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## Assessment of Reusing Plastic Waste as Filaments for 3D Printers and its Environmental Implications: A Chilean Case Study

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### Abstract

Climate change is still an undeniable reality. Although literature on the subject recognizes that the Earth's climate has undergone variations in the past, the current rate of change is increasing at a rate that is largely due to anthropogenic causes. The increasing rate is characterized by major effects, which include mega-droughts, long summer seasons, and increased temperature fluctuations. Pollution, which comes in the form of air, water, soil, light, and noise, is one of the causes of the increasing rate of climate change. In Chile, 11.4% of the total amount of waste is made up of plastics, polluting the ecosystems where they collect. To address this issue, several reuse methods have been developed and supported by modern technology. This study aims to conduct a quantitative and qualitative analysis of the environmental impact of plastic waste in recent years in the metropolitan region of Santiago (Chile), evaluating whether its reuse as Three-Dimensional (3D) printer filament effectively reduces pollution. If results are positive, large-scale implementation of plastic-collection centers could extend the material's life cycle, promote sustainable production, and generate new economic opportunities.

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## 1. Introduction

The history of polymers dates back to as early as 1845, when a British inventor named Alexander Parkes began exploring the use of cellulose nitrate. Parkes successfully produced a material that was both stiff and flexible enough to be molded. He named this new product Parkesine [1]. This product never really caught on, but it paved the way for later developments.

It was not until nearly three decades later, in 1870, that a chemist named John Wesley Hyatt revived Parkes' ideas and succeeded in producing a new product called celluloid [2]. This product was used to produce a wide array of items, but due to its flammability, it was eventually phased out and replaced with other polymers.

As the 20th century began, the fundamental ideas of modern polymer science began to emerge. In 1907, a Belgium-born inventor named Leo H. Baekeland, who later settled in America, invented the first fully man-made plastic, called Bakelite. This product was later used to produce the first plastic electronic and telephone casings. Later on, a man named Hermann Staudinger also began exploring the molecular structure of polymers, a subject that was met with a great deal of skepticism but eventually earned him a Nobel Prize in Chemistry in 1953.

The following decades, especially the 1950s and 1960s, saw the introduction of new polymers like linear polyethylene, PolyPropylene (PP), polyacetal, polycarbonate, and polyethylene oxide. Simultaneously, new copolymers were introduced to the market, causing plastics to surpass traditional materials like wood and glass, and lowering production costs up to four times. However, this rapid growth had an unforeseen consequence that the majority of people were not aware of initially: the explosion of plastic waste. This was largely due to the lack of an appropriate strategy for handling the waste, which ultimately ended up being dumped randomly across the fields and the ocean under the assumption that plastic was not a major environmental concern.

However, over the years, this concern grew into the development of the concept of the Circular Economy [3], which emphasizes the reuse of materials to create new resources. This was accompanied by the development of global standards such as the ISO 14001 and the ISO 50001, which dictate the ways in which organizations are taking greater responsibilities for the environment [4].

From this new perspective, many small and medium-sized businesses were established, which focused on the recycling of plastic waste through different techniques. The most promising of these is the recycling of plastic waste into 3D printing filaments. Despite its promising results, little research has been conducted to evaluate its effectiveness in mitigating plastic waste's adverse effects on the environment. This paper aims to contribute to this growing body of knowledge and assess the effectiveness of different techniques to solve the problem of plastic waste accumulation.

## 2. Related Work

Plastic has become a common commodity throughout the world, appreciated for the low cost of production as well as the versatility of the material to be molded for a multitude of purposes. Despite the widespread presence of plastic within almost every industry, however, less than 10% of the plastic produced is recycled every year [5]. Many organizations have not made recycling a top priority, not only because of a lack of knowledge about the management of wastes, but also because of the additional cost of recycling plastic wastes [6]. This is no longer the case as organizations are forced to look for strategies to help recycling through the implementation of Extended Producer Responsibility (EPR) [7].

Among the various options, mechanical recycling is the most commonly used. This works effectively with thermoplastics and also requires less investment compared to the other processes. Nevertheless, with every cycle of recycling, the material becomes weaker. Additives are therefore necessary to achieve some of the mechanical properties of the material [8][9]. In comparison, chemical recycling, although effective, is far more energy-intensive and operationally challenging [10]. The other processes, such as energy recovery and biological recycling, are not feasible due to environmental concerns [11] and are also too expensive [12].

Studies have also been conducted on the properties of the recycled materials when used in the 3D printing process. Not all materials can be recycled, and fewer materials can be used to create the filament necessary for the 3D printer

[13][14][15]. Some materials, when melted, release harmful chemicals, which can be detrimental to the environment and the user. This contradicts the concept of sustainability, which is a major factor.

Nevertheless, some of the most popular polymers used in daily life, such as PET (Polyethylene Terephthalate), Despite the challenges, a small number of commonly used polymers such as PET, HDPE (High-Density Polyethylene), PP, ABS (Acrylonitrile-Butadiene-Styrene), and HIPS (High-Impact Polystyrene) show good properties when recycled and reprocessed, which is why they are commonly used for recycling.

However, polymers like PET, HDPE, PP, ABS, and HIPS have been found to show good properties when recycled and processed properly, making them a common option for recycling into recycled filaments.

### 3. Methodology

The methodology employed by this research is descriptive and analytical, combining both quantitative and qualitative approaches to investigate the possibility of utilizing waste plastics as a material for a 3D printing process in the Metropolitan Region of Santiago, Chile. This research can be seen as exploratory in nature and aims to investigate the potential of a new and emerging field of waste plastics recycling.

The sources of the study are based on secondary sources such as government reports, academic journals, and international online databases focused on waste plastics management, recycling techniques, and environmental impact assessment studies. No primary experimental sources are considered for the study.

Moreover, the methodology for the study is outlined in the following phases:

- **Phase 1 – Characterization of waste plastics:** Analysis of the available secondary sources to understand the types of waste plastics available in the region for reuse as a filament for a 3D printer.
- **Phase 2 – Analysis of waste plastics management techniques:** Analysis of the available techniques for the management and recycling of waste plastics, specifically the reuse of waste plastics as a filament for a 3D printer.
- **Phase 3 – Proposal for the process:** Proposing the mechanical recycling process to reuse waste plastics as a filament for a 3D printer based on the available parameters.
- **Phase 4 – Impact assessment:** Estimation of the potential impact on the environment and society based on standardized indicators such as Carbon Dioxide (CO<sub>2</sub>) emissions, resource use, and social benefits.

### 4. Results

#### 4.1. Plastic recycling methods characterization

As indicated in the related work, the most common recycling methods for plastics comprise four categories: mechanical recycling, chemical recycling, energy recovery, and biological recycling. Among these, the six unknown recycling methods of polymers are pyrolysis, hydrogenation, gasification, cracking, alcoholysis, and glycolysis.

Table 1 shows the ranking of different plastic polymers for recyclability as filaments for 3D printing. The table details that while several polymers can be recyclable, only a subset exhibits the thermal and mechanical properties required for filament extrusion.

#### 4.2. Proposal of existing treatment methods for plastic waste into 3D printer

As it was stated before, the use of a comparative method in this study, mechanical recycling was selected as the most suitable method for filament production due to its operational simplicity, lower implementation costs, and compatibility with extrusion-based processes [13][14]. The proposed process integrates six main stages: grinding, washing, agglutination, extrusion, cooling, and filament shaping. The pelletizing stage commonly used in conventional recycling processes is adapted in this framework to directly obtain a continuous filament suitable for additive manufacturing applications [16].

Table 1. Categories of plastic and their recyclability.

Category	Type	Name	Subtypes	Recyclable	Recyclable as 3D Printer Filament
1	PET	Polyethylene Terephthalate		Yes	Yes
2	HDPE	High-Density Polyethylene		Yes	Yes
3	PVC	Polyvinyl Chloride		Yes	No
4	LDPE	Low-Density Polyethylene		Yes	No
5	PP	Polypropylene		Yes	Yes
6	PS	Polystyrene	Expanded PS	Yes	No
			Extruded PS	Yes	No
			High-impact Polystyrene (HIPS)	Yes	Yes
7	PC	Polycarbonate		Yes	Yes

For the impact and time evaluation, the proposed framework considers the production of functional prosthetic devices as a representative application. This case was selected due to its widespread adoption and its relevance in terms of material performance and social impact. The proposed filament production process is designed to meet the biocompatibility and sterilization requirements established by ISO 10993, under the supervision of national regulatory authorities. As shown in Fig. 1, the flowchart of the proposed mechanical recycling process for converting plastic waste into 3D printer filaments, illustrating the sequence of processing stages and their integration with filament extrusion.

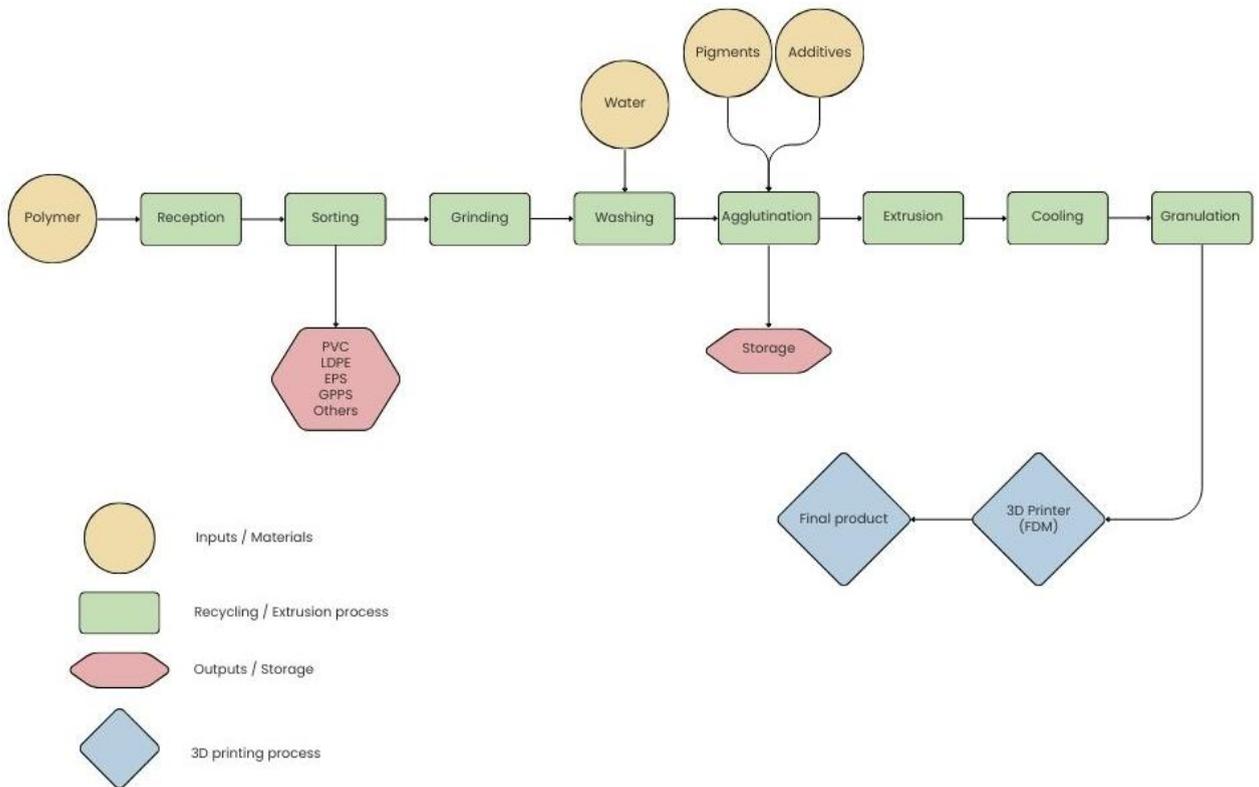


Fig. 1. Flowchart of the proposal for reuse of plastic waste as filaments for 3D printers.

### 4.3. Evaluation of environmental and social costs of the reuse of plastic waste using 3D printer

#### 4.3.1. Environmental impact assessment

Under the Chilean law “19.300”, the mechanical recycling method proposed in the study is included in a group that needs to be evaluated from the environmental point of view. This is mainly attributed to the additives and cleaning materials applied, as well as the process carried out under high-temperature conditions. In assessing the proposed project, as outlined in the study, the environmental impacts were found to be the same as those associated with the mechanical recycling method, including the creation of microplastics, water consumption during the washing process, and the emission of CO<sub>2</sub> during the recycling process.

The mechanical recycling method, however, is not entirely devoid of environmental benefits, as the process could result in the reduction of greenhouse gas emissions, the amount of waste going to landfills, the conservation of natural resources, and the promotion of a circular economy [13]. Although the environmental impacts associated with the mechanical recycling method, such as the creation of microplastics during the grinding process, the large amount of water consumed during the washing process, and the emission of CO<sub>2</sub> during the recycling process, are not desirable, the overall environmental impacts are less significant than those associated with the creation of resin from natural materials, which requires more energy input and natural resources [14].

In order to ensure the proper management of environmental risk, the environmental assurance plan should be integrated, focusing on the major environmental impacts, such as the release of microplastics, the energy input, and the energy-intensive process involved in the recycling method. According to the data available on the energy consumption of these printers, the professional printers operate on an average of 1,000 to 2,000 watts, whereas the home-based printers operate on an average of 350 to 500 watts. This means that the entire process of creating a prosthetic hand can take as much as 20 hours, but the amount of energy required to recycle the plastics is significantly less than the virgin material.

#### 4.3.2. Social impact assessment

A social assessment of the project reveals environmental benefits such as reduced CO<sub>2</sub> emissions as the main advantages of the project. Given the nature of the present project, the most relevant social benefit is its environmental improvements, particularly the reduction of CO<sub>2</sub> emissions. These emissions are valued according to the Social Prices Report issued by the Ministry of Social Development and Family. However, the final magnitude of the benefit will depend on the operational characteristics of the project once implemented (machinery used, number of shifts, required labour, and energy efficiency). These factors determine the amount of CO<sub>2</sub> emissions released and the resulting impact on communities surrounding the polymer-treatment facility.

Then, the social benefit was estimated using a simplified production and emissions model. Indeed, the daily production is calculated using (1).

$$\text{Daily Production} = \text{Machine Operating Hours} \times \text{Production Capacity}. \quad (1)$$

Machine Operating Hours correspond to the operational shift length, while Production Capacity depends on the extruder type., ranging from domestic units of 50 kg/h to industrial units of up to 1,200 kg/h. Therefore, CO<sub>2</sub> emissions are estimated according to (2).

$$\text{CO}_2 \text{ Production} = \text{Daily Production} \times 1.7 ; \quad (2)$$

where a constant emission factor of 1.7 kg CO<sub>2</sub>-eq per kilogram of recycled plastic was applied.

Finally, the social value of the avoided CO<sub>2</sub> emissions per day is calculated using Equation (3):

$$\text{Social Value} = \left( \frac{\text{CO}_2 \text{ Production}}{1000} \right) \times 56.083. \quad (3)$$

The CO<sub>2</sub> emissions were calculated per metric ton and priced at 56.083 per ton, as per the official social pricing formulas.

It is important to note that while these formulas provide a general idea of the potential benefits of a project from a social perspective, actual assessments of a project must also consider external influences such as transportation costs, sources of energy, and influences on local communities.

The overall results of the assessment indicate that mechanical recycling for the production of filaments offers environmental and social benefits such as reduced CO<sub>2</sub> emissions.

## 5. Conclusion

The increased rate of utilization of plastics is considered a primary cause of environmental degradation. The high rate of production and the low cost of plastics have contributed to the increased rate of utilization, which in turn has increased the effects of climate change and the rate of landfills, both formal and informal. Therefore, the increase in the demand for plastics has thus led to the generation of wastes, which exceed the capacities of the existing waste management systems, thereby impacting the integrity of the environment as well as the carbon footprint of the wastes.

In this regard, recycling is considered a vital mechanism for reducing the degradation of the environment as well as the emission of carbon dioxide (CO<sub>2</sub>) into the environment. However, the recycling of plastics is still at its infancy stage, facing a number of barriers, including the cost of recycling as well as the lack of appropriate waste management systems. In addition, the low recyclability of plastics, as well as the lack of appropriate research and training, is considered a barrier to the development of plastic recycling.

The results of this study show that the recycling of plastics through the production of filaments for three-dimensional (3D) printing is considered a vital mechanism for the extension of the lifespan of the wastes generated from plastics. This is because the lifespan extension of the wastes generated from plastics is likely to reduce the generation of wastes, thus creating a clean and healthy environment for the future generation.

In addition, the recycling of the wastes generated from plastics is likely to benefit society at large, as it is considered a vital mechanism for the reduction of carbon dioxide (CO<sub>2</sub>) as well as the development of a Circular Economy within the system. The recycling of the wastes generated from the system is likely to be influenced by the availability of appropriate technology as well as the development of the appropriate regulatory framework to ensure the recycling of the wastes generated from the system. A comprehensive understanding of the recycling of the wastes generated from the system is thus considered vital for the realization of the benefits of recycling the wastes generated from the system. In conclusion, the recycling of the wastes generated from the system is considered a vital mechanism for the development of a sustainable future while creating a clean and healthy environment.

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