27th INTERNATIONAL CONGRESS OF MECHANICAL ENGENEERING
Brazilian Society of Mechanical Sciences and Engineering
27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-0340
MAPPING OF URBAN SOLID WASTE, RECYCLABLE AND ORGANIC MATERIALS: CASE STUDY OF SÃO JOSÉ DOS PINHAIS/PARANÁ
27th COBEM

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Abstract. *The Linear Economy (LE), the dominant model in the world, does not contribute to environmental, economic, and social sustainability. The transition process from LE to the Circular Economy (CE) depends on public policies, regulatory instruments, incentives for RD&I, changes in consumer habits and society's awareness of the importance of environmental, economic. and social sustainability. Global actions have not been enough to achieve sustainable development and thus, in this work, some local actions will be discussed, which can be replicated in any municipality, for the generation of clean energy, reduction of the use of fossil raw material, basically oil, and pollution reduction, which contribute to the achievement of CE and the Regenerative Economy. The main objective of this work is the mapping and application of the PDCA (Strategic Planning) tool for recyclable materials and organic waste in São José dos Pinhais (SJP), PR. A PDCA was prepared to study the inputs and outputs of organic waste and waste of recyclable materials generated in the municipality of São José dos Pinhais to carry out the strategic planning of urban solid waste. The PDCA tool (P-plan, Do-Execution, C-check, A-action) is widely used for diagnosing and managing production processes. The production of organic waste was mapped for the study of the implementation of a biodigester that generates clean and renewable energy. The mapping showed an annual quantity of recyclable materials of more than one million kg/year. A questionnaire was applied to 96 SJP restaurants to quantify the generation of organic waste per day, totaling 286kg/day. Considering that the city has in operation more than 2000 food production establishments, only with this organic waste it is possible to feed 01 biodigester. This organic waste can produce electrical energy through biogas for the plant of the biodigester, biomethane, biomass and biofertilizer.*

Keywords: *ODS, ESG, Circular Economy, Regenerative Economy, waste management, biodigester, recycling*

1. INTRODUCTION

The Sustainable Development Goals - SDGs represent a global action plan to eliminate extreme poverty and hunger, offer quality education throughout life for all, protect the planet and promote peaceful and inclusive societies by 2030. The first report of the Program UNEP (2021) estimated that food waste from households, retail establishments and the food service industry in 52 countries totaled 931 million tonnes each year. The report also revealed that the average is 74 kg per capita of food wasted each year and that this is essentially similar in lower-middle-income countries and in high-income countries, suggesting that most countries need action to reduce this impact (UNFCC, 2015). The reduction of food waste, in addition to bringing positive impacts with regard to the "hunger disease" in the world, also reduces the large volume of organic waste destined for landfills, which can be better used in biodigestion units to be transformed in biogas, biomethane and biomass and biofertilizer (HELLVIG&FLORES-SAHAGUN, 2021).

The Linear Economy, the predominant economic model in the world, does not efficiently meet the regional needs for the development of the economic potential of cities. The lack of environmental, economic and social sustainability is a worrying scenario, but at the same time it presents an opportunity from the social macroeconomic aspect to implement innovations to the current economic models. Several authors (MÉNDEZ, 1998 and 2002; MAILLAT, 2002; VELIS, 2015) state that, with the mastery of knowledge, appropriation and active participation of society in relation to the destination of city resources, it is possible to elaborate a strategic planning to better meet the needs of the population.

The Circular Economy associates economic development with better use of natural resources, through new business models and the optimization of manufacturing processes with less dependence on virgin raw materials, prioritizing more durable, recyclable and renewable inputs. The regenerative economy covers the needs of all people, without depleting the planet's resources (MOHANTY, A, 2002.; MISRA, M.; DRZAL, L; CASSIOLATO et. al, 2003; BORSATTO et. al, 2020; COSTA, 2021). Thus, to achieve the SDG Goals, cities must adhere to the Circular and regenerative economy model.

In this work, a mapping of solid organic waste and recyclable materials in the municipality was carried out of São José dos Pinhais. An analysis of the inputs and outputs of recyclable materials was carried out and a strategic planning of recyclable materials was carried out using the PDCA tool. After mapping and strategic planning, it was possible to suggest the implementation of an organic waste treatment unit, a biodigester. As for recyclable waste, the entry and exit logistics of recyclable materials in two SJP associations (Moranguinho and Semente do Amanhã) were studied for subsequent implementation of the PDCA.

2. CIRCULAR ECONOMY AND REGENERATIVE ECONOMY

Associations of recycled materials in Brazil represent a great potential for generating income, work and reducing solid urban and organic waste destined for controlled and uncontrolled sanitary landfills. The implementation of a model that operates in a Circular Economy and not in a Linear Economy can promote greater economic, environmental and social sustainability for the planet. The long-term implementation of the Circular Economy promotes the Regenerative Economy, which recognizes the real value of the environment – the human life support system (UNDP, 2021). The Circular Economy (CE) has its origins in the 1990s and has Industrial Ecology as its structuring base, since while the Linear Economy works from a manufacture-use-discard perspective, the Circular Economy works from an approach where there is greater harmony between the economy and the environment, in which waste can be reused and reused (LASTRES, 2005). EC aims at environmental preservation and the search for more sustainable economic models, where the production factors used in the manufacture of goods and products can present a longer production cycle, reducing greenhouse gas (GHG) emissions, harmonizing the cycle productive to the environment and preserving the Ecosystems (NARAJAN, R, 2006).

Economic and environmental sustainability must be included in the industrial policy agenda of Brazilian states to promote actions to mitigate CO2 and reduce pollutants, stimulating the development of sustainable ecosystems. The National Solid Waste Policy (PNRS, 2009) describes the general guidelines for how states and municipalities should conduct the management of their solid waste, however it is necessary to adapt the particularities of each municipality to their budgets. The most common solid waste management model consists of recycled material associations and consortia, which are provided for in the State Plan for Solid Waste (PERS) of the State of Paraná (SEDEST, 2021).

2.1 Biodigestor

The reuse and reuse of products generate environmental gains when their disposal is reduced, as well as recycling, as the reprocessing of what would be considered waste also reduces energy and water consumption (TARMUJI et al, 2016). Given this, the implementation of EC for organizations is challenging, as a radical change in the production and consumption model is required, and a change in processing that involves the entire production chain. Therefore, it is necessary to change the attitude of governments and society as a whole, since the search for sustainability requires interactive cooperation (NARAJAN, R, 2006).

The biodigester is fed by organic residues of domestic garbage, coming from selective collection, a characteristic of this type of collection is that the garbage is usually deposited in bags of polymeric materials. Inside the Plant, this material is separated from the organic waste that goes to the biodigestor and the polymeric material is sent to sanitary landfills.

Biodigesters consist of hermetic and impermeable equipment inside which organic material is deposited to anaerobically ferment organic matter, resulting in the formation of gaseous products, mainly methane and carbon dioxide (PAVAN, P. et al, 1999). The biogas is retained in the free part of the biodigester and can then be channeled to be used in various applications, such as heating and cooling processes, or in the generation of electricity. According to Amaral (2004), the fermentation of biomass in anaerobic reactors presents itself as an excellent alternative, as it reduces the rate of pollution and contamination of the production cycle, promotes the generation of biogas, allows the use of the final residue, the biomass, which when diluted in digestate ponds, it is transformed into biofertilizer (ARAUJO, 2017)

In a previous study, it was shown that São José dos Pinhais has 286 kg/day of organic waste from 96 restaurants (HELLVIG&FLORES-SAHAGUN, 2021). For the operation of a Biogas Thermoelectric Power Plant, an organic waste collection system, an organic waste processor, a biomass tank for the generation of biogas which is called a biodigestor, one or more bioreactors and a system that sends the methane for an engine, generating mechanical energy, which is taken to a transformer where it becomes electrical energy (PAVAN, 1999).

2.2 Biogas

Biogas is a gaseous mixture composed mainly of carbon dioxide (CO2) and methane (CH4). It is produced by anaerobic digestion, which is a fermentation process that has the purpose of removing organic matter, forming biogas and producing biomass that can be transformed into biofertilizer. The liquid product generated after anaerobic digestion is the biomass that is dumped into a lagoon for stabilization, and after quarantine (3 months), this precipitate is analyzed and can present nitrogen (N) contents between 1.5 and 2. 0%, phosphorus (P), between 1.0 and 1.5%, and potassium (K), between 0.5 and 1.0%, with potential to become a high quality organic fertilizer (JUNQUEIRA, 2014).

Biogas is composed of a mixture of gases, the type and percentage of which vary according to the characteristics of the type of waste and the operating conditions of the digestion process (CBIOGÁS, 2015). The main constituents of biogas are methane and carbon dioxide, in which biogas is composed of an average of 65% methane, the remainder being basically carbon dioxide. Biogas generates electrical and thermal energy, as well as biofuel such as biomethane, a gas resulting from the biogas purification process. During the process, the polluting potential of the waste is reduced and the nutrients present are maintained, resulting in a liquid product that can then be classified as a biofertilizer (CBIOGÁS, 2015).

2.3 Biomethane

The transformation of biogas into biomethane is carried out through a treatment that has the following objectives:

1) Clean the gas, removing residual components that are harmful to the Natural Gas (NG) distribution transport network or to combustion engines;

2) Perform the upgrade, in which the CO2 is removed to adjust the Higher Calorific Value (PCS) and the relative density, in order to reach the specifications of the "Wobbe Index (Oliveira, 2006)" (which depends on these two parameters);

After this transformation, the product will present in its ideal composition values between 95 – 97% CH4 and 1 – 3% CO_2. Once this composition is reached, it can be used as a substitute for NG in most of its applications. The production of biomethane can be valued from three points of view, energy valuation (heat, electricity, volume injected into the network or vehicle application), valuation of the final compost resulting from anaerobic digestion, and economic valuation through the reduction of GHG emissions. (JUNQUEIRA, 2016).

The use of anaerobic digestion technology in biodigesters has been presented as a possibility to reduce greenhouse gas emissions. The use of biodigesters has received important attention due to aspects of sanitation and energy, in addition to stimulating the recycling of nutrients. The anaerobic digestion of animal waste through the biodigester results in the production of biogas. The transformation of biogas into biomethane is carried out with the separation and cleaning of the methane and CO2 streams, where traces of components that are harmful to the NG distribution transport network or to combustion engines are removed.

2.4 Biofertilizer

Biofertilizers are agroecological technologies. The main components of a biofertilizer are: N - Nitrogen, P - Phosphorus, K - Potassium, Ca-Calcium, Mg - Magnesium, and even some micronutrients, such as Cu, Fe, Mn, Zn, Co, Mo, Bo. Another important point is in relation to the PH of the soil, which must be between 6.0 - 6.5.

Table 1 presents the physicochemical characteristics of solid urban waste most commonly found in sanitary landfills in Brazil, and for most landfills, waste is classified as good.

Table 1: Physical-chemical characteristics of waste from controlled sanitary landfills

characteristics	Excellent	Good	Low	undesirable
Moisture %	<25	25-35		
pH	>7,5	6,0-6,5		<6,0
Mat. org. total%	>60	50-60	<50	
Mat. org. resistente%	<10	10-15		>16
Cinzas%	<20	20-40		>40
N total%	<3,5	1,8-3,5		<1,8
C/N ratio	8-12/1	12-18/1		>18/1

Source: CEBDS, 2021

Table 2 shows the percentage of nutrients P, K, Ca, Mg and S found in solid waste from Brazilian controlled sanitary landfills.

Table 2: Percentage of nutrients P, K, Ca, Mg, S in solid waste from controlled sanitary landfills

%	High	Averange	Low
P	>0,6	0,2-0,6	<0,2
K	>1,2	0,4-1,2	<0,4
Ca	>2,8	1,4-2,8	<1,4
Mg	>1,2	0,6-1,2	<0,6
S	>0,5	0,2-0,5	<0,2

Source: CEBDS, 2021

In general terms, the NPK mixture needs to reach 1%, that is, 0.33% of K, P and N. However, depending on the characteristics of the soil and the type of agricultural crop, other proportions of NPK can be accepted. In solid waste from controlled Brazilian landfills, the most common is to find percentages at the average level, which represents a great potential for transformation into biofertilizer.

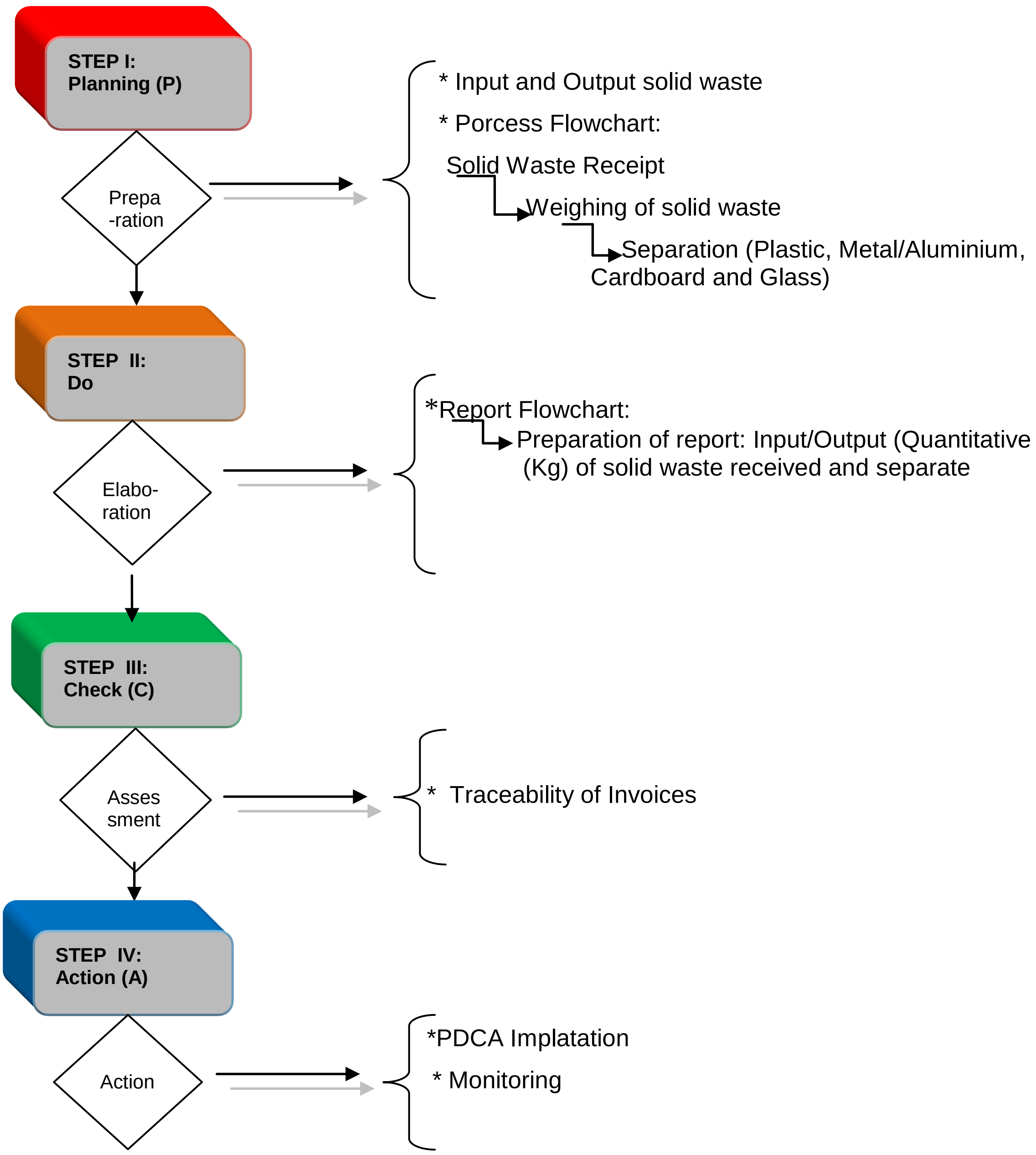
2.5 Applied Methodology

The mapping of residues was separated into two main stages:
1- Use of the results of the questionnaire applied in 96 restaurants in SJP;
2- Observational analysis at the Moranguinho and Semente do Amanhã associations for the application of the PDCA tool.

The result of the questionnaire applied via email to 96 restaurants in SJP and generated a total of 286 kg/day of organic waste.

Regarding the observational analysis, the PDCA tool was applied to plan, do, check and act in relation to the recyclable materials collected, in locu, in the associations of São José dos Pinhais, as shown in figure 1.

Figure 1: PDCA applied in Associations - Strawberry and Seed of Tomorrow



Source: Adapted from KOTLER, 2006

Figure 01 shows the PDCA tool applied in the observational analysis of the Moranguinho and Semente do Amanhã associations. In the Planning stage (P) it was possible to map the total amount of recyclable waste. In the elaboration stage (Do), it was possible to prepare a report of the inputs and outputs of the waste and to know the type of waste (paper, plastic, metal and glass). In the evaluation stage (C), it was possible to separate the Invoices for the traceability of waste to its destination after sorting. The Action (A) step is being implemented and will be reassessed after the execution of the first PDCA cycle.

2.6 Results and Discussions

Currently, the municipality of São José dos Pinhais is served by four Associations of recyclable collectors, located in the urban region of SJP, distributed in four regions. The urban area of the municipality is served with selective collection and the associations receive recyclable waste from public collection. The sheds for the activities of the associations are rented by the municipality, where the technical and logistical operation of the waste takes place. In associations, there are also Voluntary Delivery Points – PEV. For this study, the associations Moranguinhos and Semente do Amanhã were selected.

Table 3 shows the amount of Solid Waste collected in the first and second half of 2022.

Table 3: Quantitative Solid Waste Moranguinho and Semente do Amanhã

MORANGUINHO (kg) = Total: 664.972 kg/ano			
MATERIAL	**1° SEMESTER**	**2° SEMESTER**	**TOTAL**
PAPER	**163.395**	**159.798**	**323.193**
PLASTIC	**91.828**	**103.301**	**195.129**
GLASS	**41.070**	**44.950**	**86.020**
METAL	**27.230**	**33.400**	**60.630**
SEMENTE DO AMANHÃ (kg) = Total: 337. 322 kg/ano			
MATERIAL	**1° SEMESTER**	**2° SEMESTER**	**TOTAL**
PAPER	**62.890**	**74.190**	**137.080**
PLASTIC	**49.891**	**56.221**	**106.092**
GLASS	**49.180**	**49.200**	**98.380**
METAL	**18.120**	**17.650**	**35.770**

Source: By Author

Table 3 shows that Semente do Amanhã recycles less than Strawberry, respectively, 59.4% of paper and 54.0% of metal. With regard to glass, Semente do Amanhã recycles 87.4% more than Moranguinho, because the glass collected at Moranguinho is kept as a financial reserve for use in emergency situations, such as truck maintenance. Analyzing the PDCA of the Moarnguinho Shortcake sorting process, it can be seen that there is greater organization, which results in greater efficiency in sorting.

With regard to solid organic waste, each person produces an average of 30 kg of organic waste per month. The population of the municipality of São José dos Pinhais, according to the new IBGE census (2022) is 364,000 inhabitants, therefore the potential for generating organic waste in São José dos Pinhais is 364,000 kg/day, that's more of 10 million kg of organic waste that can feed 10 biodigesters for the production of renewable energy, biomethane, biomass and biofertilizer. SJP is considered the green belt of the eastern region of the State of Paraná (HELLVIG&FLORES-SAHAGUN, 2021) and uses a large amount of fertilizers that could come from organic waste transformed in biodigesters.

Currently, the municipality of SJP does not have a controlled sanitary landfill and, therefore, adhered to the consortium MSW management model. SJP, as it is located in the eastern region of the State of Paraná, belongs to the CONRESOL consortium, which sends urban solid waste to Fazenda Rio Grande, a neighboring municipality that has a controlled sanitary landfill. This service costs the public coffers of the municipality of SJP R$ 26 million per year. This waste management model does not contemplate the principle of efficiency and economy of public resources, which could be better applied, for example, in health and education.

2.7 Final Considerations

In order to implement biodigesters in Brazil, it is necessary to broadly apply public policies aimed at sustainability, so that administrative and legal sanctions are applied in case of non-compliance by economic agents.

The implementation of a biodigester has the ability to promote the Circular Economy and the Regenerative Economy since organic waste is used more efficiently with regard to the production of renewable energy, biomethane, biomass and biofertilizer, in addition to reducing waste incorrectly disposed of in landfills.

With the implementation of biodigesters, it is possible to reduce the volume of organic waste destined for landfills, increasing everyone's awareness of better separation of organic waste and, consequently, better separation of recyclable waste.

Urban solid waste, when properly separated, generates income and employment for selective collection workers, in addition to reducing environmental pollution. They also generate greater reuse of materials, without the need to produce new products of fossil origin, promoting climate mitigation by reducing the potential for atmospheric pollution from greenhouse gases (CO_2 and CH_4).

The PDCA tool was an important evaluation instrument, which after application in the two Associations studied, it was possible to carry out the organization of information, the compilation of information and the treatment of input (input) and output (output) of recyclable waste. The implementation phase is being built, as it is necessary to change the internal culture of the members of the associations, of the public agents involved, and to carry out training for employees.

Despite SJP's Environmental Master Plan (2024-2034) foreseeing an expansion of processes related to the mitigation of greenhouse gases and mentioning the importance of adopting the SDG as a goal to be achieved, SJP does not carry out the strategic planning of MSWs. The R$ 26 million spent annually by the municipality to send solid waste to the municipality of Fazenda Rio Grande could be better used, for example, in the implementation of biodigesters, in encouraging family and organic agriculture with the use of biofertilizers and in increased collection of recyclable materials.

3. ACKNOWLEDGEMENTS

The authors would like to thank the São José dos Pinhais Municipal Secretary of the Environment, in particular Sandra Miotto, CNPq (process 304421 / 2017-0) and PGMec/UFPR.

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