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APPLICABILITY OF RECYCLING AND RESOURCE RECOVERY FOR SOLID WASTE OF SRI LANKAN SUPERMARKETS

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ABSTRACT

Every day, supermarkets create municipal solid waste, which makes up about 25% of all solid waste made in urban areas of Sri Lanka. Poor waste management in Sri Lankan supermarkets can have a big effect on greenhouse gas emissions, climate change, and public health by contaminating water, soil, and the air. To address this challenge, recycling, and resource recovery are two of the best sustainable waste management practices. Hence, the study aims to investigate the applicability of recycling and resource recovery techniques for Sri Lankan supermarket solid wastes. The research choice adopted in this study was a mixed method with a questionnaire survey and semi-structured interviews. A questionnaire survey with 70 participants from top-level management, middle management, and the front-line staff was conducted to identify waste types and management practices, and a semi-structured interview with three professionals who have experience in this field was conducted to validate the survey. Further statistical analysis and manual content analysis were used to analyse the data. The findings revealed that the main waste types generated by Sri Lankan supermarkets are food, plastic, polythene, paper, and cardboard. Biogas and composting were found to be the most applicable on-site resource recovery techniques for these types of waste, and other techniques such as gasification, deinking for paper recycling, and recycling of plastic and polythene waste required the involvement of third-party resource recovery plants. The study can aid researchers, practitioners, and policymakers in coming up with and using waste management policies, laws, and guidelines for Sri Lankan supermarkets and other similar contexts.

Keywords: *Recycling; Resource recovery; Solid waste; Sri Lanka; Supermarket.*

1. INTRODUCTION

Solid waste management has become a significant challenge in Sri Lanka, where inefficient waste management practices are causing environmental damage and health risks (Saja et al., 2021). Over 7,000 tonnes of solid waste are generated in Sri Lanka every day, but only 20% of that waste is collected by local authorities, and only approximately

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5% of that waste is recycled. The balance of the waste is disposed of in open dumps or landfills (Nishanthi & Kaleel, 2021). One of the main places where solid waste is produced in Sri Lanka is supermarkets (Reitemeier et al., 2021). According to the Central Environmental Authority (CEA, 2021), supermarkets make up about 25% of all the solid waste made in urban areas of Sri Lanka. The increasing consumerism and changing lifestyles of people have resulted in more packaging waste, food waste, and other types of waste generated by supermarkets (Diaz et al., 2017). The amount of plastic waste that supermarkets produce is one of the biggest problems in Sri Lanka. Gunaruwan and Gunasekara (2016) support the idea that plastic bags, containers, and wraps used to package food are a big part of the country's waste problem. The authors also said that because there aren't enough waste management facilities and methods, a lot of this plastic ends up in landfills or the ocean, where it hurts the environment. For example, it has contributed to the pollution of several major waterways, including the Kelani River, which provides drinking water to over five million people in the country (Saja et al., 2021; Reitemeier et al., 2021). In addition, the traditional approach to managing this waste has been to dispose of it in landfills, which has proven to be unsustainable and harmful to the environment (Pitawala et al., 2022). For example, organic waste can attract vermin and pests, leading to the spread of diseases. This has created a pressing need for sustainable and effective solid waste management practices in Sri Lankan supermarkets (Gunaruwan & Gunasekara, 2016). Accordingly, there is an urgent need to find more sustainable solutions for managing supermarket solid waste. Recycling and resource recovery techniques have gained widespread attention as sustainable solutions to the solid waste management problem (Rene et al., 2021). The authors mentioned that these techniques involve the collection, sorting, processing, and reuse of solid waste materials. These techniques can be used to reduce the amount of waste generated by supermarkets and divert waste from landfills, thereby reducing environmental pollution (Van Yken et al., 2021). However, a report by the World Bank (2021) states that Sri Lanka has one of the lowest recycling rates in South Asia, with only 6% of the waste being recycled. This is significantly lower than other countries in the region, such as Bangladesh and India, which have recycling rates of 30% and 25%, respectively (Zaman, 2016). These statistics indicate that Sri Lanka is lagging in the adoption of recycling and resource recovery techniques for solid waste. There is a need for the country to prioritise waste management practices that focus on reducing waste generation, promoting recycling and resource recovery, and adopting sustainable practices to manage the remaining waste. Hence, this paper aims to analyse the applicability of recycling and resource recovery techniques for solid waste management in Sri Lankan supermarkets. The following section presents the literature review, followed by the research methodology. Then came the main part of the paper: the research findings and discussion, and finally, the conclusions.

2. RECYCLING AND RESOURCE RECOVERY FOR SUPERMARKET SOLID WASTE

Recycling is the process of collecting, sorting, and processing materials that would otherwise be thrown away as trash and turning them into new products (Soomro et al., 2022). Recycling aims to reduce the amount of waste that ends up in landfills or incinerators, conserve natural resources, and reduce greenhouse gas emissions. In addition, recycling to return waste materials lowers costs and opens new opportunities. Commonly recycled materials include paper, glass, plastic, metal, and electronics (Dias & Junior, 2016). It helps to reduce the amount of waste that is sent to landfills or

incinerators, which can have negative environmental impacts (Oshodi et al., 2020). When waste is recycled, it is transformed into new products, reducing the need to extract and process virgin materials from the earth, conserving natural resources, reducing greenhouse gas emissions, and helping to protect ecosystems (Van Yken et al., 2021). On the other hand, this uses less embodied energy as the recycled materials have already been extracted and processed (Zaman, 2016). For example, recycling aluminium cans uses 95% less energy than producing new aluminium cans from raw materials. Accordingly, it plays an important part in sustainable waste management and has a critical role in protecting the environment and conserving resources (Gunarathne et al., 2019).

Resource recovery is the process of getting materials or energy out of the waste that would otherwise be thrown away (Lag-Brotons et al., 2020). It involves collecting, sorting, and processing trash to get valuable materials that can be used again or recycled, such as metals, plastics, and organic matter. It also includes making energy from waste, such as by making biogas from organic waste or burning waste to make electricity (Velenturf & Purnell, 2017). Resource recovery can create economic opportunities by creating new markets for recycled materials and by generating revenue from the sale of recovered energy. This can help to support local economies and create jobs in the waste management industry (Dias & Junior, 2016). The goal of resource recovery is to reduce the amount of waste sent to landfills or incinerators, conserve natural resources, and minimise the environmental impacts of waste disposal. Resource recovery helps to conserve natural resources by reusing and recycling materials that would otherwise be discarded as waste (Dawson, 2007). This can help reduce the demand for virgin materials, such as minerals and fossil fuels, that are used to produce new products. It is a key strategy for sustainable waste management and is an important part of the circular economy (Gunarathne et al., 2019). Table 1 summarises the types of waste generated in supermarkets along with their overall contribution and the method of waste management applicable to each type of waste.

Table 1: Types of waste in supermarkets and applicable waste management methods

Type of waste along with their overall contribution (%)	**Recycling and resource recovery Methods**							**Source**
	Recycling	**Anaerobic digestion**	**Composting**	**Dark fermentation**	**Gasification**	**Pyrolysis**	**Dissolution**	
Food (48%)		✓	✓	✓	✓	✓		[1] - [4]
Paper and cardboard (20%)	✓							[5] - [9]
Glass (12%)	✓							[10] - [13]
Plastic (8%)						✓	✓	[14] - [16]
Wood (7%)	✓		✓					[17] - [19]
Non-ferrous metal (3%)	✓							[20] - [21]

Sources: [1] (Rashid & Shahzad, 2021); [2] (Oshodi et al., 2020); [3] (Lukajtis et al., 2018); [4] (Filimonau & Gherbin, 2017); [5] (Ma et al., 2016); [7] (Gunaruwan & Gunasekara, 2016); [8] (Dias & Junior 2016); [9] (Ozola et al., 2019); [10] (Nishanthi & Kaleel, 2021); [11] (Velenturf & Purnell, 2017); [12] (Lag-Brotons et al., 2020); [13] (Dias & Junior 2016); [14] (Gunarathne et al., 2019); [15] (Gunaruwan & Gunasekara, 2016); [16] (Armenise et al., 2021); [17] (Velenturf & Purnell, 2017); [18] (Saja et al., 2021); [19] (Berger et al., 2020); [20] (Reitemeier et al., 2021); [21] (Brooks et al., 2019)

3. RESEARCH METHODOLOGY

This study aims to investigate the applicability of recycling and resource recovery techniques for Sri Lankan supermarket solid wastes. Initially, a background study was undertaken to determine the research problem. After that, a comprehensive literature review was done to identify the different types of solid waste that supermarkets produce and the ways that those wastes are managed around the world. This study adopted a survey strategy to get an overall idea of Sri Lankan supermarket solid waste generation and management and particularly to check whether recycling and resource recovery is applied in the Sri Lankan context. Accordingly, an online questionnaire survey using Google Forms was carried out among 70 participants, who are operations managers, facilities executives, and housekeeping labours of supermarkets in the Colombo Municipal Council area based on convenience sampling, which is a non-probability sampling technique where the entire population is not considered in selecting the sample (Dawson, 2007). The respondent rate is 82.9% (58 respondents). To analyse the survey data, descriptive statistical analysis techniques were applied. Measures such as means, standard deviations, and frequency distributions were calculated to summarise the quantitative data obtained from the questionnaire responses. Following that, an expert interview was conducted to validate the questionnaire survey and to gain additional knowledge about recycling and resource recovery, with three professional experts who have experience with recycling and resource recovery of waste as mentioned in Table 2. Manual content analysis techniques were then applied to analyse the qualitative data. This involved systematically reviewing the interview transcripts, identifying recurring themes and patterns, and deriving meaningful insights from expert perspectives.

Table 2: Profile of expert interview respondents

Respondent No	Designations	Experience in the Waste Management sector
R1	Director - Waste Management Authority	More than 15 years
R2	Director - Central Environmental Authority	More than 25 years
R3	Engineer - Central Environmental Authority	More than 11 years

4. RESEARCH FINDINGS AND DISCUSSION

This section includes three sections which are types of Sri Lankan supermarket solid waste, current recycling and resource recovery techniques used in Sri Lanka, and the applicability of identified recycling and resource recovery techniques on Sri Lankan supermarket solid waste.

4.1 TYPES OF SRI LANKAN SUPERMARKET SOLID WASTE

The percentage of solid waste types generated in the supermarket according to the literature (section 2) slightly differs from the Sri Lankan perspective. The questionnaire survey allows for the involvement of a larger number of participants, such as supermarket managers, operations staff, and other relevant stakeholders and this provides a broader perspective on waste generation and management practices in Sri Lankan supermarkets. Hence the solid waste types generated in the supermarket which is collected using the questionnaire survey is illustrated in Figure 1.

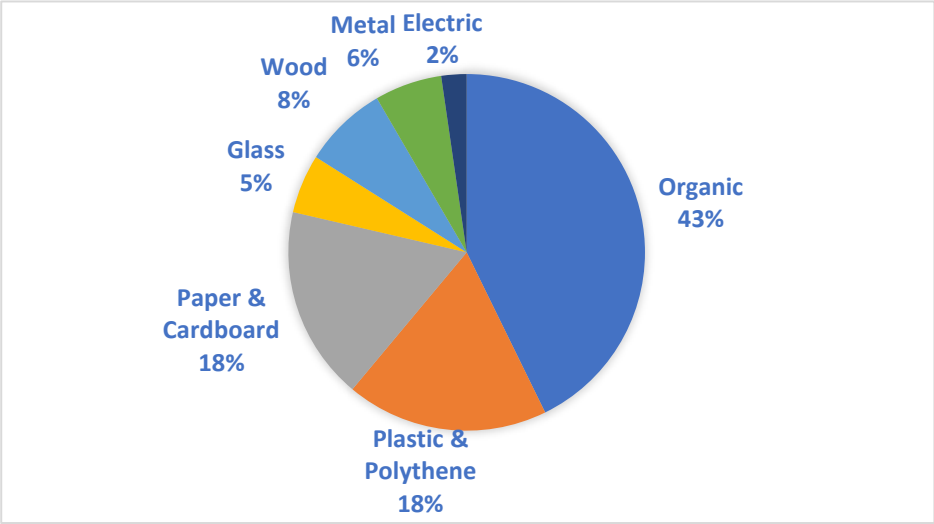

Figure 1: Types of Sri Lankan supermarket solid waste

Organic foods include food waste, fruit and vegetable scraps, and other biodegradable waste generated in supermarkets. The significant contribution of organic waste, including food waste and biodegradable materials, aligns with findings from previous studies. Accordingly, it is estimated to contribute around 30% to 50% of the total waste generated in supermarkets (Rashid & Shahzad, 2021). On a similar note, as per the findings, it is estimated that organic waste contributes to about 43% of the total waste generated in supermarkets. Further, supermarkets use a lot of plastic and polythene packaging material for their products, including plastic bags, bottles, and containers, and is estimated to contribute to about 18% of the total waste generated in supermarkets. Further, supermarkets also generate a significant amount of paper and cardboard waste from packaging boxes, bags, and receipts. According to the literature, supermarkets generate a significant amount of paper and cardboard waste from packaging boxes, bags, receipts, and other paper-based materials. This waste stream is estimated to account for approximately 10% to 20% of the total waste generated in supermarkets (Ma et al., 2016). Similarly, the questionnaire findings revealed that this waste contributes to about 18% of the total waste generated in supermarkets. In addition, the wood waste in supermarkets can come from a variety of sources, including packaging crates, pallets, and shelving units. While the contribution of wood waste in supermarkets may vary, it is estimated to be a relatively small percentage (8%) of the total waste generated. On the other hand, hazardous wastes such as electrical waste, metal waste, and glass waste are generated in very fewer amounts.

To conclude, the targeted waste types for recycling and resource recovery of supermarket waste were identified as food waste, plastic and polythene waste, and paper and cardboard waste. Due to the high quantity of weekly waste generation, these three waste types were selected as the main treatable waste types. Though glass waste, metal waste, wood waste, and E-waste were identified in the supermarket facilities due to the inconsistency of the generation of waste, four waste types were excluded from on-site recycling or resource recovery.

4.2 CURRENT RECYCLING AND RESOURCE RECOVERY TECHNIQUES USED IN SRI LANKA

The recycling and resource recovery techniques that have been used for different types of supermarket solid wastes in Sri Lanka are shown in Table 3.

Table 3: Recycling and resource recovery techniques used in Sri Lanka

No	Recycling and Resource Recovery Techniques / Types of Waste	Incineration	Biogas	Gasification	Pyrolysis	Composting	Recycling
1	Food waste		30/58			28/58	
2	Plastic and polythene	18/58		5/58	5/58		30/58
3	Paper and cardboard	23/58					35/58
4	Glass	50/58					20/58
5	Wood						58/58
6	Metal						58/58

According to the literature, for food waste, composting and anaerobic digestion are commonly used methods. Similarly, the questionnaire findings revealed that biogas and composting are the techniques used for managing food waste, as they can convert it into useful resources like energy and fertiliser. Recycling, biogas, and gasification are all effective techniques for managing plastic waste. Plastic waste can be recycled to produce new products, while biogas and gasification can convert it into energy. Incineration can also be used for plastic waste, but it can produce harmful emissions. Recycling and pyrolysis are used to manage paper and cardboard waste. Recycling can turn paper waste into new products, while pyrolysis can convert it into energy. Incineration and biogas are not recommended for paper waste. Further, recycling is the most common technique for managing glass waste, as it can be melted down and used to produce new glass products. In addition, composting and pyrolysis are used to manage wood waste. Moreover, recycling is the most common technique for managing metal waste, as it can be melted down and used to produce new metal products. Further, out of the resource recovery techniques found in the literature, biogas, gasification, pyrolysis, and composting were found to be current resource recovery techniques in Sri Lanka. Subsequently, the respondents were asked to rate the resource recovery and recycling techniques concerning profitability and environmental impact, as depicted in Table 4. A rating system was used, where the profitability and environmental impact of each technique were rated on a scale of 1 to 5, with 1 indicating the lowest profitability/low impact and 5 indicating the highest profitability / high impact.

Table 4: RII of profitability and environmental impact

No	Recycling and resource recovery method	RII	
		Profitability	Environmental impact
1	Recycling	3.57	1.00
2	Incineration (WtE)	3.14	3.00

No	Recycling and resource recovery method	RII	
		Profitability	**Environmental impact**
3	Gasification	3.00	1.29
4	Pyrolysis	2.71	1.71
5	Biogas	1.85	1.43
6	Composting	1.57	2.14

The investigation has determined that recycling is the optimum method for recovering resources or energy. This is due to the profitability's high RII value and low environmental impact, which have a total score of 3.571 and 1.0 out of 5, respectively. This is likely since recycling has many environmental benefits, such as reducing waste volumes, conserving natural resources, and reducing greenhouse gas emissions associated with the production of new materials. In addition, the availability of different waste recycling plants in Sri Lanka which are both profitable and the impact on the environment by those plants are low. Yet the environmental impact by the recycling plants is low the greenhouse gas emissions and consumption of fossil fuels due to waste transportation cannot be neglected. Even though the RII values of incineration are higher than those of gasification, the environmental impact of incineration is nearly double that of gasification. However, it is important to note that incineration and gasification methods are not as environmentally friendly as recycling and can lead to emissions of greenhouse gases and other pollutants. Incineration was perceived to have the highest environmental impact among the recycling and resource recovery methods considered. Some of the reasons for this belief are worries about the emissions from incineration, such as air pollutants and greenhouse gases, and the possible risks of dumping incineration ash. However, gasification was also perceived to have a moderate environmental impact. Gasification can have environmental benefits, such as reducing waste volumes and producing syngas that can be used as a fuel, but it can also produce air pollutants and requires energy inputs. Other methods get the lower places in the order of importance for resource recovery, such as pyrolysis, biogas, and composting, indicating that they are less important. All three methods were perceived to have a moderate environmental impact. This is because biogas production has some positive environmental benefits, such as reducing methane emissions from organic waste, but it also requires energy inputs and can produce some greenhouse gas emissions during production. Pyrolysis has some environmental benefits, such as reducing waste volumes and producing biochar that can be used as a soil amendment, but it also requires energy inputs and can produce some air pollutants. Composting has environmental benefits, such as reducing methane emissions from organic waste and producing a nutrient-rich soil amendment, but it can also require significant land use and energy inputs. However, it is important to consider the specific context and waste materials being used when evaluating the effectiveness and suitability of each method.

4.3 APPLICABILITY OF IDENTIFIED RECYCLING AND RESOURCE RECOVERY TECHNIQUES ON SUPERMARKET SOLID WASTE

According to the experts interviewed, the only methods that can be used are anaerobic digestion (biogas) and composting, which were chosen by seven and five out of seven respondents, respectively. None of the respondents mentioned any other techniques. All

of these people agreed that anaerobic digestion (biogas) is a way to reuse resources that can be done on-site with waste from supermarkets. It is easier to turn food waste into biogas on the site of a supermarket than to collect food waste and move it to a different place. Also, by using biogas produced by the supermarkets themselves or by selling it to third parties, profits could be earned. Moreover, the reduction of food waste handed over to the municipal councils by the supermarkets will be reduced through the application of on-site biogas units. Respondents who agreed with composting said that composting food waste on-site is a good way to reuse resources because you don't need a lot of technology to start the process. This makes composting easier to use than biogas systems. R1 and R2, on the other hand, stated that composting is not applicable in the Sri Lankan context because R2 highlighted that "*composting attracts flies, leeches, and creates an odour that is not suitable for a supermarket area. These disruptions have the potential to harm supermarket business*".

Plastic sand brick is a plastic and polythene waste recycling technique that is currently not used in Sri Lanka. Two respondents, R3 and R4, agreed that plastic sand brick is a recycling technique that applies to supermarket plastic and polythene waste. According to R3, "*plastic and polythene waste generated in supermarkets can be recycled into plastic sand bricks. The relatively small area required for the process and the fact that waste generation is not massive is an advantage in terms of space*". Whereas with daily small collections of waste, the recycling process can be continued once a week, which would not require a large area. Yet respondents R1 and R2 were against the applicability of plastic sand bricks. According to R1, "*It is not safe to construct a recycling plant near a supermarket. The gases produced by the heating of the plastic will have an impact on both the environment and people's health*". This explains why plastic sand brick an applicable recycling method in an urban area is not. Considering the arguments of R1 and R2 and considering the negative impacts on the surrounding environment of plastic sand bricks, it can be concluded that plastic sand brick is not an applicable on-site recycling technique.

In the literature review, both gasification and pyrolysis were identified as resource recovery techniques that can be used on food waste and plastic and polythene waste. The respondents revealed that although in the Sri Lankan context gasification and pyrolysis are used only for plastic and polythene waste processing, these techniques cannot be used on an on-site supermarket basis. The reason for this is that a daily bulk waste quantity of 300 metric tonnes should be used in continuous operation gasification and pyrolysis plants, which supermarkets lack. Also, the literature review emphasised that the capital investment for a gasification plant or a pyrolysis plant is comparatively high. Even though gasification and pyrolysis were rated as moderately economical techniques by all three respondents, due to the lack of waste generation, they can be categorised as non-profitable investments for investors. Apart from that, the space needed for a plant is moderately higher than for biogas or composting. Where in the supermarket premises is the lack of space the main concern?

The technology for precipitation/dissolution is not yet familiar in Sri Lanka. This is why all three respondents responded that precipitation/dissolution is not an applicable resource recovery technique for the Sri Lankan supermarket context. This can be elaborated by the statement in R2 that "*we do not use precipitation or dissolution as a waste management technique in Sri Lanka*". Moreover, R6 stated that "*implementing an unknown technology when there are known alternative technologies is a risk*". This can lead to the conclusion

that precipitation/dissolution is not yet ready for use in Sri Lanka. Further, as discussed in the literature review, dark fermentation is a resource recovery technique that still has few practicalities with its initiation from an engineering point of view. Similarly, all seven respondents stated that dark fermentation cannot currently be used in Sri Lanka. R3 stated that the "*dark fermentation process cannot be applied on an on-site basis at supermarkets due to the lack of technology and lack of knowledge by its users*".

According to all three waste management experts, converting paper waste into building material is an environmentally friendly recycling technique for paper and cardboard waste that cannot be applied to supermarket waste. According to the literature, paper waste can be recycled up to ten (10) times before it loses its quality. Where the paper and cardboard waste collected in supermarket premises has not been recycled before, this poses an issue in the recycling of paper waste into building materials. R2 emphasised this issue, stating, "*The paper used in supermarkets is of high quality." Making building material from high-quality paper when it can be recycled is a waste*". The supermarket does not have such a space." Which highlighted the need for space for the recycling of paper waste into building materials. This concludes that converting paper waste to building material is not applicable due to the quality of the waste and lack of space.

All seven experts in waste management agreed that deinking paper to recycle it is not something that can be done in a supermarket. The main problems with using the on-site paper deinking process were that there wasn't enough space and there wasn't enough paper waste. According to their responses, the paper waste generated from a single supermarket is not enough for the processing of a deinking plant. Accordingly, deinking of paper waste on the premises of supermarkets is not an applicable recycling method. Furthermore, selling paper waste to recycling third parties could be more profitable. Paper waste converted into bioethanol as a resource recovery technique for paper waste was denied as an applicable resource recovery on-site supermarket by all respondents. Bioethanol production by paper waste is not a resource recovery technique currently used in Sri Lanka, which makes the technology unknown to waste management experts. With the responses of the seven respondents, it can be concluded that bioethanol production from paper waste on-site is not an applicable resource recovery technique.

Hence, anaerobic digestion (biogas) and composting were identified as on-site resource recovery techniques for food waste. Plastic and polythene waste can be recycled with the assistance of a third party, and it can also be a gasifier. Paper and cardboard waste can be recycled into pulp with the help of a third party. Finally, a framework is created based on the research findings shown in Figure 2.

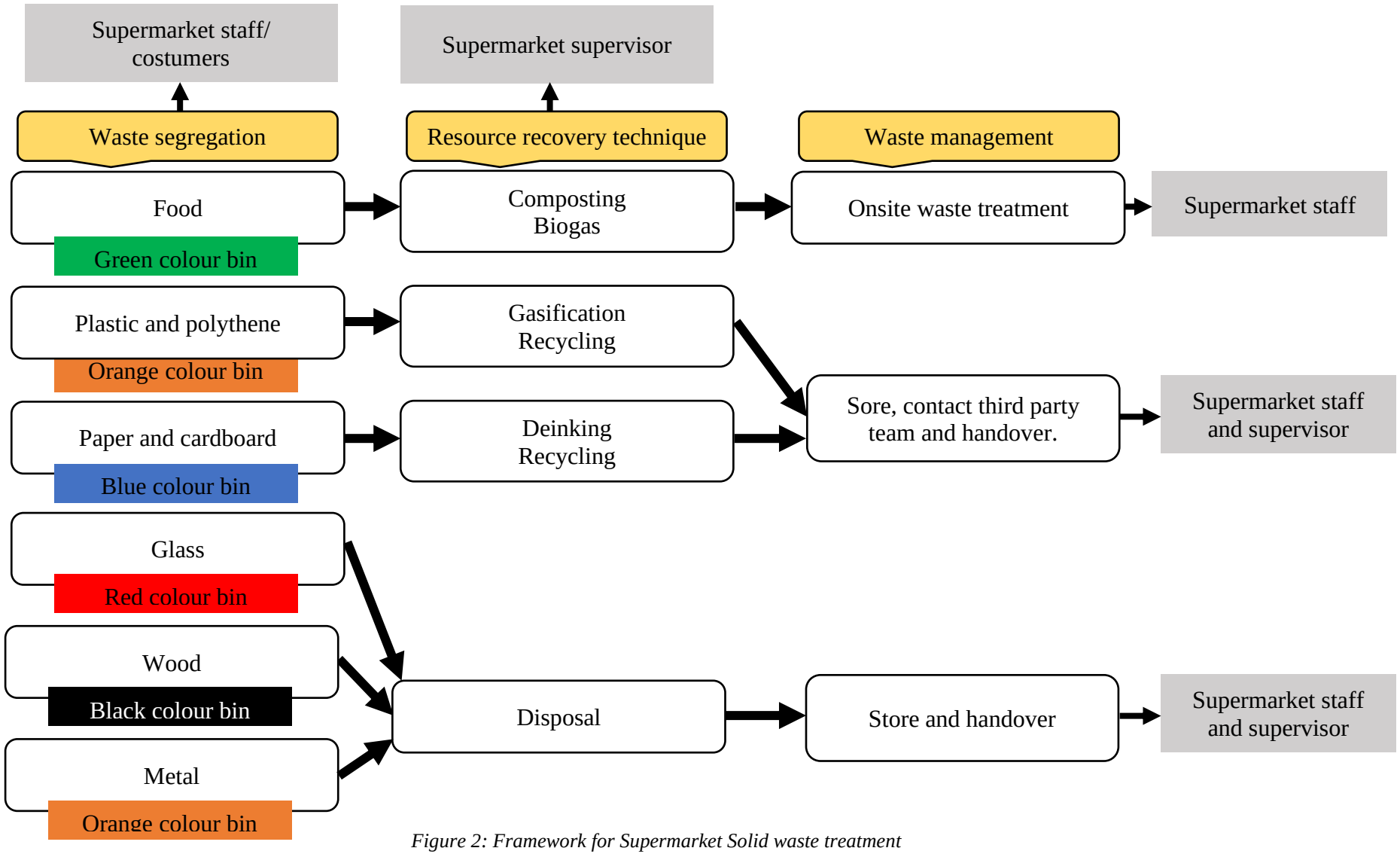

Figure 2: Framework for Supermarket Solid waste treatment

5. CONCLUSIONS

This study conducted a survey to identify the types of waste generated by supermarkets in Sri Lanka and examined the recycling and resource recovery methods currently employed to manage these wastes. The study revealed that food waste, plastic and polythene waste, and paper and cardboard waste are the primary treatable waste types in supermarkets. In Sri Lanka, the common resource recovery techniques used for waste management include biogas production, gasification, pyrolysis, and composting. The study also evaluated the profitability and environmental impact of these techniques and found that recycling is the most profitable and environmentally friendly method for managing most waste types, followed by gasification and pyrolysis, as per the ratings provided by waste management experts. Biogas production and composting were identified as effective techniques specifically for managing food waste. By identifying the predominant treatable waste types in supermarkets, industry practitioners can prioritise the implementation of effective recycling and resource recovery techniques for managing these wastes. Furthermore, the research findings can assist industry practitioners in understanding the most viable and environmentally sustainable techniques for managing different types of waste. This research can serve as a valuable guide for developing effective waste management strategies that reduce waste, enhance environmental sustainability, and increase profitability within the supermarket industry. Additionally, the study's insights can contribute to the development of theoretical frameworks and models for waste management in the supermarket sector. Importantly, it is worth noting that this study solely assessed the profitability and environmental impact of waste management techniques in Sri Lanka. The study is limited to the supermarkets in the Colombo Municipal Council. Additionally, the study might not account for potential variations in waste generation and management practices among different types or sizes of supermarkets, which could affect the applicability of the recycling and resource recovery techniques suggested. Future research should compare the effectiveness of different waste management techniques employed in other countries or regions. Moreover, conducting detailed cost-benefit analyses of various waste management techniques would provide a more comprehensive understanding of their economic feasibility. Overall, this study offers valuable insights for policymakers, waste management authorities, and supermarkets in Sri Lanka, aiming to improve waste management practices and foster a transition towards a more sustainable and circular economy. By implementing the findings from this research, stakeholders can contribute to mitigating environmental impacts, reducing waste generation, and promoting sustainable practices within the supermarket industry.

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