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Status of Plastic Waste Generation and Propose a Circular Economy-Based Policy Framework to Manage Plastic Waste in Sri Lanka

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Abstract:
Background: *Plastics are inexpensive, lightweight, and durable materials, which can be used to develop a variety of products in a wide range of applications. The production of plastic waste has steadily increased over the past 30 years and poses several threats to wildlife and human being. The recycling techniques commonly used for plastic wastes include filling, incineration, chemical or mechanical recycling, and fuel conversion. Circular Economy is an alternative concept for the present linear model of make, use, and dispose of plastics. Recycling aims resource efficiency to extract maximum value by improving waste minimization strategies. In Sri Lanka, the use of plastics has created enormous quantities of waste that causes socio-economic, health, and environmental issues. Currently, circular economy is not effectively practiced in Sri Lanka, since there are no proper circular based structure, plastic recycling, and necessary policies. Therefore, present study reports the amount of plastic waste generated, future trends, gaps in current management strategies, and recycling in order to propose a circular economy-based policy framework to manage plastic waste in Sri Lanka.*
Materials and Methods: *Data on export and import quantities (from 2008-2018) of different plastics categories were gathered from the Statistical Division of Sri Lanka Customs and they were sorted according to major plastic types in order to analyzes the quantities of import, export, and waste generation. Recyclers were interviewed to classify the information regarding plastic waste recycling practices within the country. Existing regulations to manage plastic waste in Sri Lanka were analyzed by gathered information from Sri Lanka Customs, Ministry of Mahaweli Development and Environment, and Central Environment Authority. The circular economy-based policy framework was proposed accordingly the summary of data obtained from recyclers, analyzed results of the import, export, and the existing laws and regulations.*
Results and Conclusion: *Plastic imports have been increased by 223,686 tons from 226,865 metric tons in 2008 to 450,551 tons in 2018. However, the exports by recycling are remarkably low compared to imports though it has increased by 6,060 tons from 24,760 tons in 2008 to 30,820 tons in 2018. In 2019, quantities (tons) of different plastic wastes has recorded, 11,750 LDPE, 3,270 HDPE, 60,480 PP, 29,060 PS, 2,200 PET and these values are expected to be increase up to 175,000 LDPE, 7,800 HDPE, 79,800 PP, 50,000 PS, 3,000 PET by 2025. The gap in waste generation and recycling will further be increased if proper policies are not adopted. Capacity and actual production of the recycling industry emphasizes the conditions that have been developed. Therefore, a circular economy-based policy framework within the concept of reducing, reuse, and recycle was suggested.*
Keywords: Circular Economy, Plastic Recycling, Policy Framework, Waste Management

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I. Introduction

Apart from the use of plastics in a multitude of day-to-day activities and in industries, during recent years, significant growth in the consumption of plastic globally has been reported due to the introduction of plastics into newer application areas such as in automotive field, rail, transport, aerospace, medical and healthcare, electrical & electronics, telecommunication, building, infrastructure, and furniture[1]. Plastics have considerable advantages over other materials, such as wood, ceramics, and metal due to high thermal, electrical isolation properties and are considered inexpensive, light weighted, solid, robust, durable, corrosion-resistant materials[2]. Therefore, the annual production is rising exponentially, making plastics ubiquitous in aquatic, atmospheric, and terrestrial systems[3]. Plastics have outgrown most man-made materials and has become a major pollution concern currently receiving worldwide attention. The concept of plastic pollution can be defined as the introduction of

plastics (regardless of sizes, shapes or types) into the environment, resulting in threats to the environment, organisms, or even human health[4]. It likely takes much longer time for plastics to degrade in environment owing to the high-polymer nature when compared to other organic materials. For example, complete degradation of plastics may take years to centuries[5], especially in the natural environments. Overall, typical characteristics of plastic pollution in the environment can be summarized as diversity, persistence, global issues, combined pollution, potential threats to organisms and human health[4]. Plastic pollution has become a global issue with no boundaries in the world owing to the long-distance transport in different systems. Plastic pollution may cause physical damage, chemical harm, and biological threats to organisms[6]. Entanglement and ingestion of plastic debris are two typical ways of physical damage to organisms. However, chemical and biological impacts are probably chronic effects, which are not easily observed, and still remain uncertain. These adverse impacts could be caused by plastic debris and associated substances, which is either originated from additives or adsorbed substances from natural surroundings[4].

Recently, the generally accepted view is that plastics can act as "vehicles" for other environmental pollutants[7,8]. For example, Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), Tetracycline, Dichloro Diphenyl Trichloroethane (DDT) and heavy metals (Cd, Pb, Cu, Zn, etc.) were observed on the surface of plastic debris, and thus leading to the formation of plastic-pollutants mixtures in the environment [9,10,11]. Moreover, plastics could also act as vectors for persistent organic pollutants (POPs) and microorganisms in the environment [12,13.14]. In addition, chemicals, including monomer, oligomer, and additives, were observed to be released into the environment from plastics, implying that plastics can also be considered sources of some toxic chemicals[15]. Global plastic production has increased from 1.5 million tons in the 1950s to 335 million tons in 2016[16,17,18]. Since 2004, the world has made as much plastic as it did in the previous half century, and it has been reckoned that the total mass of virgin plastics ever made amounts to 8.3 billion tons, mainly derived from natural gas and crude oil, used as chemical feedstocks and fuel sources[19].

It is estimated that 4 percent of the world's annual consumption of petroleum is utilized as feedstock for plastic, and more than one third of plastic are consumed as packaging that is discarded quickly[20]. Between 1950 and 2015, a total of 6.3 billion tons of primary and secondary (recycled) plastic waste was generated, of which around 9% has been recycled, and 12% incinerated, with the remaining 79% either being stored in landfills or having been released directly into the natural environment[21].

Various efforts have been made worldwide to reduce the volume of the resulting plastic waste, promote recycling of plastic goods and to mitigate the consequent environmental contamination[22]. Oxo-biodegradable plastics; a less persistent alternative to conventional plastics[23], bioplastics; derived from renewable sources of biomass or from agricultural waste, disposed-of plastic bottles and other containers by microbial degradation[22], a bacterium, *Ideonella sakaiensis* 201-F6; recently identified, which displayed the remarkable ability to use Polyethylene Terephthalate (PET) as a major carbon and energy source for its growth[24] were few such attempts to mitigate this alarming issue.

Moreover, recycling of plastics will definitely diminish the waste material at waste disposal while reducing the piling up of plastic virgin material on the earth. Plastic recycling can be mainly done in two ways specifically, mechanical recycling and chemical or feedstock recycling. There are also energy savings to be had, since up to about 130 GJ of energy per ton can be saved through recycling plastic, rather than producing primary new material. The statistic has been given that, if all global plastic waste were recycled, the equivalent of 3.5 billion barrels of oil would be saved, which is worth approximately 176 billion dollars (at 50 per barrel) [25].

The prevailing evidence indicates that a major problem from plastic may very likely exist, whose consequences could prove catastrophic if it is ignored. Since 6% of the current global oil production (including NGLs) is used to manufacture plastic commodities – predicted to rise to 20% by 2050 – the current approaches for the manufacture and use of plastics (including their end-use) demand immediate revision[19]. More extensive collection and recycling of plastic items at the end of their life, for re-use in new production[26] to offset the use of virgin plastic, is a critical aspect both for reducing the amount of plastic waste entering the environment, and in improving the efficiency of fossil resource use[19]. This is central to the ideology underpinning the circular economy, which replaces the 'end-of-life' concept with rebuilding, shifts towards utilize of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the prevalent design of materials, products and systems[27]. The concept of circular economy can be applied worldwide in order to address the complex issues caused by plastics.

Asia has become world's largest plastic consumer for several years, accounting for approximately 30% of the global consumption excluding Japan, which has a share of about 6.5%[28]. Geographically, the five heaviest plastic polluters are China, Indonesia, Philippines, Vietnam and Sri Lanka, which between them contribute 56% of global plastic waste; this is mainly as a result of large populations living within 50 km of the coast, and relatively poor waste management facilities[29].

Sri Lanka Imports annually a considerable amount of plastic raw materials, finished products and a major portion of them end up as "Consumer Plastic Waste" causing serious environmental issues. It is estimated that

approximately 160,000 tons of plastic raw materials and products are imported and out of this 30% has been exported as finished products and the remaining are utilized in the local market[20]. The main types of plastics in used in Sri Lanka fall into the class of thermoplastics, which soften on heating and harden again when cooled; this property makes them appropriate for mechanical recycling. Most plastic recycling enterprises in Sri Lanka are small-scale operations, generally processing approximately 75-100 tons of plastic per month. The most commonly used raw materials are Polypropylene (PP), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Polyethylene Terephthalate (PET), and Polystyrene (PS), with polycarbonate and Polyvinyl Chloride (PVC) also being recycled[30].

It is evident that there is an immense gap between the amount of plastics imported and recycled or exported in Sri Lanka, releasing an enormous amount of plastic waste into the environment annually. Even though, number of studies have been conducted on microplastics and its effect on marine or freshwater ecosystems in Sri Lanka, published literatures on other types of plastics, such as nanoplastics and macroplastics are limited. Overall, there still remains a huge knowledge gap in understanding the total amount of plastics imported as raw materials or finished good, the amount recycled and amount of plastics exported, to understand the level of plastic pollution in Sri Lanka.

Hence, the present study aims to study the annual plastic waste generation and recycling in Sri Lanka and to propose a circular economy-based policy framework to mitigate the plastic waste generation in Sri Lanka.

II. Material and Methods

Data on export and import quantities of different plastics categories[31] from 2008 to 2018 were gathered from the Statistical Division of Sri Lanka Customs. Plastics were categorized under 39th chapter of Harmonized System Codes (HS Codes) and again they were sub divided into two major categories as "primary forms of plastics" and "waste, paring & scrap": semi manufactures/articles[31]. Data were sorted according to major plastic types, namely LDPE, HDPE, PP, PS, PET, PVC and other types of plastics.

LDPE is considered less toxic than other plastics and safe for use. LDPE is a semi-rigid and translucent polymer. Compared to HDPE, it has a higher degree of short and long side-chain branching and produced at high pressure (1000-3000 bar; 80-300°C) via free radical polymerization process. HDPE is the foremost commonly recycled plastic and is considered as the safest form of plastic. It is a relatively simple, cost-effective process to recycle, hard-wearing and does not break down under exposure to sunlight, heating or freezing. PP is tough, lightweight, and has excellent heat-resistance qualities. It serves as a barrier against moisture, grease and chemicals. PP is a rigid and crystalline thermoplastic, produced from propylene monomer. It is a linear hydrocarbon resin with chemical formula of $(C_3H_6)_n$. PS is an inexpensive, lightweight and easily-formed plastic with a wide variety of uses. PS may leach styrene, a possible human carcinogen, into food products specially when heated in a microwave. Chemicals present in polystyrene have been linked with human health and reproductive system dysfunction. While the technology for recycling polystyrene is available, the market for recycling is small. The presence of the phenyl (C_6H_5) groups is key to the properties of polystyrene. PET is a thermoplastic polymer which belongs to the polyester family of polymers. As well as a highly flexible, colorless and semi-crystalline resin in its natural state. Depending upon how it is processed, it can be semi-rigid to rigid. It shows good dimensional stability, resistance to impact, moisture, alcohols and solvents. PVC is a soft, flexible plastic and relatively impervious to sunlight and weather. PVC contains numerous toxins which it can leach throughout its entire life cycle. Almost all products using PVC require virgin material for their construction; less than 1% of PVC material is recycled. Other plastic category was designed as a catch-all for Nylon (PA), Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC) Layered or multi-material mixed polymers plastics and reuse and recycling protocols are not standardized within this category[32,33].

Table 1: Identification codes and uses of Plastics[19].

Symbol	Name	Example	Can be recycled in to
4 LDPE	Low Density Polyethylene	Food wrap, grocery bags, sandwich bags	Bags, paneling, garbage cans, lumber, composters
2 HDPE	High Density Polyethylene	Detergent containers, bleach, shampoo bottles	Liquid detergent bottles, pipes, recycling bins, picnic tables, lumber
5 PP	Polypropylene	Tupperware, yogurt containers, diapers	Bins, flower trays and pots
6 PS	Polystyrene	Coffee cups, disposable cutlery, trays, Styrofoam.	CD Cases, Disk Accessories
1 PETE	Polyethylene Terephthalate	Beverage containers, food containers	Fiber (polyester), bottles, clothing, furniture, carpet
3 V	Polyvinyl Chloride	Pipes, shower curtains, cooking oil bottles	Packaging, binders, films, flooring, pylons, carpet, cables
7 OTHER	Other	Baby bottles, Nalgene water bottles, glass lenses	Customized products, synthetic lumber

Plastic waste generation

Plastic waste generation within the country was identified as the function of two factors: the importing quantity and exporting quantity of plastics. No plastic was produced as raw materials within the country other than the imports during the study period. It was assumed that the amount of recycled plastics in the local market was negligible compared to the amount of recycled plastics which is being exported. Plastic waste generation by single use plastics, i.e., LDPE, HDPE, PP, PS and PET was calculated by subtracting export quantities made by recycling processes within the country each year from the total import quantities to the country each year as shown below.

Plastic Waste Generation (LDPE, HDPE, PP, PS & PET) = Import quantity – Export quantity

Plastic waste generation by PVC and other plastic types was calculated by subtracting export quantities made by recycling processes within the country each year from the total import quantities to the country each year and then multiplying by 88%. Because only 88% of 'PVC and Other type of plastics' are released into the environment every year as waste[34].

*Plastic Waste Generation (PVC and Other) = (Import Quantity – Export Quantity) * 88%*

Then all the plastic waste recyclers spread around the country were identified by examining Post-Consumer Plastic Waste Management Project of Central Environment Authority (CEA) of Sri Lanka. Thereafter, 35 of randomly selected recyclers from them were surveyed by a questionnaire based structured interview.

Study of government policy framework related to the plastic waste management

Data on plastic waste recycling activities in Sri Lanka and existing regulations to manage plastic waste in Sri Lanka were gathered from Sri Lanka Customs, Environment Pollution Control division of Ministry of Mahaweli Development and Environment and National Post Consumer Plastic Waste Management Project (NPCPWM) conducted by Central Environment Authority (CEA) and analyzed quantitatively & qualitatively to study the government policy framework related to the plastic waste management.

Proposal for Circular Economy-Based Policy Framework

Barriers of the industry, limitations of the existing recycling activities of the country, quality of recycled products, the government involvement for the recycling industry and other issues were examined through the questionnaire survey. Finally, based on summary of primary data obtained from questionnaire survey, analyzed results of the annual import and export data of plastic and the existing laws and regulations on plastic and plastic waste management, a circular economy-based policy framework was proposed for Sri Lanka to mitigate the alarming issue of plastic pollution.

III. Result and Discussion

The Imports trends of Plastic in Sri Lanka

Plastics imports of Sri Lanka were evaluated for the eleven years period (2008 to 2018). The amount of plastics import has fluctuated during the study period (**Figure 1**).

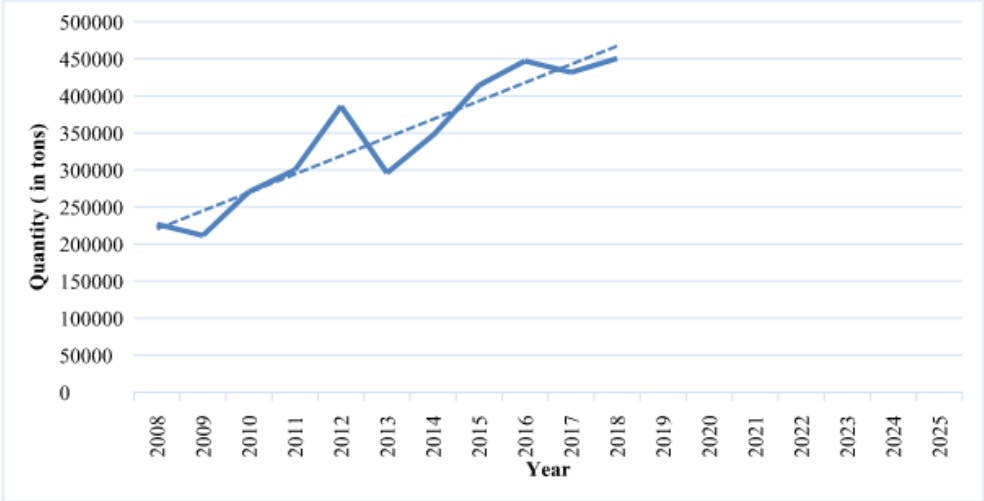

Figure 1: Amount of Plastic import to Sri Lanka during the year (2008 - 2018) period

Figure 1 shows that there has been a steady rise in imports of plastic from 2008 to 2018. Because plastics have gained popularity among the Sri Lankan community as a low-cost packaging material in a wide range of industries. From 2008 to year 2009, a declining trend was observed marking the lowest value of 211,629 tons in year 2009. The government imposed an "Environmental Conservation Levy" with a focus on specified items owned by consumers, specified items imported in to or manufactured in Sri Lanka and specified services provided in Sri Lanka which are likely to have a harmful impact on the environment through the enactment of the Environmental Conservation Levy Act No. 26 of 2008[35] in 2008. The main objective of the enactment was to change the behavioral patterns of the Sri Lankan community in order to encourage usage and production of eco-friendly alternatives for the plastics. Since the enactment helped to get the attention of the local community, it might have been a responsible factor to the decline of imports in year 2009. But after 2009, import quantity has started rising from 2009, more rapidly from 2011 to 2012. This increasing trend of plastic imports has led to a rapid consumption which in turn caused further growth of plastic imports to Sri Lanka from 2013 to 2016. Central Bank Annual Reports indicates this has been a common situation for all import categories. Again, 2017 to 2018 time period recorded a slightly decreasing trend of imports due to the partial band imposed by the government to prohibit the use of the single use polythene. According to the **Figure 1**, it is estimated by the year 2025, annual plastic imports would reach up to 650,000 tons which is more than double the quantity that has been imported in year 2013. However, a previous study which was conducted from 2005 to 2012 has estimated that the import plastic quantity would be 430,000 tons by 2025[36]. Therefore, there will be an enormously increasing trend in plastics imports compared to the previous predictions.

The law enforcement directly influences the plastic import quantities of a country. China implemented an unprecedented ban on imports of the plastics to the country resulting the advancement of the treatment structures of the plastic recycling industries and showed a sharp decline of the global recycled plastic waste trade too[37].

The Plastic import trends in different categories: LDPE, HDPE, PP, PS, PET, PVC and Other plastic types

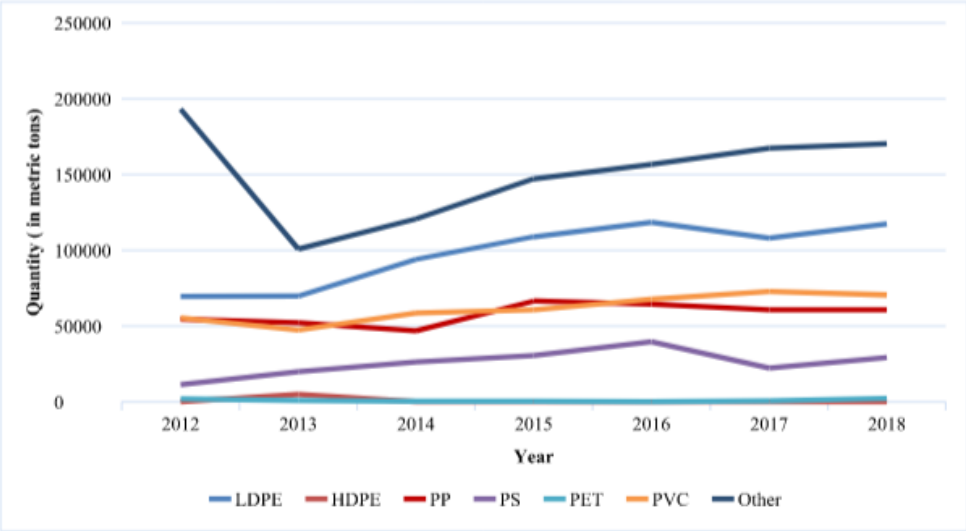

Figure 2: Amount of different categories of plastics; LDPE, HDPE, PP, PS, PET, PVC and Other plastic types imported to Sri Lanka during the year (2008 - 2018) period

Figure 2 presents the import trends of the different categories; LDPE, HDPE, PP, PS, PET, PVC and Other types of plastic within 2012 to 2018. HDPE and PET import quantities were observed in the lowest levels compared to other categories of plastics.

LDPE import was gradually increased from a quantity of 69,696 tons in 2012 to 118,468 tons in 2016 and suddenly dropped in 2017 to 107,954 tons and again rose in 2018 to 120,000 tons. Compared to the other plastic materials, HDPE import quantities were lower each year due to high consumption of alternative plastic materials for HDPE. The import of HDPE has increased from 33.9 tons (2012) to 4837.5 tons (2013) at the beginning of the period and rapidly decreased to 51 tons in 2014 and again it became lower since 2018.

In 2015, PP imports slightly increased and again decreased in to 60,861 tons in 2018. There has been a gradual increase in the import of PS from year 2012 to year 2016 from a quantity of 11,247 tons to 39,627 tons because of the high consumption rate. PS is an inexpensive, light weighted and easily formed plastic with a wide variety of uses such as disposable Styrofoam drinking cups, take-out clamshell food containers, egg cartons, plastic picnic cutlery and foam packaging[19]. In 2017, it suddenly dropped to 22,346 tons and again rose to 30,000 tons in 2018.

PVC is a soft, flexible plastic used to make clear plastic food wrapping, cooking oil bottles, teething rings, children's and pets' toys, and blister packaging for myriad consumer products. It is commonly used as the sheathing material for computer cables, to make plastic pipes and parts for plumbing, and in garden hoses[19]. The graph illustrates that from year 2013 to year 2017, there has been a gradual increase in the imports of PVC quantity from 47,402 tons to 72,688 tons. PET is one of the most commonly used plastics among consumer products, and is found in most water and pop bottles, and some packaging [19]. From year 2012 to year 2014 there has been a steep decrease in the imports of PET amounts from 1909 tons to 299 tons, but in 2016 PET import increased rapidly due to the high consumption rate. Other types of plastic's fluctuation was gradually increased from 2013 to 2018 due to the high consumption rate. The imports of the plastics in Malaysia have steadily increased from 20,000 tons per month in 2017 to 110,000 tons per month in the beginning of 2018 and then declined to around 35,000 tons per month[39].China, Hongkong, India are the leading countries of the import plastics not only in the raw form, but also by the waste plastic imports. Fifty percent of the total waste plastic imports of China comprised of Polyethylene terephthalate (PET). Due to the environmental and health issues raised with the recycling process of the PET caused to ban the imports of waste plastics to China in the 2018[40].

The trend of plastic exports in Sri Lanka

Currently, Sri Lanka has over 204 companies and organizations engaged in plastic waste collecting and recycling activities. The capacity of the local plastic processing industry at present is nearly 140,000 tons per year with an annual average growth rate of around 10% – 12 %. USA has been the dominant buyer of plastic products from Sri Lanka with nearly 40% of the total exports going to USA market. Products such as sacks and bags, articles of apparel /clothing accessories, and cellulose are manufactured through plastic processing and exported directly and indirectly[41].

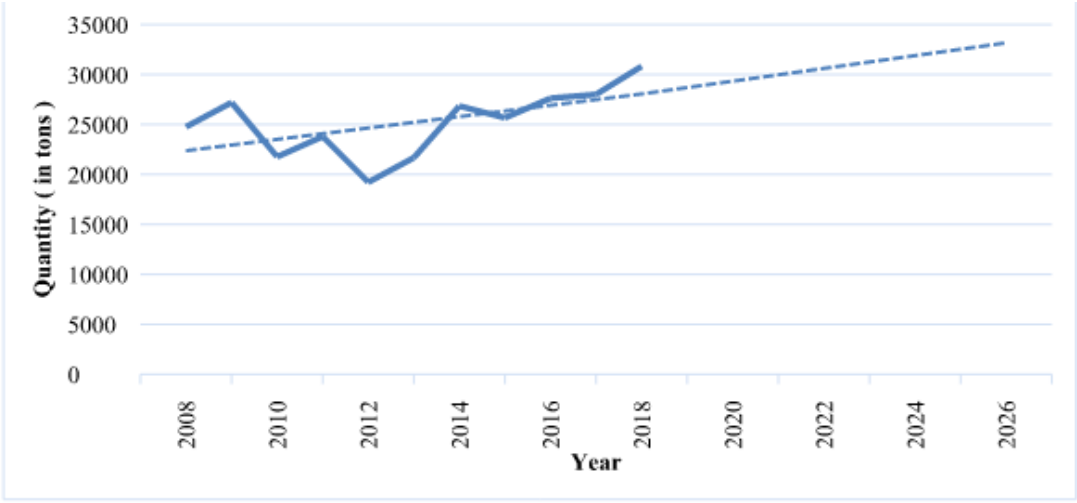

Figure 3: Amount of Plastic Export from Sri Lanka during the year 2008 - 2018 period.

Based on plastics export data from year 2008 to year 2018 the trend of plastic exports was analyzed. According to **Figure 3**, from 2008 to 2012, there has been a gradual decrease in the quantity from 24,760 tons to 19,218 tons in exports. From the year 2012 onwards there has been a gradual growth in exports, more rapidly during 2013-2014, marking the maximum export quantity of 30,820 tons in the year 2018. During this period, the government has expanded the export market for plastics and has encouraged the domestic plastic manufacturers to export their products more and more. Hence, the export quantity has increased rapidly during this period.

In year 2015, a sudden drop to a quantity of 25,665 tons was observed mainly due to the economical and the political condition prevailed in the country. But in year 2016, once again the export quantity has increased to 27,619 tons. When analyzing, it was noted that due to the rapid increase of the prices of plastics the consumption has been decreased creating a production excess in the market. In order to avoid the structural imbalance in imports and exports, this excess quantity has been exported. Bangladesh also has limited recycling facilities including 300 small units which recycle 138 tons of plastic waste within a day. The plastic recycling industry is economically attractive due to low transportation and production cost in Bangladesh. The recycled PET hakes and shredded plastics exported into India, Korea, Thailand, and Vietnam. China has been one of the major importers of used plastics in recent years[42]. Japan, Germany, USA, France, Italy like industrialized nations are popular as the main exporters and Turkey, Vietnam, Malaysia, Laos and India are identified as the import destinations. Because in most of these countries, regulations are not yet in place to stop the environmental crisis due to plastic[43].

The Export trends of different categories of Plastics; LDPE, HDPE, PP, PS, PET, PVC and Other types of plastics

Figure 4 displays export quantities of LDPE, HDPE, PP, PS, PET, PVC and Other types of plastic from the years 2012 to 2018. According to the graph it can be observed most exported plastic type is "Other types of plastics".

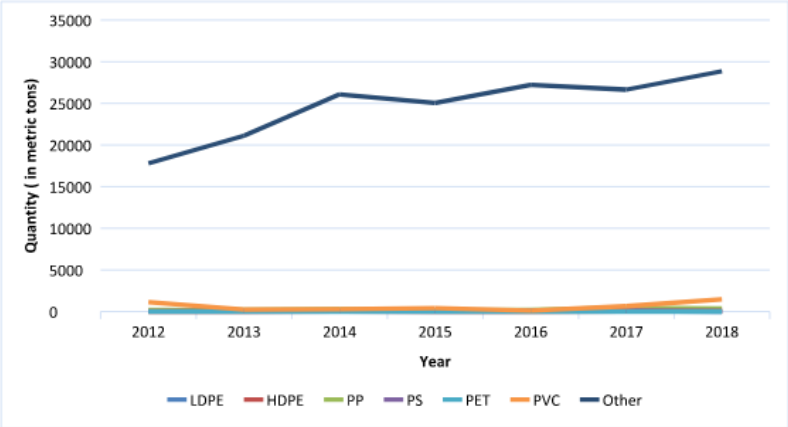

Figure 4: The Export trends of different categories of Plastics; LDPE, HDPE, PP, PS, PET, PVC and Other types of plastics

Compared to the import quantities, the export quantities of LDPE, HDPE, PP, PS, PET and PVC were observed in very lower levels. Razzaque et al[42] states that the Plastic exports in Bangladesh are highly focused on the Sacks and bags of polymers of ethylene (HS 392321), household and toilet articles of plastics (HS 392490) and plastic waste and scrap (HS 391590). The sacks and bags of polymers of ethylene (HS 392321) accounted the higher proportion; 26.61% in the total exports. The household and toilet articles of plastics (HS 392490) and plastic waste and scrap (HS 391590) were 24.18% and 10.63% from the total exports, respectively.
The gap between these two scenarios (imports and exports) points out the waste generation. High amount of waste was generated and remained in the country due to the lack of proper management practices.

Plastic Waste Generation in Sri Lanka

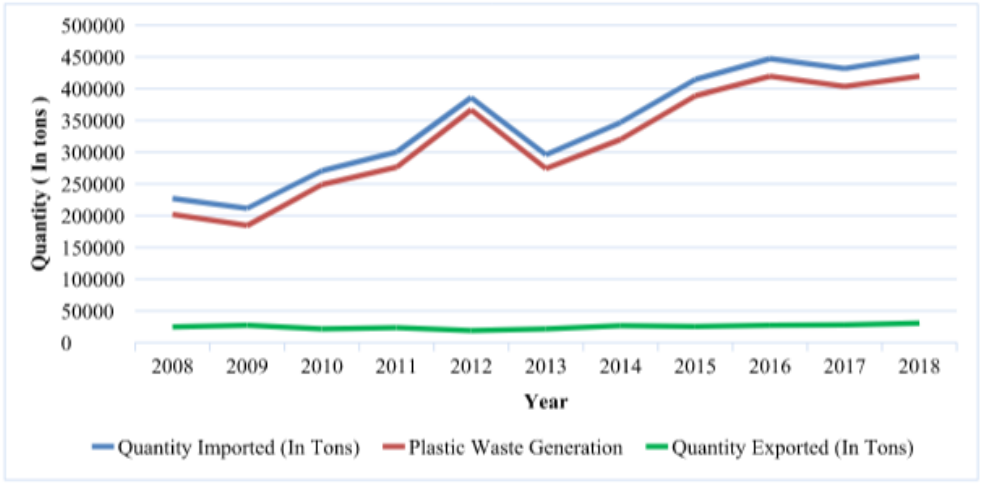

Figure 5: Plastic Waste Generation

Based on statistics of plastics import and export data from year the 2008 to year the 2018, plastic waste generation was calculated and analyzed. According to the **Figure 5**, import quantity and the waste generation showed a similar trend of fluctuation during the studies time period. Export quantity was observed at a very low level compared to the import and it was below 50,000 tons each year. The graph illustrates a minor gap between plastic import and waste generation. So that, it can be predicted that most of the imported plastics are discarded as waste after use. The reason for this situation is most of the plastics that import into the country are single-use plastics such as Polyethylene, Polypropylene and Polystyrene and are quickly discarded as waste. Geyer et al.[21] reported that 6400 tons are released as waste in the globe.

Plastic waste generation in different categories; LDPE, HDPE, PP, PS, PET, PVC and Other types of plastics

LDPE, HDPE, PP, PS, and PET are considered as single-use plastics and are thrown away after one use, but previously conducted researches have observed that PVC and other plastic types are durable than single-use plastics and not easily discarded[44].

Figure 6 illustrates the plastic waste generation in the year 2012 to 2018. The graph showed a similar trend as the plastic import data fluctuation during this time period. It represents LDPE and other plastic types were the main waste generating types of plastics compared to the others and fluctuated in same quantity. After that, respectively PVC, PP, PS, PET, and HDPE waste was generated and gradually increased from 2012 to 2018. Approximately 8 million tons of plastic products are consumed every year and it shows an increasing trend of plastic consumption in India[45]. Geyer et al.[21] reported the total plastic waste generation based on different categories of plastics in the world. According to this study LD, and LDPE plastics were the most generated waste types, comparatively other polymers recorded lower quantities of waste generation.

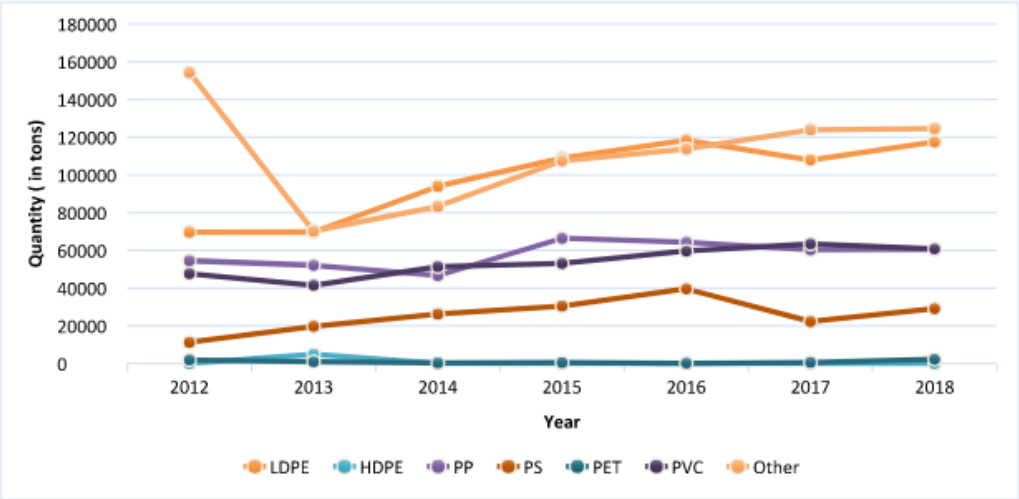

Figure 6: Plastic waste generation in different categories; LDPE, HDPE, PP, PS, PET, PVC, and Other types of plastics

There is no documented information available on the capacity of the recycling, and the number of businesses actively engaged in the recycling activities in Sri Lanka. Based on the field observations, the plastic recycling industry is active in Sri Lanka to a certain extent. Two hundred and four plastic waste collectors and recyclers have been registered in Post-Consumer Plastic Waste Management Project of Central Environment Authority in 2018. But, only 82 plastic recyclers are engaged in this business actively. The majority of these businesses are located in or near the capital: Colombo. The survey results revealed an increment of plastic recycling industries from the year 2009 to 2019.

The recycling process includes the collection, separation, and processing of waste. The waste comprised not only of plastics but also of paper, metal, and glass which are recyclable materials[46]. In the recycling centers, before recycling, most plastics are sorted according to their resin type by inspecting. A few plastic items are separated by color before they are recycled. The plastic recyclables are then shredded and chopped. These shredded parts, then undergo a process of drying and eliminating the impurities by filtering. This material is melted by using heat, pressure and frequently extruded in the form of pellets which are then utilized to manufacture other products[36].

Table 2: Number of Recycling Centers (Registered in CEA)

Year	Number of Active Recycling centers
2009	37
2019	82

Plastic waste generation and Recycling capacity

Most of plastic waste was generated from single-use plastics such as LDPE, HDPE, PP, PS, PET, and PVC. Since, Other types of plastics were more durable than single-use plastics, only 88% of them generate waste annually.[32] PVC is commonly used in the manufacturing industries of pipes, floor covering, roofing sheet and cables which have a broad range of applications in the household items, industrial products and the building materials and are discarded at higher rates[44]. Gunaratna,[36] reported that the plastic recycling capacity is increased by 10% every year with respect to existing recycling amount. Present study recorded that, waste generation of LDPE, HDPE, PP, PS, PET, PVC and their annual amount of recycling has increased in the past few years. Based on the trend line, in 2025 LDPE, HDPE, PP, PS, PET, and PVC will increase to 200,000; 8000; 80000; 60000; 3500; 90000 metric tons respectively same as the previous years. According to the trend line, in 2025, Other types of plastic waste will increase to 130,000 metric tons. However, the recycling capacity trend has not increased in a satisfactory level.

Recycling Capacity and Actual Production

The process of plastic recycling is practiced to a certain extent in Sri Lanka and it is always doubtful whether this industry is functioning at its maximum strength. Based on the survey results, relationship between recycling capacity and the actual production was analyzed.

Table 3: Recycling Percentages vs Current Capacities

Plastic Type	Annual Capacity	Annual Actual Production	Recycling percentage (%)
LDPE	10428.05	5475	52.50
HDPE	12413.65	5840	47.04
PP	13676.55	7469.725	54.62
PS	3347.05	2394.4	71.54
PET	14377.35	8946.15	62.22
PVC	730	292	40.00
Other	365	109.5	30.00

Figure 7 shows the gaps between actual production and annual recycling capacities. According to the **Table 3** actual production is going over 50% of its capacity in LDPE, PP, PS and PET plastic types. HDPE, PVC and Other types of plastic/ are recycled at a rate below 50%. Because PVC and most of Other types of plastic have high shelf life compared to the single-use plastics. Recycling quantities are always below the level expected. Main reasons for this are not receiving enough amount of waste to process, lack of sorting technologies, and other issues like cost & maintenance.

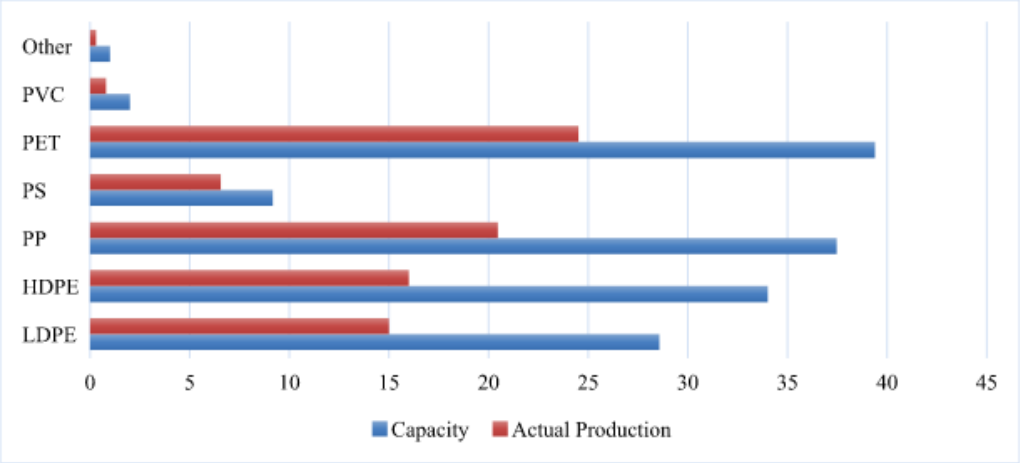

Figure 7: Capacity vs. Actual Production

Barriers and Management practices of recycling industry

The Plastic recycling industry and the solid waste management approaches are implemented with a number of obstacles and challenges. Continuation of these operations must adapt to the prevailing economic and social conditions. The observations of the survey lead to identify the major barriers and management practices in the recycling industry of Sri Lanka.

The plastic waste recycling industry is running under low capacity due to insufficient collection of waste plastic material. The quantities of plastic waste supplied to the recycling centers are not adequate at present. The main reason for this condition is mainly due to low participation of the public for plastic recycling activities by providing their plastic waste to the collection centers or collectors. The collaboration between government and non-government parties are the leading factor to maintain the linkages between plastic consumer and the recycling industry. The continuous supply of the plastic waste throughout the year is also another governing factor for the production in recycling industries. Because plastic waste supply is varying in different seasons such as Christmas, New year, Sinhala-Tamil New year periods of the year. T'ing et.al,[47] stated that there is a significant and positive relationship between attitude, perceived behavioral control, personal habit, available facilities, and the norm with the human intention for the recycling process with the 3R concept among the Malaysians.

The obtained quantities of the waste plastics must undergo lengthy preprocessing steps for sorting and removing the impurities. Because the full process of sorting plastic wastes is carried out by laborers manually with their experience, and occasionally they fail to recognize the exact type of plastic. On the other hand, most of the waste plastic recyclers identify and sort of plastic wastes using color as a sorting technique. However, color should not be considered as a good sorting technique as different types of plastic products can have the same color. When different types of plastics are mixed together during the recycling process, the final product can show defects. The labor wages also increase the cost of production. Novel and efficient sorting techniques which are

available in other developed countries should be introduced to the country at a low price in order to make the process more efficient. A technique used in Germany with the support of infrared rays where plastics are detected and sorted according to the functional groups they are made of, can be a good solution to this. In the meantime, it is practiced in India using a sorting machine to sort plastic wastes would be very much practical and cost effective to a country like Sri Lanka[44].

Furthermore, the effective modification of the waste collecting mechanism to properly sort out the waste in respective categories and quick transformation to money will attract the local communities to the recycling process. The problems associated with the infrastructure facilities of the recycling industries are identified as major constrains for the expansion of the recycling industry. Some recyclers do not have a suitable land to construct large scale recycling plants. Also, they have a problem in finding space for the storage of collected plastic waste. In order to overcome these problems, the government should provide sufficient storage facilities to the recyclers along with suitable lands to construct plants. During the survey, it was noted that most of the recyclers use well water as a water source to clean their collected plastic waste, which could be considered reliable and cost-effective. But it was observed that none of the plastics recycling industries in Sri Lanka has a wastewater treatment facility for effluent discharged by washing off plastic waste. Therefore, discharging of wastewater should be done in an environmentally friendly manner since it can create health and environmental issues. The situation can be crucial with the washing effluent containing heavy metals, oil and grease. Hence the recyclers must be severely advised to treat the waste effluent with a cleaning agent before discharging it into inland water bodies. The odor and destruction of scenic beauty of the environment may cause a negative perception in the society.

During the survey it was observed that plastic waste collectors and recyclers show less motivation to cordially work with the Central Environmental Authority, the authority itself carry out a waste plastic recycling project under the title 'National Post Consumer Plastic Waste Management Project' (NPCPWMP). It had been implemented with the intentions of developing the regional plastic waste collection system and the plastic recycling network. It would be much appreciated if the government could provide more assistance to develop and function this at its maximum strength which in turn could also be considered as a short-term recycling trend. The development of an online platform with a mobile app to link all the recycling industries, collectors, and the local communities is timely needed. This online platform must provide the geographical location of collecting point, its capacity, opening hours and direct contact methods.

Furthermore, it was observed that all plastic waste recyclers are having a low market price for their recycled products as virgin plastics are available at low prices. Hence, while planning to introduce recycled products to the export market, introducing a reliable local market price enabling the recyclers to gain a higher income is highly recommended. Apart from all the above, most of the recyclers face the problem of lack of funds to conduct the business. Therefore, this can be overcome by facilitating to obtain loans from Small Business Development Board and Rural Development Bank at reduced interest rates.

Circular Economy based Policy Framework to mitigate the plastic waste in Sri Lanka

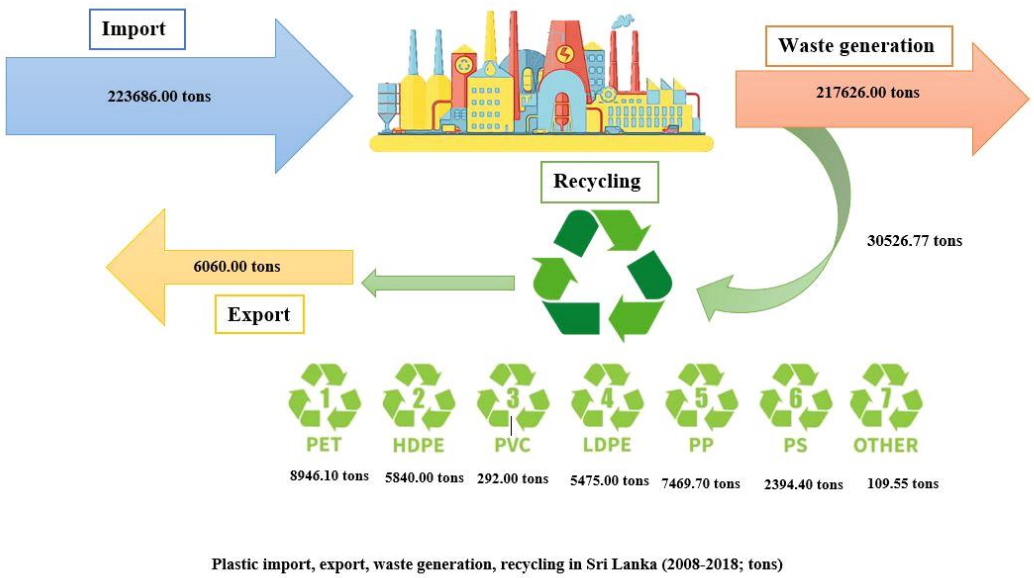

Figure 8: The value chain of plastics in Sri Lanka

According to Gazette No. 2034/33 under the National Environmental Act No. 47 of 1980, Sri Lankan government introduced regulations to standardize the plastic waste generation and management within the country. This act was implemented to ban the manufacture, sale, offer for sale, offer free of charge, exhibition or use any polythene or polythene product which is 20 microns or below in thickness. However, effective implementation and monitoring of this ban has not been adequate and a number of oppositions by the industrial sector, requesting for a more phased and practical solution to be adopted within a given time period was raised[48,49]. Even though, there are persisting issues in terms of discarding polythene due to the lack of a proper system[49].

Circular economy-based policy framework was introduced by MacArthur [50], to reduce the linear concept of plastic waste management and move to the circular economy. Plastic production and consumption could not be stopped and separated from human lives today. Due to that, we have to move the circular economy-based concept to manage resources effectively and efficiently. Implementing economic, policy, and regulatory measures such as direct surcharges, taxes, extended producer responsibility, mandatory requirements and standards for circular or eco-design, and a ban on certain plastic types could be practiced. In this study, we wish to propose a circular economy-based policy framework for the country.

Recycling industry promote a circular economy which increases the collection of waste material successfully, and the perception of the society is a key factor to success; we have yet to achieve that as a community. Moreover, we must understand the economic conditions and environmental impacts of recycling, so we can clearly determine how much beneficial recycling would be. Waste management facilities, such as recycling plants, have to be grown exponentially in both number and capacity to cater current trend of plastic waste generation.

Before moving to the recycling process society should gain knowledge about the types of plastics that can be recycled in the country. The manufacturer should provide clear details about the product package such as plastic type. Plastic type can be labelled 'compostable' or 'biodegradable' and how they should be handled after use. Consumers of society have to be empowered to buy reusable or recyclable plastic products after initial use, otherwise refuse it, even though manufacturers have adopted innovative marketing tricks. Applications with clear environmental benefits should be identified in those cases, and government should consider measures to stimulate innovation and drive market developments in the right direction. To allow adequate sorting and avoid false environmental claims, the government should propose harmonized rules for defining and labelling compostable and biodegradable plastics. It will also develop lifecycle assessment to identify the conditions under which the use of biodegradable or compostable plastics is beneficial, and the criteria for such applications.

The packaging should include the current resin code (three chasing arrows with coded numbers and sometimes letters). These are intended for industry insiders, such as waste pickers, recyclers, and sorters. However, many consumers currently fail to understand whether the packaging is recyclable or not. If the package is qualified as "Recyclable", packaging must be recycled in practice and this information must be reviewed regularly.

Sometimes, sorting different materials is nearly impossible because many of the finished products are created by layering different types of plastic. This is a growing practice in flexible films, as seen with juice pouches, bags, and most food packaging films and toys. Cartons are another product that utilizes multiple layers; although they are marketed as "recyclable" each of these containers have complex layering of paper, several types of plastic, and metal. Often these plastics look the same but each type of plastic is a completely different chemical and they are not compatible together. Recycling these plastics require first separating and then sorting them which can be difficult because they are often visually indistinguishable, and recyclers would need to separate each of these materials. Although, it is technically possible to recycle all polymer types, in reality, a raft of limiting factors such as minimum government involvement, lack of infrastructure, market conditions, equipment, or budgetary limitations are affecting in terms of promoting them than other types. So that government can introduce the way of separating these combined plastics and further recycling or introduce a new regulation which regulates the whole packing process of manufacturing in term of facilitating the recycling process.

In the meantime, it has also recognized that provincial and municipal councils only collect and distribute plastic waste but do not involve in the recycling process. If the government could implement a common strategic plan to introduce plastic recycling at provincial and municipal council's level, it could also be considered as another short-term recycling trend that would help to achieve the goal of plastic waste reduction. The government shall start promoting plastic waste recycling industry and plastic waste recycling-related projects in Sri Lanka by providing financial assistance for the local authorities. In addition to that, the government can install major recycling plants covering each and every district and facilitate sufficient storage facilities, transport facilities to carry on the business with the cooperation of local authorities.

Exporting of recycled plastics and products made by recycled plastics within the country is a major factor in terms of reducing import quantities within the circular-based economy concept. Therefore, the resale price and quality of recycled plastics and their products should be attractive and the government can take actions to maintain a stable price in the market since the plastic waste recycling industry will be becoming a profitable industry that people are willing to invest.

The challenges in recycling extend beyond the types of plastic, their forms, and contaminants. There is a general misconception of closed-loop recycling as all plastic types can be recycled over and over again indefinitely. This is not the reality of plastics recycling[51]. To recycle plastic, it must pass different steps which are collected, sorted, decontaminated, and grounded into flakes; it must also be melted and remanufactured into a new product. Contaminated materials are a significant issue in this process. Contamination can be occurred during the production itself, during the use of the plastic, and during disposal. Materials can be contaminated with anything from hazardous chemicals that pose a threat to workers at the facility, damage processing equipment, spread diseases due to microorganisms, and reaction of contaminants which were added during the usage (e.g.: A bottle that contained bleach and one that contained ammonia. If these two bottles are baled together during recycling, the bleach and ammonia can combine creating toxic chloramine gas and liquid hydrazine which is an explosive and toxic liquid). Some risky places such as hospitals, laboratories, and industries would deliver contaminated plastic waste to the recycler. Plastic waste may consist of chemicals, pathogens, and dangerous substances. Therefore, there should be an established hygiene mechanism to assure the receiving of clean plastic materials before entering the recycling centers or different mechanism such as burning by incinerators. Therefore, contamination poses a serious risk to recycling various types and bigger quantities together. So that the government should pay attention to govern the regular process of cleaning plastic waste during the recycling process.

Most of the recycling centers established in Sri Lanka face the major problem of not receiving enough plastic waste to carry on the process. Machine capacity is higher than the waste that they are receiving. So that, collectors and recyclers agreed to an exact quantity of waste providing and receiving monthly or weekly for the production. It should be a regular process to make it profitable to both parties. The market for recycled and innovative plastics shall be successfully established, with clear growth perspectives to cater more products. As the demand for recycled plastics has grown up, a stable flow of revenues and job security of workers will be ensured. According to the analysis of the results, the proposed policy framework can be summarized as below (Table 4).

Table 4: Summary of the Circular Economy based Policy Framework

Responsible Party	Actions
Custom	Propose rules and regulations for importing plastic items
	Reduce importing of low useful and non-recyclable plastic items
Government	Establish taxes for importing plastic items
	Reduce the enormous usage of plastic materials and encourage to move to alternatives
	Highly avoid the production, sale and usage of single use plastics
	Aware and practice the society for 3R concept (Reuse, Reduce & Recycle)
	Install a major recycling plant in term of covering particular administrative area
	Implement strategic plan to introduce plastic waste collecting facilities at provincial and municipal council's level which are directed to closer recycling plant by providing financial assistances
	Maintain standard price and quality of recycled plastics and their products in term of facilitation as input of manufactures
	Implement a policy to minimize hazards and ensure the environment hygiene when recycling
Manufactures	Provide the clear details about the product package
	Packaging will be included the current resin code
	Implement the process to carry out plastic packages by their own way from the markets
Recyclers	Introduce enough recycling plants as having island wide coverage
	Increase the production capacity of existing plants acquiring spaces and introducing state of the art technologies

IV. Conclusion

According to the analysis, the annual plastic imports would exceed 600,000 metric tons in the year 2025 which is double the quantity of imports in the year 2015. When the export pattern was considered, rapid growth was observed from the year 2012 to the year 2018 and trend line forecasts it should be 30,000 metric tons by 2025. Plastic waste generation is also increasing with the import quantity since the recycling process does not cater these increasing figures. Single-use plastic types such as LDPE, HDPE, PP, PS, and PET waste generation was higher than PVC and Other plastic types. Plastic recycling plays a major role in plastic waste management and has a high potential to be implemented as a well-established industry in Sri Lanka. According to the results, PVC and Other

plastic type waste recycling industries should be improved furthermore. The gap between waste generation and recycling capacity emphasizes the need for a circular economic concept to the country. Moreover, the gap between capacity and actual production emphasizes a rapid development of the recycling industry is highly required. Survey results revealed the need for a government policy framework related to the plastics recycling industry through the circular economy concept.

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