Use of Waste to Obtain Energy in Latin America: A Systematic Review

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Abstract

It is forecasted that by 2050, waste generation will increase to 2.2 billion tons per year, this is due to the poor management of waste, leaving approximately 33% untreated residues. Along with this, in recent years new energy sources have been sought to replace the use of non-renewable energy. The objective of this study is to identify and characterize the experiences in using the procedures to convert waste to obtain energy. To achieve this, we followed the PRISMA method obtaining a result of 109 selected articles that were reviewed for the collection of information. Thus, obtaining as a result that the application of the methodologies provides valorization of agro-industrial waste, utilization of animal waste, biogas generation and generation of electric energy from waste.

Keywords
Waste-to-energy, Renewable energy, Waste Management, Literature Review

1. Introduction
In recent years there has been an increased interest in obtaining energy through different methodologies with the aim of replacing fossil fuels, through the recycling of organic waste such as biomass (Caposciutti et al., 2020).

This interest has been worldwide, mainly in countries within Europe and Asia. It should be noted that in Latin America there are more and more countries that cover this issue, the recovery of organic waste, the latter, generated in homes, restaurants, food industries, among others, have a high potential for contamination (Manzi Tarapués et al., 2020).

There are methodologies that allow the use of large volumes of organic waste to convert them into energy. For this there are technological strategies, which are analyzed to comprehensively manage waste, examining the indicators of the operations and qualities of the implemented processes and thus give an energy value to this type of waste (Montiel-Bohórquez et al., 2019). According to Alzate et al. (2019), conversion technologies have great potential to recover energy from solid waste. Among them is the biological conversion technology, which allows the exploitation of biogas produced from the mass fraction of solid waste, also the thermal conversion technology, being one of the most used in developed countries such as China and Japan, using methods such as incineration and gasification, the latter method being the least polluting. Consequently, these technologies provide advantages, such as reducing the volume of waste generated.

The environmental impacts, because of uncontrolled accumulation of solid waste, are significant for the safety and health of the community. Although certain concentrations are low, they can significantly affect the conditions of the ecosystem. Contingent recovery methods are needed to see the benefits of being able to reduce solid waste, through the implementation of a control plan (Gonzáles et al., 2020). According to Montiel-Bohórquez et al. (2019), one of the ways to mitigate these impacts is the energy assessment of solid waste. Since, over the years, the accumulation of waste brings consequences, among them are phenomena, such as climate change, among others. Likewise, these residues grow more and more each year, which is why there has been a global concern to try to mitigate the pollution generated by the generation of waste by humans (Álvarez et al., 2017).

The global solid waste generation rate is estimated to increase to 2.2 billion tons per year and is projected to increase by 16% in high-income countries and 40% in low-income countries by 2050, in developing countries. This is produced by the lack of management separation, collection, storage, and treatment of waste, 33% of this waste is not treated properly (Moya et al., 2017). The increase in the volume of waste in landfills generates a need to look for alternatives that convert solid waste into energy, since these generate an increase in problems in the field of health and the environment (Agaton et al., 2020). According to Firtina-Ertis et al. (2021), by implementing the methodologies to convert waste into energy and combine them with the circular economy, converting solid waste into energy sources, a double positive impact is created because by building facilities and organizing operations to apply these methods contributes to social development, job creation, and the income of local societies.

Over the years and technological progress, processes have been implemented for the conversion of waste into energy, either as biofuel or electricity, likewise, the application of these processes depends on the type and characterization of the waste. There are thermochemical and biological processes, those biological processes are based on bacteria and algae. Thermochemical processes are in the form of pyrolysis or gasification (Caposciutti et al., 2020).

1.1 Objectives

Identify and characterize the experiences of converting waste to obtain energy, of authors who were interested in the subject of the recovery of organic waste, in pilot or real tests.

The research questions used for the orientation of this study were the following:

- What is the contextualization of the publications?
- What experiences of waste-to-energy have been developed?
- How are these waste-to-energy experiences characterized?
- What processes are applied to obtain energy?
- What are the contributions that applying these processes provide?

For the analysis of the articles, VOS viewer software and Excel pivot tables were used to organize them according to the proposed categories and subcategories. Table 1 shows the categories and subcategories related to the research topic.

Table1. Literature Review Categories

Category	Sub-category
Publication Characteristics	Number of Articles Per Year
	Journals of Published Articles
	Characterization of the Authors
Methodologies Used	Type of Methodologies
Characteristics of the Methodologies Used	Waste Characteristics
	Type of Energy Obtained
Effects of the Procedures	Contributions of Applying the Methodologies

2. Methods

The development of the methodology chapter for this systematic review is based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) method.

2.1 Search

The search for information began in the Scopus database. First, the sources were delimited using key terms "Waste-To-Energy", "Waste Management" and "Energy", obtaining 145,004 sources. Then, the sources were filtered by selecting the type of document; for the development of this study, scientific articles were used, obtaining 94,745 publications. To continue with the selection, articles with "Open Access" were filtered, obtaining 20,369 documents. Next, approaching the purpose of the study, publications between 2017 and 2021 were selected, obtaining 12,188. Then, for research purposes, it was filtered by region, collecting articles originating from Latin America. Finally, it was filtered by selected keywords and later a manual selection was made based on its own criteria which would help the development of the systematic literature review, finally obtaining 107 articles that were used for a thorough analysis to obtain results and conclusions according to the objectives.

2.2 Inclusion Criteria

After collecting the sources related to the research topic, we selected the articles that would specifically help with the development of the study based on the following inclusion criteria:

- Empirical studies explaining or detailing waste-to-energy keywords or abstract
- Studies that present a scientific or economic perspective of those procedures that lead to obtaining energy from waste
- Articles indexed in the Scopus database
- Articles published between the years 2017 and 2022
- Articles originating from Latin America

3. Data Collection

3.1 Statistical Data Analysis

The final selected articles were analyzed to identify trends based on the established criteria: countries, journals and years of publication. Figure 1 shows the classification of articles by country on the map, with the quantities represented by blue shading.

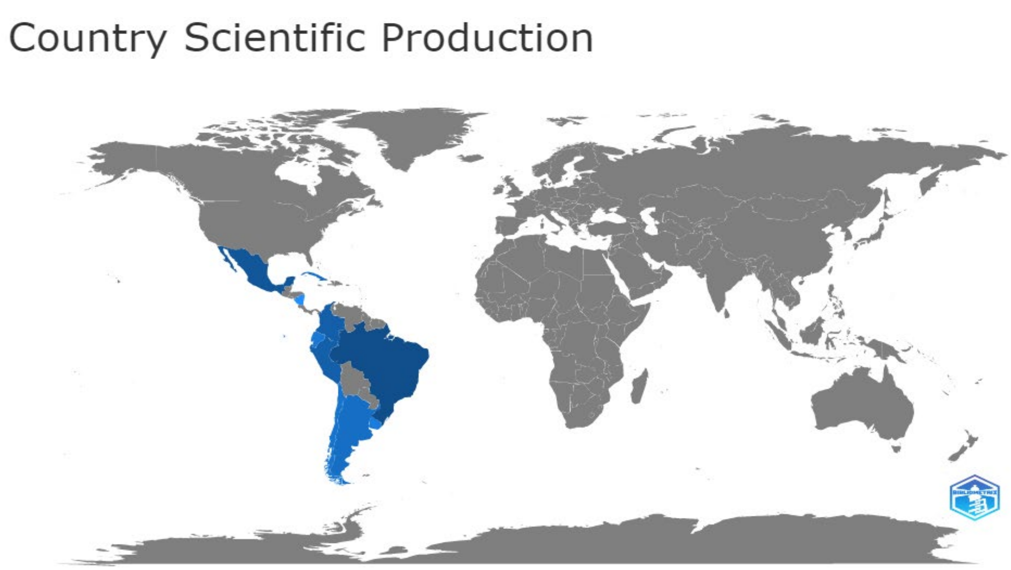

Figure 1. Graphical Representation of Classification of Articles Produced by Country

The figure shows the representation within the map by country based on the number of articles produced. In order to give a visual classification, different shades of blue are used, going from less to more intense in direct relation to the lowest and highest amount of scientific production. The graph shows that Brazil, Mexico and Colombia are the countries with the highest scientific production on the use of waste to obtain energy.

As for the most representative author, the number of scientific articles produced about waste utilization for energy generation was taken as a reference as seen in Figure 2. The most representative author was Victor Pretell (Pretell, V) with 7 productions; he is currently a professor at the National Engineering University of Peru, specializing in science. The next author is Williams Ramos (Ramos, W) with 5 publications. And finally, with 3 publications are the authors Sandra Inmaculada Mantinguer (Mantinguer, SI) and Naguel Schrimer (Schrimer, N).

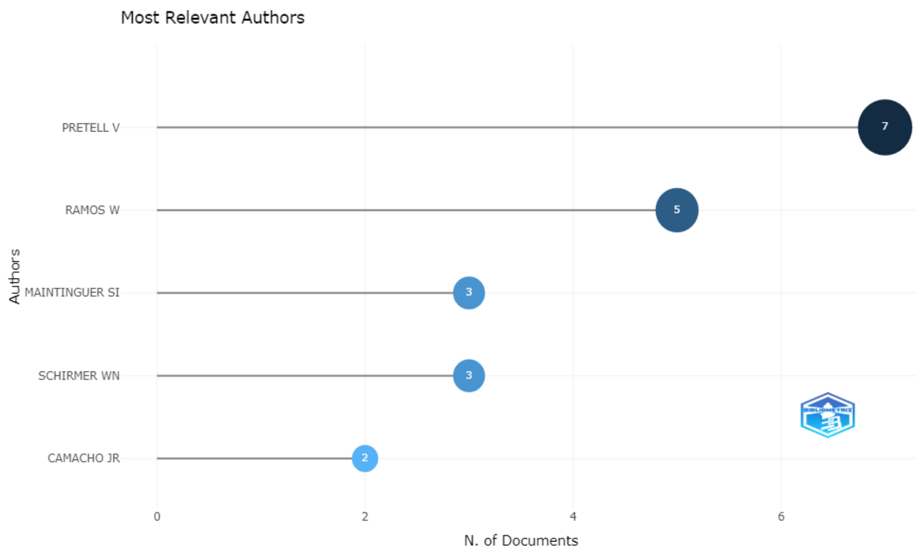

Figure 2. Graphical Representation of Most Relevant Authors

4. Results and Discussion

4.1 Bibliometric Analysis

The digital tool VOS viewer was used to perform the bibliometric analysis of the study. A total of 109 articles were selected, in English and Spanish, collected from scientific journals indexed in the Scopus database.

To start with the analysis, the software was used to group the keywords using clusters, which represent the union of the most frequently used words among the publications of different authors. This grouping was done to observe the number of findings and the criterion of having at least 5 repetitions to be considered in the map was used. Figure 3 shows the set of keywords found.

Within this map different clusters can be observed, they are divided into 3 main ones. First is the red color cluster, whose most relevant keyword was "biomass", then in the blue zone, the word that stands out among all is "biogas" and “anaerobic digestion”, finally, there is the green zone composed of different words, among them “energy recovery” and “electricity generation” can be identified more easily.

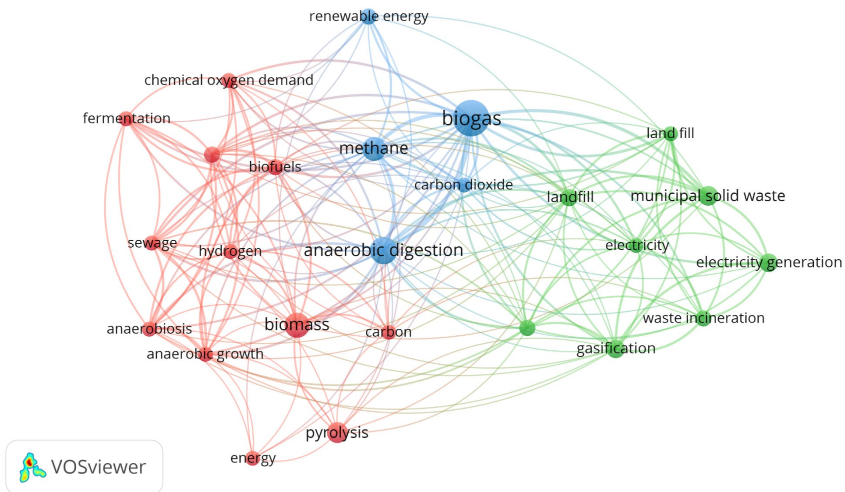

Figure 3. Graph of Co-occurrence Relationship Between Keywords

As shown in Figure 4, it can be observed the number of articles that have been published in the same Journals and classified by year. MS Excel was used to create a table that was used to group by the different segments and to create a graph that shows the Journals with the highest number of articles. In this case we took 5, of which “Proceedings of the LACCEI International Multi-Conference for Engineering, Education and Technology” presented a greater number of articles related to the topic studied because they focus on waste management and energy production through these. In addition, there is a growing trend by year in the number of publications by topic, which leads to the conclusion that there is an optimistic future for this area.

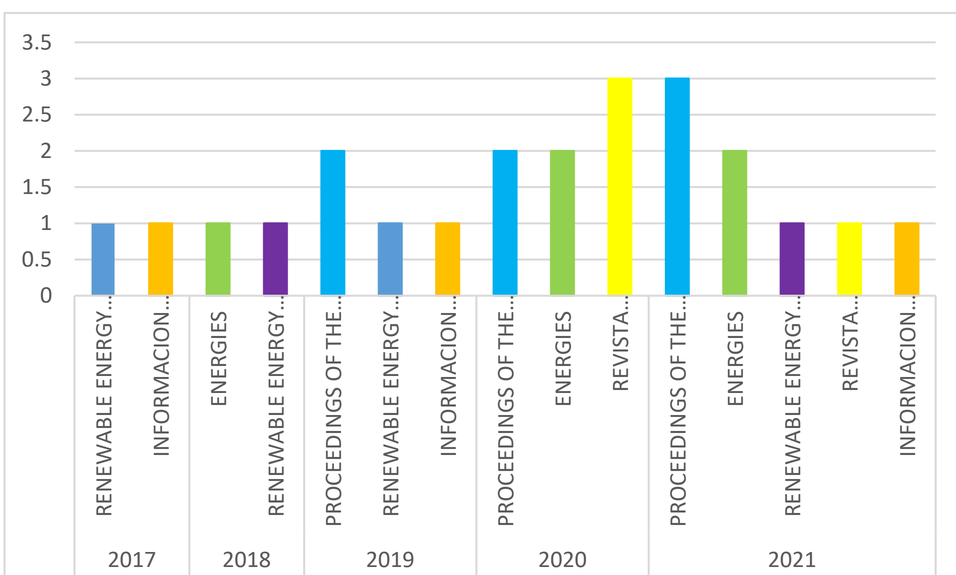

Figure 4. Graph of Number of Publications per Journal and Year

4.2 Processes to Generate Energy

There are various methodologies that can be divided into three groups. On the one hand, there are technologies that allow waste to be converted into energy biologically. On the other hand, there are those that allow thermal conversion. And finally, there are the methodologies that convert energy that have been analyzed for future use. (Alzate et al., 2019).

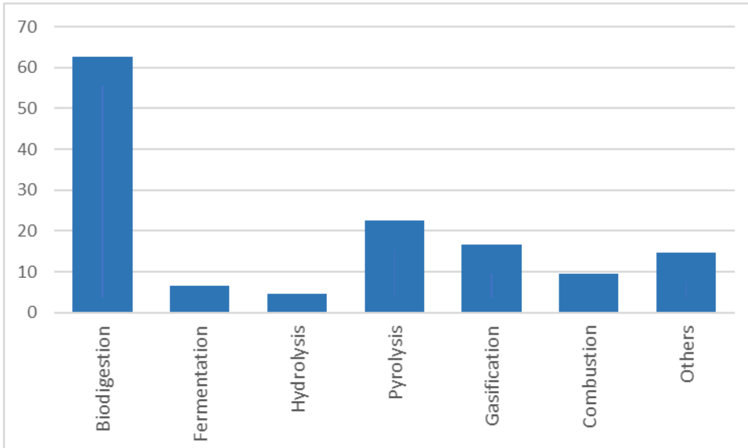

Figure 5. Bar Chart of Methodologies to Generate Energy

Table 2. Frequency Chart of Methodologies to Generate Energy

Waste-to-Energy Methodologies		Frequency	Percentage
Biochemical	Bio digestion	59	52.68
	Fermentation	3	2.68
	Hydrolysis	1	0.89
Thermochemical	Pyrolysis	19	16.96
	Gasification	13	11.61
	Combustion	6	5.36
Others	Transesterification	3	2.68
	Landfill gas collection	2	1.79
	Microbial fuel cells	2	1.79
	Densification	2	1.79
	Algae Biotechnology	1	0.89
	Hydrothermal carbonization	1	0.89
	Total	112	100

As can be seen in Figure 5 and Table 2, the process that has been used the most is Bio digestion with a representation of 50% of the articles. In second place is Pyrolysis with 19 of the total number of sources reviewed. And those that have not yet been widely explored are found in the category "Others" represented by a total of 9.82%.

4.3 Waste-to-Energy Experiences

The experiences seen throughout this research by the authors have been diverse. There have been experiences at the micro level, experiences that took place within laboratories, pilot tests, and others at the macro level, which were on a large scale, with large volumes even within communities.

Some experiences have had positive results at both the environmental and economic levels, and others only at the economic level. Regardless of the facts or conclusions of the studies or research, they have had positive contributions to society and the environment.

According to Moya et al, in populations of less than 2 million, the use of thermochemical methodologies yields 5,970 KW/tMSW (Kilowatt per ton of Municipal Solid Waste). In addition, using biochemical methodologies yields 62 KW/tMSW. Finally, by using the methodologies, the approximate cost of energy arising from the conversion has been evaluated and would reduce the price. As for incineration, the price per KW per hour would have a total of 3 cents, it is also estimated by implementing pyrolysis and the price would be 7 cents, which summarized that not only the environmental problem of lack of waste management is solved but, problems of sustainability, profitability, and safety.

4.4 Experiences Characteristics

The articles reviewed present 2 important characteristics, the first one is the type of waste used. As can be seen in Figure 6 and Table 3, organic waste has been the most used due to their decomposition characteristics with a percentage of 24.04, followed by agro-industrial waste with 23.08%, almost as relevant as the previous one. Finally, we can see that the use of individual residues such as tires, plastics, oils, and other specific waste are being evaluated, but they do not play a very important role, accounting for 11.54% of the total number of mentions in the articles cited.

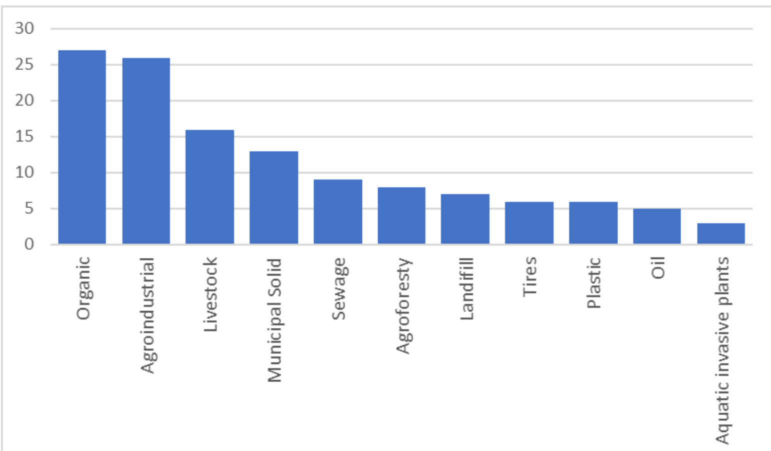

Figure 6. Bar Chart of Type of Waste

Table 3. Frequency Chart of Type of Waste

Type of Waste	Frequency	Percentage
Organic	25	24.04
Agro-industrial	24	23.08
Livestock	14	13.46

Municipal Solid	11	10.58
Sewage	7	6.73
Agroforestry	6	5.77
Landfill	5	4.81
Tires	4	3.85
Plastic	4	3.85
Oil	3	2.88
Aquatic Invasive plants	1	0.96
Total	**104**	**100**

The second most important characteristic mentioned is the type of energy obtained from waste. In Figure 7 and Table 4, it is very noticeable that the generation of biogas by means of biological conversion processes is the most relevant, being mentioned in 40 of the articles reviewed. Then with fewer repetitions is the electricity or electricity produced from biogas with 20.65 percent in total. Finally, with less relevance for now, are relatively new processes such as ethanol production and the use of briquettes and pellets for energy conversion. All three have appeared in only one of the selected articles.

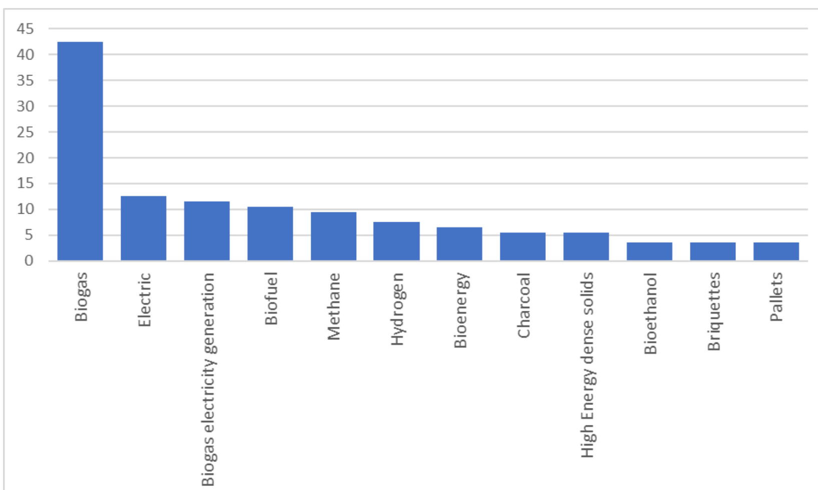

Figure 7. Bar Chart of Type of Energy

Table 4. Frequency Chart of Type of Energy

Type of Energy	Frequency	Percentage
Biogas	40	43.48
Electric	10	10.87
Biogas Electricity Generation	9	9.78

Biofuel	8	8.70
Methane	7	7.61
Hydrogen	5	5.43
Bioenergy	4	4.35
Charcoal	3	3.26
High Energy Dense Solids	3	3.26
Bioethanol	1	1.09
Briquettes	1	1.09
Pallets	1	1.09
Total	92	100

4.5 Contributions

There are different results within the articles reviewed, however, it is possible to highlight common contributions that have been identified within the articles. As shown in Table 5, the contributions that stand out are the valorization of agro-industrial waste, the use of animal waste, obtaining biogas from waste and finally the generation of electric energy from waste.

Table 5. Contributions of applying the methodologies

Contributions	References
Valorization of agro-industrial waste	Evaluates the amount of energy produced from fishing industry waste and the feasibility of using it for industrial processes (Cadavid-Rodriguez et al., 2019). Evaluates the conversion process of orange peel to charcoal by pyrolysis (Gonzalez-Canche et al., 2021). Evaluates the energy use of coffee beans and spent crops (Evaristo et al., 2021).
Use of animal waste	Valorization of poultry manure to obtain methane gas (Arriagada et al., 2019). Valorization of cattle manure to obtain biogas through the process of anaerobic co-digestion (Los Barbosa et al., 2018). Characterizes and evaluates the process of converting camel manure into energy (Al-Rumaihi et al., 2021).
Obtaining biogas from waste	Evaluates and verifies the implementation of an electromagnetic field in anaerobic digestion for the conversion of organic waste into biogas (de Souza Matos

	et al., 2020). Biogas production from fruit and vegetable waste (Islas-Espinoza et al., 2017). Shows the process of obtaining biogas from organic material (De Mendonça et al., 2017).
Generation of electric energy from waste	Evaluates the economic feasibility of implementing technologies for the conversion of waste to biogas in rural areas in the face of an energy crisis (Bernardes & Camacho, 2019). Economically evaluates the conversion of organic waste to biogas and electricity (Alvarez et al., 2021). Calculates the amount of bioenergy that can be produced from organic waste and whether it meets the demand for electricity (Acosta et al., 2018).

5. Conclusions

It is concluded that these experiences are characterized by evaluating and characterizing waste-to-energy conversion procedures. It should be noted that not all of them follow the same model; some experiences use large volumes of waste, at a macro level, such as agroforestry waste, livestock, etc. Others are at a micro level, such as obtaining energy from wastewater from a university campus. Finally, there is the pilot test, which could be based on software, on laboratory experiments obtaining small- or large-scale results.

It can be observed that for the implementation of the methodologies regarding the social and economic aspect, the impact of the application of technologies in cities with variable population has been seen. It can be observed that for the implementation of the methodologies it is necessary to encourage a culture of recycling, since in this way the waste is used optimally.

There are various conversion processes, which can be divided into biochemical, thermochemical and others. The most outstanding processes in the biochemical section are those of bio digestion, but fermentation and hydrolysis are also found. The former being the most used by researchers. On the other hand, there are the thermochemical processes, which are: pyrolysis, gasification and combustion, among them, the most outstanding and efficient is the pyrolysis process, because it generates energy with a higher yield. Finally, we have other processes such as landfill gas capturing gasses from those wastes that have been deposited for many years, generating GHG, so this process captures these gasses and converts them into energy. Another important process is densification, which is a physical process based on compacting waste to generate briquettes or pellets.

In closing, the contributions provided by the application of these processes are beneficial, since waste, agro-industrial, agroforestry, etc., is valorized and used to convert energy and thus reduce the environmental impact. On the other hand, it seeks to replace traditional energy sources that generate GHG.

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Biographies

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