

RELISE

COMPARATIVE ANALYSIS OF MUNICIPAL MANAGEMENT OF SOLID WASTE IN MARIANA, BRAZIL AND ROTTERDAM, NETHERLANDS[1]

ANÁLISE COMPARATIVA DAS GESTÕES MUNICIPAIS DE RESÍDUOS SÓLIDOS DE MARIANA, BRASIL E ROTERDÃ, HOLANDA

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ABSTRACT

Municipal solid waste presents great complexity and diversity and often becomes a problem to be faced by public authorities. The Brazilian National Solid Waste Policy (PNRS) establishes that municipalities are responsible for the collection, treatment and environmentally appropriate disposal of waste. Brazil faces challenges in complying with PNRS determinations, in Mariana/MG, it is no different. The Netherlands is considered a world reference for Municipal solid waste management (GRSU), a center of knowledge and innovation in the field of circular economy, and the city of Rotterdam is a pioneer in the subject. The objective of this study is to compare the solid waste management of Mariana and Rotterdam, seeking to understand the positive aspects, advances, and challenges of GRSU in both contexts. An exploratory bibliographic review was carried out, and official documents from the municipalities, scientific articles and studies related to the subject were analyzed, after which a comparison was made, demonstrating distinctions and similarities between the realities. It is concluded that Rotterdam has been implementing advanced waste management technologies and circular economy policies, while Mariana continues to struggle to implement and sustain more basic policies, however, advances and improvements are taking place. There is a need to progress towards more advanced forms of waste management, prevention and circularity. However, there are no perfect solutions that can be generalized, each city must develop strategies suited to its specific history, economy, demography, culture, and its human, environmental and financial resources.

Keywords: Solid Waste Management, Mariana, Rotterdam.

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RESUMO

Os resíduos sólidos urbanos apresentam grande complexidade e diversidade, e muitas vezes tornam-se um problema a ser enfrentado por autoridades públicas. A Política Nacional de Resíduos Sólidos (PNRS) brasileira, estabelece que os municípios são responsáveis pela coleta, tratamento e disposição ambientalmente adequada dos resíduos. O Brasil encontra desafios no cumprimento das determinações da PNRS, em Mariana/MG, não é diferente. A Holanda é considerada referência mundial sobre gestão de resíduos sólidos urbanos (GRSU), um centro de conhecimento e inovação no campo da economia circular, e a cidade de Roterdã é pioneira no assunto. O objetivo deste estudo é comparar a gestão de resíduos sólidos de Mariana e Roterdã, buscando compreender os aspectos positivos, avanços, e desafios da GRSU nos dois contextos. Foi realizada uma revisão bibliográfica exploratória, e analisados documentos oficiais dos municípios, artigos científicos e estudos relacionados ao tema, após foi elaborada uma comparação demonstrando distinções e semelhanças das realidades. Conclui-se que Roterdã vem implementando tecnologias avançadas de gerenciamento de resíduos e políticas de economia circular, enquanto, Mariana, continua lutando para implementar e sustentar políticas mais básicas, porém, avanços e melhorias vêm ocorrendo. Há a necessidade de progredir em direção a formas mais avançadas de gestão de resíduos, prevenção e circularidade. Contudo, não há soluções perfeitas e que possam ser generalizadas, cada cidade deve desenvolver estratégias adequadas à sua história específica, economia, demografia, cultura, e aos seus recursos humanos, ambientais e financeiros.

Palavras-chave: gestão de resíduos sólidos, Mariana, Roterdã.

INTRODUCTION

The increase in waste is a natural consequence of urbanization, population growth, and economic development; therefore, an increasingly large amount of solid waste is inevitable (AGUIAR & BARROS, 2017). According to the report What a Waste 2.0 (2016), as countries prosper, become more populous, and offer more products to citizens, the amount of waste consequently increases. Countries are developing rapidly without adequate systems to keep pace with changes in the composition of citizens' waste. This is concerning because global waste is expected to increase to 3.40 billion tonnes by 2050 (KAZA et. al., 2016).



The ideal way to address the problem is a change in habits that leads to a reduction in waste generation, that is, prevention. However, this is a complex issue, since there are still no answers regarding what to change and how to change it (AGUIAR & BARROS, 2017). One way to address the situation is to take a step back and consume less. However, this solution is unrealistic and unlikely, since everyone is accustomed to a certain level of comfort, and there is a lack of political and social willingness to “give something up” (DEELSTRA et. al., 2020).

From the perspective of Calgaro et al. (2009), the production of consumer goods is not an evil, as many proclaim, but a necessity arising from the human struggle for survival, security, and dignity. The production and consumption of goods are part of human nature, and capitalist society is the result of this nature. However, human beings possess intelligence and rationality and are capable of reflecting on the mode of production, the hierarchy of consumable goods, and the return of waste to nature, with a view to ensuring the survival and dignity of present and future generations (CALGARO, 2009).

In this regard, according to Deelstra et. al. (2020), a more feasible solution is to make better use of available raw materials by closing the loops. “Garbage” contains many substances that can still be used. According to the author, adopting a circular economy, in which the waste or by-products generated, previously considered garbage, are reintegrated into the production cycle, leads to a change in the very concept of waste, which comes to be considered a resource, since much of it can be reused (DIJKEMA et al., 2000).

Law No. 12,305/2010 establishes the National Solid Waste Policy (PNRS) in Brazil and sets out objectives, instruments, and principles proposing integrated management; shared responsibility among consumers, managers, and public authorities; and more sustainable consumption. Article 9 of the PNRS establishes the following order of priority: “non-generation, reduction, reuse,



recycling, treatment of solid waste, and environmentally appropriate final disposal" (BRASIL, 2010). This order resembles the principles of the circular economy advocated by Deelstra et. al. (2020). The enactment of the PNRS represents progress in Brazilian waste management; however, the country has not yet succeeded in effectively implementing this legislation. According to ABRELPE - the Brazilian Association of Public Cleaning and Special Waste Companies (2019), Brazil still needs to find solutions to basic problems such as open dumps.

Under Brazilian legislation, municipalities are responsible for waste collection, treatment, and environmentally appropriate disposal (BRASIL, 2010). Thus, many municipal managers need to find ways to restructure their services to achieve sustainable goals, as is the case in Mariana. Given the complexity of the subject, an assessment of waste handling is important for finding more effective solutions and seeking models that best suit the local context.

The Netherlands is considered a global benchmark in municipal solid waste management (MSWM) and is viewed as a center of knowledge and innovation in the field; in this country, almost 80% of all solid waste generated is recycled (NEVES, 2011; DIJKGRAAF & GRADUSA, 2014). Dutch cities have taken the lead in the transition to a circular economic model. Rotterdam, located in South Holland, is a pioneer in this area and has been implementing advanced waste management policies and technologies.

The objective of this study was to compare solid waste management in the cities of Mariana and Rotterdam, seeking to understand the positive aspects, advances, and challenges of management in two different contexts. The study is justified by the difficulties Brazilian municipalities face in practically applying the instruments indicated in the PNRS and achieving the objectives of the legislation. To implement a solid waste management model that encompasses the multiple aspects required to address this issue, it is necessary to understand local



advances and learn how other regions address the problem, especially nations that have moved ahead in the search for solutions.

METHODOLOGY

Initially, an exploratory literature review was conducted through the analysis of official documents from both cities, publications, and scientific articles, and information on management in each location was gathered. Following a critical content analysis, the characteristics to be highlighted were selected. The two management systems were then compared, seeking to understand the positive aspects, advances, and challenges of MSWM. Part of the characterization of the cities is presented in Table 1.

Table 1: Characterization of the municipalities selected for the study.

Characteristics	**Mariana**	**Roterdã**
Population (inhabitants)	61.830[1]	582.949[4]
Area (km²)	1.194,208[1]	206[4]
Growth rate (%)	10,9%[3]	0,2%[4]
GDP per capita	33.674,08[2]*	765,800[4]**
HDI	0,74[2]	0,96[4]
MSW generation per capita/day/kg	0,70[3]	1,46[4]

[1] IBGE (2021), [2] IBGE (2010), [3] MARIANA (2019) [4] UN-HABITAT (2010). *reais **millions of USD

STUDY AREAS

Mariana/Minas Gerais

The city of Mariana was founded in 1696, during the historical period known as the Gold Cycle, following the first recorded gold discoveries in the regions of Vila Rica and Arraial do Carmo (SOUZA, 2004). The municipality is located in the south-central region of Minas Gerais, approximately 112 km from the capital, Belo Horizonte (BORSOI, 2011).

As a result of the failure of the “Fundão” mining tailings dam in 2015, there was a sharp decline in the municipal Gross Domestic Product (GDP), but mining companies continued to influence the economic landscape. The city’s



economy is dominated by the industrial sector, with iron ore extraction as its main activity. In addition to mining-related activities, the service sector, which includes tourism, and agriculture also stand out (MARIANA, 2019).

The terrain is undulating, with mountains, the climate is tropical, and the biome is the Atlantic Forest. The municipality is located in the Rio Doce Federal Basin.

Figure 1 – Municipality of Mariana in the Context of Minas Gerais, Brazil



Rotterdam/South Holland

Rotterdam originated after the construction of a dam on the Rotte River as a measure against regular flooding, attracting residents to the location. A small fishing village formed in the region, and in 1340 the village was granted city rights (ROTTERDAM PARTNERS, 2018).

Initially, the economy was based on herring fishing and the trade of goods on the Rotte and Schie rivers. After 1568, trade with England, France, America, and Spain increased, leading to a period of prosperity and economic growth. In the eighteenth century, the municipality was densely populated, filled with houses, industries, and department stores, and new industries were also developing (sugar, coffee, tobacco, and gin) (ROTTERDAM PARTNERS, 2013).



During the French occupation (1795–1813) and the First World War, which lasted until 1926, there was a period of recession. In the Second World War, the city's historic center was completely destroyed. After the war, a spacious urban layout and modern architecture were chosen for reconstruction (ROTTERDAM PARTNERS, 2013). The port grew and petrochemical industries became important; oil refineries were established, and much of the port's cargo consisted of crude oil and petrochemicals (CATARINELLA, 2017).

Today, Rotterdam is a world-famous port city and a metropolis (ROTTERDAM PARTNERS, 2013). The port's transit function is the driving force of the economy, but the municipality has also specialized in producing dairy products for international markets.

Most raw materials and "urban inputs" are imported, and the city is threatened by climate change due to the expected rise in sea level. Rotterdam has been making efforts to become a greener city (DEELSTRA & STEEKELENBURG, 2005).

Figure 2 – Municipality of Rotterdam in the Context of the Netherlands



RESULTS AND DISCUSSION

Solid waste management in Mariana/MG, Brazil

The municipality of Mariana generated 42,099.40 kg/day of household solid waste in 2018, representing an average per capita production of 0.70 kg/inhabitant/day. Of this amount, 45% is organic waste, 38% is recyclable, and



17% is other waste. Urban cleaning waste corresponds to 0.04 kg/inhabitant/day and a total of 2,500.65 kg/day (MARIANA, 2019). The city has both separate collection and conventional collection.

Separate collection has been carried out by the waste pickers' association - CAMAR since 2008 and is partial, as waste generators separate materials at the source. In the municipal seat and the district of Passagem, collection is door-to-door. In the other districts, there are 19 voluntary drop-off points where the population delivers recyclables. Waste collection and maintenance of these points take place twice a week (MARIANA, 2019). Following collection, the association manually sorts and sells the materials.

The coverage rate of separate collection is 70%, and there was an average annual increase of 24% in the materials collected between 2012 and 2018. The municipality provides the association with two trucks and drivers and pays the rent for the sorting shed (MARIANA, 2014). In 2021, three additional trucks were delivered, and the municipal government will continue covering vehicle expenses and providing drivers (ROBERT, 2021).

An innovative feature, already considered traditional, is the motivational strategy used by CAMAR, which seeks community involvement in separate collection through "musical" garbage trucks playing a melody that teaches how materials should be separated. At the time recyclables are collected in each neighborhood, the truck passes by playing the melody to remind the population to hand over their recyclables. CAMAR is also involved in social awareness activities and, in partnership with the municipal government, gives talks in neighborhoods, schools, and companies. On the floor above the association's sorting shed, there is a library containing approximately 200 books and historical items originating mainly from the collected waste (GOMES, 2020).

However, Mariana's Integrated Solid Waste Management Plan states that 18,944.73 kg of the household solid waste generated daily is recyclable.



Nevertheless, CAMAR does not handle all this material and can collect only 2,958.90 kg/day, that is, approximately 17% of the recyclables generated. Separate collection has limitations, since it does not take place door-to-door throughout the municipality (MARIANA, 2019). It is also important to highlight that CAMAR's sorting shed does not have the infrastructure to process a much larger quantity of waste (GOMES, 2020). Thus, public policies aimed at increasing the municipality's recycling rate are needed. Even so, CAMAR's fundamental role in solid waste management and material recovery stands out, since the association is responsible for all recycling carried out in the city.

Conventional collection also takes place door-to-door, is outsourced, and is carried out on pre-established days and times (MARIANA, 2019). The coverage rate of conventional collection for the urban population is 100%; when considering the total population (urban and rural), the service coverage rate is 99.57% (MDR, 2019). A compactor truck is used in the municipal seat, and there are six teams of workers, each consisting of one driver and three waste collectors. In areas that are difficult to access, collection takes place with the assistance of a pickup truck and one team of workers. There are also voluntary drop-off points (PEVs), consisting of 120 containers of 1,000 ml. At these points, waste often accumulates outside collection hours, another aspect to be improved in waste management (MARIANA, 2019).

Mariana's former open dump was decommissioned in 1999, after 20 years of operation. The area was rehabilitated by Companhia Vale do Rio Doce. Following the decommissioning of the open dump, municipal solid waste began to be directed to the "controlled landfill," the term used in the municipal waste plan. In 2009, the "controlled landfill" was decommissioned without appropriate environmental rehabilitation. Subsequently, following the issuance of the Operating License (LO No. 0304 ZM on 03/23/2009), the municipal sanitary landfill began operating, although irregularly (MARIANA, 2019).



After one year, expansion became necessary, and construction of a second platform for waste disposal began, but the work was not continued. During the 2009–2012 term, the municipality was led by seven different mayors, with a total of nine changes in administration, preventing the continuation of various activities and/or construction projects that had been started (MARIANA, 2012). From that point onward, the sanitary landfill once again took on the characteristics of a “controlled landfill,” subsequently becoming an “open dump,” and in 2015 it lost its operating license. The constant change of executive representatives in Mariana is not specific to this period; these changes occur frequently and, as observed, have been affecting solid waste management.

At the time the license was lost, the landfill had several operational problems, such as excessive waste deposition on the platforms, posing a risk of failure of the waste masses; inability to adequately compact and cover the waste due to its inappropriate geometry and volume, making the masses completely unstable and creating a risk of failure; clogging of the leachate drainage system, retaining leachate within the waste masses; seepage at several points and free leachate percolation throughout the landfill area, leading to a high risk of contamination of the groundwater and Lavoura Stream (FUNDAÇÃO RENOVA, 2017, MARIANA, 2019).

It should be highlighted that the Bento Rodrigues Resettlement is being built near the sanitary landfill as a means of restoring the right to housing of those affected by the failure of the Fundão Dam. Lavoura Stream is the main interface between the sanitary landfill and the resettlement (MARIANA, 2019). Despite the technical and operational problems reported above, no evidence of contamination of the groundwater or Lavoura Stream was found following the results of analyses conducted by the Renova Foundation in the piezometers and watercourse, as stated in the Emergency Adaptation Plan (2017).



Municipal landfills generally have a significant adverse impact on individuals who own property, reside, or use nearby areas, which has already led affected people in the United States, for example, to take action, a group that became known as “NIMBY” — Not in My Back Yard (LEE et al., 1994). In Mariana, the selection of a location near the sanitary landfill for the construction of the Bento Rodrigues Resettlement has been changing municipal waste management, since the Renova Foundation became technically and operationally responsible for the landfill due to the impacts it could have on the Bento Rodrigues Resettlement.

In 2017, a commitment agreement was signed in public civil action No. 0400.15.003713-5 between Mariana and the Renova Foundation before the State Public Prosecutor’s Office. The foundation became responsible for preparing the sanitary landfill adaptation project and was required to carry out the relevant works and operate it for a period of five years. In the same year, the environmental regularization process for the landfill began through administrative proceeding No. 00184/2000/005/2017, formally submitted to SUPRAM CM. In compliance with the requirements of the aforementioned commitment agreement, the Renova Foundation prepared the Emergency Adaptation Plan, began the adaptation works, and took over the operation of the Mariana Sanitary Landfill in 2019, remaining responsible for the facility to the present time.

Currently, the final waste disposal facility is the municipal sanitary landfill, located in the rural area on the road connecting Mariana to the district of Antônio Pereira (which belongs to the municipality of Ouro Preto). The site, located on land owned by the municipal government, covers an area of 26 hectares, of which approximately 6.3 hectares are used for waste landfilling operations (MARIANA, 2019).

Final waste disposal in sanitary landfills is the main option chosen by most Brazilian municipalities. However, this form of final disposal is criticized in



the literature because it is considered a sanitary solution but not an environmental one (LEE et al., 1994; STLENGER, 2015; DIJKEMA et al., 2000, THEMELIS et al., 2014, FUUS, et al., 2018). The sanitary landfill should be the last option for the disposal of residual waste, and only what truly cannot be reused or recycled should be taken to the landfill.

At the Mariana landfill, there is a Sorting and Composting Unit (UTC) comprising a covered waste reception area and a sorting area with a conveyor belt and a press with a capacity of one tonne; however, it is currently inactive (MARIANA, 2019). Thus, none of the waste collected through conventional collection is sorted, resulting in a lost opportunity to recycle and reuse various materials. Waste composition studies also demonstrate the considerable potential for implementing treatment systems for the organic fraction, since 45% of the waste generated is organic. However, there is no municipal policy encouraging this type of treatment, for example, through composting.

The Sanitary Landfill operated under a conduct adjustment agreement until October 2020, and from the 30th of that month onward, it began operating under Corrective Operating License No. 106/2020 (with several conditions). In 2022, the Renova Foundation reported that all works required to adapt the landfill had been completed. Regarding its current infrastructure, the landfill has entrance control with a gatehouse, an administrative office, a cafeteria, restrooms, and a workshop for maintaining the vehicles used for conventional collection and housing the equipment used at the landfill, including a waste weighing scale (MARIANA, 2019).

The municipal government of Mariana charges fees for public cleaning and waste collection monthly, together with the Urban Property and Land Tax (IPTU). The municipality does not receive funding from federal or state programs, nor are there projects to raise funds. It was also found that, over the past five



years, fee revenue represented an average of only 6.1% of total expenditure on solid waste management services (MARIANA, 2019).

In November 2018, a conduct adjustment agreement signed between Samarco and its shareholders and the federal government and the governments of the states of Minas Gerais and Espírito Santo stipulated that the Renova Foundation would also be responsible for implementing the “CAMAR-ECOPONTO-RCC Complex” project. The facilities are intended to meet the conditions of the solid waste approval established in the environmental licensing of the Paracatu de Baixo Resettlement, aiming to resolve the issue of the final disposal of construction and bulky waste. Thus, the Renova Foundation also became responsible for designing and establishing a duly licensed area for the final disposal of solid construction and bulky waste; designing and building the new headquarters of the CAMAR association; and designing and building a shed for the municipal ECOPONTO to collect unusable tires.

Following the handover of the Mariana sanitary landfill by the Renova Foundation to the municipality, there is a possibility that the Piranga Valley Multisectoral Intermunicipal Consortium (CIMVALPI) will incorporate the landfill. In 2022, models for consortium-based management of the final disposal of solid waste were presented, and municipal managers have been showing interest in this management model (CIMVALPI, 2022).

The completion of the CAMAR-ECOPONTO-RCC Complex and the integration of Mariana’s sanitary landfill into CIMVALPI may represent a significant change in municipal solid waste management, since the consortium plans to initiate recycling and organic matter treatment processes. Through the complex, the consortium plans to treat waste not only from Mariana but from all CIMVALPI member municipalities.

Given these data, it is possible to identify improvements for solid waste management in Mariana, such as sorting the materials sent to the landfill,



increasing the recycling rate, treating organic waste, more effective fee collection, raising public awareness of separate collection, ensuring the continuity of public policies already initiated, etc. However, Mariana is still struggling to implement and sustain solid waste management policies, and there is a positive outlook for the future.

Solid waste management in Rotterdam, the Netherlands

Excessive waste generation causes serious problems; therefore, it is important to identify how much it is reasonable to generate and how much is truly inevitable. Encouraging a reduction in waste generation is a practice in Rotterdam. Over the past centuries, consumption has increased excessively, reaching what has come to be called hyperconsumption in the twenty-first century. All this production requires raw materials and space to dispose of residual waste. “In this area, the planet is already beginning to show signs of insufficient capacity, both in terms of supplying raw materials and absorbing residual waste” (CALGARO, 2009, p. 15).

According to Gladek et. al. (2018), Rotterdam is already experiencing a shortage of raw materials and a lack of space for residual waste disposal. The municipality may also be severely affected by climate change due to rising ocean levels, as its territory lies below sea level. Managers began to experience these effects in practice and consequently to invest in awareness and public policies aimed at changes in lifestyles. One of the objectives of municipal management is the adoption of a fully circular economy.

The need to handle raw materials differently became apparent due to shortages of materials such as plastic, wood, and metal. The city depends on raw materials from other countries, and this has caused many problems. Physical scarcity is not the only factor causing supply risks and price increases. Changes in the global economy, supply problems due to trade conflicts, and incidents such



as the blockage of the Suez Canal have already created supply risks and high prices. Making the economy circular solves two problems: less carbon dioxide and greater security regarding raw material availability (RIJKSWATERSTAAT, 2021). The linear economy is the opposite of the circular economy. In the linear economy, products are manufactured, used, and then discarded. In the circular economy, there is a systemic approach to maintaining the circular flow of resources, contributing to sustainable development (GLADEK et. al., 2018).

In Rotterdam, continuing to adopt the linear economic model involves risks for managing, replacing, and developing public space, real estate, and residential assets affordably. Thus, there is greater commitment to extending useful life and reusing materials. In this way, purchases are put to better use, innovations are supported, and ways of using residual streams to ensure high quality are investigated (RIJKSWATERSTAAT, 2021).

The adoption of a circular economic model helps preserve the natural environment by minimizing raw material extraction and waste generation (GLADEK et. al., 2018). It includes the following principles: avoiding and reducing the use of raw materials; extending the useful life of products; reusing products and parts; and recycling materials (AKKERMAN, 2019).

The increasing use of products with shorter life cycles and disposable packaging has contributed to the precarious state of MSWM (BARROS, 2012; GONÇALVES; TANAKA; AMEDOMAR, 2013). According to Calgaro (2009), products are manufactured with increasingly shorter lifespans so that they lose their properties, requiring consumers to replace them sooner.

In Rotterdam, municipal managers encourage citizens to acquire only materials considered high-quality and easily reused, refurbished, or recycled, and all waste is processed for reuse, with only waste that has no remaining handling options or poses an environmental risk being incinerated. According to the Rotterdam Circular Program, becoming circular means much more than merely



achieving “zero waste.” Rotterdam intends to reduce the consumption of materials made from raw materials that cause biodiversity loss, toxic materials, or materials that generate greenhouse gases (GLADEK et. al., 2018).

Waste management data are also essential for developing local policies and plans. Understanding the amount and types of waste generated allows local governments to select appropriate management methods and plan for future demand. With accurate data, governments can realistically allocate budgets, assess relevant technologies, and consider strategic partners, such as the private sector or nongovernmental organizations, for service provision (KAZA et. al., 2016). In this regard, Rotterdam’s practices can also be viewed as a model; frequent studies are conducted on the policies needed, the effectiveness of those adopted, etc. The municipality demonstrates a political willingness to solve problems, which is reflected in effective actions and programs.

Total solid waste generation in Rotterdam (UN-HABITAT, 2010) in 2010 was approximately 6,900 tonnes per year; the waste consisted of paper (27%), glass (8%), metal (3%), plastics (17%), organic waste (26%), and other waste (19%). In 2010, 30% of solid waste was already recycled, while almost none was sent to landfills (UN-HABITAT, 2010).

The infrastructure used for collection is based on containers, and waste generators are responsible for depositing their waste at these locations. Separation is carried out at the source. Collection follows a weekly routine, using plastic bags holding 240 liters, 1,100 liters, or bags of 3 m³, 4 m³, and 5 m³ for underground containers (UN-HABITAT, 2010). Plastic bags and containers have different colors for each type of waste: residual waste (gray), glass (yellow), paper (blue), textiles (purple), and organic waste (green). Some residents have household containers (clickies) for residual waste, paper, and organic waste (MUNICÍPIO DE ROTERDÃ, 2022).



Containers are installed in neighborhoods and may be underground, aboveground, or semi-sunken, and are emptied at least once a week. There is a website and an app containing a calendar indicating collection dates. Placing garbage next to containers and blocking their openings is prohibited and may result in a fine (MUNICÍPIO DE ROTERDÃ, 2022).

The collection of household waste and waste from mixed areas (residential/commercial) is carried out by the municipal waste management department (ROTEB), which is managed as a public company, although its budget comes from the municipality. The private sector also works alongside ROTEB in collecting commercial and institutional waste. The collection coverage rate is 100% (UN-HABITAT, 2010). Recyclable waste from separate collection is sent to AVR, where it is recycled and transformed into new products at the plant itself.

Some materials should not be discarded in the garbage but delivered to environmental parks, such as clothing, small chemical waste (batteries, paints, medicines), fat and oil, electronics, and bulky waste. Rotterdam's environmental parks are Charlois, Delfshaven, Hillegersberg-Schiebroek, IJsselmonde, Prins Alexander, Hoek van Holland, and Rozenbrug (MUNICÍPIO DE ROTERDÃ, 2022a). The plan is for environmental parks to become circular "hotspots" where everyone can go to separate their waste and, in the long term, purchase materials (MUNICÍPIO DE ROTERDÃ, 2022). There are also secondhand shops whose operators collect clothes that would otherwise be discarded from people's homes.

The waste separation rate has continued to increase: 30.4% in 2018, 35.4% in 2019, 36% in 2020, and 40% in 2021 (ROTTERDAM CIRCULAIR, 2021). Municipal managers seek to ensure that separation is simple and accessible. Frequent studies, including psychological studies, investigate how to motivate people to adopt circular behavior. Innovative technologies are



developed, and objectives and targets are established. Proposed actions are monitored and adapted as necessary.

Some examples of actions carried out by municipal managers include providing bicycles with cargo racks so residents can take their waste to environmental parks; painting garbage trucks gold to remind people that waste is worth gold; installing illuminated containers or containers surrounded by gardens to remind the population not to discard garbage outside them; collecting clothes in good condition and sending them for donation in Africa; donating equipment that makes household waste disposal more convenient for high-rise residents; and installing plastic collectors that remove garbage from the water using the Seabin and the Wasteshark (MUNICÍPIO DE ROTERDÃ, 2022b).

In Rotterdam, violating local waste-related regulations constitutes a criminal misdemeanor punishable by up to six months' imprisonment or a fine, including storing or having waste stored outdoors in a location visible to the public; offering household waste to another person for collection; placing garbage out for collection without having paid the fee; distributing unaddressed advertising material; among others (PORTARIA DE RESÍDUOS DE ROTERDÃ, 2009).

Unfortunately, most organic waste in Rotterdam is still not separated at the source and goes to the incinerator together with residual waste (TILLIE, 2018; KOERKAMP, 2019). Household organic waste represented 14% of the total amount of waste produced in 2017, and its separation rate was only 28.4% (CBS Statline, 2018). A relatively small portion is collected for processing into biogas and compost; however, the organic waste collected usually contains residual waste.

The Rotterdam Circular Program states that one of the management plans for the 2019–2022 period was to raise residents' awareness of the importance of clean organic waste for producing biogas and good compost (KOERKAMP, 2019). In the circular economy, waste comes to be viewed as raw



material, resulting in changes in collection and reuse methods and requiring innovative solutions for waste collection and treatment that facilitate its reuse.

In the municipality, the alternative to landfills is the use of waste-to-energy (WTE) plants. Stengler (2005) advocated this practice, considering it a safe treatment option to help achieve environmental protection objectives by reducing waste deposition in landfills (STENGLER, 2005). However, the Netherlands now has a directive restricting household waste incineration, since incineration releases gases that can pollute the atmosphere and cause environmental impacts; there is also a 1997 decree prohibiting the deposition of household waste in landfills (AKKERMAN, 2019). Thus, Rotterdam, which already deposits almost no waste in landfills, also intends to reduce incineration increasingly.

Waste that is not separated is placed in gray garbage bags and is called residual waste. It is incinerated by AVR, but mechanical separation is carried out before incineration. AVR's facilities are equipped with the latest and most modern technical devices: flat screens, wind shifters, ballistic separators, a shredder, and near-infrared scanners. Approximately ten to fifteen percent of the waste passing along the conveyor belt consists of plastics and cartons, which are intercepted. The remainder is transported by a conveyor belt to the waste-to-energy plant. AVR's separation plant also removes plastic packaging and beverage cartons from the residual waste of all households. Separation for the separate collection of plastics, cans (metals), and beverage cartons will no longer be necessary (MUNICÍPIO DE ROTERDÃ, 2022).

Because combustion smoke is known to be harmful to health, flue gas cleaning facilities were built at AVR to minimize impacts. These make the smoke released during combustion as clean as possible. After collection, this waste is deposited in a bunker and fed into one of the incinerators. The incinerators are surrounded by water-filled pipes; as the garbage bags are burned, this water boils



and releases steam used for district heating and electricity. After burning, approximately 20% remains, the so-called bottom ash residues. Metals are removed from this ash using special magnets. These metals are recycled in the metallurgical industry, and what remains are minerals. These are cleaned and delivered to the concrete industry and processed into concrete for roads, paving stones, and clinker bricks (MUNICÍPIO DE ROTERDÃ, 2022).

Most Dutch citizens pay a waste fee; some households receive exemptions under special circumstances, generally of a financial nature. In 2021, the waste fee averaged 286 euros per household member. Studies on the fee amount are conducted in the Netherlands every year, and each municipality charges according to its chosen criterion: 1- fixed fee; 2- number of people in the household; 3- volume; 4- volume and frequency; 5- number of sacks or bags; 6- weight; 7- weight and frequency; 8- frequency and number of people; 9- volume; 10- frequency and number of people. The Municipality of Rotterdam charges according to the number of people in the household (RIJKSWATERSTAAT, 2021). Rotterdam is an example of a city that knows its costs and uses them precisely in setting fees, which is considered good practice, since knowing financial costs makes it possible to better control management, both financially and technically (UN-HABITAT, 2010).

The city intends to adopt a fully circular economy by 2050. Managers estimate that by 2030, 98% of all waste will be collected separately, and only 5%, considered very low-quality or hazardous, will be incinerated (GLADEK, et. al., 2018). There is a project to equip households with smart sorting containers that simplify the separation of different materials. The containers already have different colors according to waste type and will have built-in sensors that alert users if they dispose of waste incorrectly. According to the plan, residents will receive financial incentives in their digital wallets for each kilogram correctly separated; these amounts can be used to purchase local products, pay energy



bills, or pay taxes. Many products will be produced or repaired using these waste streams (GLADEK et. al., 2018).

The Rotterdam Circularity Dashboard will be a real-time raw material monitoring platform that will continuously monitor the availability of and orders for various materials. Raw materials will be taken to processing facilities managed by small and large business owners. Regarding orders for the products generated, the dashboard itself will determine shipment to the bidder as quickly as possible. These innovations will result in the supply of pure, high-quality raw material streams (GLADEK et. al., 2018).

The first phase of the Rotterdam Circular Program was a start-up phase intended for learning and applying circular working methods. During this exploratory phase, important steps were taken and excellent results achieved. Projects and innovations that contribute to smarter and more sustainable use of raw materials are developed within the circular program (RIJKSWATERSTAAT, 2021).

In Rotterdam, frequent studies are conducted to define more effective forms of management. The municipal government strives to involve the entire community in the Rotterdam Circular Program: residents, business owners, social partners, etc. Assessments of problems observed in management and possible solutions are frequently conducted, and targets are established and put into practice. Practices are monitored annually to assess their effectiveness and improved if necessary. The municipality identifies where problems are occurring and the best solution for each specific situation and has become an example of good practices in MSWM.

The city adopts a systemic view that allows all variables to be encompassed within a management model integrating new possibilities and perspectives. Changes in ways of thinking and using natural resources are proposed, aiming to reconcile development, consumption patterns, and



environmental interests. There is strong awareness of the kind of world they want and the legacy to leave for future generations.

CONCLUSION

Inadequate solid waste management is one of today's environmental and sanitary problems. Given this scenario, considering the complexity, large generation, and high cost of treating solid waste, new alternatives are important. There is a need to progress toward more advanced forms of waste management, prevention, and circularity. In Rotterdam, changes are proposed to ensure universality, equity, decentralization, and good governance in solid waste management.

Minimizing solid waste generation is not solely related to a reduction in consumption. In this context, a new paradigm has been adopted in Rotterdam regarding what to do with the waste generated. Rotterdam is considered a pioneer, with major advances in the circular economy. The basis of a movement toward a cyclical economy resembles the way natural ecosystems are built: a network of integrated processes forming cycles, constituting strategies for sustainable development. Thus, from this perspective, waste management infrastructure should not be treated in isolation from the systems that generate these waste products but requires an approach that considers interconnection and communication between systems.

In Rotterdam, public awareness of good management is not recent, separate collection is efficient, virtually no waste is deposited in landfills, and advanced technologies for material recycling are adopted. Rotterdam plans for only what cannot be recycled to be incinerated by 2030. The following objectives are already implemented in practice: an order of preference (prevention, reuse, recycling, other types of recovery, for example, energy recovery, and final disposal); strict waste treatment standards; adherence to national planning;



extended manufacturer/importer responsibility; and the use of various instruments to encourage prevention and recycling (RIJKSWATERSTAAT, n.d.).

In Brazil, the ineffective implementation of important instruments related to the PNRS means that the objectives established in Brazilian legislation remain far from being achieved. The provisions of Article 9 of the PNRS (non-generation, reduction, reuse, and recycling) are not effectively implemented. Regarding Mariana, there are still limited data on waste management. The main destination for waste is the Sanitary Landfill; only materials collected through separate collection are sorted and recycled by CAMAR, while materials collected through conventional collection are not sorted. The municipal waste plan proposes several alternatives for improving management, such as treating the organic fraction, increasing material recycling, improving the efficiency of separate collection, and improving the charging method. However, it identifies problems without providing specific actions to address each identified problem. There is also a need to improve the method of charging for solid waste management services to achieve a more sustainable economic and financial system.

Implementing recycling and composting policies in Mariana is a challenge for the public sector, and the constant changes in executive representatives interfere with the continuation of important public policies. There is also a need for greater public environmental awareness to separate waste at the source and participate in the existing separate collection system. This information is essential for establishing targets and objectives consistent with the municipality’s reality.

The linear management model (generate, consume, and discard) needs to be reconsidered. Circular waste management, adopted by Rotterdam, appears to be a good model to follow, in which all waste continuously enters the cycle within a flow, returning to the processes, and only after passing through this entire cyclical path is what remains appropriately disposed of.



Initially, a better understanding of local solid waste generation and management is important to make progress toward the planet's sustainable development possible. Solid waste management is a critical component in planning sustainable, healthy, and inclusive cities and communities for all.

There are no perfect solutions! Rotterdam's reality is very different from Mariana's. Thus, each city should be encouraged to develop strategies appropriate to its specific history, economy, demographics, culture, and human, environmental, and financial resources.



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