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Technology Roadmap for Plastic Waste Utilization Based on Sustainability Criteria. Case Study: Medium Sized Municipality in Latin America During COVID-19 Pandemic

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Bucaramanga is a city of more than 1 M inhabitants located in the northeastern region of Colombia. Currently, metropolitan area has problems related to utilization and elimination of plastic waste, which have increased due to the COVID-19 pandemic. This led to difficulties in plastic waste management, such as the low rate of rubbish and recycling collection activities and the increase of water, land, and air pollution; exposed at risk the ecosystems and the inhabitants of the region. The main objective of this work is to present a set of activities to respond to the increase in plastic waste related to COVID-19, through the development and implementation of a technology roadmap for Bucaramanga's Metropolitan Area (BMA). It could enable environmental impacts minimization, through actions that will implement new technologies for conversion of plastic waste into energy in a short, medium, and long-term period.

1. Introduction

The current COVID-19 pandemic has generated acute environmental effects due to the sudden surge in the demand for and use of plastic products to protect the public and critical hazardous waste management issues are emerging due to the need to ensure destruction of residual pathogens in household and medical waste (Klemeš et al., 2020a). In view of the situation described during the COVID-19 outbreak, the World Health Organization (WHO) recommends increasing the efficiency in the management and treatment of this type of waste, which requires a structural change in the solid waste management, from the rules of classification, collection, separation, storage, transportation, treatment, safety protocol for collection workers, to disposal. To improve the management of plastic waste, several previous investigations and studies have indicated the importance of appropriate techniques for waste treatment (Singh et al., 2011). Waste to Energy (WtE) conversion is one of the possible waste treatment approaches to supply energy and support continuing economic growth and industrial development (Klemeš et al., 2020b).
It is important to evaluate several options with existing treatment technologies, where several are based on thermal processes such as incineration, which is considered the most profitable technique to eliminate or remove pathogens, steam treatment, plasma treatment and microwave treatment; pyrolysis and gasification are under development, being more sustainable waste treatment options (Celis et al., 2020).
In Colombia, the environmental crisis due to inefficient solid waste management already existed before the pandemic (Antolinez, 2018), for which COVID-19 has caused an increase of up to four times the generation of waste due to the high consumption of single-use plastic products such as bags, food containers and the equipment that constitutes personal protection such as masks, face shields , gloves, among others (Saadat et al., 2020), this has produced a serious health emergency in the country, a clear example can be seen in the Bucaramanga's Metropolitan Area with its designated landfill called "El Carrasco", an open-air area that has already exceeded its capacity to store waste and is causing a great environmental and health damage to people (Antolinez, 2018). Since its opening, this site has had different technical and legislative problems and has not

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complied with the obligations required by the competent environmental authorities, which makes it, according to the Single Solid Waste Information System, the most critical disposal area in the country.
Sanitary landfills in Colombia are selected and designed places of operation for controlled final disposal of solid waste, through confinement, isolation, and compaction of waste. Landfills provide daily coverage for gases and leachate treatment and located on the outskirts of the city for waste disposal (Superintendency of Residential Public Services, 2021). In Colombia there is only one sanitary landfill, located in the capital Bogota, with methane capture through organic waste deposited, and it is a source of biogas for energy production. The treatment plant currently has the capacity to produce 1.7 MW of power. In the rest of the country, including the BMA's area, there are no technologies on gas emissions capture or treatment.
This problem has led to propose different scenarios to present some alternative solutions in a series of activities to respond the increase of plastic waste related to COVID-19 and improve the final disposal of waste in a technology roadmap, which will allow, through short, medium, and long-term actions, implement new technologies in the country in the treatment of plastic waste.

2. Methodology

Next steps were conducted to comply the main objective in the research on the development of a technology roadmap to minimize the environmental impacts generated by plastic waste related to the pandemic:

Stage 1: Diagnosis of available technologies in the treatment of plastic waste in Colombia and data collection associated with plastic waste in Colombia generated during COVID-19 pandemic.

Stage 2: Data collection on the amount of plastic waste generated in Bucaramanga's Metropolitan Area that are processed by the companies in charge of waste management during the pandemic, based on technology surveillance using specialized engine for information software tools as the "National Library of Energy" (US data search base) and the "CiteSeerX" software, a search engine specialized in scientific and technical information on existing methods for the disposal and treatment of plastic waste. Key actions to improve these systems were also proposed.

Stage 3: Development of a technology roadmap that allows identifying actions and improvements in the short, medium, and long term, to minimize the environmental impacts generated by plastic waste related to COVID-19 in Bucaramanga, until the year 2050.

3. Results and discussions

3.1 Plastic waste in Colombia generated before and after the pandemic.

Globally, the production of plastic waste is equivalent to 12 % of all the waste generated, whose waste reaches 37 % of the total plastic material discarded (Kaza et al., 2018). In Latin America and the Caribbean, the outlook is no less discouraging since a production of 17,000 t/d of plastic waste is estimated for the region (Savino, et al., 2018). In Colombia there are equally alarming figures, data provided by the national solid waste disposal reports from 2017 to 2020, and the exploitation activity sectoral reports from 2018 to 2020, are shown in Table 1.

Table 1: Annual tons of solid waste disposed of and used for different purposes in Colombia (Obtained from Superintendency of Residential Public Services in Colombia, 2021)

Year	Final disposal of solid waste (t/y)	Annual tons used	Tons of used plastics
2017	10,327.551	529,447	----
2018	11,305.133	972,793	97,279.3
2019	11,329.915.34	1,407.785	211,167.75
2020	11,600.849.21	1,903.269	494,850

From the above mentioned, it is observed in the final disposal data of solid waste, that, despite the increasing of amount of plastic waste, it can be acknowledged that from 2017 to 2018 a higher rate of increase was generated than the other periods reporting a growth of 9.47 % while for the year 2019 and 2020 the percentage of increase was 0.22 % and 2.39 % respectively. The variations presented may be subject to population growth throughout the period of analysis, the quality of the information reported to the Unified Information System (UIS) by the public service providers or to the precision and improvements in the control processes and measurement by the operators of the final disposal sites (Superintendency of Residential Public Services, 2021).
Within the report of annual tons used, a decrease was observed in terms of the percentage of annual growth, as shown in the following table.

Table 2: Percentages of variation in the use of solid waste

Year	% Variation of solid waste used	% Variation of plastic waste used
2017-2018	83.74	----
2018-2019	44.72	117.07
2019-2020	35.20	134.34

The variation of solid waste in tons refers to the amount used for reprocessing and recycling. And the "% variation of plastic waste", is the percentage of variation of the amount that has been used between the years 2017-2018, 2018-2019, and 2019-2020.
An increase is observed for 2020 in the variation of used plastics, since 494,850 t of plastic were reported for that year and for the year 2019 an average of 211,167 t was reported, which indicates that the current pandemic has increased both recyclable and single-use plastic waste, confirming the reports made by the UN 2021, where it reports that the use of plastics has skyrocketed since the declaration of emergency by COVID-19 in 2020 due to the use of masks, gloves, hand sanitizer bottles, protective medical suits, test kits, takeout containers, delivery packaging, and many other products that have become ubiquitous, overwhelming recycling systems.
However, for 2020, the lowest growth in total tons used is reported, which could also be related to the current pandemic. One of the main technical concerns at the beginning of the pandemic was the lack of knowledge in emergency control in the country, and therefore how this would affect the generation of solid waste with biological or infectious risk for the care of patients infected by the virus (IHMES, 2020).

3.2 Plastic waste treatment technologies in Colombia

According to the national solid waste disposal report for 2021 presented by the Superintendence of Domestic Public Services for the year 2020, Colombia generated 11,600,849.21 t of solid waste per year and according to the data provided by the sector report in 2020's exploitation activity, 16.4% of solid waste is used, that is, a total of 1,903,269 t, in which plastic is found with a 25 % share, approximately 486,231 t/y. Despite the high figures of solid waste generated in Colombia, there are no adequate technologies for its treatment and disposal, so that the most used method currently is sanitary landfills (Arboleda, 2015), recycling for some plastic materials, composting for organic waste and incineration for hazardous waste in which ash waste is deposited in landfills, according to information from companies in the sector.

3.3 Plastic waste treatment technologies currently used in the BMA

According to the last national solid waste report for 2020, the tons of use in 2020 for Bucaramanga in the "El Carrasco" landfill were 20.1 t/d. In the Metropolitan Area of Bucaramanga, in addition to the final disposal system in a sanitary landfill, other options are used, such as the use/valorization through recycling processes for the management of plastic waste. (Superintendency of Residential Public Services, 2021).
Due to health emergency problems cause by COVID-19, the Ministry of Health and Social Protection, through resolution 385 of March 12, 2020, carries out a specific analysis of waste related to health care, which presents a large percentage of plastics, where it is established that the final disposal of the waste must be carried out through thermal treatment with combustion (incineration) or thermal treatment with steam vaporization (IHMES, 2020). It should be noted that, according to the information provided by the companies in the sector, the ashes from this treatment end up in the landfill.

3.4 Key actions to improve plastic waste management in the BMA

As the health emergency continues, it is very important to promote and implement the strategies to help minimize the generation of waste and reduce the environmental impact that single-use plastics generate. Some of the alternatives to improve plastic waste treatment technologies are:

- Regarding the model of use and recycling that the city has, a strict and committed process of education can be implemented aimed at citizen culture on proper disposal of plastic waste and social awareness of the importance of reducing this type of waste (emphasizing single-use waste). Through the active dissemination of information, taking advantage of the use of digital tools and making use of didactic guides that seek to raise the awareness and commitment of people, involving all sectors of the city, the educational community, universities, companies, local entities, and associations.
- Another key action aimed at reducing single-use plastics is to seek, through political entities, the creation of drastic environmental policies that at least restrict single-use plastic bags for both companies and people, helping them to be develop new patterns of sustainable production and consumption, promoting reusable bags.

- Increase number of collection centers, classification and use stations, which carry out a weighing and classification of all usable solid waste in the Bucaramanga's Metropolitan Area and thus minimize the generation of solid waste that is taken to the landfill.
- A key action would be to carry out a study for the location of a new landfill that implements the production of compost and organic fertilizers that are produced by the decomposition of organic waste.
- Establish an energy use model where plastic is used as fuel, due to its high calorific value, taking advantage of all types of plastics, including those that show deterioration or dirt.

3.5 Technology roadmap

In this technology roadmap, three different waste treatment technologies are mentioned, incineration with energy recovery, pyrolysis, and gasification. Represented in three times periods, short-term (2022-2025) see Figure 1, medium-term (2026-2035) see Figure 2, and long-term activities (2035-2050) presented in the final part. In addition, Figure 1 and Figure 2 show some technical aspects and improvements in technology, developed in different countries. Wich supports the implementation of sustainable alternatives to convert plastic waste into energy, especially those that are related to the COVID-19 pandemic. The roadmap with three time periods and their activities are described below.

Path 1. It was established in a short-term period from 2022 to 2025. This axis takes the key actions previously proposed, to improve the existing plastic waste treatment technologies in BMA and strengthen environmental processes in the community. Short-term actions are summarized in Figure 1 and are presented to indicate which sector (BMA government, industry, or academia) should take the lead to ensure proper compliance.

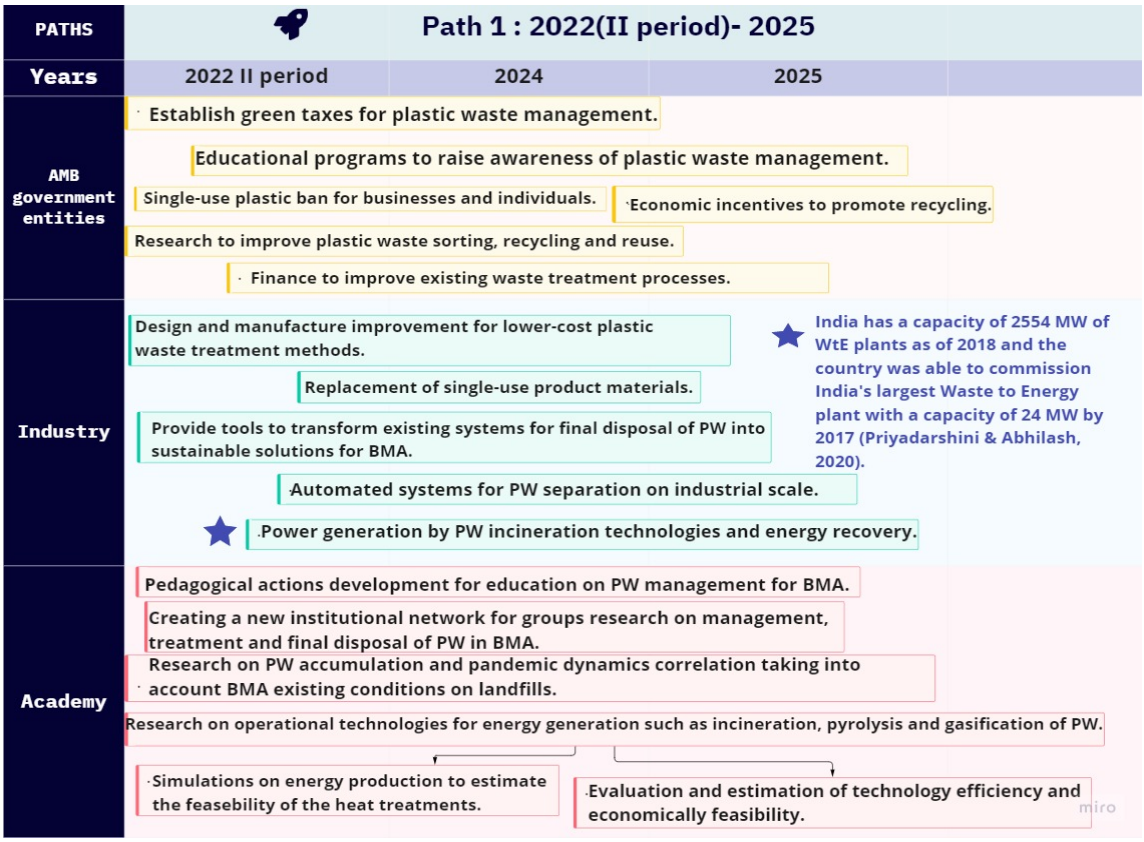

Figure 1: Technology roadmap - actions of the first paths (from 2022 to 2025)

Path 2. It was established in a medium-term period developed between the years 2026 to 2035. During this path the installation of new technologies for treating plastic waste in the Bucaramanga's Metropolitan Area its evaluated, considering the different aspects of the different sectors (BMA government, industry, or academia), adopting measures: legal, technical, environmental, and economic. Medium-term actions are presented in Figure 2.

Figure 2: Technology roadmap – - actions of the second path (years 2026-2035)

Path 3. For the final path, it is established in a long-term period developed between the years 2035 to 2050, focused on the permanent implementation of new technologies for the treatment of plastic waste for energy generation and the analysis of the reduction of environmental impacts.

Among the activities to be carried out in this stage is the analysis of results regarding the minimization of CO_2 emissions, analyzing the capture and use of carbon for the reduction and sequestration of CO_2, as well as the studies carried out by (Ghiat and Al-Ansari, 2021), or the research carried out in the Republic of Korea on carbonaceous adsorbents to improve the capture of CO_2 (Kamran and Soo-Jin, 2021), achieving an appropriate capture of this gas by the year 2050, improving air quality, following methodologies such as those proposed in Oslo-Norway with the installation of a pilot plant for carbon capture (Fagerlund et al., 2021); in addition to observing a noticeable reduction of plastic waste in landfills by 2035 and open dumps and other monitoring that demonstrate the benefits of the implementation of new technologies for treating plastic waste in the Metropolitan Area of Bucaramanga.

4. Conclusions

The data presented in this research show the lack of information about technologies for plastic waste treatment management in Colombia. In a medium size municipalities application of mechanical recycling and landfills are the most common way for waste disposal, including plastic waste which has potential for energy production. There is also an increase of plastic waste, from 211,167 t generated in 2019 to 494,850 t in 2020, related to the COVID-19 due to the use of single-use plastics to prevent the spread of the pandemic.

A technology surveillance for new and sustainable plastic waste treatment technologies was developed for BMA. Key actions were recommended to promote strategies that would allow to minimize environmental impacts in BMA, such as the application of an optimized and automated system for plastic waste sorting to improve the existing processes. Some strategies for the improvement of the management of plastic waste were presented

for BMA till 2050. Incineration with energy recovery was proposed as the first process with implementation term until 2025, pyrolysis as the second technology introduced till 2030, and gasification for implementation between 2030 - 2050, representing new options for conversion of plastic waste into energy together with the total elimination of CO_2 emissions by 2050.
The developed technology roadmap could be adapted for other cities in Latin America, promoting plastic waste as an alternative source for sustainable energy production.

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