Plastic Recycling Feasibility with the Triple-Layered Business Model Canvas

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The massive consumption of plastic material and its waste worldwide has made it necessary to find alternative solutions to reduce the size of landfill areas and recover their energy content. Pyrolysis is one of the chemical recovery technologies for plastics whose return on investment is estimated between 16% and 21%. This article aims to use the Triple Layer Business Model Canvas tool, which considers the elements of a business model visually and dynamically based on the three pillars of sustainability (economic, environmental, and social). This approach allowed for a comprehensive analysis of the sustainability-oriented business model. As a result, we concluded that pyrolysis is viable as a complementary process to other means of mechanical recycling and energy recovery.

Keywords: Pyrolysis. LCA. Sustainability.

Introduction

The growing production and demand for plastic materials, coupled with the disposable use of most polymers by the consumer sector, exacerbates the problem of plastic waste, mainly when the "environmentally adequate“ final destination is restricted to landfills. According to data from Plastics Europe, 359 million tons of plastic materials were produced worldwide in 2018, of which 39.9 % went to packaging use [1]. This fact implies that a considerable part of the plastic generated in the world is consumed and disposed of after a single use, thus becoming a threat to the integrity of ecosystems [2]. This issue raises the need to look for alternatives such as chemical recycling, in which, in addition to reducing the sizes of landfill areas, it is possible to take advantage of the energy source of these materials [3].

Pyrolysis is a chemical recycling technique involving the degradation of long-chain polymers into smaller molecules [4]. The polymeric chemical structure is modified by heat or a catalyst, generating less complex molecules. These products can be used as raw materials to manufacture new petrochemicals. Depending on the process conditions and the type of feed residues, the products obtained from pyrolysis reactions can be liquid, gaseous, or solid residues such as ash, tar, and pigment [5]. The processing of Polyethylene (PE) and Polypropylene (PP), for example, has olefins, paraffin, and waxes as main products [6]. Usually, pyrolysis processes only require a little infrastructure, making it possible to set up small and mobile units [6]. One of the most apparent advantages of pyrolysis processes is converting materials with low energy density into products with a high energy density [7]. Pyrolysis has received attention in recent years from the scientific community due to its operational and environmental advantages, considering the demand for energy and the instability of the fossil fuel market [3].

Monteiro (2018) [5] provided in his thesis a detailed study on the contribution of chemical recycling to sustainable development, presenting the Life Cycle Analysis (LCA) as a tool for the prevention and minimization of adverse environmental impacts. Joyce and Paquin (2016) [8] developed a methodological approach called Triple Layered Business Model Canvas (TLBMC) to address the elements of a business model

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visually and dynamically based on the three pillars of sustainability (economic, environmental, and social). This tool enables effective decision-making that includes all aspects of sustainable development, generating value and benefits for society and the environment. In addition to these works, a literature review was carried out on the positive and negative impacts of the increasing use of pyrolysis processes worldwide. This work aimed to build a model that simulated the implementation of a pyrolysis unit in Brazil based on data found in the literature and applied it to the TLBMC model.

Materials and Methods

A literature review was carried out, which initially focused on data collection. The topics investigated dealt with installing pyrolysis plants and their economic feasibility analysis, the Life Cycle Analysis for the chemical recycling of plastic waste, and the social impact of recycling plastic materials. The bibliographic research was developed in four sub-steps, which were: the definition of the database (SCiELO, ScienceDirect, Web of Science, along with others), the definition of descriptors (use of terms such as LCA, pyrolysis, canvas, chemical recycling, along with others); definition of titles and abstracts, and finally, the analysis of the texts. In this last stage, not only a textual analysis was carried out, but also an interpretive one, leading to discussions on the author's message and a re-elaboration of this message based on personal reflection. All of this allowed for delimiting the focus of the work on applying the Triple Layer Business Model Canvas (TLBMC) to a hypothetical pyrolysis unit. Finally, the documents in question were analyzed to collect data that complemented the assembly of the business model.

Results and Discussion

Economic Layer

The business model initially proposed by Osterwalder and Pigneur (2010) provided only an economic analysis based on nine interconnected components: value purpose, customer segment, customer relationship, channels, partnerships, key activities, critical resources, costs, and benefits [9]. Figure 1 brings an infographic depicting the Canvas model setup with the display components applied to a pyrolysis unit, which are still shown individually.

Value Proposition

Pyrolysis uses Waste-derived Fuel (WDF), generally PE and PP, from packaging and other applications. This WDF can be obtained by shredding substantial amounts of waste, enabling the reuse of what is neither organic nor recyclable. Urban solid waste (household and commercial) and non-hazardous industrial waste undergo mechanical sorting and homogenization to obtain the best ratio between dry and wet materials. One such processing unit is located at ESTRE in Paulínia, São Paulo, with a daily processing capacity of 1,000 to 2,000 tons.

Customer Segments

Due to the nature of the plastic recycling operation, there are three segments of interested customers: the waste processor, the polymer producer, and the municipalities. The waste processor can add value to the WDF material through pyrolysis by marketing the product as a higher calorific fuel or a raw petrochemical material. The polymer producer may have a raw material source recognized as renewable, with associated image gains. Municipalities responsible for waste collection and treatment may have a sustainable option.

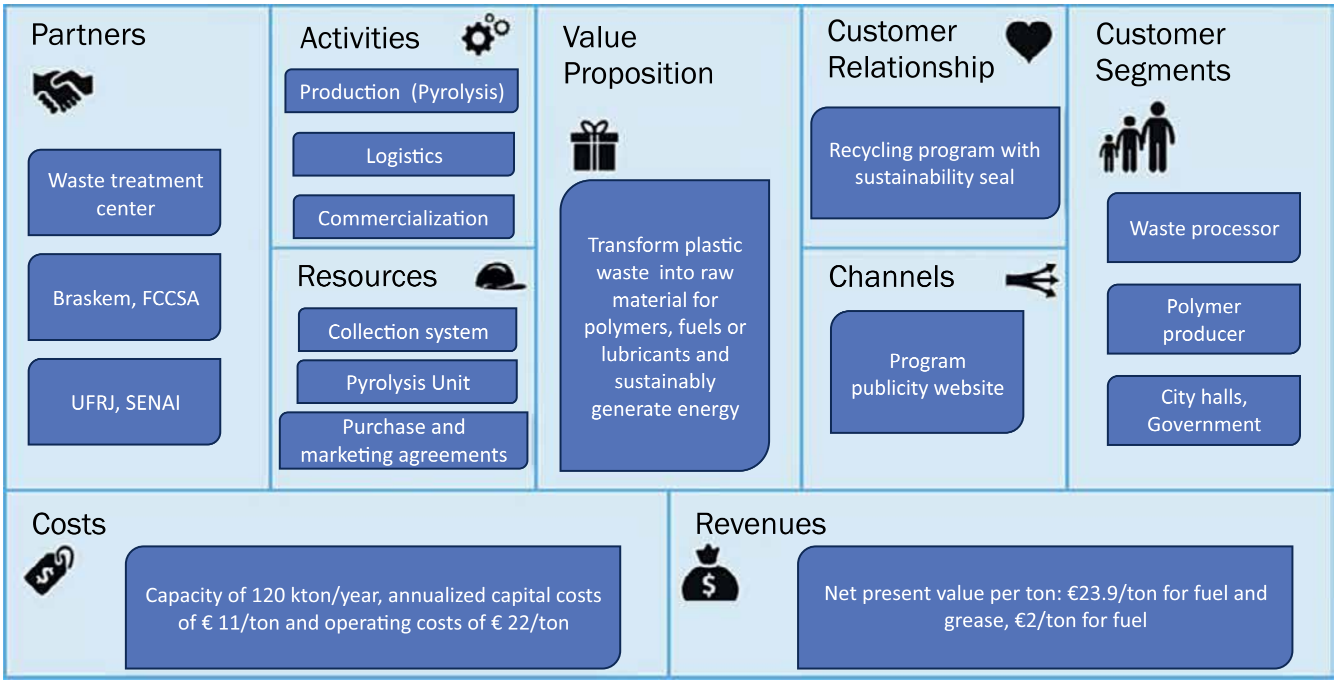
Customer Relationship

Considering the polymer producer, issuing a sustainability seal will allow the disclosure of the recycling action. The relationship between the municipalities and the waste processor will be through contracts to supply raw materials and minimum recycled quantities.

Channels

A web page will be able to collect all information on the logistics of collection and subsequent sale of

Figure 1. Infographic of the economic layer analysis of the Triple Layer Business Model Canvas of a hypothetical pyrolysis unit.



Source: Joyce and Paquin (2016) [8].

materials. The traditional channels of municipalities and the processor will be used to carry out the whole collection, processing, conversion, and sale cycle.

Partners

The critical point of partnerships depends on establishing a relationship between the city and the recycler. Other partnerships with the academy and the polymer producer or other associated industries will be of excellent value in facilitating the required investment and the disclosure of the entire process.

Activities

The process has three key steps: waste collection and segregation, the pyrolysis conversion process, and the logistics and commercialization of products.

Resources

The collection and segregation system must be available, i.e., financial investment for installing the pyrolysis unit and contracts signed between the city and the processor and between the processor and consumers of the pyrolysis products, either as fuel or as petrochemical raw material.

Costs

A plant production capacity of one ton/hour with 0.3 £/kg or R$ 2.1/kg is adopted as a cost basis.

Revenues

A rate of return between 16 and 21% and a net present value per ton between R$ 12 and R$ 15 were assumed for the expected profit based on data collected in the literature [10].

Environmental Layer

A purely economic analysis, disregarding the environmental impact data discussed worldwide, is inefficient. In this sense, a new tool requires direct integration between economic and environmental values in a holistic view that addresses corporate sustainability [8]. The environmental layer of Canvas integrates nine other components and an infographic of the environmental layer analysis

(Figure 2). The values described in this section are based on the values expressed in the work of Khoo (2019) [11]. A scenario was adopted in which 82.1% of the plastic waste received would be sent to energy recovery by incineration, 10.6 % to mechanical recycling, and 7.3 % to pyrolysis.

Functional Value

This value uses lifecycle evaluation to simulate a functional unit with a quantitative description of service performance. According to the State Inventory of Municipal Solid Waste, 39,859 tons of municipal solid waste were collected throughout São Paulo in 2018, totaling 14.54 million tons annually [12]. Unfortunately, data on the selective collection were unavailable in the literature, so estimating the amount of plastic waste that could be adequately separated from this amount was not feasible. Therefore, for this work, we assumed that 15.6 % of all residues are of plastic composition [13], reaching a functional value of 2.37 million tons of mixed plastic waste per year. Considering the above scenario, the pyrolysis unit receives 7% of this residue, i.e., 165,900 tons of plastic waste are processed yearly.

Materials

The composition of the plastic residue was estimated at 40 % polyethylene, 17 % vinyl polychloride, 12 % polypropylene, 4 % polystyrene, 4.8 % polyethylene terephthalate and 22.2 % of other mixed polymer fractions.

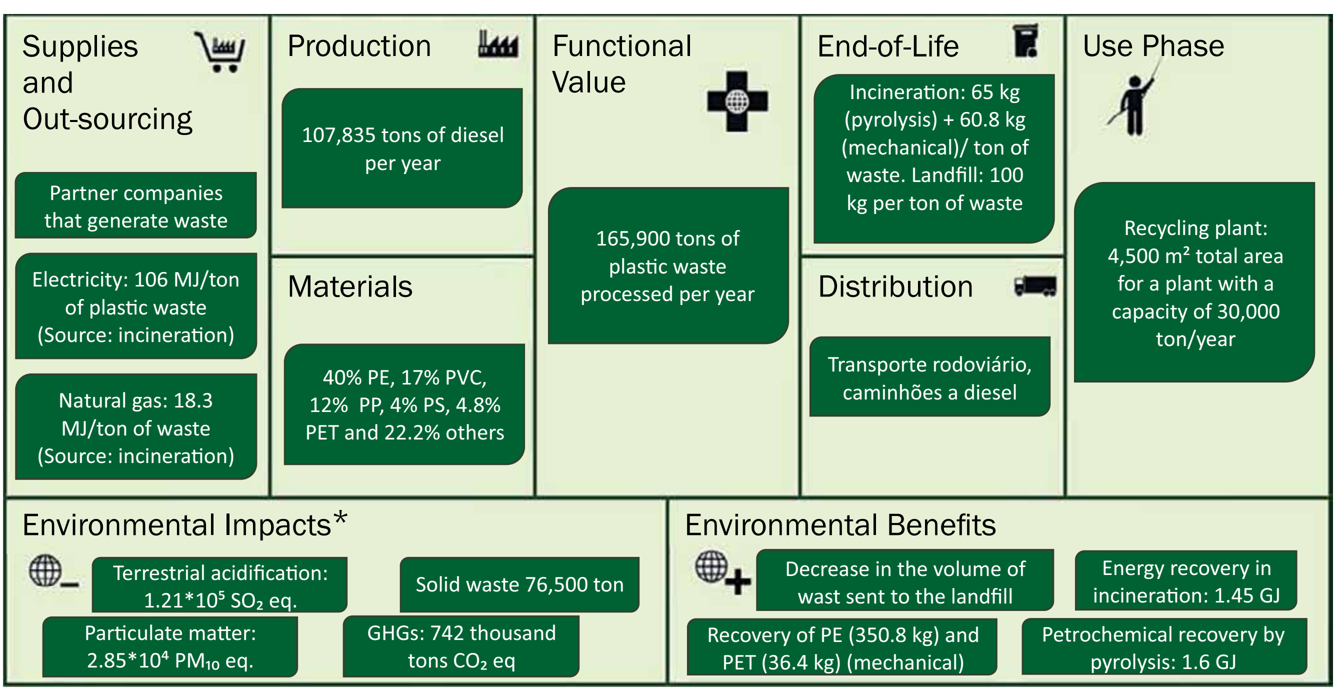
Production

It was estimated that 650 kg of diesel oil per ton of plastic residue production was sent to pyrolysis. Annual production of 107,835 tons of diesel oil was calculated in this sense.

Supplies and Out-Sourcing

This component considers plastic waste collection partner companies. Khoo (2019) analyzes the implementation of pyrolysis along with other alternatives, such as mechanical recycling,

Figure 2. Infographic of the environmental layer analysis of a pyrolysis unit's Triple Layer Business Model Canvas.



*Scenario: 87.5 thousand tons (mechanical recycling), 674.7 thousand tons (incineration), and 60 thousand tons (Pyrolysis). Source: Joyce and Paquin (2016) [8].

incineration, and gasification, determining what percentage of the waste is directed to each unit to generate higher profit and lower environmental impact [11]. In addition, the pyrolysis unit has an electrical energy demand of 124.3 mJ per ton of plastic waste processed, which the incineration unit can supply.

Distribution

Diesel trucks will be used in the logistics of the plastic waste and in the distribution of the products. Pollution generated by land transportation between units was not considered due to its minimal impact.

Use Phase

It is estimated that a pyrolysis chemical recycling plant capable of processing 30,000 tons of plastic waste per year would require a usable area of 4,500 m^2 [11]. In the Brazilian reality, to process all the plastic waste destined for the pyrolysis unit, an area 5.53 times larger would be needed.

End-of-Life

Plastic waste collected and sent for pyrolysis and mechanical recycling produces solid residue. 65 kg and 60.8 kg per ton of plastic are estimated to be processed, respectively. This waste goes to the incineration plant, generating 100 kg of solid waste per ton of processed material destined for the landfill.

Environmental Impacts

The calculations for the environmental impact require the use of software to which we did not have access, so we could not apply the State of São Paulo generation values in this component. We consider the scenario described by Khoo (2019), where 87,500 tons of waste are sent for mechanical recycling, 674,700 tons for incineration, and 60,000 tons for pyrolysis, used as sustainability indicators for the LCA. The potential for climate change was characterized by the emission of greenhouse gases (742,000 tons of $CO_{2\text{-eq}}$), terrestrial acidification (121 tons of $SO_{2\text{-eq}}$), and the formation of particulate matter (28.5 tons of PM 10-eq). In addition, 76,500 tons of waste from recycling processes were ultimately sent to landfill. It is worth noting that this value corresponds to less than 10 % of the total waste sent for recycling [11].

Environmental Benefits

A significant reduction in waste volume sent to landfills can be calculated. The estimated recovery of petrochemicals by pyrolysis is ~ 1.6 GJ, the energy recovery is ~1.45 GJ, the recovery of polyethylene is 350.8 kg, and of PET is 36.4 kg per mechanical recycling.

<u>Social Layer</u>

A sustainable business model also requires the development of a social layer that considers social value through the actions of an organization [8]. The Figure 3 presents the assembly of the Business Model Canvas from a social perspective.

Social Value

The conversion of plastic waste through pyrolysis contributes to reducing the impact of marine contamination and improves the integration of stakeholders such as the polymer producer, balanced commercial relationships with waste pickers' cooperatives, and support to municipal governments in their urban waste treatment missions.

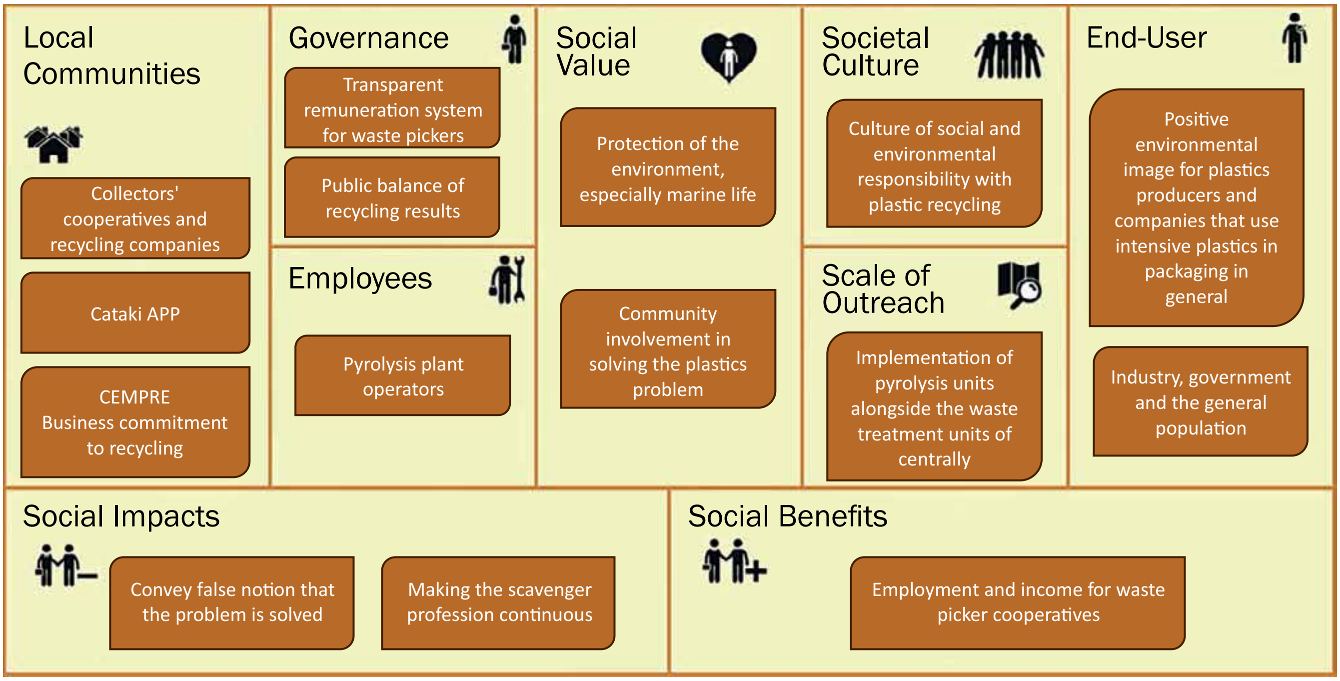
End Users

Fuel, grease, and polymer producers can use the pyrolysis product. Working with NGOs or waste pickers' cooperatives may promote a change in how society deals with the problem.

Range

Development with NGOs at the national or international level, such as Precious Plastic (https://preciousplastic.com/), polymer-producing companies, and polymer end-using companies and their circularity actions with society, should be evaluated.

Figure 3. Infographic of the social layer analysis of a pyrolysis unit's Triple Layer Business Model Canvas.



Source: Joyce and Paquin (2016) [8].

Social Culture

This component recognizes the potential impact of an organization in society. How do people behave towards plastic waste, and what actions must be developed to promote recycling? NGOs and business organizations (e.g., CEMPRE – Business Commitment for Recycling, AEPW – Alliance to End Plastic Waste) collaborate in developing a more conscious positioning of society.

Governance

This component captures the organizational structure and decision-making policies, defining which stakeholders an organization will likely identify and engage. Polymer producers and governments as stakeholders have critical decision-making responsibilities. The recycler is responsible for a transparent system that considers adequate remuneration of waste pickers and an audited public balance sheet on recycling performance.

Employees

Employees are the central part of the organization. It must be considered the number of jobs, types of functions, and essential demographics such as wage variations, gender, ethnicity, and education within the organization. The number of recycling jobs can range from 10 (sorting centers) to 300 (cooperatives/recycling associations).

Local Communities

Here, the role of waste pickers' cooperatives is fundamental because they are a relevant link in the supply of waste.

Social Impact

The social impact component addresses the social costs of an organization. It complements the financial costs of the economic layer and the biophysical impacts of the environmental layer. There are two issues: taking the false conclusion that the recycling problem is solved and perpetuating the current working conditions of waste pickers.

Social Benefits

These are the positive aspects of social value creation from the organization's actions. A clear indicator of social benefits will be the improvement of income and working conditions of waste pickers' associations.

Conclusion

This article analyzed the chemical recycling of plastic waste using the Canvas of triple layer business model application from a sustainable development perspective with economic, environmental, and social impacts. This approach allowed a comprehensive analysis of the sustainability-oriented business model. Pyrolysis is one of the plastics' recovery technologies. Although the return-on-investment rates are estimated between 16 and 21%, is not enough to justify a project because of the risks of a reliable supply of the material to be processed or the product to be commercialized, being necessary to consider also the environmental and social benefits. The collaboration of value chains is critical to achieving the full benefits of plastic regeneration. We can conclude that pyrolysis is viable only as a complementary process to other mechanical recycling and energy recovery methods. We can also identify clear social benefits for waste pickers' cooperatives in structuring a more dignified and sustainable relationship, as well as image and recycling obligations on the part of companies and waste treatment obligations on the part of municipal governments.

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