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THE ROLE OF PLASTIC RECYCLING SHOPS IN KHULNA CITY WITHIN A CIRCULAR ECONOMY FRAMEWORK

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ABSTRACT

Plastics are widely used in many industries, leading to a growing plastic waste problem. To address this, a shift from a linear economy to a circular economy is required. In Bangladesh, the waste management sector predominantly relies on the informal sector, which remains underappreciated and inadequately supported. This study evaluates the environmental, economic, social, and urban development dimensions of recycling shops within the informal sector, highlighting their potential to alleviate ecological burdens, enhance energy efficiency, and generate local employment. A comprehensive methodology encompassing field surveys, environmental and economic benefit calculations, and fuzzy logic analysis are employed. The findings demonstrate that recycling shops, through a circular economy approach, substantially mitigate greenhouse gas emissions, reduce litter, save energy, and conserve landfill space. Among the 35 recycling shops examined, 22.86% were identified as low-volume recyclers, 48.57% as medium-volume recyclers, and 28.57% as high-volume recyclers, each group exerting correspondingly low, medium, and high positive impacts on the environment and society. Collectively, these shops manage 6.68 tons of PET bottle labels, reduce greenhouse gas emissions by 509.35 MTCE, prevent 202,186.9 tons of litter, save 5,728.1 m³ of landfill space, and conserve 406.8 barrels of oil monthly. Additionally, they employ 427 individuals. Expanding recycling shop operations, exploring new recycling technologies, and examining supportive policies are crucial for improving Khulna City's plastic waste management and overall sustainability.

Keywords: *Circular economy, Environmental & economic benefits, Plastic waste, Recycling shop, Sustainability*

1. INTRODUCTION

Plastics have become ubiquitous and play a crucial role in the functioning of various industrial sectors, being utilized in nearly every aspect. They are employed in a range of sectors, including packaging, electronics, healthcare, sports, aerospace, transportation, construction, and many more. Their affordability, lightness, and chemical resistance make them a favoured choice over other materials, resulting in a growing amount of plastic waste in both household and industrial refuse (Duru et al., 2019). As the human population grows, plastic waste also continues to rise. The global production of plastic waste is increasing drastically, faster than expected, as a result of the "take-make-use-dispose" linear economic system, with obvious negative effects on the environment (Ng et al., 2018). The way to balance our use of limited natural resources while strengthening our economic system is to switch to a circular model (Bianchi & Cordella, 2023), in which resources and byproducts experience many production and consumption cycles. Shifting to a circular economy (CE) is also the best way to fight plastic pollution (Jambeck et al., 2018). It's becoming more important to reduce plastic waste and improve eco-friendly designs. A CE framework aims to minimize plastic waste and environmental contamination, addressing all value chain phases from design to end-of-life (Syberg et al., 2021).

In Bangladesh, the per capita consumption of plastic witnessed a significant increase, moving from 3.01 kg in 2005 to 9.0 kg in 2020 (World Bank, 2021). Due to the traditional methods of collection, transportation, and crude dumping of municipal solid waste, the environment and sanitary conditions in Bangladesh are typically rapidly deteriorating (Moniruzzaman et al., 2011). Waste collection rates in developing countries in Asia and the Pacific range from low to moderate. These rates are between 40–80% in developing nations, but in more developed economies like Japan, Australia, the Republic of Korea, and Singapore, they approach nearly 100% (Jain, 2020). In the context of sustainable and ecologically responsible management, the effective recycling of solid wastes, particularly plastics, has become a focal point at the local level. Within the domain of municipal solid waste

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management, recycling has been identified as a sustainable and well-regarded strategy (Moniruzzaman et al., 2011).

In many developing countries, waste management is dominated by the informal waste sector (Schluep, 2014) and they play a crucial role (Awasthi, 2022) and this is so evident in Bangladesh. Low-skilled labor force, outdated infrastructure, poverty, and a lack of reasonably priced services are some common factors to exacerbate the existence of the informal waste sector in developing countries (Morais et al., 2022). Waste pickers, waste collectors (hawkers), waste traders (dealers or middlemen), and recycling shops (RS) work in a chain to manage municipal solid waste (MSW) informally in Bangladesh. The waste hawkers purchase different types of solid waste including plastic from households, institutions, and businesses which is a common practice in almost every city of the country. The waste traders buy that waste from waste hawkers and waste pickers and sell it to local RS. Individuals working in the informal waste sector make a living by collecting, sorting, and trading waste materials (Wilson et al., 2006), thus generating income for small businesses and other organizations. RSs are top of the informal sector hierarchy and play a significant role ecologically and economically. In plastic recycling, waste materials are initially collected, subsequently categorized based on their polymer types, and then processed either by reducing them to minuscule flakes or melting them into pellet form (Kabir et al., 2021) which is also practiced by plastic RSs situated in Khulna and other cities of Bangladesh.

In Khulna city, the existing RSs have been actively converting urban plastic waste, which includes types such as PET, HDPE, PVC, LDPE, PP, PS, and more, into derivatives like plastic flakes, granules, and new plastic commodities (Bari et al., 2012; Kabir et al., 2021; World Bank, 2021). These flakes and pellets are sent to plastic industries, mainly located in the capital city, Dhaka, in bulk to be used in further production as raw materials. According to the Recycling Centre at Stanford University, USA, 1 ton of recycled plastic saves 16.3 barrels of oil or 5,774 kilowatt hours of electricity (UNDP, 2022). Recycling plastic waste also significantly reduces carbon emissions by 42% compared to conventional plastic production (Saleem et al., 2023). The ecological and economic significance of local plastic RSs has not been statistically evaluated in Bangladesh until now. Therefore, this study aims to assess the integral role of plastic RSs in Khulna City, emphasizing the contribution of the informal sector to the city's municipal solid waste (MSW) management, particularly plastics. The findings of this study may assist Khulna City Corporation (KCC) and other municipalities in Bangladesh, as well as those in other developing countries, in recognizing and formalizing the informal waste management sector. It highlights that the RSs and the informal waste sector have a significant contribution to both the environment and society.

2. CIRCULAR ECONOMY

Over recent years, plastics have become widespread globally due to their versatile uses, even with their dependence on non-renewable resources. In advanced technology industries, plastics play a crucial role in replacing metals and other scarce resources (P G C & Ratnayake, 2024; Plastics Industry Association, 2024). Both in developed and developing nations, the production and distribution of plastics are on the rise. A worldwide (CE) approach could be the solution to this concern (Kirchherr et al., 2023). The CE aims to use resources for an extended period, maximizing their value during use, and then refurbishing and recycling products and materials once they reach the end of their lifespan (Mrowiec, 2018). Improved plastic product design, increased recycling rates of plastic waste, and superior quality recycled materials will enhance the market for recycled plastics. This will lead to a sustainable, low-carbon, resource-efficient, and competitive economy (Mrowiec, 2018). Therefore, many governments and international organizations have been promoting the CE concept (Van Eygen et al., 2018).

In many regions, including the USA, Japan, China, and the European Union (EU), there are compulsory legal measures and recommended guidelines in place that advocate for increased recycling rates and a decreased reliance on primary or virgin plastics at state, national, or international levels (Shamsuyeva & Endres, 2021). For example, in 2018, the EU established recycling goals for all packaging materials: 65% by 2025 and 70% by 2030. Specifically for plastics, the targets are 50% by 2025 and 55% by 2030 (European Commission, 2018). There are primarily two recycling methods: "closed-loop recycling" and "open-loop recycling" (Huysman et al., 2015; Valerio et al., 2020). In "closed-loop recycling," the intrinsic properties of the recycled plastic remain largely unchanged, allowing the recycled material to be used for the same purpose as the original material, such as recycling bottles back into bottles (Welle, 2011). On the other hand, "open-loop recycling" entails a change in the inherent properties of the recycled plastic, making it unsuitable for its original application. However, it can be repurposed for different plastic products, like turning bottles into fibers (Sarioğlu & Kaynak, 2018).

To promote a CE, it is essential to efficiently and cost-effectively retrieve and repurpose used materials for production. However, this process often faces several challenges. Materials recycling facilities (MRFs) grapple with numerous operational complexities, including identifying recyclable materials, sorting and separating various types of materials, maintaining the purity of materials to prevent value degradation from contamination, and securing or facilitating transportation to potential markets for the recovered materials (Jacobs et al., 2022). These challenges often amplify as products evolve to be more complex or robust in their design and manufacturing processes. This complexity is further intensified when products contain a mix of materials, especially if some of them are hazardous, or when components are tightly integrated (Jacobs et al., 2022). A proposed CE model is illustrated in Figure 1 where local plastic RSs and plastic industries in the country simultaneously play an important role in this chain.

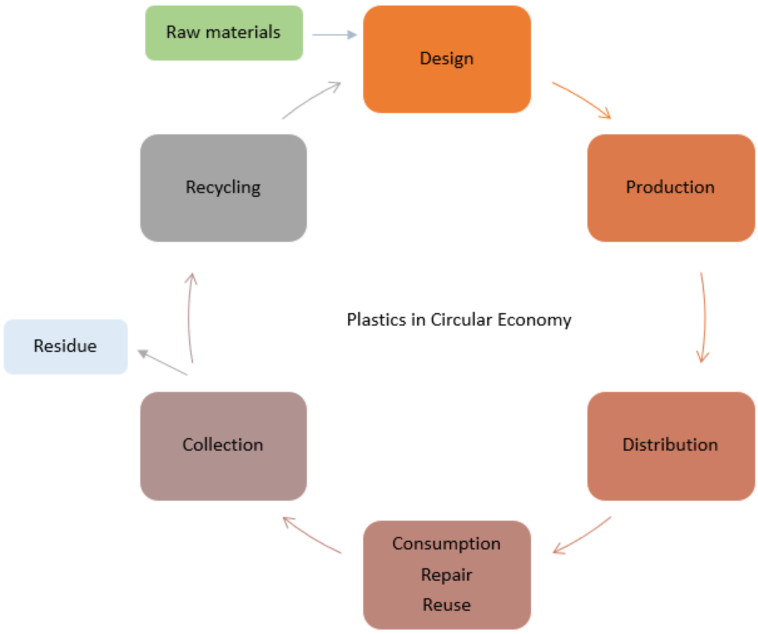

Figure 1: Plastics in the CE

3. MATERIALS AND METHODS

3.1 Study Area

In the context of this research, Khulna, located in Bangladesh's southern region adjacent to the Bay of Bengal, is of primary interest. Khulna is the third-largest city in Bangladesh and one of eight major administrative divisions of Bangladesh. The city area is governed and managed by the KCC. The KCC is subdivided into thirty-one specific local administrative divisions, commonly referred to as "wards". Spanning an area of 45.65 square kilometers, the city houses approximately 1.5 million inhabitants (KCC, 2022) and generates approximately 1000 tons MSW daily (Noman et al., 2023). In 2022, the southern region of Bangladesh was connected to the country's capital via the Padma Bridge, significantly improving communication and transportation. As a result, Khulna is anticipated to undergo rapid urbanization, which may lead to increased waste generation and evolving consumption patterns. To explore this issue, a comprehensive field survey was conducted to identify RSs in Khulna city that primarily focus on recycling plastic waste. These shops are mainly located near the intercity railway station, bus terminal, and city river port. The areas included in this research are Fulbari, Daulatpur, Khalishpur, Sonadanga, Sheikh Para, Dakbangla, Zero Point, and Lobonchora, each comprising multiple wards, as depicted in Figure 2.

3.2 Field Survey

The number of RSs in Khulna city varies significantly. Previous data may not accurately represent the current situation. This survey identified and categorized plastic RSs based on their operations, resulting in the identification of thirty-five plastic RSs in Khulna City. These shops were classified into three distinct groups: low-volume, medium-volume, and high-volume recyclers based on their monthly recycling metrics. Collectively they recycle around 835 tons of mixed plastic waste every month. A direct measurement approach was used to assess both recyclable and non-recyclable (PET bottle label) plastic waste for each RS. The average monthly recycled plastic waste by each shop was recorded to illustrate the role of RSs within a CE framework. Additionally, the current number of workers in these shops was recorded to understand the employment capacity of RS.

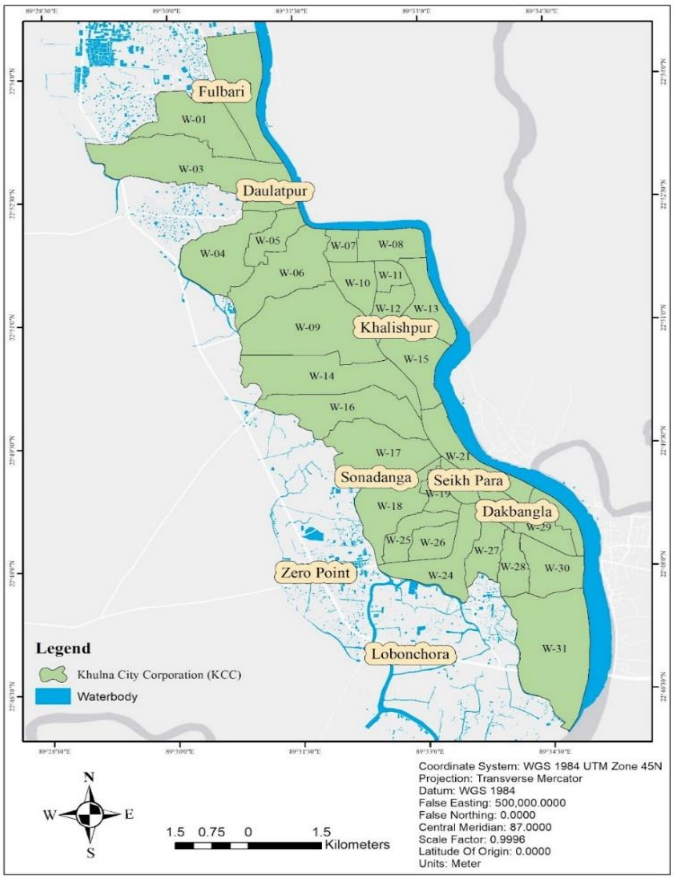

Figure 2: Detailed map of KCC with locations of RS

3.3 Environmental and Economic Benefits Calculations

The ecological advantages of recycling plastic waste can be gauged through various metrics, including the conservation of landfill space, reduction in waste litter, mitigation of greenhouse gas emissions, and energy savings (Global Green USA, 2002; Morris et al., 2005). Those benefit indexes are calculated by multiplying environmental and economic benefits (shown in Table 1) from established life cycle analysis (LCA) studies of plastics with the amount of plastic waste recycled per month in the RS. For example, let an RS recycle "T" tons of plastic waste per month. So, the contribution to saving energy per month by that shop is equal to (T * 4.08) barrels of oil, and this calculation procedure was shown in a study by (Nasiri & Huang, 2008).

Table 1: Environmental and economic benefits of plastic waste recycling (Morris et al., 2005; Nasiri & Huang, 2008).

Environmental & economic benefits	*Plastic Waste*
Energy savings (barrels of oil/ton)	4.08
GHG avoided (MTCE*/ton)	0.61
Litter avoided (tons/ton)	242.14
Landfill space avoided (m^3/ton)	6.86

Note: *MTCE = Metric tons carbon equivalent*

3.4 Fuzzy Analysis of the Positive Impact of RS

Fuzzy sets are sets with ambiguous boundaries. A fuzzy set offers a way to represent the degree of membership rather than accepting or denying it, and its wide use and popularity are related to its ability to tolerate imprecise and linguistic data (Milutinović et al., 2016). Fuzzy logic is essentially a multi-valued logic that enables intermediate values to be established between conventional evaluations, such as yes/no, true/false, high/low, and so on (Preeti & Manju, 2015). It offers a fairly simple approach to drawing firm conclusions from hazy, ambiguous, or imprecise information (Surya & Abhishek, 2023). Three linguistic terms named Low, Medium, and High are set up as membership functions for the numerical representation of all the inputs and an output illustrated by triangular fuzzy quantities (Zadeh, 1975) as shown in Figure 3. RSs are classified into low, medium, and high categories based on their monthly waste recycling volumes. Therefore, the positive impact varied based on their activities.

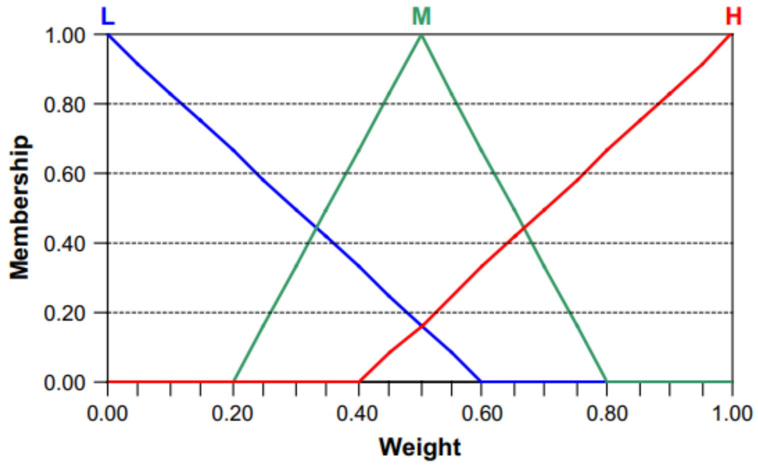

Figure 3: Membership distribution for fuzzy weights

The recycled volume, key environmental and economic benefit indicators (GHG avoidance, non-recyclables management, landfill space avoidance, litter avoidance, energy savings), and worker count are incorporated as fuzzy input parameters. Utilizing these, nine fuzzy rules are devised to determine the resulting fuzzy output, denoted as the "positive impact" of each shop. The steps are described below.

Step 1: Input and fuzzy rules setup

The quantity of plastic waste recycled by each shop monthly, along with their contributions to GHG emission avoidance, non-recyclable management, landfill space avoidance, litter avoidance, energy savings, and employment, are considered fuzzy inputs. The Mamdani model is used in this study. This model expects the output membership functions (MF) to be fuzzy sets (Garcia-Diaz et al., 2013). Based on the fuzzy inputs, "if-then" linguistic fuzzy rules have been set. Nine rules are derived from existing and possible practices. The rules are a combination of fuzzy sets (input variables) that deduce a result. This phase is called *Inference* (Milutinović et al., 2016) as shown in Figure 4.

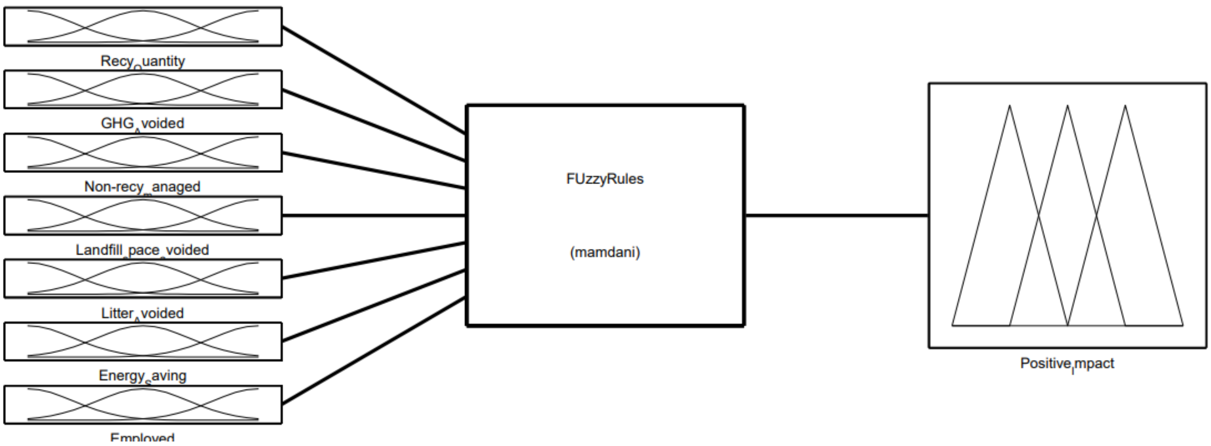

Figure 4: Fuzzy Inference System

Step 2: Recycled quantity (First input)

Three ranges (membership functions) named low, medium, and high are set for this variable. Numerically, the total range is selected between 0 and 125 tons. The low is set between 0 and 9.5 tons, the medium is set between 9.5 and 20.5 tons, and finally, the high is set between 20.5 and 125 tons. This grouping is based on the real-site scenario of RS's monthly activities in Khulna city.

Step 3: GHG avoided (Second input)

The specified range is demarcated between 0 and 75 MTCE. Categories are defined such that the 'low' range encompasses 0 to 5.8 MTCE, the 'medium' range lies between 5.8 and 13 tons, and the 'high' range extends from 13 to 75 MTCE. These categorizations are derived from calculations concerning the environmental benefits of reducing GHG emissions.

Step 4: Non-recyclables managed (Third input)

The designated range spans from 0 to 1 ton. The classifications are as follows: the 'low' category encompasses weights from 0 to 0.076 tons, the 'medium' ranges between 0.076 and 0.175 tons, and the 'high' category extends from 0.175 to 1 ton. These divisions are established based on actual monthly observations of non-recyclable handling procedures in RS.

Step 5: Landfill space avoided (Fourth input)

The delineated range extends from 0 to 825 m^3. Within this spectrum, the 'low' classification ranges from 0 to 65 m^3, 'medium' is between 65 and 150 m^3, and 'high' spans from 150 to 825 m^3. These divisions are derived from calculations associated with the environmental advantages of conserving landfill space.

Step 6: Litter avoided (Fifth input)

The defined range is established from 0 to 29,060 tons. Within this framework, the 'low' category spans from 0 to 2,300 tons, 'medium' ranges between 2,300 and 5,300 tons, and 'high' extends from 5,300 to 29,060 tons. These categorizations are formulated based on calculations emphasizing the environmental benefits of mitigating litter.

Step 7: Energy saving (Sixth input)

The designated range spans from 0 to 492 barrels of oil. Within this spectrum, the 'low' classification is defined from 0 to 38 barrels, 'medium' lies between 38 and 90 barrels, and 'high' covers from 90 to 492 barrels. These divisions are anchored on calculations related to the environmental advantages of energy conservation.

Step 8: Employment (Seventh input)

The specified range is delineated from 0 to 33 workers. Within these parameters, the 'low' category comprises 0 to 9.5 workers, 'medium' spans from 9.5 to 14.5 workers, and 'high' ranges from 14.5 to 33 workers. These categorizations are grounded on empirical observations from actual laborer counts at RS.

Step 9: Fuzzy rules

In this study, a series of nine "if-then" linguistic fuzzy rules were established to facilitate the processing of inputs to derive the desired output. For example, If (Recy_Quantity is Low) and (GHG_Avoided is Low) and (Non-recy_managed is Low) and (Landfill_space_avoided is Low) and (Litter_Avoided is Low) and (Energy_Saving is Low) and (Employed is Low) then (Positive_Impact is Low). The rest of the rules followed this pattern. Where Recy_Quantity, GHG_Avoided, Non-recy_managed, Landfill_space_avoided, Litter_Avoided, Energy_Saving, and Employed are linguistic variables, and ‘low’, ‘medium’, and ‘high’ are their possible fuzzy values.

Step 10: Output

The output variable, termed 'Positive Impact', is quantified on a scale of 0 to 100. Within this scale, a 'low' impact is defined from 0 to 40, a ‘medium' impact ranges between 40 and 70, and a 'high' impact is between 70 and 100. For instance, an output value of 65 indicates a 65% positive impact, categorizing it as a medium positive impact.

4. RESULTS AND DISCUSSION

Out of thirty-five shops surveyed, eight shops (representing 22.86%) were identified as recycling less than ten tons of plastic waste monthly, categorizing them as low-volume recyclers. In contrast, seventeen shops (48.57%) fall into the medium-volume bracket, recycling between ten and twenty tons per month. The remaining ten shops (28.57%) process over twenty tons monthly, placing them in the high-volume category.

4.1 Management of Non-Recyclables

Non-recyclables found in the RSs are mainly PET bottle labels. While shredding the PET bottles for flakes, affix labels are gathered for storage in the sacks. The higher the volume of recycled PET bottles processed in these facilities, the greater the generation of such non-recyclable by-products. Figure 5 shows the volume-based generation in the shops.

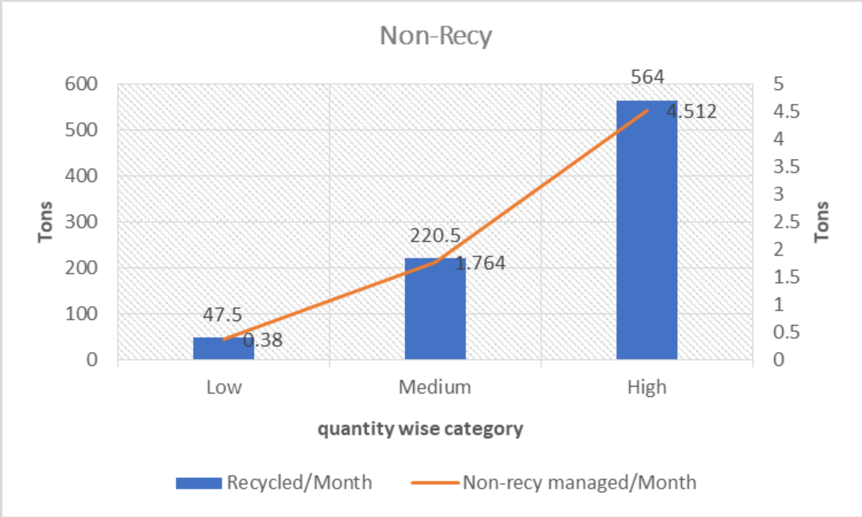

Figure 5: Non-recyclables managed per month

In the context of recycling capacities, shops defined as low volume recycled an average of 47.5 tons monthly and generated 0.38 tons of non-recyclable materials. Conversely, shops of medium volume processed 220.5 tons of plastic waste each month and had to manage 1.764 tons of non-recyclables, a figure roughly 4.5 times greater than that of low-volume establishments. On a particular note, the peak recycling throughput observed was 564 tons, with associated non-recyclable waste amounting to 4.512 tons. They have energy potential (Antelava et al., 2021), as KCC has inaugurated an energy-extracting plant called the "3R Pilot Project" (Saju et al., 2024) to convert municipal solid waste (especially plastic) to fuel. KCC might assess optimal methods for collecting non-recyclable materials to integrate into future initiatives, potentially reducing unwanted litter in the city.

4.2 Greenhouse Gas Avoidance

RS with high-volume recycling capacities demonstrated the most substantial mitigation of GHG emissions, in contrast to their low-volume counterparts, which showed minimal mitigation. This distinction is visualized in Figure 6.

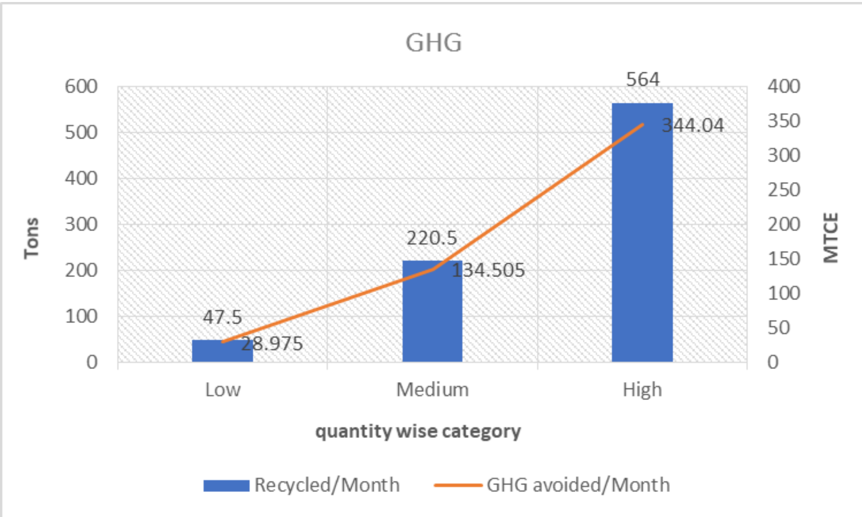

Figure 6: GHG avoided per month

As part of the CE, per month, low-volume shops contribute to averting an average of 28.975 MTCE in greenhouse gas emissions. In contrast, medium and high-volume shops prevent emissions of 134.505 MTCE and 344.04 MTCE, respectively. Ultimately, it will bring benefits to the environment of the whole country. According to (The Circular Initiative, 2022), recycling all mismanaged plastic waste in India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam can reduce GHG emissions by 229 million tonnes by 2030. So, greater levels of plastic waste recycling are directly associated with a more pronounced reduction in greenhouse gas emissions.

4.3 Littering Avoided

High-volume RS in Khulna City has the potential to divert approximately 136,566.96 tons of waste monthly. In comparison, medium- and low-volume shops may prevent 53,391.87 and 11,501.65 tons of litter, respectively, as depicted in Figure 7.

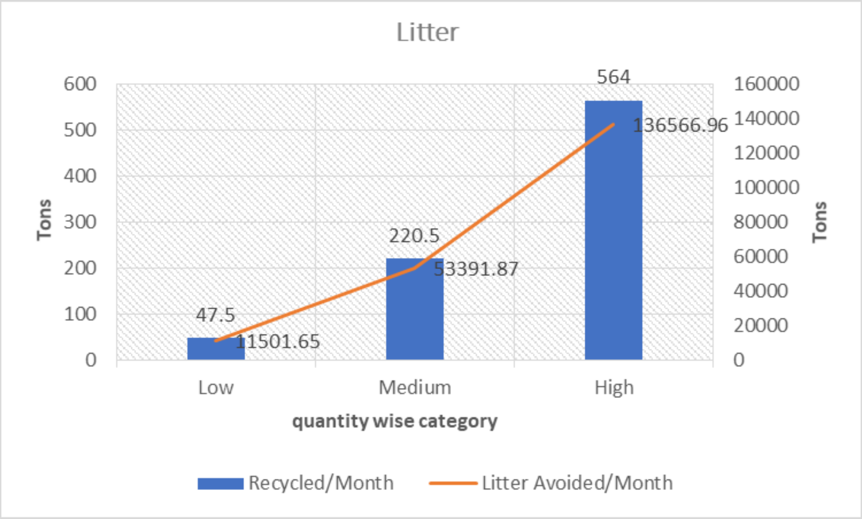

Figure 7: Litter avoided per month

In the circular process, their positive impact on the environment is undeniable since they contribute to keeping the drains and canals blockage-free, reducing the chance of flooding during the rainy season. Reducing littering enhances the quality of life and cleanliness in urban areas and makes cities more attractive to tourists and residents from other regions. The example of Singapore demonstrates the potential impact of such measures (Masud, 2016).

4.4 Landfill Space Saved

Shops across various categories have notably contributed to land conservation. Each month, their efforts account for the preservation of approximately 5,707.52 m^3 of landscape due to the role of RS in the CE. Detailed insights on this are presented in Figure 8.

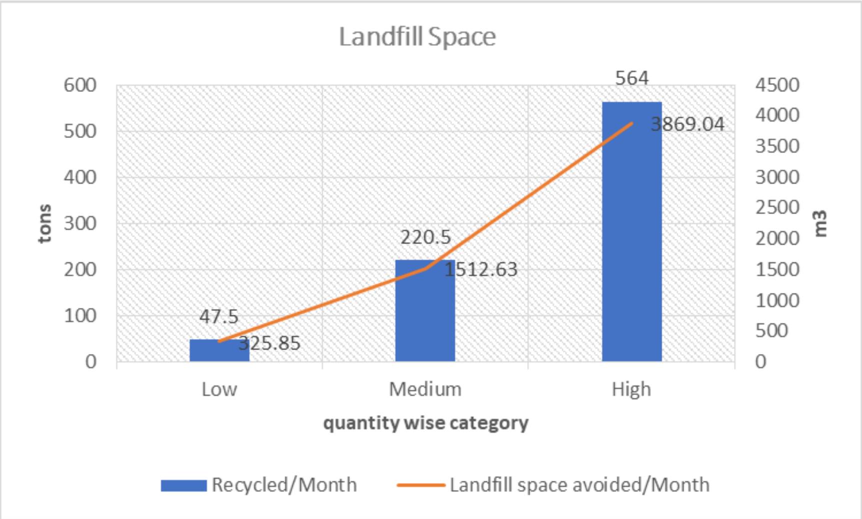

Figure 8: Landfill space saved per month

Khulna City can conserve 68,490.24 m^3 of land every year, through plastic waste recycling efforts. In a study by Ferdous et al. (2021) shown that 1 ton of recycled plastic can save 22.9 m^3 landfill space. Given Khulna city's limited area of 45.65 km^2 and its rapidly growing population, conservation efforts are paramount. Prioritizing land preservation can facilitate and accelerate infrastructure development, addressing potential future land scarcity.

4.5 Energy Savings

Due to the collective efforts of RSs, an average of 3,395 barrels of oil are conserved monthly. This data is illustrated in Figure 9.

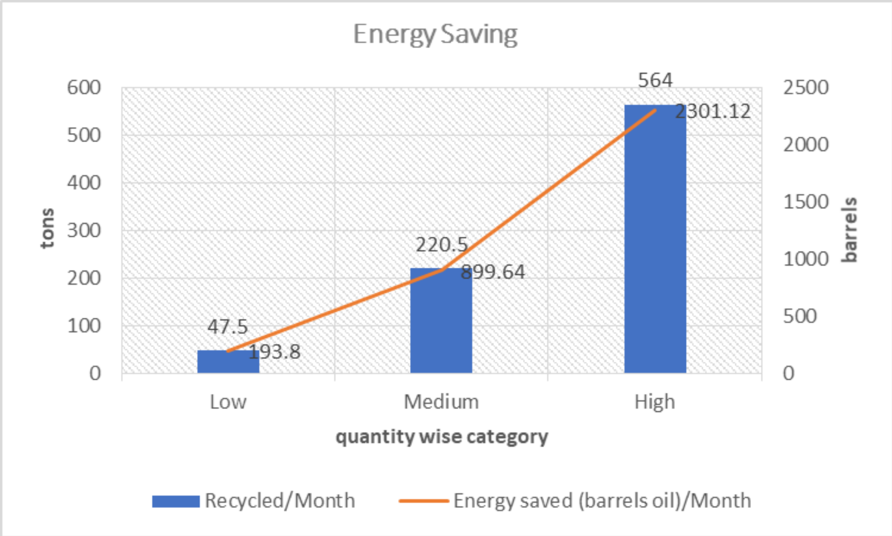

Figure 9: Energy savings per month

The impact of RSs extends nationally and globally since recycling plastic reduces energy production by 70% (Luke & Jamie, 2024). The country's plastic manufacturing industries purchase plastic flakes from the local plastic RSs to produce finished goods. This practice may reduce crude oil demand, thereby saving money. As the demand for crude oil decreases in these industries, the global extraction of fossil fuels is consequently reduced.

4.6 Employment

The study reveals that thirty-five plastic RSs currently employ 427 individuals. The distribution of these workers among low, medium, and high-volume shops is 70, 167, and 175 respectively, as detailed in Figure 10.

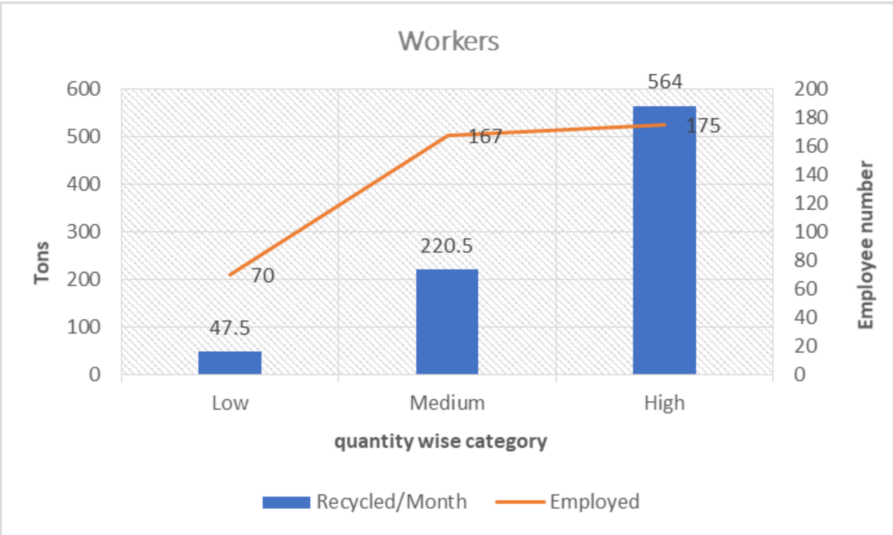

Figure 10: Number of workers employed in RS

The workers in these RSs primarily come from the city's underprivileged sections and rely on these jobs for their sustenance. In addition, even the informal waste recycling chain benefits from RSs. Increasing recycling efforts can lead to greater job opportunities compared to landfilling. Ferdous et al. (2021) demonstrated in their study that recycling 10,000 tons of waste can create 9.2 jobs, whereas disposing of the same amount in a landfill only generates 2.8 jobs.

4.7 Overall Positive Impact of RS in Khulna City

The outcomes of the fuzzy logic analysis indicate that 22.86% of RSs have a minor positive influence on the environment and well-being of Khulna City. Meanwhile, 48.57% exhibit a moderate positive impact, and 28.57% significantly positively influence the city's environment and development. Figure 11 depicts the result.

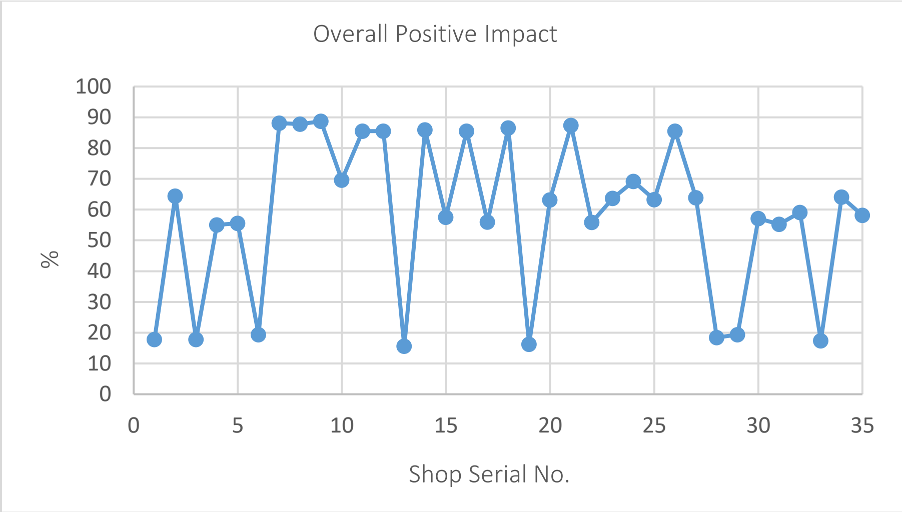

Figure 11: Overall Positive Impact of RS

Collectively, RSs play a significant role in the sustainability of Khulna City, regardless of their individual classifications and varying impacts on the urban landscape.

5. LINK BETWEEN FINDINGS OF THIS STUDY AND CE

The study underscores the imperative of reuse, recycling, and repurposing to minimize waste, ensuring that products and resources maintain their economic value over prolonged periods. The findings establish a robust connection between the principles of the CE and the pivotal role existing RSs play in Khulna city. RSs in Khulna city emerge as a key contributor to waste reduction by transforming plastic waste into valuable products like plastic flakes, granules, new-end products, etc. The study underscores their positive impact on the environment through litter avoidance, landfill space conservation, and a reduction in greenhouse gas emissions. This not only exemplifies resource efficiency but also aligns with the CE's ethos of continual resource use. Economically, the research identifies that RSs generate local job opportunities, emphasizing the CE's principle of creating economic value through sustainable practices. By repurposing discarded materials into valuable products, these shops contribute to the national economy, reducing dependence on imports and primary resources (fossil oil).

Beyond economic benefits, the study highlights the role of RSs in fostering community engagement and environmental stewardship since people in the city are aware of plastic waste's monetary value. This aligns with the CE's emphasis on involving communities in sustainable practices and promoting a shared commitment to environmental preservation. In the realm of urban planning and development, the study emphasizes the significance of recycling in freeing up space by reducing landfill requirements. So, there will be many opportunities for the city's infrastructure development which aligns with the CE's goal to create attractive, efficient, and environmentally responsible urban spaces.

In summary, the study's empirical evidence demonstrates how RSs in Khulna city, operating within a CE framework, contribute to environmental sustainability, economic development, and community well-being. It reinforces the notion that embracing CE principles, exemplified by RS, leads to a more resilient, efficient, and sustainable urban environment.

4. CONCLUSIONS

This study provides a comprehensive analysis of the significant contributions made by RSs in Khulna City toward environmental sustainability, economic development, and community engagement. The findings reveal that RSs effectively reduce greenhouse gas emissions, conserve landfill space, and prevent litter, all of which align with the principles of the CE. From an economic perspective, RSs are generating local job opportunities for the informal waste sector and contributing to saving money by reducing crude oil imports. The significance of this study lies in its thorough evaluation of RSs within a CE framework in an urban context, providing empirical evidence of their environmental and socio-economic benefits. These insights could inform initiatives by KCC and other municipalities in Bangladesh for efficient MSW management by incorporating the informal waste sector into the formal sector. Future research should focus on comparative analyses of RSs in different urban settings, domestically and in other developing countries, to identify best practices and varying impacts. Longitudinal studies are needed to assess the long-term sustainability and economic viability of RSs. Additionally, exploring technological innovations in recycling processes and examining policy frameworks that support RS growth will be crucial for maximizing their impact.

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