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Plastic Waste to Energy, Technology Solutions Based on Sustainability Criteria for Medium Size City in Latin America, Considering COVID-19 Pandemic

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In Colombia, solid waste constitutes one of the most important environmental problems that the State must face due to the difficulties in its management in most of the country's municipalities (Montes, 2018); the lack of environmental education, control measures and supervision exacerbate the current problem. Despite the existence of a legal framework and a comprehensive management plan for the treatment of this type of solid waste. It is possible that implementing the concepts of environmental footprint and LCA in the decision-making process on the implementation of new technologies for the treatment of plastic waste, it will allow minimizing the environmental impacts and the risks to human health provided by the waste. plastics related to COVID-19, especially in developing countries like Colombia. The main objective of this research is the selection of a set of technological solutions for the utilization and transformation of plastic waste through energy generation, considering the environmental, social, economic, and COVID-19 pandemic aspects. Case study: Bucaramanga, Colombia.

1. Introduction

Even before the start of the COVID-19 pandemic, the management of plastic waste was considered to be a major environmental issue due to growing concerns about pollution in terrestrial and marine ecosystems (Rajmohan et al., 2019). The case study is Bucaramanga, a city located in the Andean region with a total population of a metropolitan area of 1.2 M inhabitants (National Administrative Department of Statistics, 2022). It is a typical Latin American city with problems related to the use and valorisation of plastic waste, just as globally waste management systems have been unable to satisfactorily deal with existing plastic waste, the imminent increase in waste volume from the COVID-19 pandemic threatens to overwhelm waste management systems. Existing waste as well as health care capacity (Klemeš et al., 2020), the increase in plastic waste due to the pandemic from household, health and sanatorium activities is a serious problem since 2019 (Klemeš et al., 2020). It is necessary to control the impact of plastic (Flores, 2020) on the environment, facilitate the design of waste treatment systems and the comparison of alternatives such as incineration, pyrolysis, and gasification, among others. During the global pandemic period, there was a 17 % reduction in greenhouse gas emissions such as CO_2, compared to the same period in 2019 (Le Quéré et al., 2020), as a consequence of the restriction of transport and industrial activities. However, this did not prevent other environmental impacts, such as the increase in the consumption of disposable plastic products (bags, food containers) and disposable medical devices: masks, face shields, gloves and protective suits, which together constitute the personal protective equipment (PPE) used by medical personnel and citizens during the pandemic, have increased the generation of waste up to four times (Saadat et al., 2020). While critical management issues arise due to the need to ensure the destruction of residual pathogens in household and medical waste. The increase in this waste is inevitable, so it is necessary to propose new alternatives that are sustainable for the environment and human health, maintaining good management of this plastic waste to minimize the effects of climate change. Therefore, the design of waste treatment systems and the comparison of alternatives such as incineration, pyrolysis,

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gasification, etc., should be facilitated. Studies have reported that an 80 to 95 % volume reduction can be achieved for waste generated using thermal conversion technologies (Singh et al., 2011). Seeking to care for human beings and the planet during and after the pandemic so that previous environmental efforts are not frustrated by unforeseeable world events.

2. Methodology

The main objective of this research is to select a set of technological solutions for the treatment of plastic waste associated with COVID-19 to determine the environmental impacts, risks to human health and its economic viability in the BMA, that is why we propose a methodology that contains the following stages:
Stage 1. Evaluate a set of technologies suitable for the conditions of the BMA based on technology surveillance, taking in to account the quantity and composition of plastic waste, needs and opportunities of local communities and sustainable development criteria using a computational tool called “Vigiale”.
Stage 2. Estimate the material and energy balances of selected technologies and determine the emissions generated, the environmental impacts and risks to human health using computational tools such as Aspen plus.
Stage 3. Based on an economic feasibility study of each of the technological solutions proposed for the treatment of plastic waste in the BMA, and environmental analysis take a final decision about the set of technologies.

3. Solid waste final disposal systems

Comparing the final disposal systems that exist in Latin America and the leading countries worldwide, it can be concluded that the most used systems in Latin America are sanitary landfills with a percentage of 52 % and open dumps with 26.8 %. Unlike the world's leading countries where waste systems with recycling and incineration with energy recovery prevail, this is due to its focus on the sustainable development of the population and the reduction of environmental impacts. Colombia has several types of systems for the final disposal of waste which, since 2008, with the first publication of the National Report on the Final Disposal of Solid Waste, have been classified by Super-services into authorized systems and unauthorized systems. Authorized systems are those that have environmental permits corresponding to an environmental license. According to the above, the sites are classified according to the authorized and unauthorized system as follows:

Table 1: Classification of final disposal systems in Colombia.

System types					
Authorized system	**Amount**	**Percentage**	**Non-Authorized system**	**Amount**	**Percentage**
Processing facilities	-	0.0 %	Burning/incineration	-	0.0 %
Contingency cell	13	4.63 %	Water system	-	0.0 %
Landfill	174	61.92 %	Burial	-	0.0 %
			Open dump	84	29.89 %
No information	-	0.0 %	Transient cell	10	3.6 %
Total	187		Total	94	33.45 %
Disposed annual tons on main cities					
Bogotá D.C.	2,263,624.57		Cartagena	418,721.53	
Cali	609,433.2		Bucaramanga	188,230.01	
Medellín	766,912.685		Santa Marta	192,359.59	

3.1 Overview of the situation with solid waste in Bucaramanga’s Metropolitan Area (BMA).

Bucaramanga is one of the most important cities in Colombia, it is the capital of the department of Santander. The metropolitan area is made up of Bucaramanga, Floridablanca, Girón and Piedecuesta. Currently, the region does not have a plastic waste treatment plant, which is why it is considered a primary need since, in recent years, environmental and health concern has arisen due to the problems caused by solid waste.
BMA generated 349,855.375 t/y of solid waste by 2020, with the city of Bucaramanga having the highest participation with 188,230.005 t/y, followed by the municipality of Floridablanca with 75,786.4 t/y and finally, the municipalities of Girón and Piedecuesta with 48,096.6 t/y and 37,742.37 t/y.

3.2 Amount of plastic waste generated in the BMA during the COVID-19 pandemic

Data related to the amount of plastic generated in the years 2020 and 2021 during the COVID-19 pandemic in the BMA was collected as shown in Table 2, considering that this was declared a pandemic on 11 March 2020 by the World Health Organization. The information was collected through the reports made by the SUI, the superintendent of residential public services and information reported by entities in charge of the treatment of plastic waste in the BMA, where there is clearly evidence of an increase in these types of plastic waste due to the health emergency.

Table 2: Adaptation of the amount of plastic waste generated in 2020 and 2021 reported by one company in charge of plastic waste treatment related to COVID-19.

Waste type	Plastic waste generated in 2020 (t)	Plastic waste generated in 2021 (t)
Biosanitary (COVID-19 vaccines, hospital waste, Gel bags, empty containers for medical supplies, contaminated plastic, recyclable plastic)	757.84	849.34
Total	757.84	849.34

3.3 Characterization of plastics according to type and quantity.

Characterization of the type and quantity of plastic waste related to COVID-19 was carried out for the Bucaramanga metropolitan area, where was it found that the material with the most participation is other plastics with 29 %, where polymers such as Polystyrene (PS) used for takeaway food containers, Low-density Polyethylene (LDPE) used in plastic bags and wrappers are found of food, High-density polyethylene (HDPE) used in bottles for cleaning and disinfectant products, the second is polyethylene terephthalate (PET) with 27 % used in plastic bottles (water, carbonated beverages, cooking oils, etc.), followed by paste and blown materials with 12 % each, the fifth material is white plastic with a 6 % share, followed by polyvinyl chloride - PVC and polyethylene with 5 % each, polypropylene with 3 % and finally acrylic represents 1 % of the total reported in the family of plastics in the year 2020. This can be seen in Figure 1.
PET has been one of the most used plastics during health emergency due to the drastic increase in the production of personal protective equipment. It is not only cloth masks that have become popular, but also rigid face shields, which usually use PET sheets for their manufacture (Plastic technology, 2020).

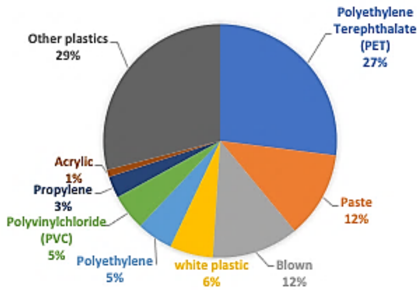

Figure 1: Report on t of Plastics effectively used in Colombia. Adapted from the Superintendency of Residential Public Services, (2021). 2020 Exploitation Activity Sector Report. Bogota, Colombia (in Spanish).

During the COVID-19 pandemic, the use of plastics increased significantly in medical devices and packaging. The increase in plastics to combat COVID-19 is made up of products such as face shields, protective suits, vinyl gloves, disposable bags, tubes, and masks. In terms of food demand per delivery, polyethylene, low-density polyethylene, high-density polyethylene, polyethylene terephthalate, and polystyrene, which are used for packaging materials, have increased (Klemeš et al., 2020).

4. Results and Discussion

Possible technology solutions for the BMA, in which the impact of plastic on the environment, there are various measures that have been studied for several decades, such as the 4R strategy, which includes reduction, reuse, recycling, and recovery (Klemeš et al., 2020). Recovery is a type of recycling where the thermal degradation of plastics is applied, such as pyrolysis, incineration, and gasification, to generate energy (Tangri, 2005). This type of recycling seeks to directly use plastic products without any prior treatment so that it is used for another function than the previous one. This is applicable to certain plastics more resistant to temperature or cracking. These activities are aimed at reducing the environmental footprint, which corresponds to the set of direct or indirect effects produced by some human activity on the environment (Boucher, 2018). In general, the strategy to reduce the impact of the use of plastics during the pandemic is similar to the used to reduce infections by SARS-CoV-2, and to flatten the curve with the application of programs such as the 10Rs (Fan et al., 2020) and also (You et al., 2020), which are circular economy concepts.

4.1 Technology surveillance

Technology surveillance was carried out on the most widely used international solid waste management and final disposal systems, considering the countries identified as world leaders in terms of recovery and use.

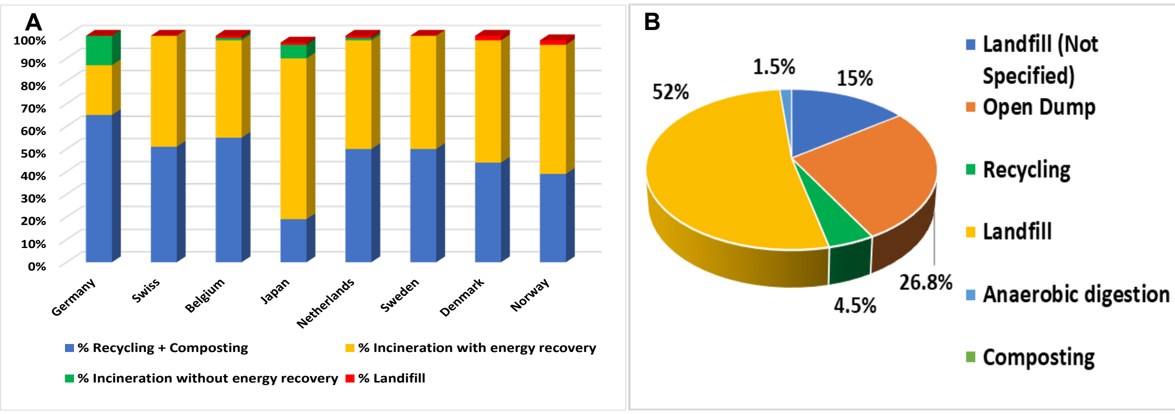

Figure 2. A: Recovery percentage and final disposal of solid waste. B: Treatment and disposal of municipal solid waste in Latin America – Adapted from Segura et al. (2020).

Technology surveillance was also carried out on the final disposal systems of solid waste in Latin America to see what technologies are being implemented by underdeveloped countries, as shown in Figure 2. A very common practice that still exists, especially in Latin America. Latin America and the Caribbean, is to dispose of waste on open land without adequate measures for its interaction with the environment, causing serious pollution problems. However, the scientifically accepted disposal of solid waste in sanitary landfills, but the adequate standards for their operation are not being complied with, causing health and environmental problems due to leachates and gases generated as a product of the decomposition of waste (Sáez et al., 2014).
Comparing the leading countries worldwide with Latin America, it can be concluded that the most used systems in Latin America are sanitary landfills with a percentage of 52 % and open dumps with 26.8 %. Unlike the world's leading countries where waste systems with recycling and incineration with energy recovery prevail, this is due to its focus on the sustainable development of the population and the reduction of environmental impact. There are three techniques where energy can be recovered, and Table 3 shows the main parameters of each technology.

Table 3: Main characteristics of the three thermal processes.

Parameters/ Technologies	Pyrolysis	Gasification	Incineration
Reaction temperature (ºC)	250 - 700	500 - 1600	800- 1450
Pressure (Bar)	1	1 - 45	1
Atmosphere	Inert/Nitrogen	Gassing agent (O_2, H_2O)	Air
Stoichiometric ratio	0	<1	>1
	Process Products		
Gas-phase	H_2, CO, Hydrocarbons , H2O, N2	H_2, CO, CO_2,CH_4,H_2O,N_2	CO_2, H_2O, O_2, N2
Solid-phase	Ash, Coke	Slag, Ash	Ash, Slag
Liquid phase	Pyrolysis oil and water		

4.2 Thermal recovery of solid waste

Plastic is a very lucrative energy source due to its nature as a crude oil by-product. However, there is the biggest economic feasibility issue in the industry when it comes to all recovery methods. The advantage of energy recovery is the possibility of overcoming this problem through the production of high-quality products that are easy to market, in addition to the fact that plastics have a high energy content similar to conventional fuels (Cardenal, 2020). New alternatives are proposed that are sustainable for the environment and human health, maintaining good management of this plastic waste to minimize the effects of climate change.
Incineration: The simulation of the incineration process was carried out using the Aspen Plus V8.8 computational software tool; the simulation was developed with the information presented in Tables 2 and 3, where the amount of plastic waste generated and the main characteristics of each process are presented. A 68 % reduction in

plastic volume was obtained. A good example of application of the incineration of raw materials rich in plastics are the member countries of the European Union (EU) such as Belgium, the Netherlands, Sweden, Denmark, Germany, Austria and Finland, incineration together with recycling plays a role very important in terms of waste treatment (Cardenal, 2020).

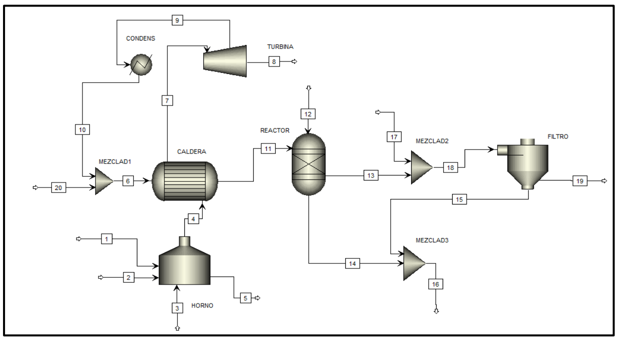

Figure 3: Flow diagram of the incineration process using Aspen Plus V8.8 software, implementing the POLYNRTL method.

Gasification: In the same way, the gasification process was developed with the Aspen Plus V8.8 software program, where its respective simulation was based on literary information compiled in the previous points, the effect that the operating conditions have on the performance of gasification with air or steam. The most influential parameters are, without a doubt, the equivalence ratio (ER) and temperature since it determines the gas yield and its H_2 composition (Xiao et al., 2007). This gasification process requires less investment in gas cleaning processes because it produces a much smaller volume and generates fewer emissions of nitrogen oxides, particles, dioxins and furans and unburned (Martínez, 2015).

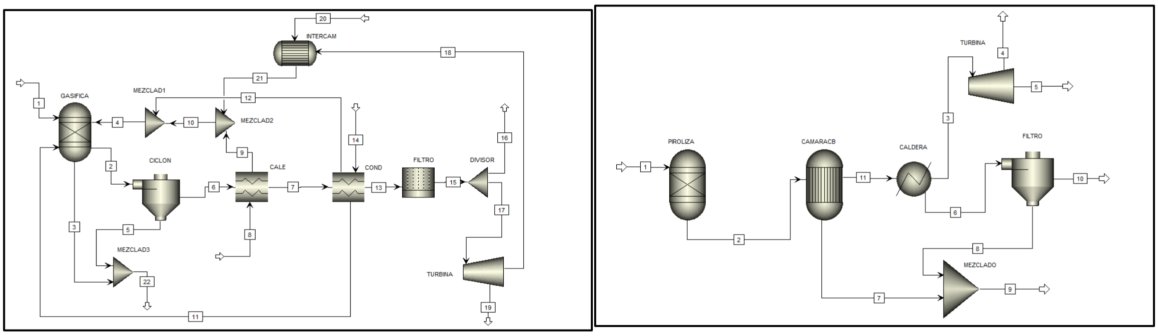

Figure 4: Left: Gasification process flow diagram using Aspen Plus V8.8 software, implementing the POLYNRTL method. Right: Flow diagram of the pyrolysis process using Aspen Plus V8.8 software, implementing the POLYNRTL method.

Pyrolysis: Finally, the pyrolysis process was developed with the Aspen Plus v8 software program in the same way as the two previous processes, where its respective simulation was based on literary information presented in Tables 2 and 3. This is a process that has been used a long time ago; that is how in the 80 s, the pyrolysis of urban solid waste to produce electricity was developed in Japan. In Spain, through this process, it was found that, at higher temperatures, the formation of more thermally stable compounds occurs. Similarly, in Ecuador, in the experiments carried out, using high-density polyethylene, diesel, kerosene and gasoline contained in the liquid fraction are obtained (Mancheno et al., 2016).

5. Conclusions

Among many of the consequences of the COVID-19 pandemic, there is great concern about the increase in the volume of plastic waste, and the priority for the future is the destruction of residual pathogens for the safe disposal of that waste; this leads to evaluate technological alternatives that allow reducing amounts of plastic waste and help reduce the carbon footprint, mainly in cities such as Bucaramanga, which produced 849.34 t during 2021, having an increase of 91.50 compared to 2020. Technological surveillance was developed in each of the treatments using software such as Aspen Plus process simulation, determining the inputs and outputs of

each of the technological processes of transformation of plastic waste produced during the COVID-19 pandemic in the BMA and economic evaluation. The formed energy that is formed is enough to run the plant's combustion furnace, conducting the most energy consumption. It can be concluded that the plant has fulfilled an important objective, that of being able to convert the burning of waste into one of its energy sources.
Gasification and pyrolysis integrated with energy production were determined as the most promising technology for the conditions of the BMA since the waste is less polluting and requires less gas treatment. The emission levels established by law must always be met; for this reason, it has been decided to use an electrostatic precipitator for particulate removal and a RNCS system for NOx removal, and this could lead to a greater negative impact on the environment, human health, and process cost. The developed methodology could be applied to solve environmental and energy problems related to the recovery of plastic waste in other Latin American cities with similar characteristics.

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