

Resource Recovery from Organic Fraction of Municipal Solid Waste in Sri Lanka – Current Status and Future Prospects

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Research Article

Open Access

How to cite this article: B.K.T. Samarasiri, Sinhara M.H.D. Perera, Dave Fernando, K.S.S. Perera. Resource Recovery from Organic Fraction of Municipal Solid Waste in Sri Lanka – Current Status and Future Prospects. *Current Research in Wastewater Management*, 2021, 1(1), 1. Retrieved from <http://www.tjsr.org/journal/index.php/crwm/article/view/166>

Received: November 12, 2020

Accepted: January 30, 2021

Published: January 31, 2021

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Abstract Owing to rapid population growth accompanied by urbanization and industrialization, waste management is an essential aspect of today's world. During 2013, total municipal solid waste generation in Sri Lanka was recorded as 10,768 tons per day, while total municipal solid waste collected was only 3,458 tons per day. Meantime, the organic fraction of municipal solid waste (OFMSW) produced in 2012 was 1,301.5 tons per day. The most widely practiced waste disposal method in Sri Lanka is currently open dumping, which is not an ecofriendly approach. Biowaste, which accounts for about 59% of MSW collected in Sri Lanka, consists of 65 percent of moisture, and valuable resources such as energy, nutrients, and minerals can be readily recovered. Resource recovery, which is linked to the circular economy, is a sophisticated technique of biowaste management. However, resource recovery principles for the local communities in Sri Lanka are fairly novel. The ultimate outcome of this study is to lay the foundation for the development of an autonomous integrated circular system integrated with the existing waste management framework in Sri Lanka, and thus allowing to circulate the vital resources needed to sustain human life in the form of energy, food, and water. Types of resources, which can be extracted from OFMSW are nutrients such as nitrogen and phosphorous, energy, and water from moisture content. Energy can be harnessed as biogas via the degradation of organic compounds in anaerobic reactors, whereas nutrients can be harnessed by converting anaerobic sludge into inorganic fertilizers. The proposed integrated standalone circular system should be able to produce energy via combined heat and power plant and produce struvite via fertilizer production plant. Based on currently available data from 2012, potential electricity generation is 10.31 W per kg of OFMSW, and minimum struvite generation potential is 3.839 g per kg of OFMSW. Excluding the operation and maintenance expenditure and depreciation cost, forecasted revenue from electricity generation and struvite production are respectively 21,155,926 USD per annum and 455,926.84 USD per annum. Therefore, resource recovery is a socio-economically and environmentally viable waste management practice in the Sri Lankan context.

Keywords Municipal solid waste, Resource recovery, Anaerobic digestion, Solid waste management, Biogas, Struvite

1. Introduction

Waste management plays a critical role in mitigating the environmental deterioration caused by the ever-increasing growth of the population accompanied by urbanization and industrialization. The global municipal solid waste (MSW) generation was estimated to be around 1.3 billion tons annually in 2012, and it is predicted to reach 2.2 billion tons annually by 2025

[1]. Moreover, the per capita solid waste generation is accelerating faster than the rate of urbanization as a result of ever-changing urban lifestyle trends. This is clearly evinced from the global per capita MSW generation being increased from 0.64 kg per person in 2002 to 1.2 kg per person in 2012 [2]. Total municipal solid waste generation in Sri Lanka during 2013 was 10,768 tons/day, whereas the total collected municipal solid waste was only 3,458 tons/day [3]. MSW management is one of the key aspects in urban planning to establish essential sanitation standards and environmental norms, and also to mitigate socio-economic and environmental issues associated with MSW. Sri Lanka is a small island located in the middle of the Indian Ocean, which accommodates about 21.8 million people in its 65,610 km² area, and the main capital city Colombo located in Western Province, which covers a 3,684 km² area has a population of 5.8 million people. The population density of Western province alone is 1,574 heads per km², and it is continuously growing as people tend to move to the capital city due to various social and economic considerations.

As a result of ever-rising city dwellers and their growing consumption, urbanization can have detrimental impacts on the ecological system as well as social and economic aspects of the area. Consequently, municipal waste management is an essential element in the process of sustainable development of cities [4]. As similar to most of the other developing countries, in Sri Lanka also, waste treatment is given lesser attention, while the focus is mainly driven in the direction of waste collection due to reasons such as lack of technological knowledge on advanced waste management practices, insufficient finance resources, poor regulatory framework, lack of public awareness, lack of political initiatives, and etc. [5]. Further, most of the solid waste management programs implemented so far have been unable to sustain, mainly due to the lack of socio-economic feasibility [6]. In Sri Lanka, the most commonly practiced waste disposal method is open dumping, while there is a single sanitary landfill located in Gampaha District, and there are very few semi-controlled landfills. Open dumping is a primary technique that most often leads to various health, socio-economic and environmental issues unless it is operated in a well-controlled sanitary landfill.

A major portion of MSW generated in Sri Lanka is biowaste, which is the short-term biodegradable organic fraction. In fact, the total collected municipal solid waste is composed of 59.20% of food waste, which consists of around 65% of moisture [8] and other valuable nutrients and minerals, which can potentially be recovered to use in value-added applications. The average organic fraction of municipal solid waste (OFMSW) generated in Sri Lanka in 2012 was 1301.5 tons per day [9], and it is escalating due to the population growth and the associated increase of consumption. Therefore, introducing sustainable and advanced waste management practices, which blend with socio-economic aspects of the local communities as well as the environmental norms, are essential for developing an efficient waste management system in Sri Lanka. Resource recovery connected with a circular economy is a growing advanced biowaste management practice all around the world [10]. The concept of resource recovery is fairly novel for the local communities in Sri Lanka. The objective here is to achieve an integrated standalone circular system embedded in the existing systems, and then circulate essential resources such as energy, food, and water to sustain human life [11]. Such an integrated standalone circular system embedded in the existing systems is capable of fulfilling all or partial resource needs by advanced resource recovery practices. The aim of this research is to evaluate the socio-economic and environmental feasibility of resource recovery from the organic fraction of municipal solid waste.

2. Materials and Methods

2.1. Current Status of Food Waste Management Technologies

There are several conventional waste management technologies, which are currently practiced in Sri Lanka. They are landfilling, incineration, aerobic composting, anaerobic digestion, and using as animal feed [12], as depicted in Figure 1. Among those, the most commonly practiced technology is landfilling, whereas aerobic composting and using as animal feed are also practiced to some extent.

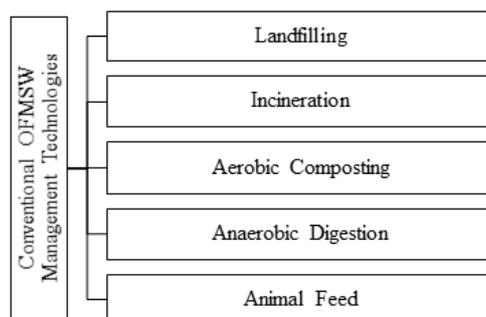


Figure 1. Conventional Organic Fraction of Municipal Solid Waste Management Technologies in Sri Lanka

Landfilling is basically carried out either as open dumping or as engineered landfilling. The former is a basic uncontrolled disposal method causing serious environmental issues, while the latter is a more ecofriendly technique in which sanitary landfills are constructed for safe final disposal of solid waste. As OFMSW consists of a high amount of moisture, landfilling causes to generate leachate over time [13]. Unless landfill-generated leachate, which contains toxic substances and pathogens, is properly collected and treated, there is a huge risk of ground water contamination, which leads to detrimental impacts on aquatic life and human health [14]. Moreover, Sri Lanka is a tropical country with a wet-climate and higher humidity, and hence biological activities are comparatively accelerated. Therefore, improper disposal of MSW can cause a rapid spread of diseases such as diarrhea, cholera, typhoid, etc., during rainy seasons. Similarly, improper aerobic composting systems and animal feeding places may equally raise issues to human health and the ecosystem. Therefore, the existing systems need to be integrated and properly managed before moving towards advanced treatment systems. Furthermore, many studies have investigated various effective biological treatment technologies for landfill leachate [15-17].

Most of the waste collected in Sri Lanka is not properly sorted at the point of collection due to the lack of knowledge and awareness on the source separation practices and their benefits. Total waste collected in Sri Lanka was only around 32.11% from the total waste generation in Sri Lanka, and the rest of the waste was incinerated or composted domestically or dumped at outside places [7][12]. Mbiba [18] has investigated the household appetite for source separation in Eastern and Southern Africa and shown the positive attitudes of the community. Source separation practices also need to be enhanced by developing simplified waste collection mechanisms and carrying out waste collection awareness sessions for the general public.

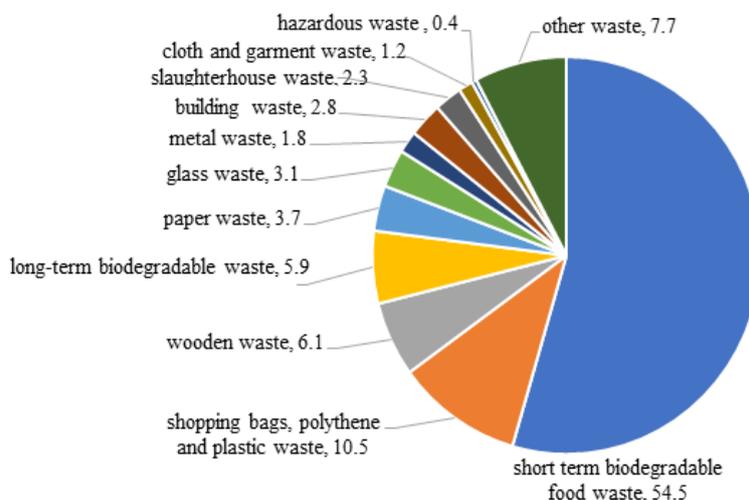


Figure 2. Composition of Total Waste Collected in Sri Lanka in 2012

According to the Central Environmental Authority in Sri Lanka, the collected waste in Sri Lanka during 2012 consisted of 54.5% short term biodegradable food waste, 10.5% shopping bags, polythene and plastic waste, 6.1% wooden waste, 5.9% long-term biodegradable waste, 3.7% paper waste, 3.1% glass waste, 1.8% metal waste, 2.8% building waste, 2.3% slaughterhouse waste, 1.2% cloth and garment waste, 0.4% hazardous waste and 7.7% other waste [12], and it is shown in Figure 2. This food waste collection per day can be enhanced by improving source separation practices and waste collection mechanisms.

After the source separation and waste collection, the biowaste should be effectively treated to avoid environmental issues, raised particularly by the landfill leachate, which causes eutrophication, death of aquatic lives, spread of diseases, and various other health issues, and the resources are subsequently recovered. Resources recovered from the waste will compensate the overall cost of the process, making solid waste management socio-economically feasible and affordable for countries with poor economies as well [19]. Therefore, an integrated process of source separation and waste collection followed by waste treatment and resource recovery can play a critical role in waste management while following best practices for source separation and waste collection [20].

2.2. Embedding Modern Concepts of Resource Recovery for Treatment of OFMSW

Anaerobic digestion is one of the conventional and robust waste treatment technologies practiced along with aerobic composting in many countries. However, anaerobic digestion has not been a favorable option in Sri Lanka due to the higher capital expenditure (CAPEX) involved and inadequate technical expertise in plant design and operation [21]. Nevertheless, considering the consequences of environmental pollution and human health issues, biowaste treatment is more beneficial towards sustainable development in the long run. In the beginning, the CAPEX and technological adoptability play vital roles in the process of embedding modern concepts of resource recovery for OFMSW in the Sri Lankan context. Types of resources,

which can be extracted from OFMSW are nutrients such as nitrogen and phosphorous, energy from organic compounds, and water from moisture content, and these resources can be used in value-added applications making the overall process economically viable [22].

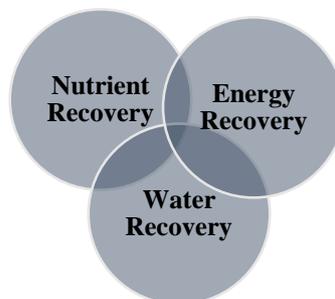


Figure 3. Types of Recoverable Resources from the OFMSW

Among these three resources, the vital resources which can generate revenue are nutrients and energy. Energy can be harnessed as biogas, which is produced by the degradation of organic compounds in anaerobic reactors. Nutrients can be harnessed by converting anaerobic sludge into inorganic fertilizers [23]. The main restraints, which hinder the implementation of this modern process are lack of knowledge, high CAPEX, and uncertainty of commercial viability. This study proposes a novel technology for resource recovery in which an integrated standalone circular system for the management of OFMSW in Sri Lanka is implemented.

2.3. Potential of Nutrient and Energy Recovery from OFMSW

The proposed treatment method for the resource recovery creates a cyclic system, which converts OFMSW to energy and nutrient sources, as depicted in Figure 4. After the source separation, OFMSW is directed to centralized waste collection facilities and then the pretreated waste will be sent to anaerobic reactors for anaerobic degradation [10]. During anaerobic degradation, complex organic compounds such as carbohydrates, proteins and lipids are degraded by anaerobic microorganisms and converted into a mixture of carbon dioxide gas and methane gas, which is known as biogas [23]. This biogas can be either stored for later usage or converted into electricity and thermal energy by a combined heat and power (CHP) plant. Once the degradation is completed, anaerobic digestate can be converted into inorganic fertilizer, which is known as struvite production by chemical treatment. This struvite can be used as inorganic fertilizer for long-term agricultural crops such as tea, coconut and rubber [24]. Once again after food consumption in the cycle, a portion of the nutrients will be recirculated back to the OFMSW collection and storage.

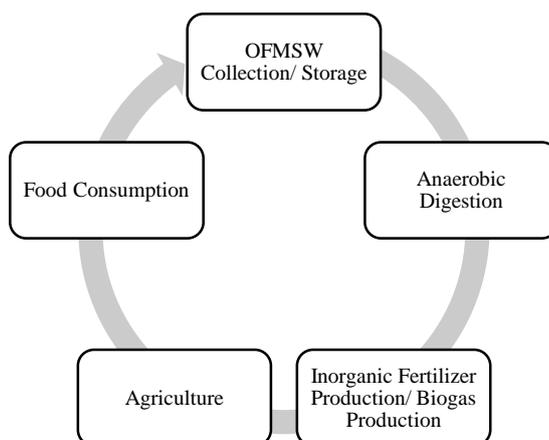


Figure 4. Proposed Circular Process of Resource Recovery from OFMSW

The proposed integrated standalone circular system should be able to produce energy via a CHP plant while producing struvite via a fertilizer production plant [25]. The existing waste collection facilities should be embedded in all phases of design, construction, testing, and commissioning of these two plants within the premises. The physicochemical characteristics of the prepared OFMSW slurry for the anaerobic digestion are given in Table 1. The key process conditions of the proposed anaerobic digester employed in the study are shown in Table 2. The physicochemical characteristics of typical anaerobic digestate of OFMSW are given in Table 3.

Table 1. Physicochemical Characteristics of Prepared OFMSW Slurry for Anaerobic Digestion

| Parameter | Quantity | Unit | Reference |
|-----------------------|----------|------|-----------|
| Total solids | 70 | g/l | [2] |
| Total volatile solids | 55.6 | g/l | [2] |
| Lipid | 3 | % | [2] |
| Protein | 13 | % | [2] |
| Carbohydrate | 58.5 | % | [2] |

Table 2. Process Conditions of Proposed Anaerobic Digester

| Parameter | Quantity | Unit | Reference |
|--|----------|------|-----------|
| Moisture content of OFMSW | 63 | % | [2] |
| Ambient temperature | 30 | °C | [2] |
| Methane percentage in biogas | 55 | % | [2] |
| Carbon dioxide percentage in biogas | 30 | % | [2] |
| Electricity conversion efficiency of CHP plant | 30 | % | [2] |
| Thermal conversion efficiency of CHP plant | 45 | % | [2] |

Table 3. Physicochemical Characteristics of Typical Anaerobic Digestate of OFMSW

| Parameter | Quantity | Unit | Reference |
|-----------------------------------|-------------|------|-----------|
| Chemical oxygen demand | 13520 ± 210 | mg/l | [12] |
| Total suspended solid | 1530 ± 125 | mg/l | [12] |
| Total Nitrogen | 2244 ± 175 | mg/l | [12] |
| NH ₄ ⁺ – N | 1861 ± 160 | mg/l | [12] |
| Total Phosphorous | 117 ± 8 | mg/l | [12] |
| PO ₄ ³⁻ – P | 104 ± 12 | mg/l | [12] |

3. Results and Discussion

3.1. Potential of Energy Recovery

According to the previous research study [9], the potential electricity generations of different provinces are as given in Table 4. The electricity generation is 10.31 W per kg of OFMSW, and hence the current flat tariff for electricity generation from biogas in Sri Lanka is 0.18 USD/kWh. The total annual revenue from the generated electricity, excluding the operation expenditure and depreciation cost, is 21,155,926 USD per annum.

Table 4. Predicted Electricity Generation from OFMSW in Sri Lanka

| Province | Daily OFMSW collection (ton/day) | Potential of electricity generation (MW) | Predicted annual revenue (USD/year) | Reference |
|---------------|----------------------------------|--|-------------------------------------|-----------|
| Western | 677.54 | 6.985 | 11,013,948 | [2] |
| Eastern | 143.26 | 1.477 | 2,328,934 | [2] |
| Central | 119.70 | 1.234 | 1,945,771 | [2] |
| Southern | 95.00 | 0.979 | 1,543,687 | [2] |
| North Western | 76.38 | 0.787 | 1,240,942 | [2] |
| Sabaragamuwa | 58.52 | 0.603 | 950,810 | [2] |
| Northern | 57.76 | 0.596 | 939,773 | [2] |
| Uva | 42.18 | 0.435 | 685,908 | [2] |
| North Central | 31.16 | 0.321 | 506,153 | [2] |
| Total | 1,301.50 | 13.418 | 21,155,926 | [2] |

3.2. Potential of Nutrient Recovery

Nutrient recovery also comes with a tremendous value-addition in the process of resource recovery from OFMSW. The Reaction mechanism of the struvite production from anaerobic digestate of OFMSW is given in Equation 1. The process flow diagram of the proposed struvite recovery process [26] is illustrated in Figure 5.

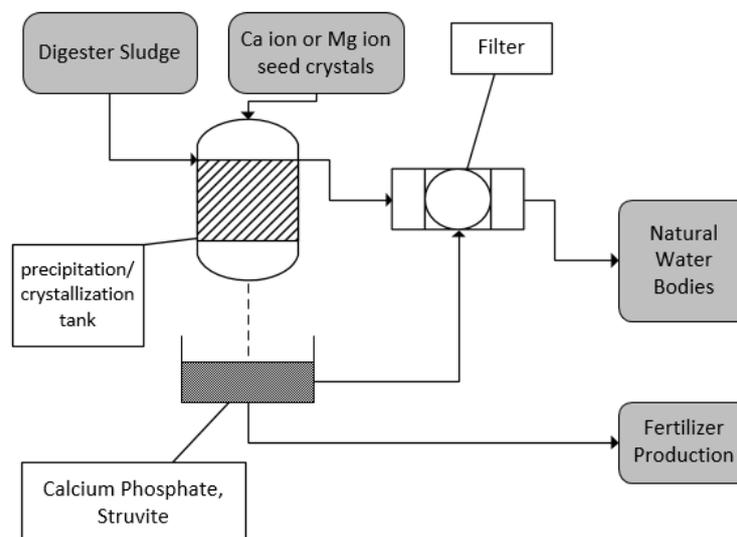
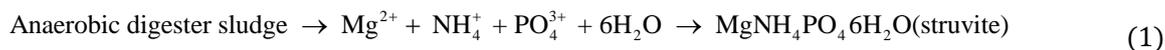


Figure 5. Process Flow Diagram of the Struvite Recovery Process from Anaerobic Digester Sludge

Hence a typical anaerobic digestate of OFMSW consists of 1861 ± 160 mg/l NH_4^+ and 104 ± 12 mg/l PO_4^{3-} , phosphate becomes the least available chemical compound for the struvite production process. Based on the assumption that the digestate has 104 ± 12 mg/l PO_4^{3-} , struvite crystallization reactors can produce up to 3.839 g struvite per 1 kg of OFMSW. Considering the current struvite market price as 250 USD/ton, the total annual revenue from struvite production, excluding operating expenditure and depreciation cost is 455,926.84 USD per annum.

Table 5. Predicted Struvite Generation from OFMSW in Sri Lanka

| Province | OFMSW collected (ton/day) | Potential of struvite generation (ton/day) | Predicted annual revenue (USD/year) | Reference |
|---------------|---------------------------|--|-------------------------------------|-----------|
| Western | 677.54 | 2.601 | 237,348.19 | [2] |
| Eastern | 143.26 | 0.550 | 50,185.23 | [2] |
| Central | 119.70 | 0.460 | 41,931.96 | [2] |
| Southern | 95.00 | 0.365 | 33,279.33 | [2] |
| North Western | 76.38 | 0.293 | 26,756.58 | [2] |
| Sabaragamuwa | 58.52 | 0.225 | 20,500.07 | [2] |
| Northern | 57.76 | 0.222 | 20,233.83 | [2] |
| Uva | 42.18 | 0.162 | 14,776.02 | [2] |
| North Central | 31.16 | 0.120 | 10,915.62 | [2] |
| Total | 1,301.50 | 4.996 | 455,926.84 | [2] |

4. Conclusion

Waste management is becoming a critical aspect in highly populated cities in Sri Lanka due to population growth accompanied by urbanization and industrialization. Currently, source separation practices are being regulated, but without having much focus on waste treatment, where most of the waste ends up in open dump sites or unsanitary landfills, causing serious health, socio-economic and environmental issues. A major portion of the daily waste collection contains biowaste, which can be efficiently converted to energy, nutrients and other value-added products by using novel resource recovery technologies. This research study summarizes the potential of electricity generation from biogas generation via anaerobic

digestion of OFMSW and fertilizer production from struvite crystallization of anaerobic digestate of OFMSW. These value-added resources recovered can generate a stream of revenue, compensating the overall operation cost of solid waste management, thus making the solid waste management process socio-economically viable. The outcome of this study will lay the foundation for the development of an autonomous circular system integrated with the existing systems to establish a sustainable waste management system in Sri Lanka.

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