 24% and the recycling rate has increased 32%. Zurich bags can be bought in different places around the city and their price depends on the capacity (17 to 110 L). In addition, an annual basic fee is charged, this fee is used for the maintenance of the waste collection points [30]. Recently, the collection of the ORG fraction was installed along with the garden fraction, the citizen interested in having this service can hire it at the ERZ department and must pay and additional cost; this collection is done once a week [31]. These fractions are treated in the Biogas Zürich AG plant, where they are transformed into compost and biogas. Waste refuse from the sorting process is treated in the WtE plants Josefstrasse e Hagenholz, both located inside the city. Thermal energy produced in those plants is used in the city's district heating network [32].

Helsinki, Finland

It is the capital and most populous city of Finland, its metropolitan region consists of four cities, Espoo, Helsinki, Kauniainen and Vantaa. Helsinki Region Environmental Services Consortium (HSY) is responsible for the WM and sanitation system of the metropolitan region. The selective collection is done door-to-door, for ORG, MX, plastic, glass, metal and paper; the collection frequency depends on the contract made with the HSY department, which can vary from once a week to every eight weeks. WM services fees are charged annually and depends on the contract made with the HSY department. For MX and ORG fractions, fees include transport and treatment. For the RCY fractions fees include only the transportation, the treatment of this fraction is under the manufacturers' responsibility [33, 34].

Finland has a well-structured tire recycling system, in 2013, 50,680 t of tires were collected, of which 1.4% went to retreat new tires, 0.7% were exported, 15.2% were treated in the WtE plant and 66.4% were used in recycling road insulation, no harmful environmental impact was detected during the 10 years of monitoring this use [35, 36]. MX and pos-recycling waste are treated in the Vantaan Energian jätevoimala WtE plant, located in the outskirt of Vantaa city. Thermal energy produced is used in the city's district heating network, providing almost half of the city's annual heating demand and 1/3 of its annual electricity demand.

In the Ämmässuo plant 70% of the ORG fraction is treated, the biodigestion unit has two reactors with a combined capacity of 51,000 t year^{-1}. The biogas is used to produce electricity and heat for its own use, the surplus energy is sold to the national grid [37].

Berlin, Germany

The Berliner Stadtreinigung municipal company (BSR) is the responsible for the WM. Selective collection is done door-to-door for three fractions: MX, ORG and RCY. Usually, the collection is done every two weeks for all the fractions but this collection can have a higher frequency, depending on the amount generated; the additional collection must be contracted with the BSR company. Berlin has 15 recycling centres where citizens can dispose bulky, electronic, hazardous and RCY waste for free, and there are 1576 glass containers. Waste Collection and treatment fee is charged quarterly and depends on the collection frequency and volume purchased [38, 39]. The ORG fraction collected in the city is treated in the BSR Biogasanlage biodigestion plant that have a capacity up to 70,000 t year^{-1}, the biogas produced is used as fuel in the collection trucks. MX fraction is treated in the Ruhleben WtE plant, that have a capacity up to 520,000 t year^{1}. Thermal energy produced is used in the city's district heating network. Post recycling waste

is treated in the Mechanical-Physical Stabilization plants (MPS) where 10,000 t of refuse derived fuel (RDF) are produced [40].
Curitiba, Brazil

The WM is performed by the municipal environment office: public cleaning department. Waste collection is done door-to-door for two types of waste: wet waste (ORG and MX) and dry waste (RCY fractions). The wet waste is collected three times a week by the public cleaning department trucks and deposited in the Estre Ambienta sanitary landfill, located in the city of Fazenda Rio Grande, about 23 km from Curitiba [41, 42].

The dry waste collection is done three or once a week, depending on the neighbourhood; this collection is carried out by the waste pickers' cooperatives. The incorporation of these cooperatives to the collection system seeks to promote social inclusion, since their members are usually people with no level of education and low economic resources, usually resident at shanty towns (named favelas in Brazil). Additionally, since 1991, the city has had the "Câmbio verde" ("green exchange") Program, where citizens of the communities can exchange recyclable material for vegetables [43].

The Great ABC region, Brazil is composed for eight cities. Landfilling is the only MSW treatment method used till now. There are two sanitary landfills: Lara private landfill, located in Maua city and Santo André municipal landfill. Seven cities are using the Lara landfill to deposit their waste, while only the city of Santo Andre uses its own landfill.

Diadema, Maua and Ribeirao Pires (RP)

The WM is executed by the city hall and the selective collection is done door-to-door. The wet waste collection in carried out by the city hall and is done three times a week. The collection of dry waste is done daily and is carried out by the waste pickers' cooperatives. The waste fee is charged annually, in a fixed fee independent of the collected volume in Diadema [44, 42]. For the cities of Maua and RP there is no waste fee [42, 43, 44].

Rio Grande da Serra (RGS)

The WM is executed by Lara company hired by the City Hall. Waste collection is done door-to-door three times a week for the mixed waste fraction; the city does not have a selective collection system. The waste fee is charged annually; it is fixed and depends on the area of the house [42, 47].

Santo Andre

The WM is executed by SEMASA local authority. Waste collection system has the same structure as the city of Curitiba, with the difference that dry waste collection is done three or once a week. The waste fee is charged monthly to the water bill; it is fixed and depends on the size of the house [42, 45].

Sao Bernardo do Campo (SBC)

The WM is executed by São Bernardo Ambiental company (SBA). Waste collection system has the same structure as the city of Curitiba, with the difference that dry waste collection is done twice a week. The fee is charged annually; it is fixed and depends on the size of the house [42, 50].

Sao Caetano do Sul (SCS)

The WM is executed by Water, Sewage and Environmental Sanitation Department (SAESA, in Portuguese). Waste collection system has the same structure as the city of Curitiba, with the difference that wet waste collection is done once a day. There is no waste fee [42, 48].

Results and Discussion

Table 1 presents the summary of the main points analysed for each European city. The waste fees presented were calculated according to the WM characteristic of each city. However, in order to make a comparison between the cities, the fee calculation for each city took into account similar characteristics, such as: waste fee applied for houses that uses a container of 140L for each fraction (It is the minimum volume used in all cities), ORG and MX fraction are collected once a week, taxes are included, 2020 fees, all currencies were converted to US dollar using conversion rate of June/2020.

Helsinki is the city with the highest recycling rate (48.1%), and also the city with the highest waste fee (89.88 US$ monthly per house). The cost of the waste fee is high compared to other cities, due to the individual charge for each fraction collected. Currently, six fractions can be collected. However, it is possible to deposit the RCY fractions free of charge at the waste. In this case, the waste fee is charged only for the collection of the MX and ORG fraction; if it is collected once a week, citizens must pay 70.17 US$ monthly per house, reducing the cost by approximately 22%.

The lowest recycling rate is reported by the city of Amsterdam (15.5%), this rate is considerably low compared to the other European cities, and may be justified because it is the only one that have a fixed fee, independent of the collected volume. It is common the waste fee be charged considering only the collected volume of the MX and/or ORG fractions. Therefore, citizens do not pay for the disposal of recyclable material, encouraging the correct waste separation. The efficiency of this WM strategy can be seen in the cities of Berlin, Stockholm, Vienna and Zurich, where recycling rates are high (29% to 43%). In this scenario, it is possible to affirm that the charging system "Polluter Pays" works as an incentive for the population, promoting correct waste separation.

The laws and regulations, must guarantee the obligation of the authorities to: offer several alternatives to dispose all the fractions; carry out educational programs that reach all social levels; and mainly, guarantee the correct treatment of all the separated fractions. This must be done through reverse logistics, involving product manufacturers; recycling and the use of different treatment/disposing technologies (biodigestion, composting and WtE plants).

Part of the high performance of European cities is due to the income of the population, which allows reaching certain higher technological and educational levels, however, it is possible to affirm that the success of the management plans is largely due to the strict and well-structured laws on which they are based. Laws that attribute responsibilities to all parties involved, as described above.

All the European cities use WtE plants for the treatment of the mixed waste fraction; which is picked up in the door-to-door collection. Mass burn system is the most usual, where unsorted MSW is treated through combustion with energy recovery for the generation of electricity and/or heat. Most of these plants are located within cities or very close to them, which represents several advantages, among them: lower transport and WM costs, as well as, enables the use of the heat produced in the city´s district heating network [49, 50].

The cities that collect the organic fraction door-to-door, usually use biodigestion as treatment method. The biogas generated is mainly used as fuel for collection trucks and electricity generation. Additionally, these cities encourage the home treatment of organic waste by making home compost. To promote this type of treatment, free educational courses are offered throughout the year.

It can be mentioned, that four cities, have implemented reverse logistics in their management system. Copenhagen, Oslo and Amsterdam use the return model, where cans, plastic and glass bottles are deposited in return machines installed in supermarkets; for each unit deposited, the citizen receives an economic incentive, which varies according the type and package size. These systems are operated and managed by companies contracted by the producers. In Helsinki city, the responsibility for the proper treatment of recyclable waste belongs to the producers, who receive the materials collected by the system.

EUROPE							
COPENHAGEN	**STOCKHOLM**	**OSLO**	**VIENNA**	**AMSTERDAM**	**ZURICH**	**HELSINKI**	**BERLIN**
Territorial Extension (km^2)							
74.4	459	454	414.87	219.3	91.88	1,493.30	891.1
Population (hab)							
613,300	923,516	681,067	1,867,582	833,989	391,400	1,154,967	3,644,826
Amount of MSW (t $year^{-1}$) and per capita (t $hab.year^{-1}$)							
233,805 – 0.38	369,532 – 0.40	218,508 - 0.32	522,655 - 0.23	310,795- 0.37	99,112 - 0.253	697,000 - 0.603	1,396,925 - 0.38
Recycling rate							
38.0%	35%	37%	40%	15.5%	43.0%	48.1%	29.40%
Treatment: Incineration (TWh) and biodigestion (Nm^3)							
Inc: 1.09 $_h$, 0.17$_E$	Inc: 1.24 x10^{-5} $_h$ Biogas:2.7x10^6	Inc: 0.90$_h$, 0.14$_E$ Biogás: 2.5x10^6	Inc: 1.2$_h$, 0.81$_E$	Inc: 1.5x10^{-4} $_h$, 0.96$_E$	Inc: 0.42$_h$, 0.104$_E$ Biogás: 7.6x10^6	Inc: 0.92$_h$, 0.6$_E$ Biogás: 6x10^3	Inc: 0.64$_h$, *0.18*$_E$ Biogás: 3.6x10^6
SELECTIVE COLLECTION DOOR-TO-DOOR							
YES	YES	YES	YES	NO	YES	YES	YES
FRACTION COLLECTED AND FREQUENCY							
MX 1xWeek ORG 1xWeek PL/MT 1xMonth PP E/8weeks HZ/ELEC E/8weeks	MX 1xWeek ORG 1xWeek	MX 1xWeek ORG 1xWeek PL 1xWeek PP Biweekly	MX 1xWeek ORG 1xWeek PP 1xWeek		MX 1-2xWeek ORG E/1-2Weeks PP biweekly	MX 1xWeek ORG 1xWeek PP E/4weeks PL E/4weeks MT/GL E/8weeks	MX 1xWeek ORG E/2weeks RCY E/2weeks
NUMBER OF RC AND WCP							
18 RC	6 & 250	32 RC	13 & 427,700	6 & 12,944	2 & 199	5 & 53	15 & 1,576
WASTE FEE: CHARGED FRACTION AND FEE TYPE (US$)[1-2]							
MX and ORG Fixed 356.25 RC Fixed 159.94	MX Basic 110.00 Collection 235.95 Treatment[3] 103.68 0.16 US$/kg	All fractions Fixed	MX Fixed	All fractions Fixed	Basic 84.8 MX S-Z BAG[4] 314.18 ORG 205.49	MX 423.07 ORG 418.96 PP 61.55 PL 83.73 MT/GL 91.22	EcoTariff 35.66 MX Fixed 314.23 ORG Fixed 54.24
MONTHLY PER HOUSE US$							
43.02	37.47	46.99	23.06	25.99	50.37	89.88	33.68

[1]All the fees reported are per house using a 140L container [2]1 DDK=0.15 US$; 1 SEK=0.11 US$; 1 NOK=0.11 US$; 1 €=1.13 US$; 1 CHF=1.06 US$; [3]COLLECTED 10kg per week = 520 kg per year per single house [4]Single house uses 1 S-Z of 110L per week, that is 52 S-Z per year. 110L S-Z cost 6 US$ **MX**: mixed waste **ORG**: organic waste **HZ**: hazardous **ELEC**: electronic **PL:** plastic **MT:** metal, **PP:** paper **GL:** glass **RCY:** recyclable **WCP:** waste collection points **RC:** recycling centres ***h*** heat production ***E*** electricity production.

Table 1: Summary of eight European cities presenting the best WM

Table 2 presents the summary of the main points analysed for each Brazilian city. The waste fee include taxes; all currencies were converted to US dollar using conversion rate of June/2020.

BRAZIL							
CURITIBA	**DIADEMA**	**RGS**	**SANTO ANDRÉ**	**SBC**	**MAUÁ**	**SCS**	**RP**
Territorial Extension (km^2)							
432.17	30.79	36.34	175.78	409.47	61.86	15.33	99.12
Population (hab)							
1,751,907	423,884	50,846	718,773	838,936	472,916	161,127	123,393
Amount of MSW (t $year^{-1}$) and per capita (t $hab.year^{-1}$)							
539,001-(0.307)	114,750-(0.271)	8,363.3-(0.164)	226,027-(0.314)	266,743.4-(0.318)	127,739.2-(0.270)	67,264.2-(0.417)	38,298.4-(0.310)
Recycling rate							
4%	1.27%	-	4.71%	4.63%	0.25%	2.26%	0.74%
Treatment: Other							
Landfill	Landfill	Landfill	Landfill	Landfill	Landfill	Landfill	Landfill
SELECTIVE COLLECTION DOOR-TO-DOOR							
YES	YES	NO[1]	YES	YES	YES	YES	YES
FRACTION COLLECTED AND FREQUENCY							
MX/ORG 3xWeek RCY[2] 1-3xWeek	MX/ORG 3xWeek RCY[2] 1xDay	MX/ORG 3xWeek	MX/ORG 3xWeek RCY 1xWeek	MX/ORG 3xWeek RCY 2xWeek	MX/ORG 3xWeek RCY[2] 1xDay	MX/ORG 1xDay RCY[2] 1xWeek	MX/ORG 3xWeek RCY[2] 1xDay
NUMBER OF RC AND WCP							
6 & 11	10 & 4		22 RC	8 & 170	4 RC		
WASTE FEE: CHARGED FRACTION AND FEE TYPE							
All fractions Fixed	All fractions Fixed	All fractions Fixed	All fractions Fixed	All fractions Fixed	NO	NO	NO
MONTHLY PER PERSON US$[3]							
4.36	4.12	3.64	3.8	5.02	-	-	-

[1]the city doesn't have a selective collection [2]Collection carried out by waste picker´s cooperatives [3]1 R$ =0.19 US$ **MX**: mixed waste **ORG**: organic waste **RCY:** recyclable **WCP:** waste collection points **RC:** recycling centres.

Table 2: Summary of WM in eight cities from Brazil

Brazilian cities have very similar collection systems, however differences can be found in the collection of the recyclable fraction; in five cities this task is under the responsibility of waste picker´s cooperatives, in two of them, it is responsibility of the administrative authorities and one does not have selective collection. There is also a difference in the waste fee: three cities do not charge the inhabitants for the collection and treatment of the waste.

The difference in the collection systems is evident when the recycling rates are analysed. The cities that reported the best recycling rates were Santo André (4.71%) and SBC (4.63%). These are the cities where the recyclable fraction collection is of the administrative authorities' responsibility. This situation, once again, highlights the importance of the involvement of the authorities in the door-to-door selective collection system.

The implementation of a unified WM system in metropolitan regions is presented as a viable solution, providing the possibility for the region of obtaining effective results and reduce the disposal of materials with an economic potential in landfills. An example of this is the city of Helsinki, which covers four cities, with a total of 1,493.30 km^2; 1,154,967 inhabitants; a waste generation of 697,000 t/y; and it is the WM system that reported the best recycling rate of all the studied cities. In this way, a unified WM system should be considered and applied in several areas of Brazil, as in the case of the great ABC region, which has seven cities, with 828.69 km^2, 2,789,875 inhabitants; and a waste generation of 609,184.8 t/y. These numbers are very close to those of Helsinki.

The lowest recycling rates were reported by the cities that collect the waste three times a week and separate the waste into only two fractions (wet and dry). In contrast, the highest recycling rates were reported by the cities that collect the waste once a week and separate it into at least four fractions. The difference between these two collection systems stands out that high collection frequency does not guarantee efficient management system indexes, but the number of fractions in which the waste is separated at source.

In all European studied cities, the disposal of MSW in landfills is prohibited. In contrast, 59.5% of residues from Brazilian cities are disposed of in landfills, while the remaining 40.5% are disposed of in open dumps. According to the Brazilian National Solid Waste Policy (PNRS – Law 12.3051/2010), only the waste without economic potential should be disposed of in landfills, establishing a deadline for the closure of open dumps (2014). However, this policy does not take place as expected, as can be seen in the recycling rates reported in Table 2, where only very low waste percentages are sent to recycling processes, whereas the remaining waste is sent to landfills and open dumps.

Conclusions

The cities that separate the waste into different fractions have the best recycling rates, in them, the laws/regulations require that the citizens separate the waste into at least five fractions, ensuring an efficient collection system, which guarantees the correct treatment of all fractions. In the same way, cities with less collection frequency present the best results, demonstrating that high frequency waste collection does not guarantee efficiency in the management and recycling system.

Door-to-door collection system can also be considered an educational tool, very effective in promoting information, through which citizens receive effective and clear information about the correct separation of their own waste, making them aware of their responsibility and importance in the whole process. This should be consistent with the authority's responsibility in the production and transmission of this information.

The Polluter-Pays charging system works as an incentive for the population to separate waste correctly, this can be seen in the high recycling rates reported by cities where the waste fee is only charged for the volume collection of non-recyclable fractions. This tax system would work in Brazil, as it does in Europe, as long as it is associated with well-structured laws, direct responsibilities to those involved and established goals that target the economic, social and environmental evolution of the system.

Despite the fact that each WM system is designed for each location, it is possible to find similarities between them, such as the frequency of waste collection, the way the service is charged and the number of fractions in what the citizens must separate the waste.

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