Investigating the Economic Feasibility of Community-Scale Plastic Recycling Facilities

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Abstract— **The increasing severity of global plastic waste crisis calls for the need to investigate the feasibility of alternate recycling approaches, particularly in low and middle-income countries such as the Philippines where people's livelihoods are reliant on affordable single-use goods. Low recycling rates in these countries illustrate the inability of their recycling infrastructure to handle the rate at which plastic waste is being generated. A new approach to recycling plastics, specifically community-scale plastic recycling facilities, has the potential to divert significant plastic waste from landfills and repurpose them into higher-value products that would be sold to boost the local economy. The community-scale approach investigated in this study is an attractive investment opportunity for entrepreneurs due to the short-term Return On Investment (ROI) with the potential return rate of 15.3% in one year, which is nearly double the rate a person would receive upon investing in the Philippines stock market. This study examines the economic feasibility of a community-scale recycling system in the setting of the Philippines with a focus on the manufacturing process and the scale of machinery.**

Keywords—community-scale, Return On Investment (ROI), economic feasibility, plastic processing phase

I. INTRODUCTION

The world's growing reliance on plastic and the deficiency of current recycling facilities to keep up with the abundant plastic waste being produced has led to the growing concerns surrounding plastic pollution. It is estimated that of the 8300 million tons of plastic produced from 1950 to 2015, 5800 million tons were only used once, of which 4600 million tons were sent directly to the landfill [1]. The plastic waste problem is exacerbated in low- and middle-income countries where people's livelihoods are reliant on inexpensive, single-use items [2]. The Philippines is one such country that exemplifies this problematic positive feedback loop and has been identified as the third-largest contributor to plastic waste worldwide [2]. Based on 2010 data, the Philippines was generating 0.5 kg of plastic waste per person per day [3], resulting in 1.80 million metric tons of mismanaged plastic waste per year [3]. The majority of plastic waste generated in the Philippines is due to packaging (35-45%) and construction (20%) [4]. Due to the inadequacies in the current recycling infrastructure and lack of resources, only 9% of plastic packaging waste is being recycled (primarily at the industry level) in the Philippines [5].

Political divisions in the Philippines have created a pathway to introduce community-scale plastic recycling in *barangays*, which are the smallest local government units within a Filipino region. A community-scale approach to recycling plastic enables a greater outreach to the people while simultaneously increasing the overall recycling rate of the country. Such an approach can be difficult to implement in regions with large-scale government interventions; however, in the case of the Philippines with *barangays*, community-scale plastic recycling is an appropriate approach to combat the plastic waste crisis. The community-scale approach would benefit the local economy from the creation of new employment opportunities and the introduction of purposeful upcycled plastic products such as bricks. Plastic bricks would deviate plastic from the landfill for a long period while creating value to the Filipino community by addressing their housing needs [6]. An article by the World Economic Forum suggests that the solution to the plastic pollution problem may be through investments by entrepreneurs, emphasizing the potential for profit [7]. The mismanagement of plastic globally showcases an opportunity in locations such as the Philippines for eager entrepreneurs to earn a profit by collecting and processing post-consumer plastic into plastic bricks. This study is intended to determine the economic feasibility of a community-scale recycling facility by analyzing whether a Return On Investment (ROI) within 18 months of producing plastic bricks can be achieved to make this an appealing business venture. Although this community recycling approach is conducted with the Philippines as the testbed, results from this study can also be applied to other middle and low-income communities across the globe.

II. PLASTIC RECYCLING PROCESS

The plastic recycling system is composed of three phases: acquisition, plastic processing, and distribution. The acquisition phase focuses on sourcing the plastic waste needed to create the plastic bricks and transporting them to the facility. The plastic processing phase involves the steps taken to turn plastic waste into plastic bricks. The distribution phase centers around the methodology in which the bricks will be sold and reach the customers' hands. The economic feasibility of a community-scale recycling facility is primarily based on the plastic processing phase, which is the focus of this study.

The plastic processing phase is composed of the following steps in order to transform plastic waste into plastic bricks: shredding, washing, drying, molding, and post-molding. The order in which these steps occur sequentially is presented in **Figure 1**. It is important to note that not all the steps shown in **Figure 1** are required to successfully fabricate a brick. Certain steps can be bypassed depending on the input into the plastic processing phase (e.g., unshredded-contaminated plastic and shredded-cleaned plastic). All the steps are displayed to thoroughly portray the entire set of processing stages that plastics can go through during this phase. To conduct this study, a select number of machinery that are currently used to execute each step are defined and categorized into levels (hobbyist, community, and industrial) based on their throughput capability or machinery price (Table I).

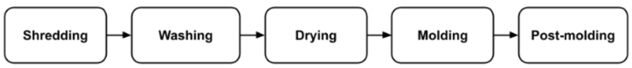

Figure 1. Plastic processing steps

A. *Shredding*

The shredding step breaks down post-consumer plastic waste into flakes so that the plastic can be easily and evenly melted. Eight options are listed for this step, including a no shredding option [8-12]. The seven machinery options selected for this step are categorized into the following levels based on their throughput capability: hobbyist (<100 kg/h), community (100-2000 kg/h), and industrial (>2000 kg/h).

B. *Washing*

The washing step removes contaminants off plastic flakes. Five machinery options and a no washing option are in this step [13-17]. The five machines are categorized into the following levels based on their costs: hobbyist (<$1000), community ($1000-$2000), and industrial (>$2000).

C. *Drying*

The drying step removes all the moisture in the plastic flakes prior to the molding step. The removal of residual water is crucial to reduce the number of air bubbles in the final brick product, which increases the brick's susceptibility to failure. There are five options in this step, including a no drying option [18-20]. The four machinery options are categorized into three levels based on their costs: hobbyist (<$500), community ($500-$1000), industrial (>$1000).

D. *Molding*

The molding step melts the dried plastic flakes to form the densified plastic brick. This step cannot be skipped and is composed of seven machinery options that are categorized into the following levels based on the machinery cost: hobbyist (<$2000), community ($2000-$7000), and industrial (>$7000) [9, 21-25].

E. *Post-molding:*

The post-molding step encompasses activities such as de-molding and removing flash (excess plastic that results from a mold that is overfilled). The actions required in the post-processing step are determined on a case-by-case basis depending on the molding step. Therefore, options are not listed for this step and it is assumed that the procedure for this step will be the same for the final product regardless of the variability in the preceding steps.

TABLE I. MACHINERY OPTIONS FOR EACH STEP IN THE PLASTIC PROCESSING PHASE

Processing Step	Options	Price	Processing Rate (kg/h)	Level
Shredding	Shredder H1	$3,200	50	Hobbyist
	Shredder C1	$2,800	200	Community
	Shredder C2	$4,800	320	Community
	Shredder C3	$3,560	1500	Community
	Shredder I1	$5,000	3000	Industrial
	Shredder I2	$10,000	5000	Industrial
	No shredding			
Washing	Washer H1	$400	<2000	Hobbyist
	Washer H2	$400	<2000	Hobbyist
	Washer H3	$400	<2000	Hobbyist
	Washer C1	$1,000	3150	Community
	Washer I1	$4,032	2000	Industrial
	No washing			
Drying	Dryer H1	$566	50	Hobbyist
	Dryer HC1	$0	50	Hobbyist/ Community
	Dryer C1	$764	100	Community
	Dryer I1	$1,053	160	Industrial
	No drying			
Molding	Compression H1	$228	<17.9	Hobbyist
	Injection H1	$287	<17.9	Hobbyist
	Extrusion H1	$1,379	<17.9	Hobbyist
	Compression C1	$3,500	17.9	Community
	Melter C1	$7,000	50	Community
	Injection I1	$16,000	381.6	Industrial
	Extrusion I1	$57,000	300 - 700	Industrial

F. *Assumptions*

Due to limited information on the plastic processing rate for some of the machinery in each step, the following assumptions are adopted based on operational information for manufacturing processes, as well as the economics of plastics processing [26]:

1. Hobbyist level washers and molding machines have a throughput rate that is less than the other machinery options within the corresponding step.
2. For dryer HC1, which is a solar drying option, there will be an average of 5 hours per day of sunlight to account for various weather conditions. Therefore, a drying time per batch (250 kg of plastics in a batch) is 5 hours, which equates to 50 kg of plastics drying per hour.
3. The production rate of both the melter C1 and compression C1 options are assumed based on our understanding of the machinery, the cooling process, and the mold geometry of the bricks. In order to obtain a more accurate production rate for both machinery, further testing will be necessary.

III. THE OPTIMAL PLASTIC PROCESSING PHASE

In order to determine an economically feasible methodology of community-scale plastic recycling, options for each step are analyzed to develop various combinations of plastic processing phases that differ in the steps and the machinery utilized. The following criteria are used to compare the machinery options for each step when creating the combinations: cost ($), throughput (kg/h), footprint (m^2), and energy usage (kW). Cost and throughput are ultimately determined to be the most critical factors when investigating the initial investment and ROI for the combinations created. While the acquisition method is not within the scope of this paper, it is important to acknowledge that the plastic processing phase is affected by the state of the input plastic material: clean versus unclean, and unshredded versus shredded. The cost of the raw material is dependent on the state of the input material which ultimately affects the cost to manufacture the plastic bricks.

Also, it is important to note that the various combinations created are centered around the machine selected for the molding step, which determines the brick production rate of the recycling facility. Combinations investigated in this study only consist of compression C1 or melter C1 as the molding machine due to their community-scale plastic processing rate. From the possible combinations investigated, the one presented in Table II is determined to be the most feasible economically for community-scale recycling after evaluating its ROI from its sales and revenue projections.

TABLE II. COST, PRODUCTION RATE, ENERGY USAGE, AND FOOTPRINT FOR THE OPTIMAL COMBINATION

Optimal Combination					
Step	**Shredding**	**Washing**	**Drying**	**Molding**	**TOTAL**
Choice	Shredder C3	Washer C1	Dryer HC1	Melter C1	
Price ($)	$3,560	$1,000	$0	$7,000	$11,560
Rate (kg/h)	1500	3150	50	50	
Energy Usage (kW)	30	22	0	1.12	53.12
Footprint (m^2)	0.9	7.2	4.6	0.9	13.7
Rationale	Community-level throughput rate & low energy use	Lower price & high rate	No drying cost	Community-level processing	

IV. ROI BASED ON SALES AND REVENUE PROJECTION

A sales and revenue projection is created for all of the combinations investigated in this study to determine whether the arrangement had the ROI of an economically viable recycling facility (ROI within 18 months or less). The sales and revenue projections, including the Cost of Goods Sold (COGS), for the optimal combination are listed in Table III.

TABLE III. SALES AND REVENUE PROJECTIONS FOR THE OPTIMAL COMBINATION

Sales and Revenue				
	Months 0-6	**Months 7-12**	**Months 13-18**	**Months 19-24**
Sale (Brick)	14976	15912	16286	17222
COGS (Brick)	$23,590	$25,065	$25,654	$27,129
Revenues	$37,440	$39,780	$40,716	$43,056
Gross Profit	**$13,850**	**$14,715**	**$15,062**	**$15,927**
Net Overhead	$17,388	$5,847	$5,889	$5,908
Net Profit	**-$3,538**	**$8,868**	**$9,172**	**$10,019**

In order to create the sales and revenue projections for all the combinations examined, few assumptions are adopted:

1. The recycling facility operates eight hours each workday, five days a week, and 30 days a month.
2. The cost of plastic waste ($0.44/kg) is based on PET plastic specifically due to their abundance in the recycling waste stream compared to other types of plastics [27]. The mass of each brick is 3.58 kg.
3. A selling price of $2.50 per brick is considered in order to compete with the current market price of $1-$3 per brick [28].
4. During the first two years, the plastic recycling facility will not be able to sell all of its bricks even if it is producing at full capacity. Therefore, a sales projection of 80%, 85%, 87%, and 92% of the combination's maximum brick production capability in increments of 6 months up to 2 years is adopted.

The net overhead costs consist of operational costs to maintain the recycling facility. The predominant differences in overhead costs between the combinations scrutinized in this study occur in the number of employees, electricity cost, and initial investment in machinery.

A. *Number of employees*

When determining the number of employees required to operate the recycling facility for the optimal combination, an evaluation of the labor hours and level of supervision for each machinery within the combination is conducted. The number of employees is an important factor to evaluate because this is the largest ongoing operational cost to maintain the recycling facility. Calculations on the number of hours that would be required for each machine within a combination to process 5000 kg of plastic are determined to evaluate the time spent by the plastics at each step within the processing phase. In addition to the amount of time required, a supervision level for each step is determined based on the amount of human interaction required to operate the machinery. Supervision levels are classified as none for no human interaction, minimal for little human interaction, and constant for frequent human interaction. A listing on the hours and supervision level required for each step in the optimal combination is presented in Table IV. An assessment of the time required in each step along with its corresponding supervision level determines the amount of full-time and part-time employees required for each combination. The optimal combination requires one full-time and one part-time employee to manufacture the bricks.

TABLE IV. NUMBER OF HOURS AND SUPERVISION LEVEL REQUIRED FOR EACH STEP IN THE OPTIMAL COMBINATION

Optimal Combination: Labor Hours & Supervision Level					
Step	**Rate (kg/h)**	**Plastic (kg)**	**Hours**	**Days**	**Supervision**
Shredding	1500	5000	3.3	0.4	Constant
Washing	3150	5000	1.6	0.2	Minimal
Drying	50	5000	100.0	12.5	Minimal
Molding	50	5000	100.0	12.5	Constant

B. *Electricity costs*

Different type and quantity of machinery in the combinations examined in this study create the need to determine the electricity costs and their implication on the ROI. The electricity cost for the combinations investigated is determined using the following information: the amount of bricks produced and sold based on the sales projections (Table III), the mass of each brick, the energy usage of each machinery (Table II), and the electricity costs in the Philippines ($0.113/h) [29]. A listing of the electricity cost that is factored into the net overhead of the optimal combination is provided in Table V.

TABLE V. ELECTRICITY COST FOR THE OPTIMAL COMBINATION

Optimal Combination Electricity Cost							
	Total Mass (kg)	**Shred (h)**	**Wash (h)**	**Dry (h)**	**Mold (h)**	**Total Energy (kW)**	**Total Cost**
Months 0-6	53614	36	17	1072	1072	2648	$299
Months 7-12	56965	38	18	1139	1139	2813	$318
Months 13-18	58305	39	19	1166	1166	2879	$325
Months 19-24	61656	41	20	1233	1233	3045	$344

C. *Initial investment in machinery*

The last differential factor in overhead costs between the combinations investigated in this study is the initial investment in machinery. The initial investment in machinery for the recycling facility is calculated into the overhead for the first six months, which is the reason behind the high overhead cost for that duration for all of the combinations. The initial investment in the machinery for the optimal combination is $11,560.

D. *ROI of optimal combination*

After evaluating the sales and revenue projections of the optimal combination, an ROI of 8.39 months is determined. The ROI calculated is below the 18 months benchmark, which classifies the combination as an economically feasible community-scale recycling opportunity in the Philippines. It is important to note that the cost for the mold to create the bricks is not included in this investigation. The varying complexities of brick geometries that currently exist in the market create a wide range of costs for the molds. The focus of this investigation is in determining an economically feasible community-scale plastic processing phase that is influenced by the machinery utilized rather than brick geometry; hence, costs for molds are not considered for simplicity. Additionally, the electricity rate and salary rate for employees that are incorporated into the net overhead of Table III are based on Filipino rate.

V. CHARACTERISTICS OF AN ECONOMICALLY VIABLE COMMUNITY-SCALE RECYCLING FACILITY

A. *High community-scale production rate*

One of the successes in the optimal combination is attributed to its higher community-scale brick production rate (13 bricks an hour) compared to the alternative community-scale molding machine, compression C1 (five bricks an hour). The melter C1's production rate enables the generation of revenue that is capable of offsetting the initial investment towards machinery quickly. An alternative combination composed of shredder C1, washer C1, dryer C1, and compression C1 is also investigated in this study. Despite having a lower initial investment ($8064) and a lower electricity cost ($10-$12 semi-annually) compared to the optimal combination, the lower brick production rate of compression C1 results in a revenue of $177-$193 every six months. The smaller revenue generation every six months leads to an ROI that far exceeds 18 months, making the alternative combination studied unappealing.

B. *Input material*

Another success factor of the optimal combination is the input material. The optimal combination is created with the intention of using contaminated-unshredded plastic as inputs, which are the most cost-effective in the plastic waste stream. It is, however, important to note that use of contaminated and unshredded plastic as input can lead to multiple complications during the recycling process *viz.*, damage to equipment by jamming and breakdown; danger to workers dealing with sharp and small pieces; contamination of upcycled products such as the bricks having less than desirable mechanical strength and toughness; health hazards due to bio-degradable wastes present in plastics as contaminants; risk of fire when flammable objects and particles are present; possibility of the workers to be infected with vector-borne diseases; and so on. Another alternative combination that is considered in this study is composed of a shredder C3 and melter C1 with an input material of clean-unshredded plastic. This combination can be seen as a simplified plastic processing phase of the optimal combination where the washer and the dryer are removed due to a change in the input material. At first glance, this alternative combination has a better outlook since it requires a smaller investment in machinery ($10,560) and requires only one full-time employee to operate the entire plastic processing phase. However, due to the input material being clean plastic, an additional $0.73/kg premium is added to the cost of manufacturing the brick [27]. The brick ends up exceeding the market price of bricks ($1-$3) and attains a COGS of $4.18 per brick. Since the sales and revenues table (Table III) is created with the assumption of selling each brick at $2.50 to be at a competitive price with the market, this combination results in investors never seeing a return on their investment.

VI. Other considerations

A. Initial investment cost

A factor that should be considered when determining an economically viable community-scale plastic recycling facility is the initial investment towards machinery. For a plastic processing rate of 50 kg/h (optimal combination), the initial investment cost should not exceed $25,000 to ensure an ROI within 18 months. The low initial investment would also allow people of low income to pursue the entrepreneurial opportunity, especially in locations such as the Philippines where a majority of the population relies on sachet-quantity of everyday essentials on a day-to-day basis.

B. Staffing

Another factor to consider when developing an economically-viable community-scale plastic recycling facility is establishing a wage gap between workers that execute low or high-skilled tasks. For the optimal combination in this study, the recycling facility requires a full-time and a part-time worker to operate the facility. The full-time worker is tasked to complete the higher-skilled job of melting and forming the bricks at a higher wage ($310 per month), while the part-time worker is tasked to simply shred, wash, and dry the plastic (low-skilled tasks) at a lower wage ($120 per month). The distribution in wages based on the skills required to complete the tasks enables greater overall cost savings.

C. Space

One last factor to consider when creating a community-scale plastic recycling facility is the amount of space (footprint) required for operation. Space is important to consider based on the intended facility location. This study considers Metro Manila, Philippines as the location for the recycling facility. Real estate in Metro Manila is scarce and can be expensive. Therefore, the smaller the footprint of the plastic recycling facility, the lower the operational cost will be for investors in this location.

VII. Economic opportunities from community-scale plastic recycling

While this study focuses specifically on community-scale plastic recycling in the Filipino setting, a study conducted in Asia (including three locations in Indonesia, Beijing in China, and Matale in Sri Lanka) also identified medium-scale platforms for recycling of organic materials to be optimal opportunities for financially feasibility relative to the larger capacity plants [30]. Advantages of medium-scale plants that were identified in the study included exerting greater control over waste input and product quality relative to larger-scale composting plants. In addition, the study also indicated extra income opportunities in managing the plant from tipping fees, which are limited in small-scale plants [30].

While operating a plastic recycling facility offers employment opportunities for those who work directly on site, the facility also has the potential to expand self-employment opportunities within the community. A study of the lifecycle of PET bottles in Southeast Asia found that an average of 26% of PET bottles is collected for recycling across six countries [31]. The results in the report exhibited a downward trend in collected-for-recycling rates as GDP per capita increased [31]. As GDP increased, so did the cost-of-living which led to recyclable collectors abandoning their jobs because it was no longer sufficient to maintain the same standard of living [31]. By incentivizing plastic recycling through the creation of value-added products such as bricks, self-employment through the collection of recyclable plastics may again be an appealing income source. The increase in plastic recycling would enable more plastics to diverge from the landfill and the ocean.

VIII. Conclusion

All over the world, and especially in urban areas, plastic waste generation has accelerated recently due to fast paced industrialization, urbanization, and population growth. The acceleration is especially prevalent in countries such as the Philippines where the majority of the population relies on obtaining goods in sachet quantities to maintain their livelihoods. The limited enforcement of plastic recycling regulations in many low and middle-income countries, such as the Philippines and their Ecological Solid Waste Management Act of 2000, can be attributed to insufficient financial and technical assistance available within the government [32]. Community-scale plastic recycling is an appealing solution to the ever-growing plastic problem in areas consisting of small governing units (e.g. *barangays* in the Philippines).

This study aimed to investigate an economically feasible plastic processing phase of a community-scale plastic recycling facility that converts post-consumer plastic waste into plastic bricks. An analysis of various potential plastic processing combinations identified a facility with a ROI of 8.39 months, due to its high plastic throughput rate (50 kg/h) and a low initial investment ($11,560), as financially viable. This optimal plastic processing phase was composed of the following steps: shredding, washing, drying, and molding. The return rate for the first year of operations with the identified optimal plastic processing phase combination and its associated technology would equate to 15.3%, which is almost double the return rate a person would receive if they invested their money in the Philippines stock market [33]. In addition to providing economic opportunities, the community-scale plastic recycling approach serves to combat the plastic waste crisis in low and middle-income countries such as the Philippines by incentivizing plastic recycling.

Future investigation on the supply chain of PET plastics along with the distribution channel of the bricks would contribute to the economic analysis that was conducted in this study. In addition, further validation on the throughput rate of the melter C1 and the dryer HC1 machines in the optimum combination would be important to verify whether the machinery has the capability in keeping the ROI low.

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