A Review of Single-Use Plastic Products (SUPPs) and their Alternatives in Sri Lanka using Life Cycle Assessment for Science-based Decision-Making

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Executive Summary

Hap hazard disposal of Single-use Plastic Products (SUPPs) is one of the major environmental issues that need to address urgently given the scale of the problem. The increasing level of consumption of SUPPs contributed to a global plastic production rate of 360 million metric tonnes in 2018, of which SUPPs represent 50%. After being used once, most SUPPs are disposed of on land, in water bodies, landfilled, incinerated or burnt in open spaces without recycling and any pre-treatment, which pollutes the environment and affects the health of humans and other living creatures, and also causes the loss of valuable resources.

With the enhanced understanding of the above negative impacts on the environment and human health, the global community has been providing more sustainable solutions and creating SUPPs reduction strategies to promote the use of reusable products, moving towards a more circular approach based on the life-cycle assessment (LCA) methods. There is also a growing concern to identify alternative materials, products and solutions to SUPPs.

Policymakers in both national and local governments have a critical role in creating the enabling environment and incentives for reducing SUPPs, as well as establishing the necessary technologies and behavioural changes that are needed to eradicate SUPP pollution in partnership with all stakeholders – public, private, and citizens. Resolution 9 of the fourth edition of the United Nations Environment Assembly (UNEP/EA.4/R.9) encourages member states to take action, as appropriate, to promote the identification and development of environmentally friendly alternatives to single-use plastic products, considering the full life cycle implications of such alternatives.

Like other countries, Sri Lanka has started several new initiatives to address plastic pollution and marine litter. The Ministry of Environment of Sri Lanka (MOE, Sri Lanka) developed a National Action Plan on Plastic Waste Management 2021–2030 and in 2021 and prioritized the actions to phase out selected SUPPs by 2021/2022. Policymakers however require science-based knowledge and evidence to introduce sound policies and regulatory interventions at different stages of SUPP lifecycles, adapted to the local capacities and conditions where the policy will be implemented and enforced.

This study, therefore, presents the results of the LCA study that was conducted for selected eight SUPPs and their alternatives in consultation with the policymakers and practitioners in Sri Lanka. It estimates the environmental impact of SUPPs and their alternatives and discusses the key advantages and challenges based on international experiences on SUPP bans in other countries. The key findings and recommendations summarized a shred of science-based evidence, not only for the Sri Lankan government but also for other countries with similar capacities, with the aim of proper management of SUPPs within the countries.

As summarized in Table A, the results of the study suggested that the substitution of SUPPs with other SUPPs made of alternative materials is not a sustainable outcome. The most important policy direction is moving towards multi-use or reusable products. Planning SUPPs management schemes or policies should have a systems perspective, including a life-cycle perspective with tradeoffs between environmental impacts. This need has a country or context-specific LCA studies, considering both geographic context (waste management infrastructure, energy mix, source and type of raw materials, recycling rates) and cultural context (acceptability of reusable alternatives – social norms, use behaviour (washing, laundering, changing etc.), access to waste management – likelihood of littering, cost). As the current study had to face one of the main issues is the data limitations for life cycle assessment. Though polylactide (PLA) products are considered one of the good alternatives for several SUPPs in the study however the government of Sri Lanka due to difficulties in the monitoring of PLA chemical content, considers it as not a good alternative for SUPPs in Sri Lanka. The government of Sri Lanka in the SUP regulations gazette no 2211/51, in the definition of Plastics, has included that the banned SUPP items cannot be manufactured/packed using Biodegradable plastic i.e. PLA. Hence, learning that Sri Lanka does not consider PLA as a good alternative for SUPPs, IGES-CCET in future research in collaboration with the Ministry of Environment (MOE), Sri Lanka, and University of Peradeniya will consider the study of selected SUPPs and their alternatives excluding PLA to estimate not only the environmental impact but also the social and economical impact of selected SUPPs and their alternatives.

Table A: Summary of LCA observations and recommendations in the Sri Lankan context

SUPPs	Alternatives	LCA observations	Recommendations
Cutlery Fork/spoon/knife	Metallic (MU)	• Steel reusable cutlery has lower impact for single use products. • Recycling of SUPPs is better compared to polylactide (PLA). • While PLA is biodegradable and minimizes impact if mismanaged, pre-production incurs higher environmental footprint.	• Promotion of reusable cutlery is highly recommended. • SUPPs with recycling end-of-life scenario are environmentally friendlier than PLA. • For SUPPs usage, recycling system development and consumer behaviour changes are needed to minimize usage, combined with introduction of more plastics into recycling.
Cotton bud with plastic stem	PLA stem 100% (SU)	No significant difference between SUPPs and PLA environmental footprints (provided environmental leakage is zero).	Substitutes and PLA are recommended, based on potential environmental leakage of SUPPs.
Joss-Stick wrapper	PLA-based (SU)	No significant difference between SUPPs and PLA environmental footprints (provided environmental leakage is zero).	Substitutes and PLA are recommended, based on potential environmental leakage of SUPPs.
Wrapper for cloth wick	PLA (SU)	No significant difference in SUPPs and PLA environmental footprints (provided environmental leakage is zero).	Substitutes and PLA are recommended, based on potential environmental leakage of SUPPs.
PET/PVC pesticide bottle ≤ 750 ml	HDPE, glass bottle	PVC has slightly lower environmental impact.	PVC is recommended over PET. Also, end-of-life management of PVC is more possible in Sri Lanka context.

SUPPs	Alternatives	LCA observations	Recommendations
Grocery bag/shopping bag	Paper-based, PLA bio bag	SUPPs have lower GWP.	• Reusable bags should be promoted over SUPPs and PLA-based products. • Consumer behaviour change and awareness raising is recommended to reduce usage of single use products.
Straw	Paper-based, reed-based, reusable metallic, PLA	SUPPs have lower GWP than PLA.	• Reusable substitutes should be promoted over SUPPs and PLA-based products. • Consumer behaviour change and awareness raising is recommended to reduce usage of single use products
PET bottle	PLA, aluminum	• Reusable aluminum bottles have lower impact than single use products. • Recycling of SUPPs is better than PLA. • While PLA is biodegradable and minimizes impact if mismanaged, pre-production incurs a higher environmental footprint.	• Promotion of reusable bottles is highly recommended. • SUPPs with recycling end-of-life scenario are environmentally friendlier than PLA. • For SUPPs usage, recycling system development and consumer behaviour changes are needed to minimize usage, combined with introduction of more plastics into recycling.

Abbreviations

CCET	IGES Centre Collaborating with UNEP on Environmental Technologies
CEA	Central Environment Authority
EPR	Extended Producer Responsibility
EU	European Union
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life-Cycle Inventory
LCIA	The Life Cycle Impact Assessment
PLA	Polylactide
SUPPs	Single Use Plastic Products
GWP	Global Warming Potential
LCSA	Life Cycle Sustainability Assessment
LCC	Life Cycle Costing

Table of Contents

Executive Summary i
Abbreviations iv
Table of Contents v
List of Tables vii
List of Figures vii
1. Introduction 1
1.1. Background 1
1.2. Objectives 2
1.3. Outline of the study 3
2. Analysis of SUPPs and their alternatives in Sri Lanka using the LCA method 4
2.1. Banning of SUPPs in Sri Lanka 4
2.2. LCA methodology 5
2.2.1. Setting the goal and scope 7
2.2.2. Inventory analysis 8
2.2.3. Impact assessment 9
2.3. Data availability and assumptions 9
2.4. PLA as alternative material for single use plastic product 10
2.5. Results and discussion 10
2.5.1. Case 1: Single use cutlery 11
2.5.2. Case 2: Cotton buds with plastic stem 13
2.5.3. Case 3: Sandalwood instant-stick wrappers 15
2.5.4. Case 4: Wrappers for cloth wicks 17
2.5.5. Case 5: PET/PVC pesticide bottles 19
2.5.6. Case 6: Grocery bags/shopping bags 21
2.5.7. Case 7: Straws 23
2.5.8. Case 8: PET bottles 25
3. Making science-based decisions to regulate SUPPs to mitigate the adverse environmental impacts 28
3.1. SUPP screening for regulation 28
3.2. Categorization of SUPPs 29
3.2.1. Composition-based categorization 29
3.2.2. Three types of SUPPs to be identified for regulation (GPML, 2021) 30
3.3. Plastic substitutes 30
3.3.1. Categorization of plastic substitutes 30
3.3.2. Plastic related conceptual and definitional issues 32

3.4. Policy Instruments 33
3.5. UNEP-LCI meta-analyses of LCA studies on SUPPs and their substitutes (UNEP-LCI, 2022) 35
3.6. Constructive policymaking initiatives on plastic substitutes 37
4. Lessons learned from other countries: A review of existing policies and legal instruments on single-use plastic product management in selected countries 38
4.1. Common policies in countries 38
4.2. European Union (EU) policies and actions 39
4.3. Policies and actions in France 41
4.4. Policies and actions in India 43
4.5. Policies and actions in Thailand 45
4.6. Policies and actions in Japan 47
4.7. Recent actions in Canada 49
5. Conclusion and recommendations 50
References 53
Appendix 57

List of Tables

Table 1: List of 16 SUPPs considered by Ministry of Environment for banning in 2021 4
Table 2: List of five additional SUPPs and two non-SUPPs to be considered for banning by Sri Lanka in 2022 5
Table 3: SUPPs and proposed alternatives 7
Table 4: System definition of selected SUP products and its possible alternatives. 8
Table 5: Analysis of process steps for forming SUPPs regulations (modified from UNCTAD, 2021).............. 29
Table 6: Types of chemicals to inventory based on life cycle stage and function (Source: OECD, 2021) 30
Table 7: Clarification of terms related to degradation and biodegradation UNEP (2017)............................ 33
Table 8: Strengths and limitations of four main groups of policy instruments 34
Table 9: Criteria narrowing the choice of policy instruments (adapted from US Congress, 1995). 1: Effective, 2: Average, 3: It depends, 4: Use with caution 35
Table 10: Policy instruments used to control SUPPs 38
Table 11: The GDP of the selected countries 39
Table 12: Regulations in EU 40
Table 13: Summary of policy development processes related to Directive on single-use plastics................ 40
Table 14: SUPPs regulations in France 41
Table 15: Regulations regarding SUPP waste management in India 43
Table 16: Regulations regarding SUP in Thailand 46
Table 17: Regulations regarding SUPPs in Japan 48

List of Figures

Figure 1: Main phases of Life Cycle Assessment (ISO 14040:2006) [10] 6
Figure 2: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – using IPCC 2013 GWP 100a 11
Figure 3: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – endpoint impact analysis using ReCiPe (H) V1.13 12
Figure 4: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – midpoint impact analysis using ReCiPe (H) V1.13 13
Figure 5: LCIA of SUP cotton bud with plastic stem vs. PLA-based stem as an alternative – based on IPCC 2013 GWP 100a 13
Figure 6: LCIA of SUP cotton bud stem vs. PLA-based stem as an alternative – endpoint impact assessment using ReCiPe V1.13 14
Figure 7: LCIA of SUP Cotton bud stem vs. PLA-based stem as an alternative – midpoint impact assessment using ReCiPe V1.13 14
Figure 8: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – using IPCC 2013 GWP 10 15
Figure 9: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – endpoint impact assessment using ReCiPe V1.13.. 16

Figure 10: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – midpoint impact assessment using ReCiPe V1.13 17
Figure 11: LCIA of SUP cloth wick wrappers vs. PLA-based wrappers as an alternative – using IPCC 2013 GWP 100a 17
Figure 12: LCIA of SUP cloth wick wrappers vs. PLA-based wrappers as an alternative – endpoint impact assessment using ReCiPe V1.13 18
Figure 13: LCIA of SUP Cloth wick wrappers vs. PLA-based wrappers as an alternative – midpoint impact assessment using ReCiPe V1.13 19
Figure 14: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as an alternative – using IPCC 2013 GWP 100a 19
Figure 15: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as alternatives – endpoint impact assessment using ReCiPe V1.13 20
Figure 16: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as alternatives – midpoint impact assessment using ReCiPe V1.13 21
Figure 17: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – using IPCC 2013 GWP 100a 21
Figure 18: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – endpoint impact assessment using ReCiPe V1.13 22
Figure 19: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – midpoint impact assessment using ReCiPe V1.13 23
Figure 20: LCIA of SUP straws vs. PLA-based alternative – using IPCC 2013 GWP 100a 23
Figure 21: LCIA of SUP straws vs. PLA-based alternative – endpoint impact assessment using ReCiPe V1.13 24
Figure 22: LCIA of SUP straws vs. PLA-based alternative – midpoint impact assessment using ReCiPe V1.13 25
Figure 23: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – using IPCC 2013 GWP 100a 25
Figure 24: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – endpoint impact assessment using ReCiPe V1.13 26
Figure 25: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – midpoint impact assessment using ReCiPe V1.1 27
Figure 26: Conventional polymers and substitute materials (UNCTAD, 2021) 31
Figure 27: Conventional plastics and bio-plastics, further divided into bio-based plastics and biodegradable plastics (modified from Lackner, 2015; Abeynayaka et al., 2022) 32
Figure 28: UNEP-LCI SUPPs summary of recommendations (UNEP-LCI, 2022) 36
Figure 29: EU plastic tax levies (European Commission, 2021) 42

1. Introduction

1.1. Background

Plastics have become a vital part of our day-to-day lives. This is mainly due to their unique characteristics, such as relatively low cost of production, chemical inertness, lightweight, extended durability, resistance to corrosion, thermal and electrical insulation, and relative convenience in fabrication and handling and hygiene, which results in a broad range of applications (Banerjee et al., 2013; Mourshed, et al., 2017; Giacovelli, 2018). Plastics are usually categorized into two groups: thermoplastics and thermosets (Giacovelli, 2018) 2018. Thermoplastics usually refers to the plastics that liquidize upon heating and can be molded and remolded into any shape or size and thus are widely used in commercial applications. Thermosets, on the other hand, degrade upon heating and therefore once formed cannot be remolded (Giacovelli, 2018).

Single-use plastic products (SUPPs), which are thermoplastics (also referred to as disposable plastics), are used once or for a short period before being thrown away. These include grocery bags, food packaging, bottles, straws, containers, cups, and cutlery. According to EU Directive 2019/904, "SUPPs means a product that is made wholly or partly from plastic and that is not conceived, designed or placed on the market to accomplished, within its life span, multiple trips or rotations by being returned to a producer for refill or reused for the same purpose for which it was conceived. Several SUPPs are also used in clinical applications such as lancets, injection phials, test strips, and saline bags. SUPPs can also include non-recyclable plastics such as thermosets, laminated or multilayer products such as sachets, paper plates lined with plastics, and plastic-coated items such as clips, a fact commonly overlooked. Similarly, the use and consumption of SUPPs, including personal protective equipment (PPE) such as masks and gloves due to the COVID-19 pandemic, have increased rapidly—indeed, SUPPs have undoubtedly played a key role in the fight against COVID-19, especially for frontline health workers. It is estimated that the advent of the COVID-19 pandemic has resulted in an additional 280 tons of medical plastic waste per day (Janairo, 2021). Moreover, the use of SUPPs has also increased during COVID-19 due to the rise in home delivery of foods, groceries and products wrapped with several types of plastic packaging and ordered via various E-commerce platforms (AIT & UNEP, 2021). Throughout the COVID-19 pandemic it has been observed that demand for food delivery services has risen; e.g., that for Grubhub and Just Eat increased by 12% and 36% respectively. In addition, owing to the fear of COVID-19 infection, the use of reusable coffee cups and shopping bags in many cities has increased sharply.

The increasing demand for SUPPs contributed to a global plastic production rate of 360 million metric tonnes in 2018, of which SUPPs represented 50% of total production (PlasticsEurope, 2019, PlasticOceans, 2020). Over one-fourth of SUP resins are manufactured in Northeast Asia (including China, Hong Kong, Japan, the Republic of Korea, and Taiwan), followed by North America, the Middle East, and Europe (Kosior and Mitchell, 2020). The market share for plastic manufacturing is dropping in regions such as the European Union (EU) while production has advanced in other parts of the world (EU, 2018). Most SUP packaging is used in business to consumer (B-to-C) activities; for instance, 39.9% of total plastic demand in the EU is for plastic packaging (EU, 2018), the majority of which is discarded in the same year as its manufacture (Giacovelli, 2018). Study suggests that only 9% of all plastic is recycled where recycling of SUPPs is much lower as SUPPs are not accepted by recycling centers due to low profitability and hard in recycling (GREENPEACE, 2022; Lindwall, 2020).

After being used, most SUPPs are disposed of on land, in water bodies, landfilled, incinerated, or burnt in open spaces, which pollutes the environment and affects the health of humans and other living creatures and also causes the loss of valuable resources (Boucher et al., 2019; Law et al., 2010; Briassoulis et al., 2015; Wang et al., 2018a, Wang et al., 2018b, Cartraud et al., 2019; Rizzi et al., 2019). There is therefore a pressing need to accelerate the sustainability evaluation, comparison, and impact mitigation of SUPPs to address the global challenges of climate change and sustainable development (Wang et al., 2018a, Wang et al., 2018b, UNEP, 2014, UNEP, 2016, UNEP, 2017, UNEP, 2019). To avoid misjudgments, the sustainability assessment of packaging alternatives needs to be carried out based on a life cycle approach (Ferrara et al., 2021).

This is also true for Sri Lanka, which makes use of various SUPPs and faces serious environmental issues. It imports annually a considerable amount of plastic raw materials and finished products, the majority of which end up as consumer plastic waste, causing serious environmental issues. It is estimated that in average 289,218 MT of plastic raw materials were imported per annum for 2016-2018, where the main materials is used in plastic packaging which consist of about 21% of LDPE and PS (Ministry of Environment, 2021). Out of this, 30% is exported as finished products and the remainder is used locally (Shantha and Samarakoon, 2019). Sri Lanka itself has over 400 companies engaged in plastic processing, the main polymers used being HDPE, LDPE, PET, PP, and PS. Many of these SUPPs end up as municipal solid waste (MSW) due to the lack of municipal capacity to manage them as well as irresponsible behaviour of consumers (Ministry of Environment, 2021), the combined result of which represents a national burden. However, there are large number of small and micro companies engaged in plastic processing which are not registered.

According to a study of the "National Action Plan on Plastic Waste Management 2021-2030" conducted by the authors, about 47% of plastic waste is openly burnt on individual premises in the country (Ministry of Environment, 2021). Further, recent beach surveys by the Marine Protection Authority show that SUPPs are ranked within the Top 10 causes of pollution and are the main cause of marine plastic pollution. Due to their nature (lightweight and small size) and poor municipal solid waste management systems in cities, most SUPPs ultimately enter sewer systems and cause problems such as blockages, which can lead to vector-borne diseases such as dengue. In consideration of the need for comprehensive plastic waste management in Sri Lanka, the Ministry of Environment of Sri Lanka developed a National Action Plan on Plastic Waste Management 2021-2030, with the technical assistance of CCET, Japan. One of its priority actions is to phase out certain SUPPs by 2021 and achieve an 80% reduction in their production and consumption by 2025 (Ministry of Environment, 2021). With the aim of implementing this priority action, Sri Lanka has imposed a ban on four items (cotton buds with plastic stems, sachets 20 mg/20 ml or less, PET/PVC pesticide bottles of less than 750 ml, and inflatable toys) as a first step, and plans to consider banning a further SUPPs in the future if required.

1.2. Objectives

In consideration of the financial and social consequences of banning SUPPs, such as socio-economic issues including job loss, reduced sales in stores that cannot provide carrier bags for groceries, as well as the fact that some alternatives result in higher negative environmental impacts, the true environmental gain related to these decisions has been called into question, prompting the need to thoroughly investigate all related factors. However, it is challenging to provide a holistic picture of the true environmental impact or gain by singling out only one aspect of a product, such as the manufacturing phase, usage, or disposal, thus the total life cycle needs to be investigated in order to reveal the overall environmental impacts. In parallel with this, imparting a lifecycle-based mindset in consumers will be needed, in order for them to understand the whole picture surrounding the products they buy. Life Cycle Thinking (LCT) is about going beyond the conventional focus on the production site and manufacturing processes to include investigating the environmental, social, and economic impacts of a product, or its alternative, over its entire life cycle (UNEP-LCI, 2022). Life Cycle Assessment (LCA) is a quantitative tool designed for this purpose, and assesses the environmental impacts of products and services across their entire life cycle, including raw material extraction, manufacturing, transportation, use, and end-of-life. In consideration of the need for such a study on SUPPs and their alternatives, including estimation of environmental impacts using the LCA approach, the IGES Centre

Collaborating with UNEP on Environmental Technologies (CCET) and the University of Peradeniya conducted the present study on selected SUPPs using LCA as well as insights gained from international experiences on SUPP bans. This report compiles the findings from the study and proposes recommendations aimed for use as science-based evidence for the Sri Lankan government for proper management of SUPPs in the country using LCA for assessment of environmental impacts However, in future study on SUPPs in Sri Lanka, the social and economic impacts from SUPPs will also be considered.

1.3. Outline of the study

The present study was conducted for the eight selected SUPPs to estimate the environmental impact of these together with their alternatives using LCA in consultation with policy makers and practitioners in Sri Lanka. It estimates the environmental impact of SUPPs and their alternatives, and discusses the key advantages and challenges based on international experiences on SUPP bans in other countries LCA analysis for SUPPs and their alternatives were performed for the determined system boundaries, and Global Warming Potential (GWP), ReCiPe midpoint and endpoint were examined. The LCA analyses was performed using SimaPro 8.3.0.0 software. Secondary data used in the model was obtained from the current ecoinvent database 3.0 in the SimaPro 8.3.0.0 software. emissions. ReCiPe midpoint impact categories provide more reliable results due to the wide range of indicators available, and the endpoint method indicates the extents of adverse impacts in categories such as human health, ecosystem quality, and resources which was used to compare environmental impact from SUPPS and their alternatives. Moreover, a review of existing policies and legal instruments on single-use plastics in selected countries and guidelines for screening of SUPPs was also conducted. This report compiles the findings of the study and proposes recommendations for use as science-based evidence for the Sri Lankan government for proper decision making for management of SUPPs in the country. The key findings and recommendations from the report could also be helpful not only for Sri Lanka but also for other countries with similar capacities, with the aim of proper management of SUPPs within the countries.

- **Chapter 1** emphasizes the need for the study on SUPPs for proper management of plastics and their impacts on the environment and explains the scope of the study.
- **Chapter 2** highlights the study on comprehensive LCA of selected SUPPs and comparison with alternatives. The key objective of the chapter is to estimate the life cycle environmental impacts of SUPPs that the Ministry of Environment, has recommended for banning.
- **Chapter 3** presents the guidelines and information for making science-based decisions to regulate SUPPs.
- **Chapter 4** is a review of existing policies and legal instruments on SUPPs in selected countries, and also introduces case studies from India, Thailand and Japan.
- **Chapter 5** draws some conclusions and provides recommendations based on the above chapters.

2. Analysis of SUPPs and their alternatives in Sri Lanka using the LCA method

2.1. Banning of SUPPs in Sri Lanka

The Ministry of Environment, Sri Lanka issued a gazette notice on 31 March, 2021 announcing a ban on the first group of four items, which went into effect on 1 April 2021, according to the Central Environment Authority (CEA) that acts as the regulator. Table 1 shows the list of SUPPs recommended by the Sri Lankan government, for the study by MOE, Sri Lanka in 2021, with the four items already banned highlighted in blue.

Table 1: List of 16 SUPPs considered by Ministry of Environment for banning in 2021

	Item description	Exceptions
1	Cutlery	
2	Cotton buds with plastic stems	Medical applications
3	Shirt clips	
4	Joss-stick wrappers	
5	Wrappers for cloth wicks	
6	Sachets 20 mg/20 ml or less	Food/medical applications
7	Netting used for wrapping fruit/vegetables	
8	Inflatable toys	Balloons/swimming pool floats
9	Advertising banners/posters	
10	Microbeads used in cosmetics	
11	PET/PVC pesticide bottles ≤ 750 ml	
12	Grocery bags/shopping bags	400 × 500
13	Bottles ≥ 500 ml	
14	Lunch sheets	
15	Multiple items used by hot food/fast food servers	
16	Toffee wrappers	

Out of that list Regulations were gazetted in 2021 banning

i. Sachets having less than or equal to a net volume of 20ml/ net weight of 20g (except for packing food and medicines).
ii. Inflatable toys (except balloons, balls, water floating/pool toys and water sports gear)
iii. Cotton buds with plastic stems (except plastic cotton buds used for medical/clinical treatment) and
iv. Polyethylene terephthalate (PET) or polyvinyl chloride (PVC) material for packing agrochemicals used for any process, trade or industry

In addition, the MOE of Sri Lanka is planning to expand its coverage in preparation for banning several new SUPPs and non-SUPPs within 2022, as shown in Table 2.

Table 2: List of five additional SUPPs and two non-SUPPs to be considered for banning by Sri Lanka in 2022

No.	Plastic/polythene/biodegradable plastic items expected to be banned	Proposed alternative(s)
Five SUPPs		
1.	Single-use straws and stirrers	Reusable or biodegradable raw materials such as reed, bamboo, paper
2.	Single-use plates, cups, spoons, forks, and knives, including yogurt spoons	Reusable or manufactured using biodegradable raw materials
3.	LDPE Shopping bags, and LDPE grocery bags of less than 10 (W) × 12 (H) inches without a handle and 10 (W) × 16 (H) × 5 (G) with a handle made of plastic or polythene	Reusable bags/paper bags
4.	Packing of incense sticks and wicks using polythene materials	Replacing current packaging materials with environmentally friendly raw materials
5.	Plastic garlands	Natural flowers/paper
Two non-SUPPs		
1.	Plastic string hopper trays	Manufacture using natural raw materials
2.	Outdoor grass mats (exemption: Indoor sports stadiums)	Natural grass

2.2. LCA methodology

Life Cycle Assessment (LCA) has been promoted as a robust quantitative tool, and a keystone in environmental decision making. While LCA was originally developed for products, the benefits of the life cycle approach may be extended to the more complex prospect of organizational assessment. Within this context, the UNEP/ SETAC Life Cycle Initiative launched the flagship project “LCA of organizations” to further explore the capabilities and applicability of Organizational Life Cycle Assessment (O-LCA) (UNEP SETAC Life Cycle Initiative, 2015). Moreover, UNEP and SETAC have worked together to develop the current work Towards a Life Cycle Sustainability Assessment. This has been achieved through the UNEP/SETAC Life Cycle Initiative. A key objective of the UNEP/SETAC Life Cycle Initiative is to help extend LCA methods and practices (United Nations Environment Programme, 2011).

In Life Cycle Sustainability Assessment (LCSA), the sustainability of a product is assessed over its entire life cycle (cradle to grave), taking environmental, social, and economic aspects into account (Müller and Hiete, 2021). Moreover, a number of Life Cycle Assessments (LCAs) with extended tools, such as Environmental Life Cycle Assessment (ELCA), Life Cycle Costing (LCC), Social Life Cycle Assessment (SLCA), Organizational Life Cycle Assessment (OLCA), and Life Cycle Sustainability Assessment (LCSA), have been developed and are now in use. ICA is not stand-alone tool; it is iterative and flexible in nature so as to assimilate various sustainable development goals (Pati, 2022).

In that respect, ‘Environmental LCA’ refers to the evaluation of environmentally relevant inputs and outputs as well as potential environmental impacts of the life cycle, as specified in International Organization for Standardization (ISO) 14040 (2006) and 14044 (2006). LCA brings a holistic perspective to decision-making and has gained acceptance as a decision-making tool within industry, procurement, and policymaking. The actual LCA assessment is divided into four phases as per the LCA methodology defined by ISO 14040 (2006) and 14044 (2006): goal and scope definition, inventory analysis, impact assessment, and interpretation, as shown in Figure 1.

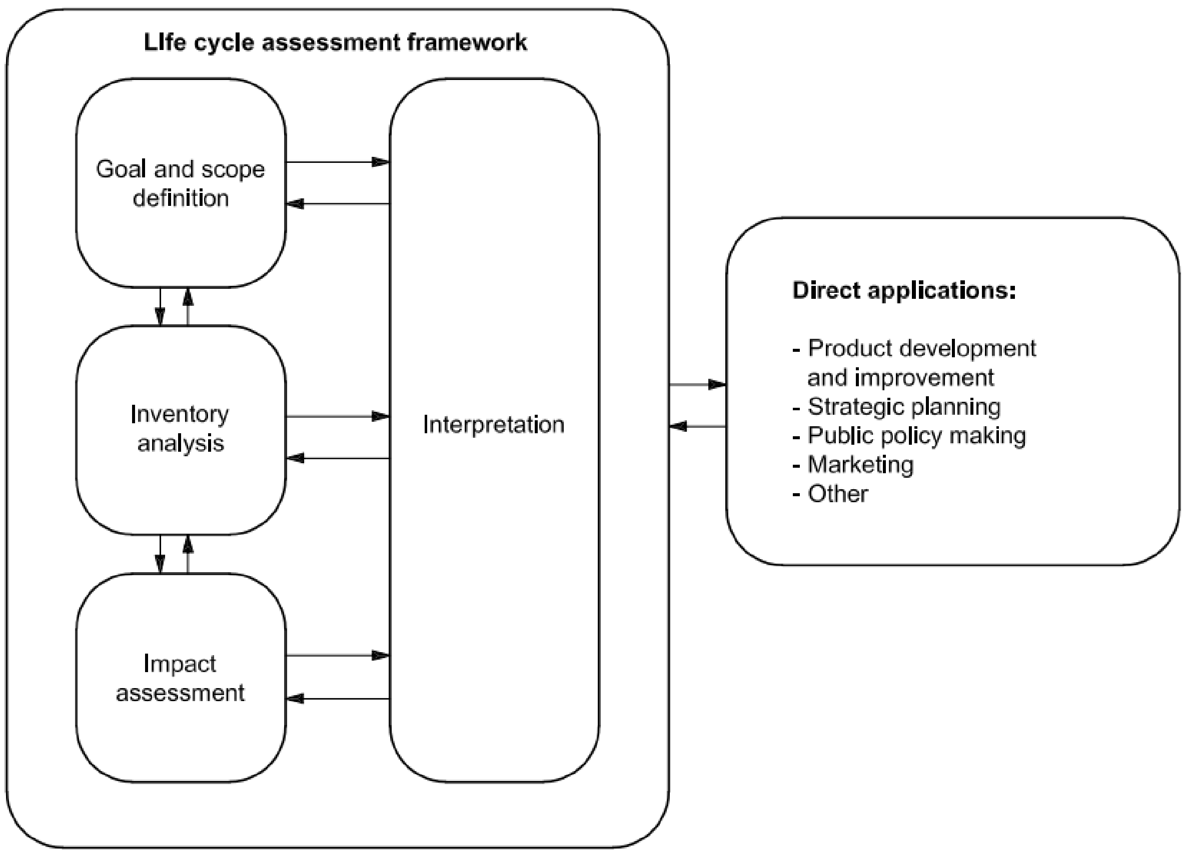


Figure 1: Main phases of Life Cycle Assessment (ISO 14040:2006) [10]

The goal and scope, including the system boundary and level of detail of an LCA, depends on the subject and the intended use of the study. The depth and the breadth of LCAs can differ considerably depending on the goal. ***The Life Cycle Inventory analysis*** phase (LCI phase), the second phase of LCA, is an inventory of input/output data related to the system being studied, and involves collecting the data necessary to meet the goal. ***The Life Cycle Impact Assessment*** phase (LCIA), the third phase, is aimed at providing additional information to assess a product system's LCI results to better understand its environmental significance. ***Life cycle interpretation*** is the final phase, in which results from the LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations, and decision-making in accordance with the goal and scope definition. There are cases where the goal of an LCA can be satisfied by solely performing an inventory analysis and interpretation, which is usually referred to as an LCI study.

Generally, the information developed in an LCA or LCI study can be used as part of a much more comprehensive decision process. Comparing the results of different LCA or LCI studies is only possible if the assumptions and contexts of each study are equivalent, which is why we use the International Standards requirements and recommendations to ensure transparency on these issues.

While LCA is only one of several available environmental management techniques (e.g., risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment), it may not be the most appropriate in all situations. LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in International Standards can be applied to such other aspects. Some of the salient features of LCA methodology are:

a) The systematic nature of LCA to assess the environmental aspects and impacts of product systems, from raw material acquisition to final disposal, in accordance with the stated goal and scope;
b) The relative nature of LCA, due to the functional unit feature of the methodology;
c) The varying depth of detail and timeframe of an LCA, depending on the goal and scope definition;
d) The provisions made for confidentiality and other proprietary aspects, depending on the intended application of LCA;
e) The ability to combine LCA methodology with new scientific findings and improvements in the state of the art of the technique;
f) The specific requirements applied in LCA, which are intended to be used in comparative assertions for public disclosure.

2.2.1. Setting the goal and scope

This study presents a comprehensive LCA of selected SUPPs in Sri Lanka, and compares alternative substitutions for such. It also provides an overview of the environmental drawbacks or benefits of SUPPs compared with other products based on existing LCAs. Moreover, based on the learnings from this comprehensive analysis, the study offers guidance to those intending to conduct LCA for SUPPs in the future, to avoid some of the common shortcomings and errors encountered. The study was ultimately aimed at performing life cycle environmental impact assessments for the eight SUPPs and proposed alternatives identified by the Ministry of Environment for banning (Table 3), using the LCA technique. A further aim was to enable to integrate LCA into the science-based decision-making process for SUPPs in Sri Lanka. In this respect, this study considers several alternatives to SUPPs based on local knowledge and availability.

Table 3: SUPPs and proposed alternatives

Product	SUPPs	Alternative Products Considered
Cutlery Fork/spoon/knife (all SU) Yogurt spoon	Polystrine (PS)	Single use: Polylactic Acid (PLA) Reusable: Steel (200 times reuse)
Cotton bud with plastic stem	Polypropeline (PP)	Single use: Polylactic Acid (PLA)
Sandalwood instant-stick wrapper	Low density polyethulne (LDPE)	Single use: Polylactic Acid (PLA)
Wrapper for cloth wick	Low density polyethulne (LDPE)	Single use: Polylactic Acid (PLA)
PET/PVC pesticide bottle ≤ 750 ml	High density polyethulne (HDPE) Polyethline terapthelate (PET)	Single use: Polylactic Acid (PLA)
Grocery bag/shopping bag	Low density polyethulne (LDPE)	Single use: Polylactic Acid (PLA)
Straws	Polypropeline (PP)	Single use: Polylactic Acid (PLA)
Water bottle (750 ml single use PET drinking water bottle)	Polyethline terapthelate (PET)	Single use: Polylactic Acid (PLA) Reusable: Aluminium (200 times reuse)

The LCA goal, scope, and system definition of this study are presented in Table 4. A cradle-to-grave scope was considered that include all stages, from pre-manufacturing to disposal.

Table 4: System definition of selected SUP products and its possible alternatives.

SUP Products	Studied SUPPs							
	Cutlery Fork/Spoon	**Cotton bud**	**Joss-Stick wrappers**	**Cloth wick wrappers**	**Pesticide bottle**	**Grocery bag**	**Straws**	**Water bottle**
Goals	• Identification of environmental impacts of the selected SUP product • Comparison of the environmental impacts of the SUP products to the selected alternatives • Environmental policy recommendations							
Scope	Cradle-to-grave							
Functional unit (Quantified description of the performance of the product systems, for use as a reference unit)	1 time use of cutlery fork /spoon/knife	1 cotton bud	1 Joss-Stick wrappers	1 Cloth wick wrappers	1 time use of <750 ml pesticide bottle	1 grocery bag	1 straw	1 time use of 750 ml water bottle
Geographical boundary (System was bounded by cutting off low level life cycle links)	Sri Lanka							
Life cycle level-based boundary (System was bounded by covering major geographical regions)	• Life cycles of infrastructure and capitals were excluded, and long-term emissions included. • Impact of manufacturing process and waste scenario data were taken from ecoinvent data base.							

2.2.2. Inventory analysis

Inventory analysis starts with constructing a life cycle flowchart and collecting the data for all relevant inputs (energy and material) and outputs (emissions and wastes) throughout the life cycle. These data are then set in relation to the functional unit(s) defined in the goal and scope definition. The data collection for the life cycle inventory preparation involved information related to the pre-manufacture, production, transportation and disposal associated with SUPPs. The data related to SUPPs at different stages through the life cycle were collected through field surveys, observations, and personal interviews. Regarding the alternative products, respective life cycle phases related to activity data have been estimated and collected from equivalent manufacturing processes, etc. A summery table of the inventory is given in Appendix.

2.2.3. Impact assessment

In this study, LCA analysis was performed for the determined system boundaries, and GWP, ReCiPe midpoint and endpoint were examined. The LCA analyses was performed using SimaPro 8.3.0.0 software. Secondary data used in the model was obtained from the current ecoinvent database 3.0 in the SimaPro 8.3.0.0 software. The IPCC 2013 GWP 100a V1.03 method indicates the effects of climate change as a result of GHG emissions. ReCiPe midpoint impact categories provide more reliable results due to the wide range of indicators available, and the endpoint method indicates the extents of adverse impacts in categories such as human health, ecosystem quality, and resources.

2.2.3.1. IPCC 2013 GWP Method

For the purpose of identifying the climate change, the IPCC 2013 GWP method was generated by the Intergovernmental Panel on Climate Change (IPCC). The Global Warming Potential (GWP) is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to carbon dioxide (CO_2eq). Further, the GWP is calculated over a specific time frame which is 20, 100, and 500 years. In this study, the characterization model for mid-point assessment was used to assess the Global Warming Potential (GWP) of greenhouse gases (GHGs) over 100 years.

2.2.3.2. ReCiPe Method

ReCiPe is an impact assessment method used in LCA which calculates the environmental impact in two different streams: midpoint level (Problem-oriented) and end pint level (Damage oriented). The midpoint indicators focus on single environmental problems such as climate change, ozone depletion, human toxicity etc. But the endpoint indicators show the impact on three higher aggregation level such as resource, human health, and ecosystems.

The DALY of a disease is derived from human health statistics on life years both lost and disabled. Values for disability-adjusted life years have been reported for a wide range of diseases, including various cancer types, vector-borne diseases and noncommunicable diseases. The DALY concept in ReCiPe, includes years of life lost and years of life disabled, without age weighting and discounting, as a default setting for quantifying the damage contributing to the human health area of protection within LCA. The loss of species during a certain time in a certain area as the basis for the endpoint indicator. The endpoint characterization factor for ecosystem damage can thus be calculated by taking the sum of the potentially disappeared fraction of species (PDF), multiplied with the species density. The ReCiPe model of resource based on the geological distribution of mineral and fossil resources and assess how the use of these resources causes marginal changes in the efforts to extract future resources. It develops a function that reflects the marginal increase of the extraction cost due to the effects that result from continuing extraction (Goedkoop et al., 2009).

2.3. Data availability and assumptions

Detail analysis was conducted to prepare life cycle inventories of respective products based on the system boundaries already defined based on four main stages of life cycles of each product category. Materials of each product have been identified and further details of material compositions currently being investigated before finalizing the LCIs. Sources of data were commercial LCI databases, public LCI databases, measured data, data from peer-reviewed literature, data from reports of public bodies and data from manufacturers. The alternatives for the selected SUPPs were selected by considering the social acceptance, adaptability to change manufacturing process by material substitution. When considering the manufacturing process, PP, PE, PS, and PLA based products undergo the same process of injection molding provided by SimaPro.

The use phase related information such as water and detergent consumption for the washing of the metal cutlery fork/spoon and aluminum water bottle was taken from the literature. Accordingly, the water and detergent consumption for the washing during the use phase is assumed as 0.4 L and 1 g for metal cutlery fork/spoon and for aluminum water bottle 0.25 L and 1 g respectively (for 200 times washing). Also, the average weight of aluminum water bottles and labels for PET water bottles were taken from literature [25,26]. Accordingly, weight of aluminum water bottle and label for PET water bottle were assumed as 105.9 g of aluminum and 0.37 g of PE respectively. The end-of-life phase of each product category was taken based on the potential and possible scenario of Sri Lankan waste management practices. This study assumed that waste from all single-use items either ends up in 100% of recycling or landfill or incineration. End-of-life process data were primarily taken from SimaPro software. End of life process data were primarily taken from SimaPro.

All the transportation distances were based on assumptions and were not measured. Transportation distances from overseas to Sri Lanka were assumed based on the import countries especially China, India, UAE. The local transportation to the factory and consumer is considered as 50 km and 150 km respectively. The municipal transportation from consumer to recycling plant, landfill and incinerations are assumed as 40 km, 20 km, and 80 km respectively. The detailed information is provided in the Appendix.

2.4. PLA as alternative material for single use plastic product

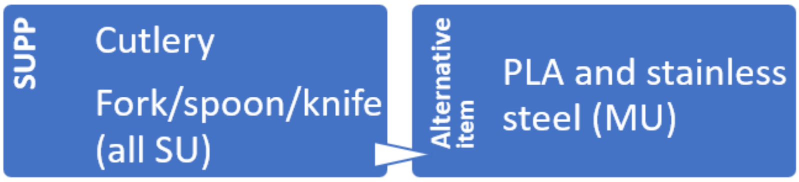
The global demand for plastics is expected to double in the next 20 years. To achieve such increased demand while combating climate change and plastics littering, novel polymers that are both bio-based and biodegradable, such as polylactic acid (PLA), have attracted much attention for single-use plastics applications (Moretti et al., 2021). PLA is both bio-based and biodegradable and has therefore attracted increased attention for single use plastics applications. PLA has good physical and mechanical properties, which makes it a good candidate for replacing petrochemical thermoplastics. PLA is used as a packaging material due to its many important properties, notably its glass-like transparency and its light weight, which, combined with its flexibility and mechanical resistance, make packaging made of this material resistant to breakage. Among the biopolymers available in the world, PLA is one of the highest biopolymers produced globally and thus, making it suitable for product commercialization.

PLA is the most widely researched and promising biopolymer that has the potential to replace conventional petroleum-based polymers due to its renewability, recyclability, biodegradability and compostability. In addition, PLA has an excellent manufacturing ability as it is suitable to be processed with various methods. PLA manufacturing processes include injection molding, film extrusion, blow molding, thermoforming, fiber spinning, and film-forming. PLA-derived products have been used in many industrial applications, including packaging, textile, biomedical, structural, and automotive. (Ilyas et al., 2021). PLA bioplastics are extremely versatile materials with a wide variety of use cases in many industries. Environmentally friendly cups, plastic containers, and bottles are all made with PLA bioplastics. They are recognized as safe for food packaging applications by the United States Food and Drug Administration (FDA) (Mulla et al., 2021).

2.5. Results and discussion

The life cycle impact assessment was conducted for eight SUPPs and respective alternatives using for the determined system boundary, and GWP, ReCiPe Midpoint (18 categories) and Endpoint (3 categories) were examined. LCA analysis is performed using SimaPro 8.3.0.0 software. The secondary data used in the model is obtained from the existing ecoinvent database 3.0 in SimaPro 8.3.0.0 software. IPCC 2013 GWP 100a V1.03 method indicates the effects of climate change as a result of GHG emissions. The ReCiPe midpoint impact categories provide more reliable results due to the wide range of indicators provided and the endpoint method indicates the extent of adverse impacts in categories such as human health, ecosystem quality, and resources.

2.5.1. Case 1: Single use cutlery



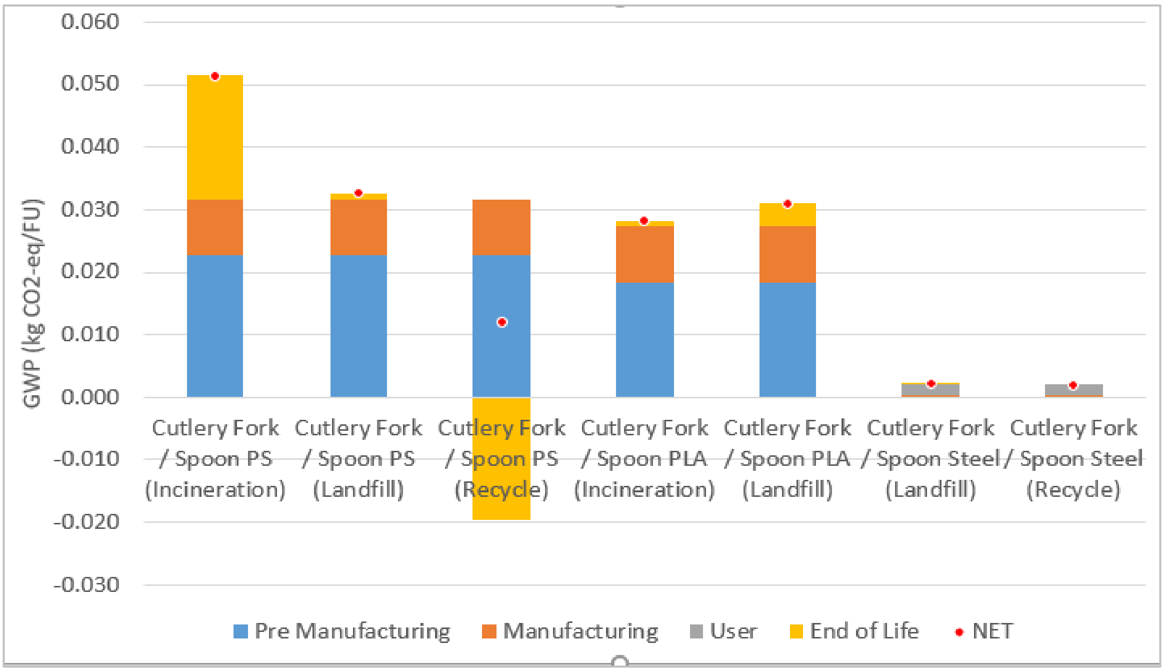


Figure 2: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – using IPCC 2013 GWP 100a

Figure 2 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of polystyrene (PS) cutlery fork/knife and stainless steel cutlery/knife. It demonstrates that the total GWP impact of PS cutlery associated with the entire supply chain was 0.033 kg CO_2-eq per unit (1 cutlery item), and 2.64×10^{-4} kg CO_2-eq for stainless steel cutlery. The GWP impact of PS cutlery was approximately 125 times that of stainless steel cutlery. This data indicates that the highest GWP of the value chain for PS cutlery pre-manufacturing was 0.022 kg CO_2-eq, which is higher than for other life cycle stages, while for the stainless steel cutlery, the manufacturing stage of the life cycle had the highest impact in terms of GHG emissions, at 2.4×10^{-4} kg CO_2-eq.

The results highlighted that the PS and PLA based cutlery fork/spoon were the most environmentally sound products in terms of GWP, while for the one time use steel cutlery fork/spoon the environmental performance was 16 times lower than other alternatives. Therefore, promoting stainless steel cutlery will be advantageous for the significant GWP reduction. Looking at the PS and PLA cutleries, the results reveal that the pre-manufacturing phase was the significant contribution for GWP and its contribution to the total impacts of the system was around 50%. Notably, the net GWP impact of cutlery with recycling practice at the end of life shows better performance that can be considered as possible potential alternative.

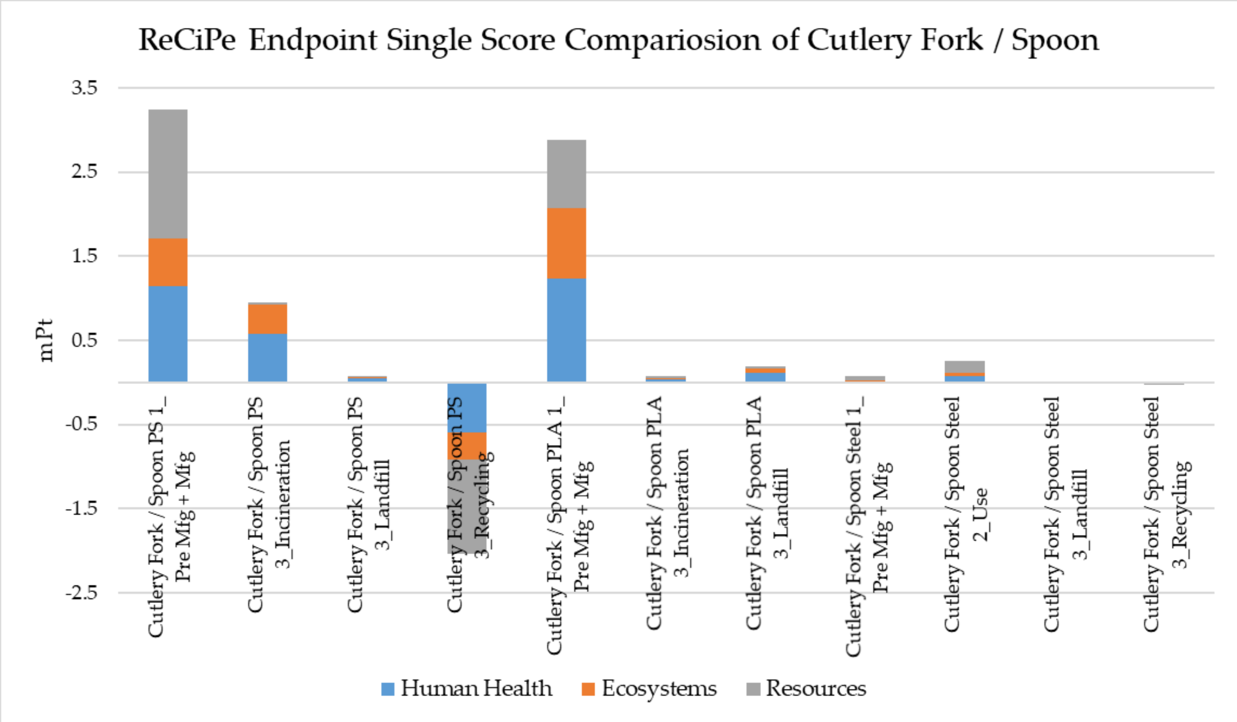


Figure 3: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – endpoint impact analysis using ReCiPe (H) V1.13

Figure 3 depicts the ReCiPe endpoint assessment of single score comparison for the PS, PLA and stainless steel cutlery fork/ knife. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing and manufacturing phase of PS and PLA cutlery fork/spoon. It is essential to consider that the recycling of PS cutlery shows the positive impact to the environment and that need to be promoted in the waste management practice.

Figure 4 describes the ReCiPe midpoint analysis of all three-cutlery fork/spoon alternatives: PS, PLA and steel. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the cutlery fork/spoon highlighted that PLA production was the most impactful for all midpoint impact categories except climate change, photochemical oxidant formation, stainless steel depletion and fossil depletion. PS production plays a significant role in climate change, photochemical oxidant formation and fossil depletion, while stainless steel depletion is affected by steel production.

Notably, PLA production has generally higher impacts than others due to PLA resin production, which contributes significantly to all impact categories. Specifically, considerable GHG emissions occur during the corn production phase and are caused by the large amount of fertilizers and herbicides that are generally used in corn cultivation. Due to the various crop-based PLA production, it is difficult to quantify the exact impacts of PLA based products, since crop inputs (i.e. pesticides, fertilizers, field activities) generally differ with different effects on GWP.

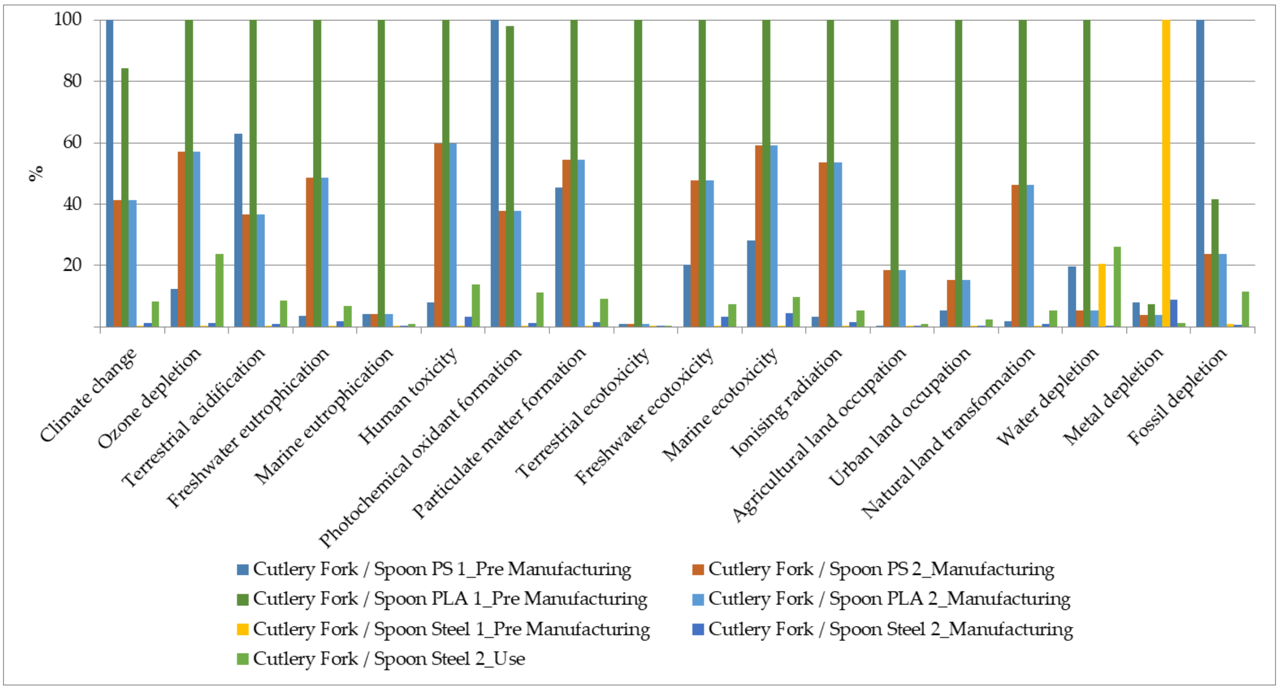
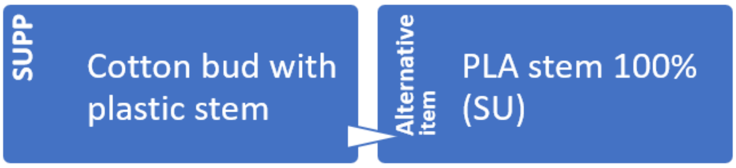


Figure 4: LCIA of SUP cutlery vs. stainless steel cutlery as an alternative – midpoint impact analysis using ReCiPe (H) V1.13

2.5.2. Case 2: Cotton buds with plastic stem



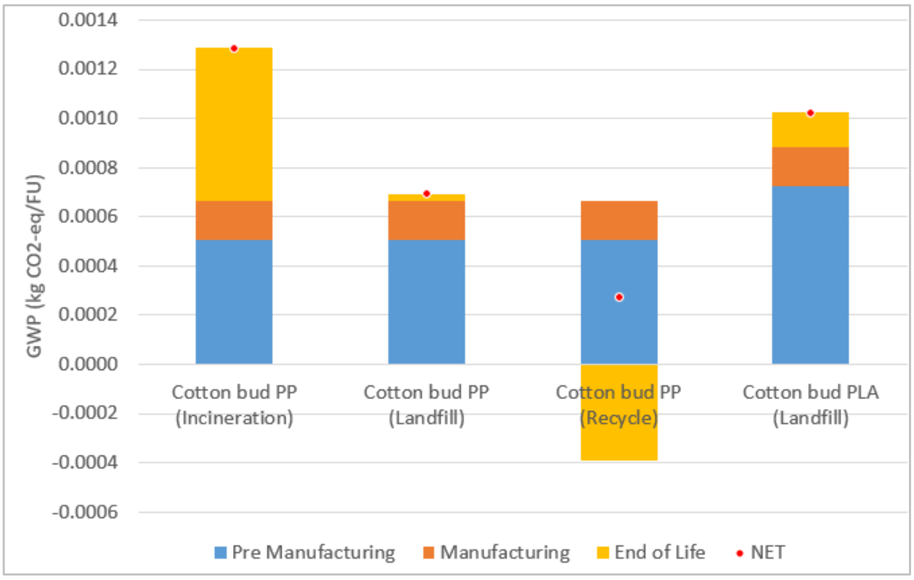


Figure 5: LCIA of SUP cotton bud with plastic stem vs. PLA-based stem as an alternative – based on IPCC 2013 GWP 100a

Figure 5 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of PP and PLA cotton buds. It demonstrates that the total GWP impact of PP Cotton buds associated with the entire supply chain was 7.17 × 10^{-4} kg CO_2-eq per unit (1 cotton bud) and total GWP impact of PLA cotton buds was 9.16 × 10^{-4} kg CO_2-eq. The GWP impact of PLA cotton buds was approximately

1.25 times that of PP cotton buds. These data indicate that the highest GWP of the value chain for PP cotton buds is pre-manufacturing, at 5.1×10^{-4} kg CO_2-eq, which is higher than for other life cycle stages. In the PLA cotton buds life cycle, the pre-manufacturing stage also had the highest impact in terms of GHG emissions, at 7.32×10^{-4} kg CO_2-eq.

Figure 6 depicts the ReCiPe endpoint assessment of single score comparison for the PP and PLA cotton bud. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing phase of PP and PLA cotton bud. In particular, the pre-manufacturing of PP severely affects the resource impact category due to the extraction of resources from the earth. The comparison shows that the PP incineration also contribute significantly to the impact category of human health. It is important to consider that the recycling of PP cutlery shows the positive impact to the environment and that need to be promoted in the waste management practice.

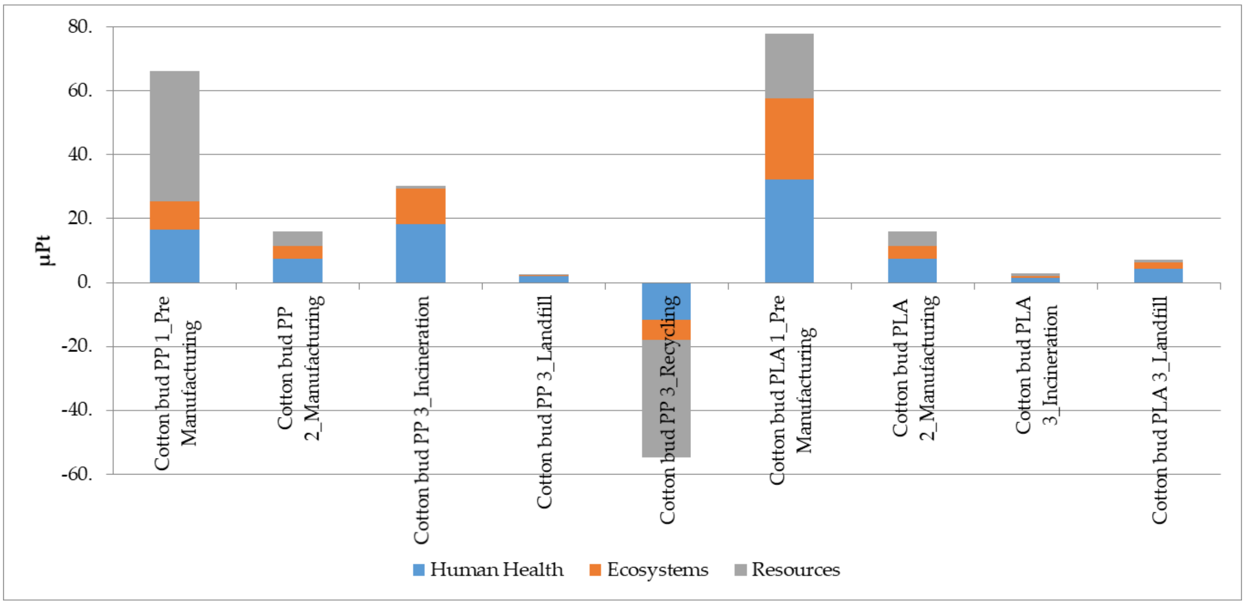


Figure 6: LCIA of SUP cotton bud stem vs. PLA-based stem as an alternative – endpoint impact assessment using ReCiPe V1.13

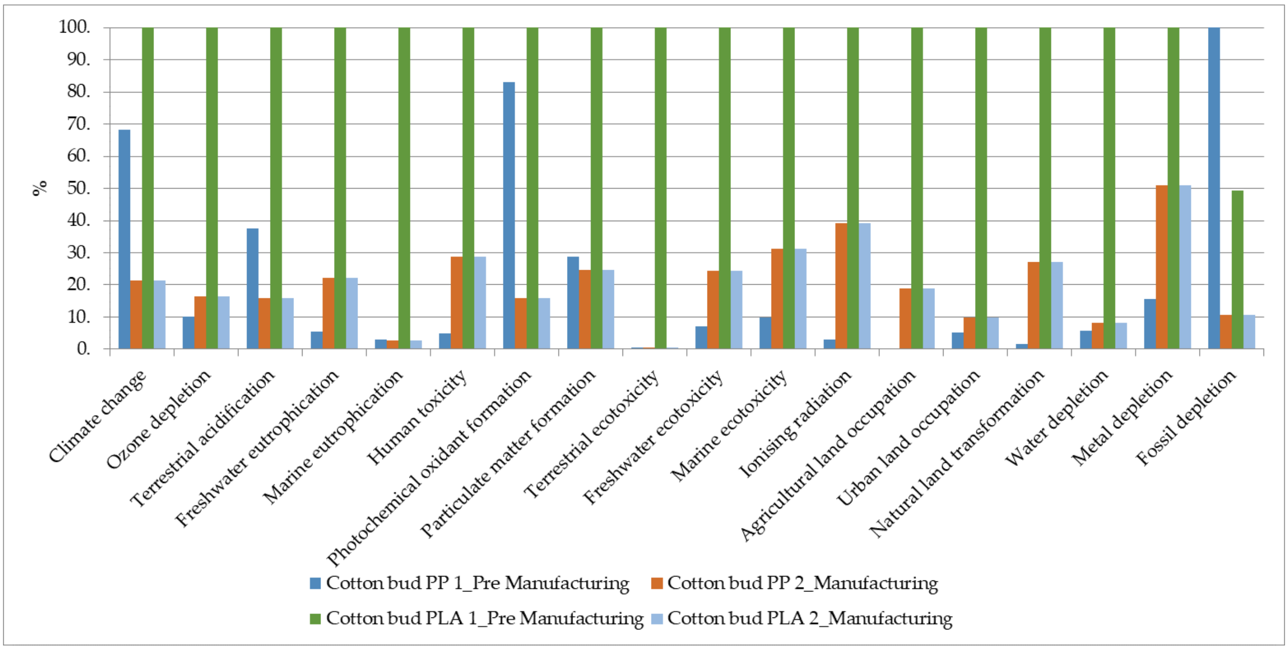


Figure 7: LCIA of SUP Cotton bud stem vs. PLA-based stem as an alternative – midpoint impact assessment using ReCiPe V1.13

Figure 7 describes the ReCiPe midpoint analysis of all cotton bud alternatives: PP and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the cotton bud highlighted that PLA production was the most impactful for all midpoint impact categories except fossil depletion. PP production plays a significant role in climate change, photochemical oxidant formation and especially fossil depletion.

Based on Figures 5 and 6, it can be seen that when PLA material is used as an alternative for PP for the stem of cotton buds, the pre-manufacturing phase shows greater environmental impact for PLA. This is mainly because PLA depends on agricultural crops, which have multiple impacts on the environment during cultivation. However, when it comes to disposal scenario, PP incineration shows higher impact whereas the PP recycling method shows positive impact to the environment.

2.5.3. Case 3: Sandalwood instant-stick wrappers

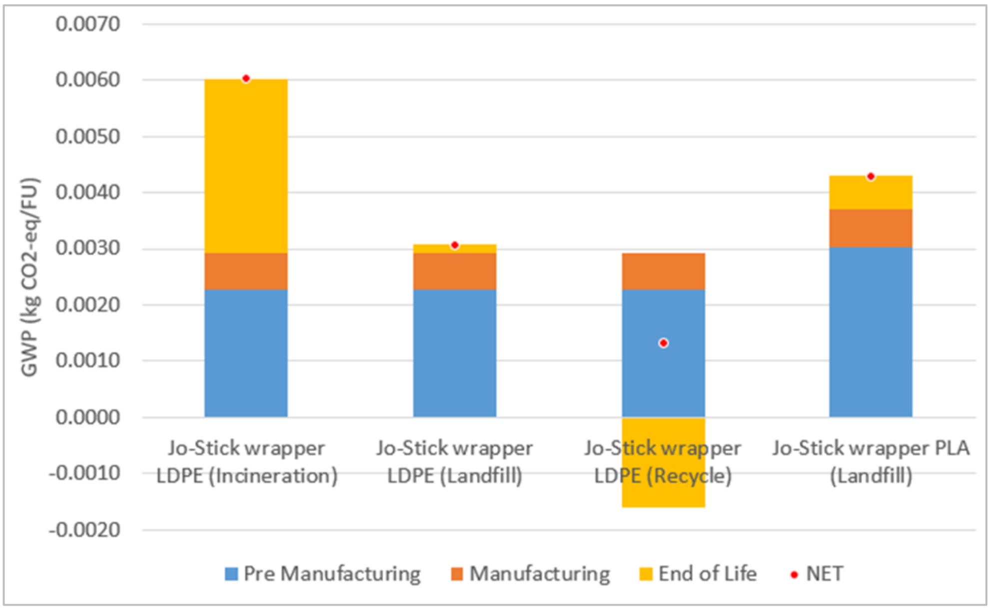


Figure 8: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – using IPCC 2013 GWP 10

Figure 8 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of LDPE and PLA Joss-Stick wrappers. It demonstrates that the total GWP impact of LDPE Joss-Stick wrappers associated with the entire supply chain was 3.66×10^{-3} kg CO_2-eq per unit (1 wrapper) of Joss-Stick wrappers, and that of PLA Joss-Stick wrappers was 3.84×10^{-3} kg CO_2-eq; the GWP impact of PLA Joss-Stick wrappers was therefore approximately 1.05 times that of LDPE Joss-Stick wrappers. These data indicate that the highest GWP of the value chain for LDPE Joss-Stick wrappers is the pre-manufacturing stage, at 2.28×10^{-3} kg CO_2-eq, which is higher than for other life cycle stages. Regarding the PLA Joss-Stick wrapper life cycle, the pre-manufacturing stage had the highest impact in terms of GHG emissions, at 3.07×10^{-3} kg CO_2-eq.

Figure 9 depicts the ReCiPe endpoint assessment of single score comparison for the LDPE and PLA Joss-Stick wrapping. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing phase of LDPE and PLA Joss-Stick wrapping. In particular, the pre-manufacturing of LDPE severely affects the resource impact category due to the extraction of resources from the earth. The comparison shows that the LDPE incineration also contribute significantly to the impact category of human health. It is important to consider that the recycling of LDPE Joss-Stick wrapping indicates the positive impact to the environment and that need to be promoted in the post-use phase.

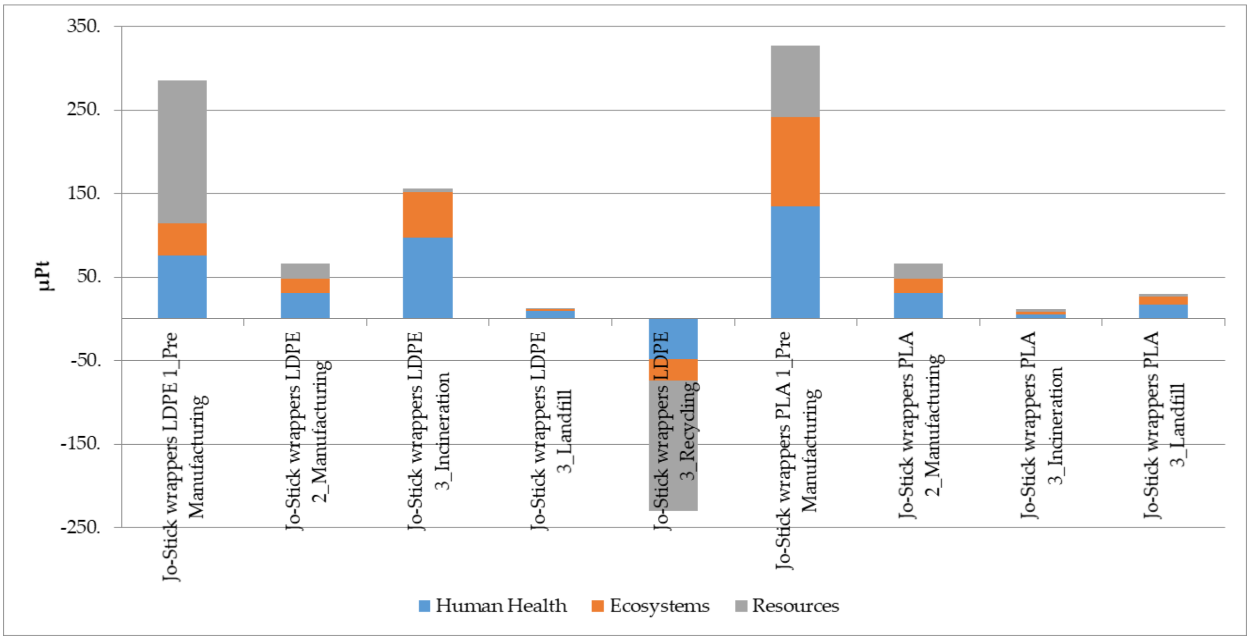


Figure 9: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – endpoint impact assessment using ReCiPe V1.13

Figure 10 describes the ReCiPe midpoint analysis of all Joss-Stick wrapping alternatives: LDPE and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the Joss-Stick wrapping highlighted that PLA material production was the most impactful for all midpoint impact categories except fossil depletion. Pre-manufacturing of LDPE plays a significant role in climate change, photochemical oxidant formation and especially fossil depletion.

From Figures 8, 9 and 10, it can be seen that PLA-based wrapping material outperformed the LDPE material for Joss-Stick wrapping. However, for the pre-manufacturing phase, PLA has higher impacts than LDPE. As regards the pre-manufacturing phase endpoint impacts, PLA's higher contribution comes from all three end point impact category, which is mainly linked with raw material extraction for its manufacture. As stated before, regarding the disposal phase, LDPE-based wrapping outperforms PLA-based wrapping in terms of landfill and incineration while LDPE recycling scenarios shows positive impact to the environment.

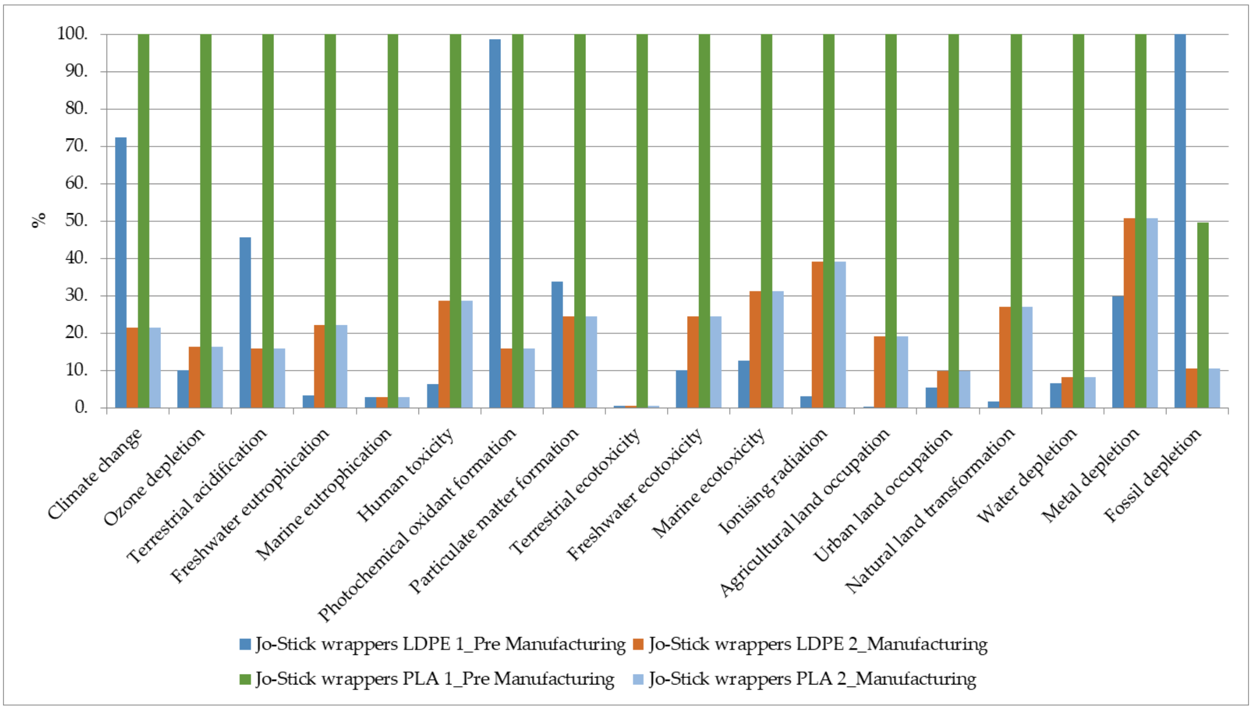
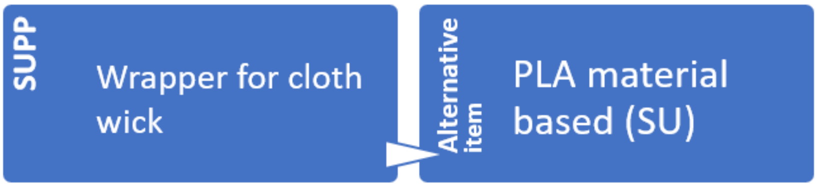


Figure 10: LCIA of SUP Instant-stick wrappers vs. PLA-based wrappers as an alternative – midpoint impact assessment using ReCiPe V1.13

2.5.4. Case 4: Wrappers for cloth wicks



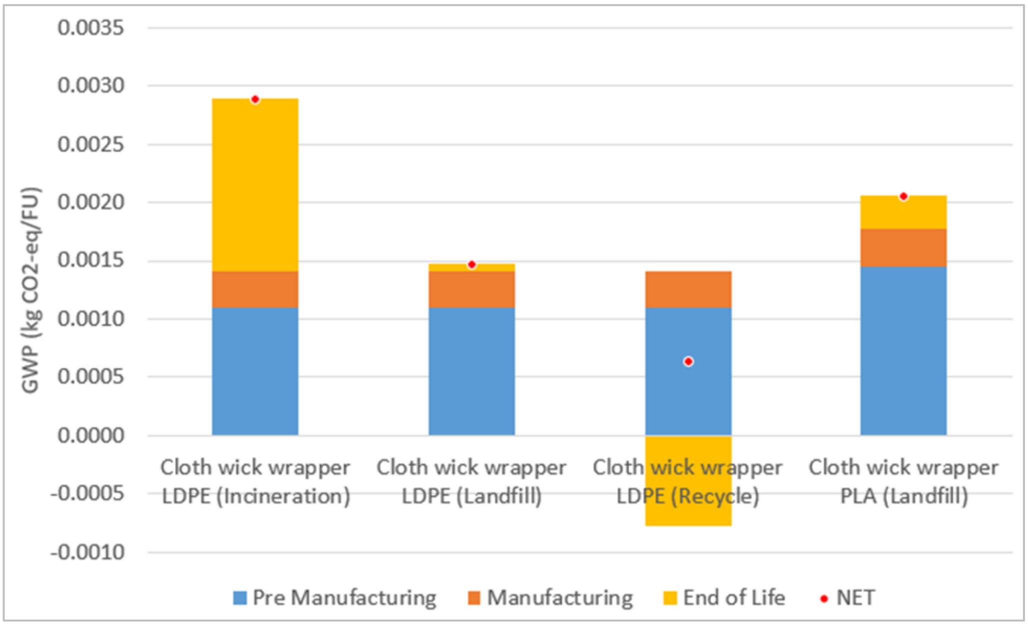


Figure 11: LCIA of SUP cloth wick wrappers vs. PLA-based wrappers as an alternative – using IPCC 2013 GWP 100a

Figure 11 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of LDPE and PLA cloth wick wrappers. It demonstrates that the total GWP impact of LDPE cloth wick wrappers associated with the entire supply chain was 1.76×10^{-3} kg CO_2-eq per unit (1 wrapper) of cloth wick wrappers, and for PLA cloth wick wrappers was 1.84×10^{-3} kg CO_2-eq. The GWP impact of PLA cloth wick wrappers was approximately 1.05 times that of LDPE cloth wick wrappers. The data indicate that the highest GWP of the value chain for LDPE cloth wick wrappers in the pre-manufacturing stage, at 1.09×10^{-3} kg CO_2-eq, which is higher than for other life cycle stages. Regarding the PLA cloth wick wrapper life cycle, the pre-manufacturing stage had the highest impact in terms of GHG emissions, at 1.47×10^{-3} kg CO_2-eq.

Figure 12 depicts the ReCiPe endpoint assessment of single score comparison for the LDPE and PLA cloth wick wrappers. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing phase of LDPE and PLA cloth wick wrappers. In particular, the pre-manufacturing of LDPE severely affects the resource impact category due to the extraction of resources from the earth. The comparison shows that the LDPE incineration also contribute significantly to the impact category of human health. It is important to consider that the recycling of LDPE Cloth wick wrappers indicates the positive impact to the environment and that need to be promoted in the post-use phase.

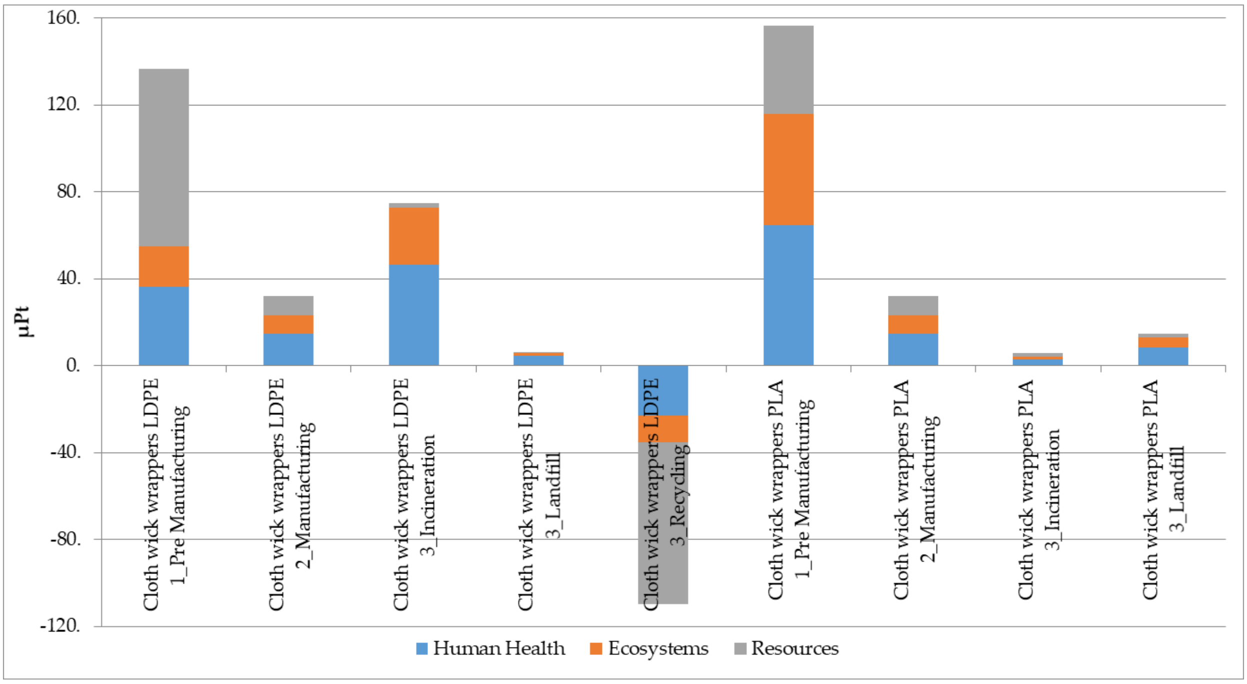


Figure 12: LCIA of SUP cloth wick wrappers vs. PLA-based wrappers as an alternative – endpoint impact assessment using ReCiPe V1.13

Figure 13 describes the ReCiPe midpoint analysis of all cloth wick wrappers alternatives: LDPE and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the cloth wick wrappers highlighted that PLA material production was the most impactful for all midpoint impact categories except fossil depletion. Pre-manufacturing of LDPE plays a significant role in climate change, photochemical oxidant formation and especially fossil depletion.

From Figures 11, 12 and 13, it can be seen that PLA-based cloth wick wrappers material outperformed the LDPE material for cloth wick wrappers. However, for the pre-manufacturing phase, PLA has higher impacts than LDPE. As regards the pre-manufacturing phase endpoint impacts, PLA's higher contribution comes from all three end point impact category, which is mainly linked with raw material extraction for its manufacture.

As stated before, regarding the disposal phase, LDPE-based cloth wick wrappers outperform PLA-based cloth wick wrappers in terms of landfill and incineration while LDPE recycling scenarios shows positive impact to the environment.

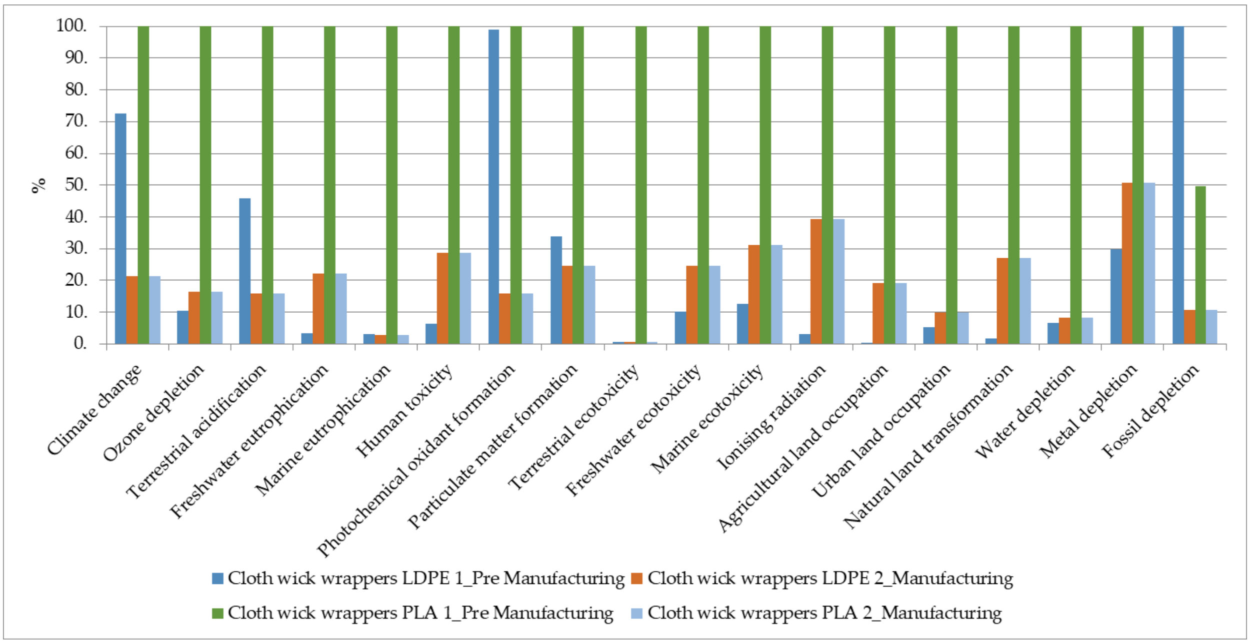
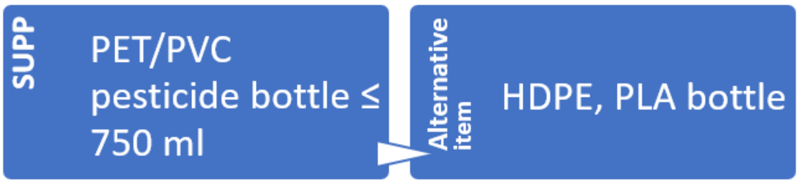


Figure 13: LCIA of SUP Cloth wick wrappers vs. PLA-based wrappers as an alternative – midpoint impact assessment using ReCiPe V1.13

2.5.5. Case 5: PET/PVC pesticide bottles



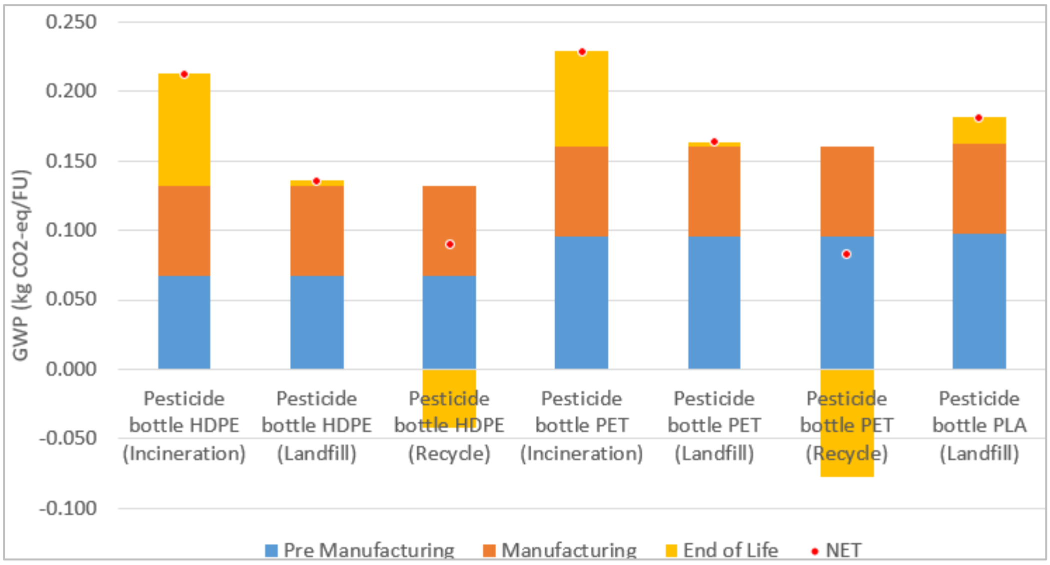


Figure 14: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as an alternative – using IPCC 2013 GWP 100a

Figure 14 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of PET, HDPE, and PLA pesticide bottles. It demonstrates that the total GWP impact of PET pesticide bottles associated with the entire supply chain was 0.18 kg CO_2-eq per unit (1 PET bottle) of PET pesticide bottles, for HDPE pesticide bottles was 0.15 kg CO_2-eq, and for PLA pesticide bottles was 0.17 kg CO_2-eq, thus PET pesticide bottles had the highest GWP impact of the three materials. Of the alternatives, PLA had a higher impact than HDPE for pesticide bottles. These data indicate that the highest GWP of the value chain for PET pesticide bottles was pre-manufacturing, at 0.09 kg CO_2-eq, which is higher than for other life cycle stages. The same was true for the PLA pesticide bottle life cycle, at 0.098 kg CO_2-eq. Further, for HDPE pesticide bottles, the manufacturing stage had the highest impact in terms of GHG emissions, at 0.068 kg CO_2-eq.

Figure 15 depicts the ReCiPe endpoint assessment of single score comparison for the PET, HDPE and PLA pesticide bottles. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing and manufacturing phase of PET, HDPE and PLA pesticide bottles almost equally. It is essential to consider that the recycling of HDPE and PET pesticide bottles shows the positive impact to the environment and that they need to be promoted in the end-of-life practice. When considering the HDPE pesticide bottles, it shows comparatively the best environmental performance in all situations throughout the life cycle. Therefore, it will be recommended to promote HDPE pesticide bottles instead of other alternatives. According to overall environmental performance and disposal scenario, recycling is the best solution, and it can be promoted instead of other scenarios for HDPE and PET pesticide bottles.

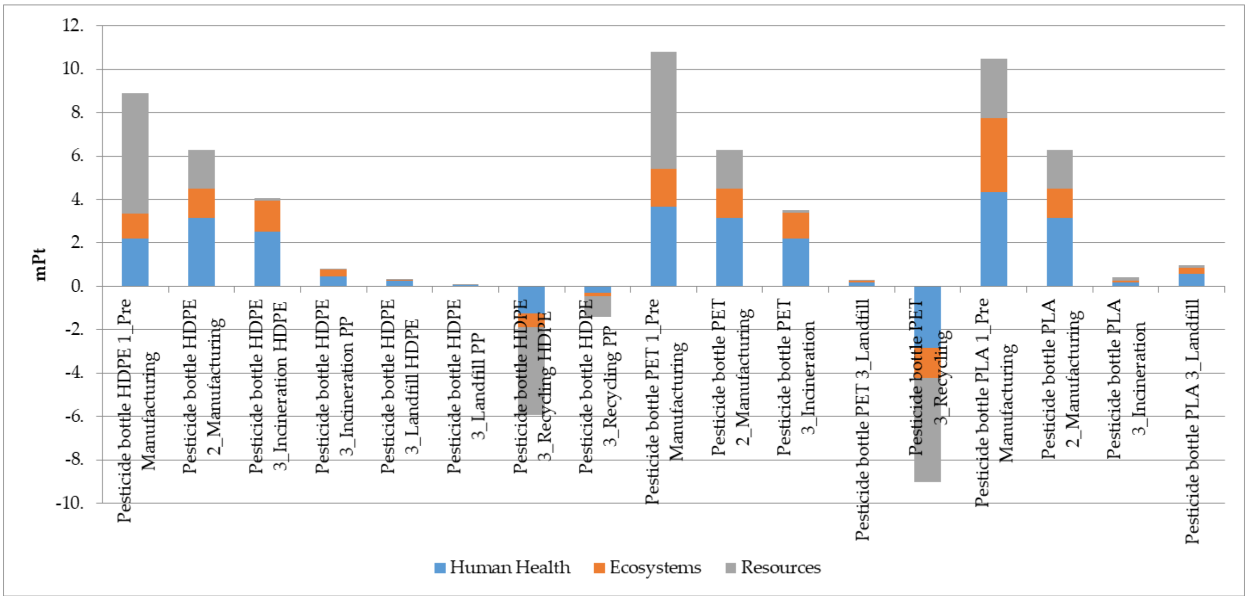


Figure 15: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as alternatives – endpoint impact assessment using ReCiPe V1.13

Figure 16 describes the ReCiPe midpoint analysis of all three pesticide bottles: HDPE, PET and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the pesticide bottles emphasized that PLA production was the most impactful for all midpoint impact categories except fossil depletion. It is due to PLA resin production that contributes significantly in all impact categories. Notably, PLA pesticide bottles offer savings for fossil fuels resource use but lead to higher impacts for other impact categories while HDPE and PET production plays a significant role in fossil depletion. Moreover, literature highlighted that PLA bottle production has generally higher impacts than HDPE and PET pesticide bottles production, globally or regionally depending on the categories.

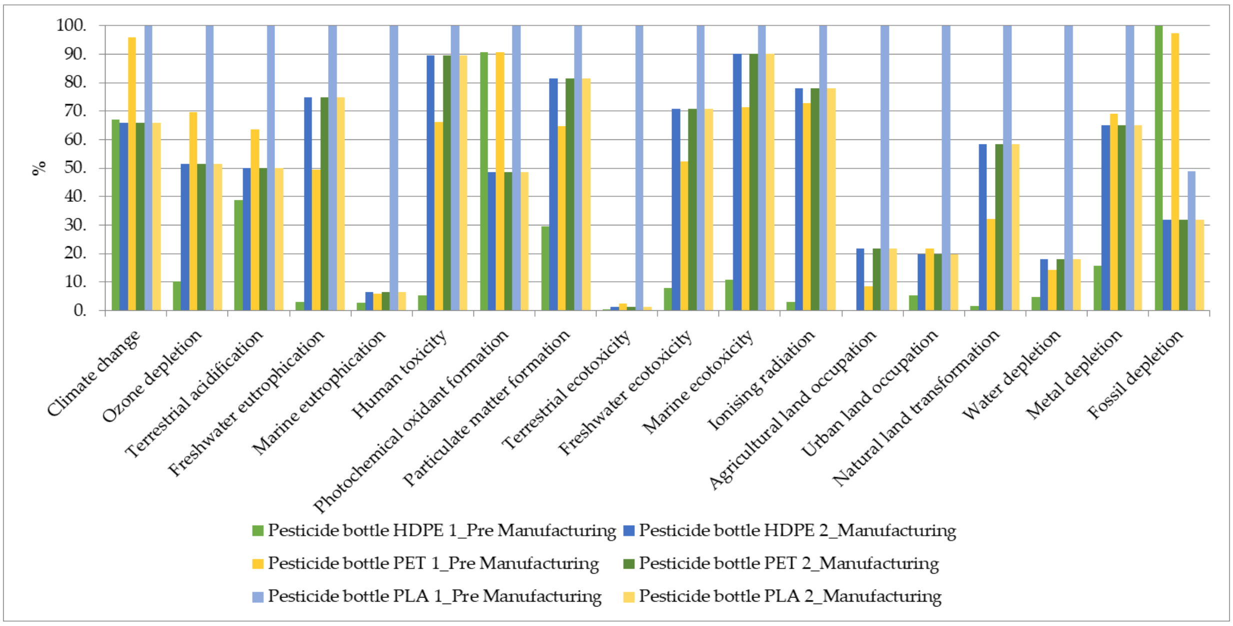


Figure 16: LCIA of SUP PET/PVC pesticide bottles ≤ 750 ml vs. HDPE and PET-based bottles as alternatives – midpoint impact assessment using ReCiPe V1.13

2.5.6. Case 6: Grocery bags/shopping bags

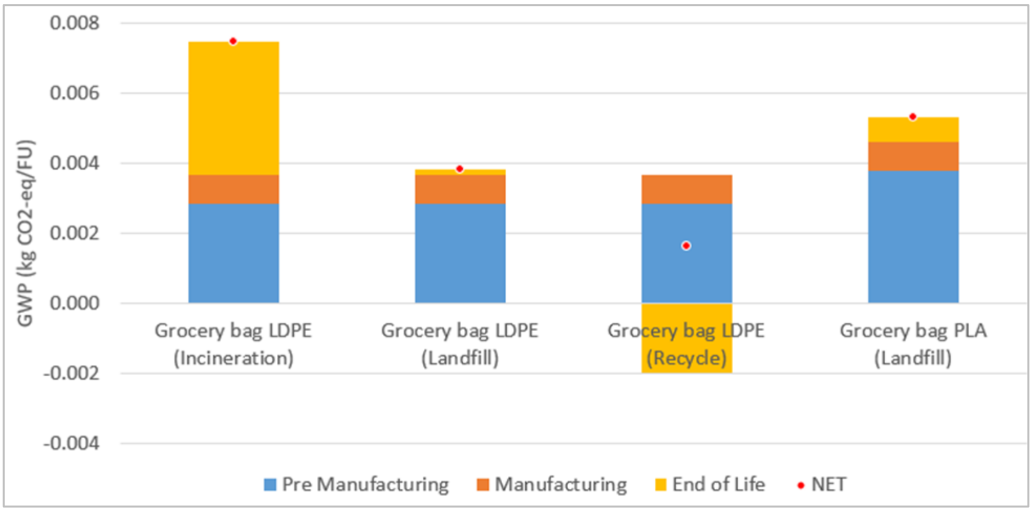


Figure 17: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – using IPCC 2013 GWP 100a

Figure 17 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of LDPE and PLA grocery bags. It demonstrates that the total GWP impact of LDPE grocery bags associated with the entire supply chain was 4.56×10^{-3} kg CO_2-eq per unit (1 bag) of grocery bags and that for PLA grocery bags was 4.77×10^{-3} kg CO_2-eq. The GWP impact of PLA grocery bags was approximately 1.05 times that of LDPE grocery bags. The data indicate that the highest GWP of the value chain for LDPE grocery bags was in the pre-manufacturing stage, at 2.84 × 10^{-3} kg CO_2-eq, which is higher than for other life cycle stages. Whilst in PLA grocery bag life cycle, the pre-manufacturing stage had the highest impact in terms of GHG emissions, at 3.81 × 10^{-3} kg CO_2-eq.

Figure 18 depicts the ReCiPe endpoint assessment of single score comparison for the LDPE and PLA grocery bags. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing phase of LDPE and PLA grocery bags. In particular, the pre-manufacturing of LDPE severely affects the resource impact category due to the extraction of resources from the earth. The comparison shows that the LDPE incineration also contribute significantly to the impact category of human health. It is important to consider that the recycling of LDPE grocery bags indicates the positive impact to the environment and that need to be promoted in the post-use phase.

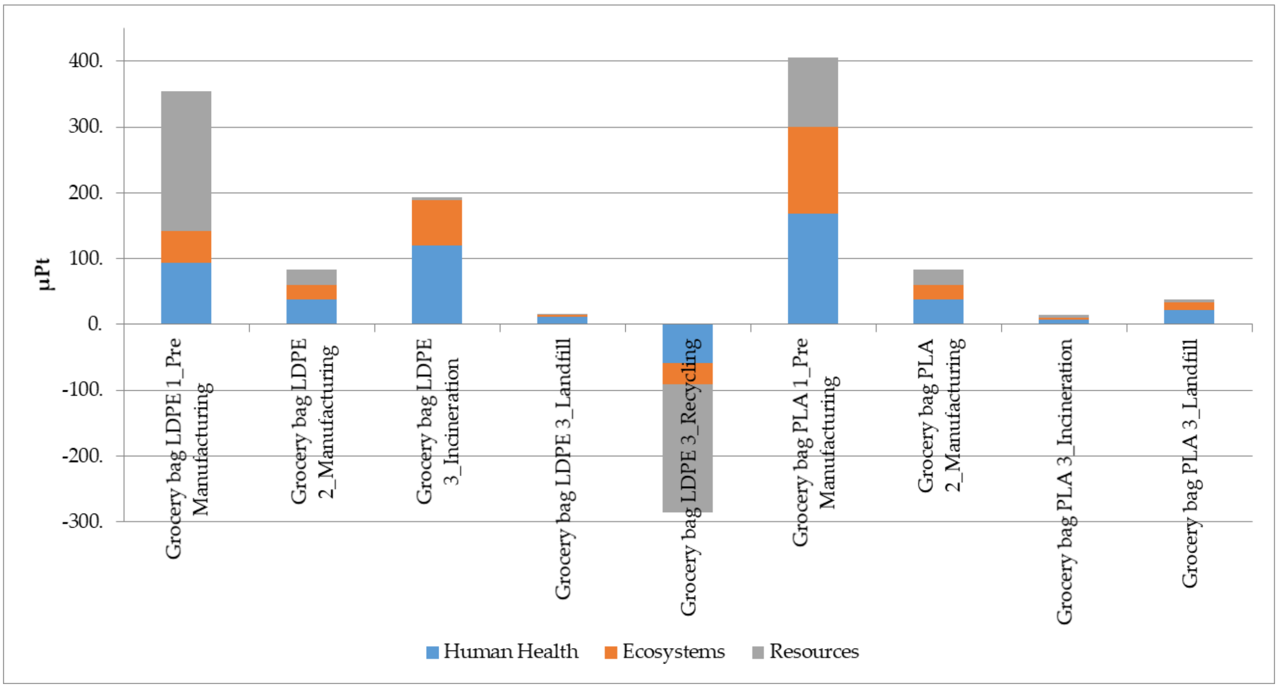


Figure 18: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – endpoint impact assessment using ReCiPe V1.13

Figure 19 describes the ReCiPe midpoint analysis of all grocery bags alternatives: LDPE and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the grocery bags highlighted that PLA material production was the most impactful for all midpoint impact categories except fossil depletion. Pre-manufacturing of LDPE plays a significant role in climate change, photochemical oxidant formation and especially fossil depletion.

Figures 17, 18 and 19 show that the PLA-based grocery bags material outperformed the LDPE material for grocery bags. However, for the pre-manufacturing phase, PLA has higher impacts than LDPE. As regards the pre-manufacturing phase endpoint impacts, PLA's higher contribution comes from all three end point impact category, which is mainly linked with raw material extraction for its manufacture. As stated before, regarding the disposal phase, LDPE-based grocery bags outperform PLA-based grocery bags in terms of landfill and incineration while LDPE recycling scenarios shows positive impact to the environment.

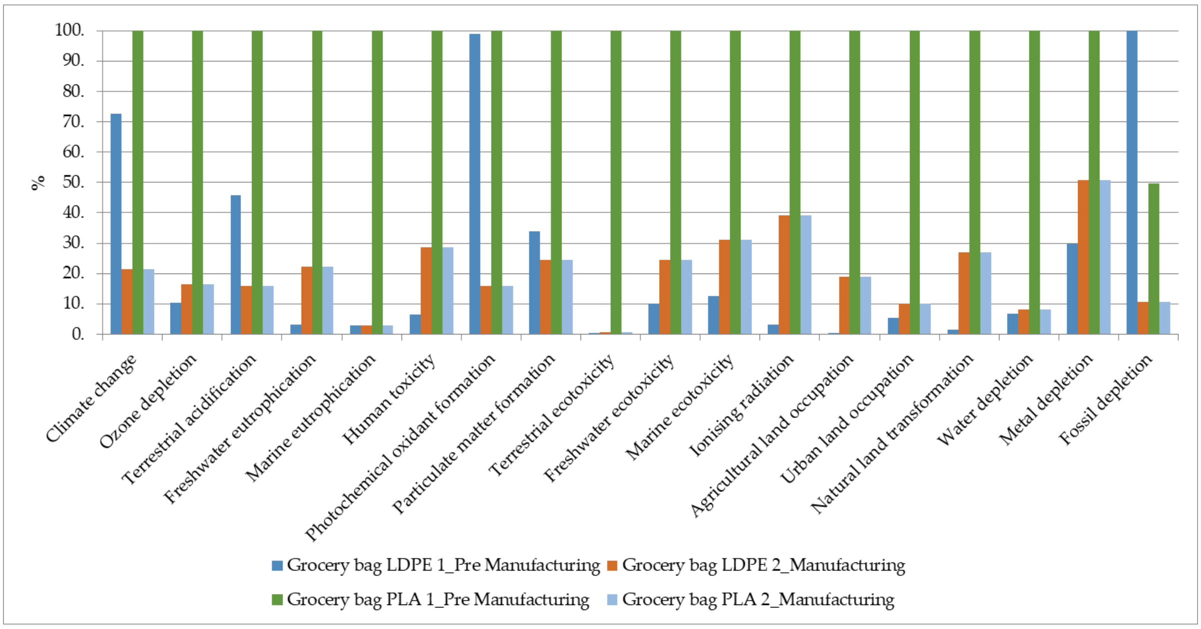


Figure 19: LCIA of SUP grocery bags/shopping bags vs. PLA-based alternative – midpoint impact assessment using ReCiPe V1.13

2.5.7. Case 7: Straws

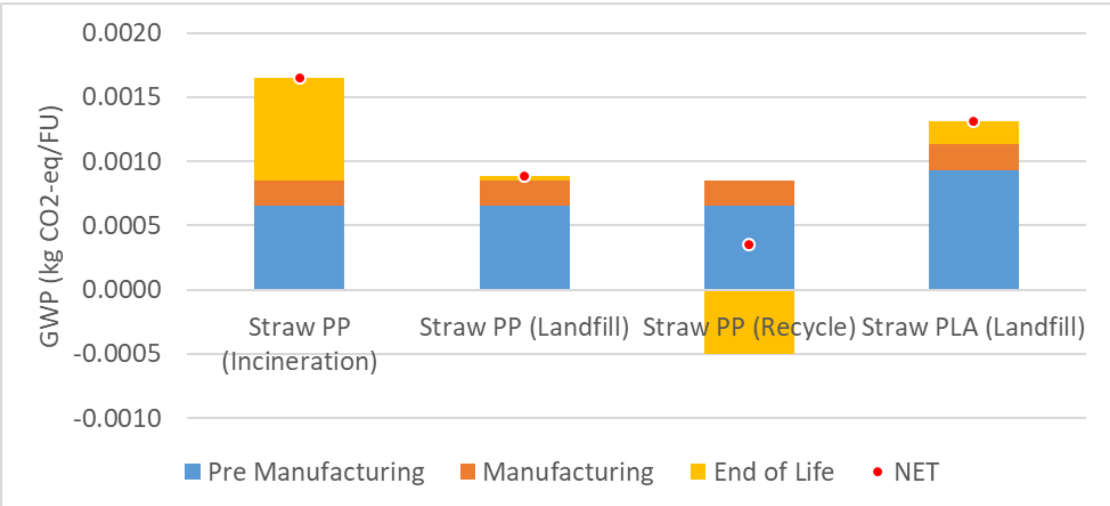


Figure 20: LCIA of SUP straws vs. PLA-based alternative – using IPCC 2013 GWP 100a

Figure 20 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of PP and PLA straws. It demonstrates that the total GWP impact of PP straws associated with the entire supply chain was 1.07 × 10^{-3} kg CO_2-eq per unit (1 straw), and that for PLA straws was 1.17 × 10^{-4} kg CO_2-eq, thus the GWP impact of PLA straws was approximately 1.1 times that of PP straws. The data indicate that the highest GWP in the value chain for PP straws was in the pre-manufacturing stage, at 6.53 ×

10^{-4} kg CO_2-eq, which is higher than for other life cycle stages. In the PLA straw life cycle, the pre-manufacturing stage had the highest impact in terms of GHG emissions, at 9.38 × 10^{-4} kg CO_2-eq.

Figure 21 depicts the ReCiPe endpoint assessment of single score comparison for the PP and PLA straws. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing phase of PP and PLA straws. In particular, the pre-manufacturing of PP severely affects the resource impact category due to the extraction of resources from the earth. The comparison shows that the PP incineration also contribute significantly to the impact category of human health. It is important to consider that the recycling of PP straws indicates the positive impact to the environment and that need to be promoted in the post-use phase.

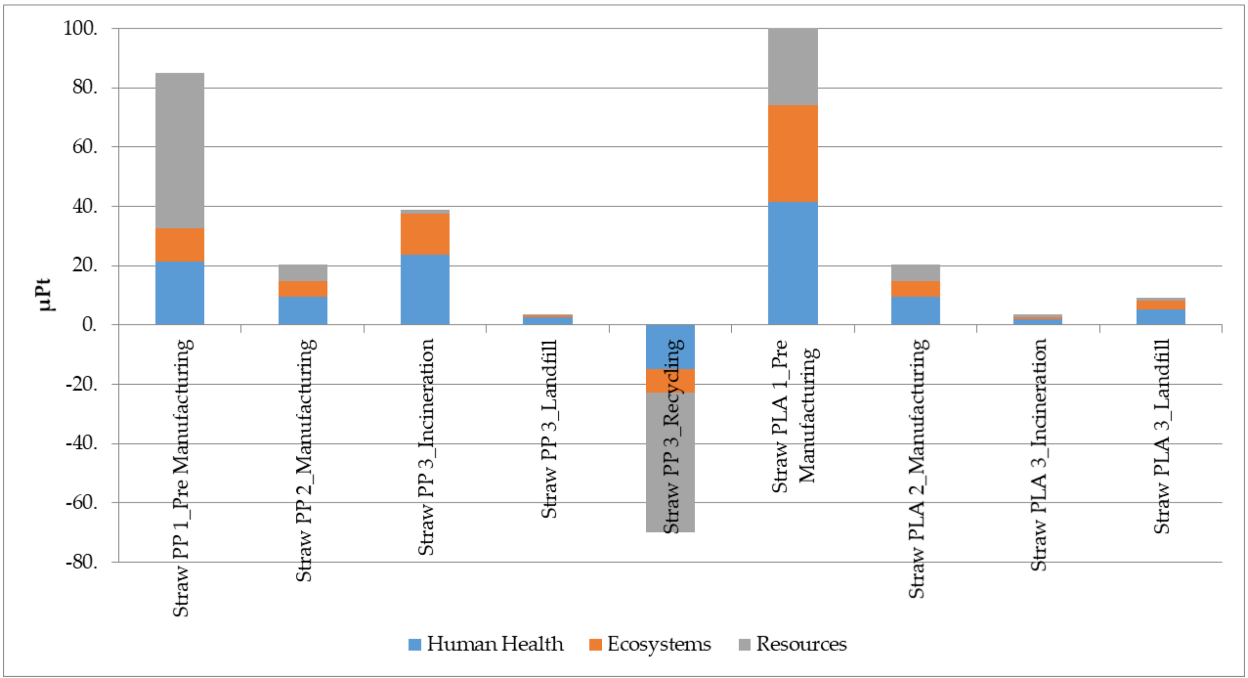


Figure 21: LCIA of SUP straws vs. PLA-based alternative – endpoint impact assessment using ReCiPe V1.13

Figure 22 describes the ReCiPe midpoint analysis of all straws alternatives: PP and PLA. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the straws highlighted that PLA material production was the most impactful for all midpoint impact categories except fossil depletion. Pre-manufacturing of PP plays a significant role in climate change, photochemical oxidant formation and especially fossil depletion.

Based on Figures 20, 21 and 22, it can be seen that the PLA-based straws material outperformed the PP material for straws. However, for the pre-manufacturing phase, PLA has higher impacts than PP. As regards the pre-manufacturing phase endpoint impacts, PLA's higher contribution comes from all three end point impact category, which is mainly linked with raw material extraction for its manufacture. As stated before, regarding the disposal phase, PP-based straws outperform PLA-based straws in terms of landfill and incineration while PP recycling scenarios shows positive impact to the environment.

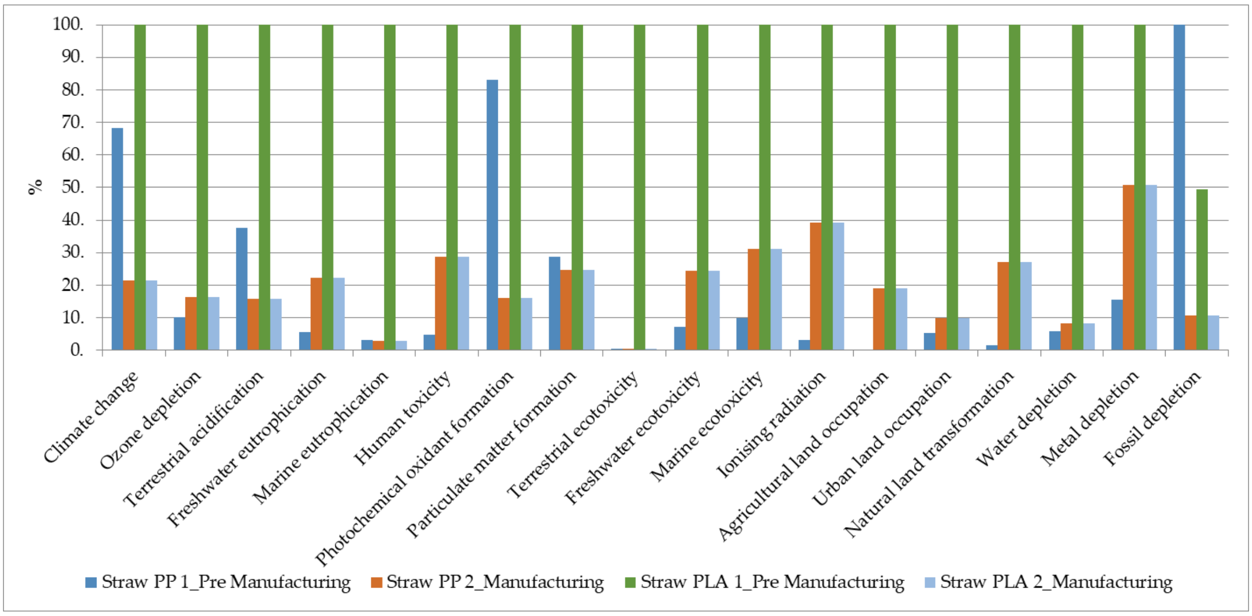


Figure 22: LCIA of SUP straws vs. PLA-based alternative – midpoint impact assessment using ReCiPe V1.13

2.5.8. Case 8: PET bottles

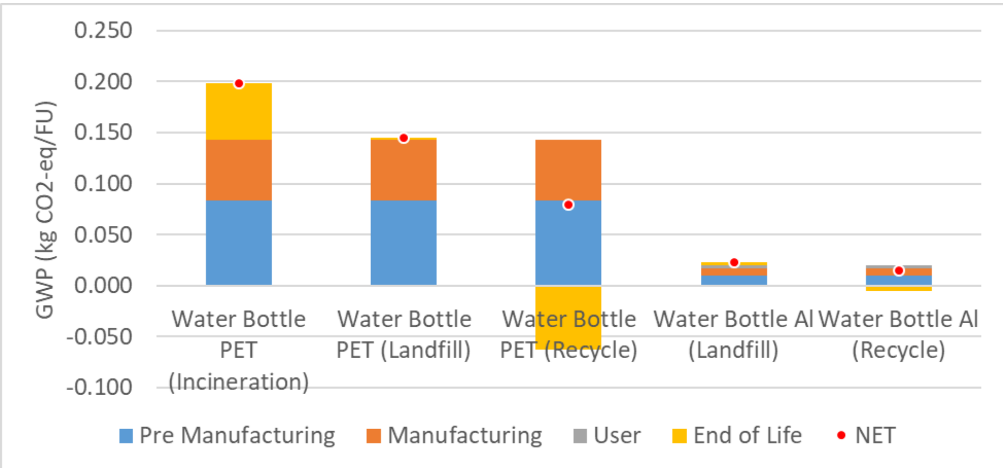


Figure 23: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – using IPCC 2013 GWP 100a

Figure 23 shows the contribution of climate change impact emissions in the life cycle stages of the cradle-to-disposal assessment of PET, Al, and PLA water bottles. It demonstrates that the total GWP impact of PET water bottles associated with the entire supply chain was 0.17 kg CO_2-eq per unit (1 bottle) of PET water bottles, that of Al water bottles was 0.035 kg CO_2-eq, and that of PLA water bottles was 0.12 kg CO_2-eq. Therefore, the GWP impact of PET water bottles was the highest compared to the two alternatives. Of the alternatives, PLA water bottles had a higher impact (3.5 times) than Al water bottles. The data indicate that the highest GWP of the value chain for PET water bottles was in the pre-manufacturing stage, at 0.086 kg

CO_2-eq, which is higher than for other life cycle stages. For the PLA water bottle life cycle, the pre-manufacturing stage had the highest impact in terms of GHG emissions, at 0.067 kg CO_2-eq. In the Al water bottle life cycle, the manufacturing stage had the highest impact in terms of GHG emissions, at 0.021 kg CO_2-eq.

The results highlighted that the PET and PLA based Water bottle were the most environmentally sound products in terms of GWP, while for the one time use aluminum Water bottle the environmental performance was 6 time lower than other alternatives. Therefore, promoting aluminum Water bottles will be beneficial for the significant GWP reduction. Considering the PET and PLA Water bottle, the results reveal that the pre-manufacturing phase was the significant contribution for GWP and its contribution to the total impacts of the system was over 50%. Notably, the net GWP impact of PET Water bottle with recycling practice in the end of life shows better performance that can be also considered as a possible potential alternative among PET and PLA Water bottle.

Figure 24 depicts the ReCiPe endpoint assessment of single score comparison for the PET, PLA and Aluminum Water bottle. According to the endpoint single score results, all three impact categories (human health, ecosystem, and resources) were significantly affected by pre-manufacturing and manufacturing phase of PET and PLA Water bottle almost equally. It is essential to consider that the recycling of PET water bottles shows the positive impact to the environment and that they need to be promoted in the end-of-life practice. When considering the aluminum Water bottle, it shows the best environmental performance in all situations throughout the life cycle. Therefore, it will be recommended to promote aluminum water bottles instead of other alternatives. According to overall environmental performance and disposal scenario, aluminum water bottle is the best candidate, and it can be promoted instead of other alternatives.

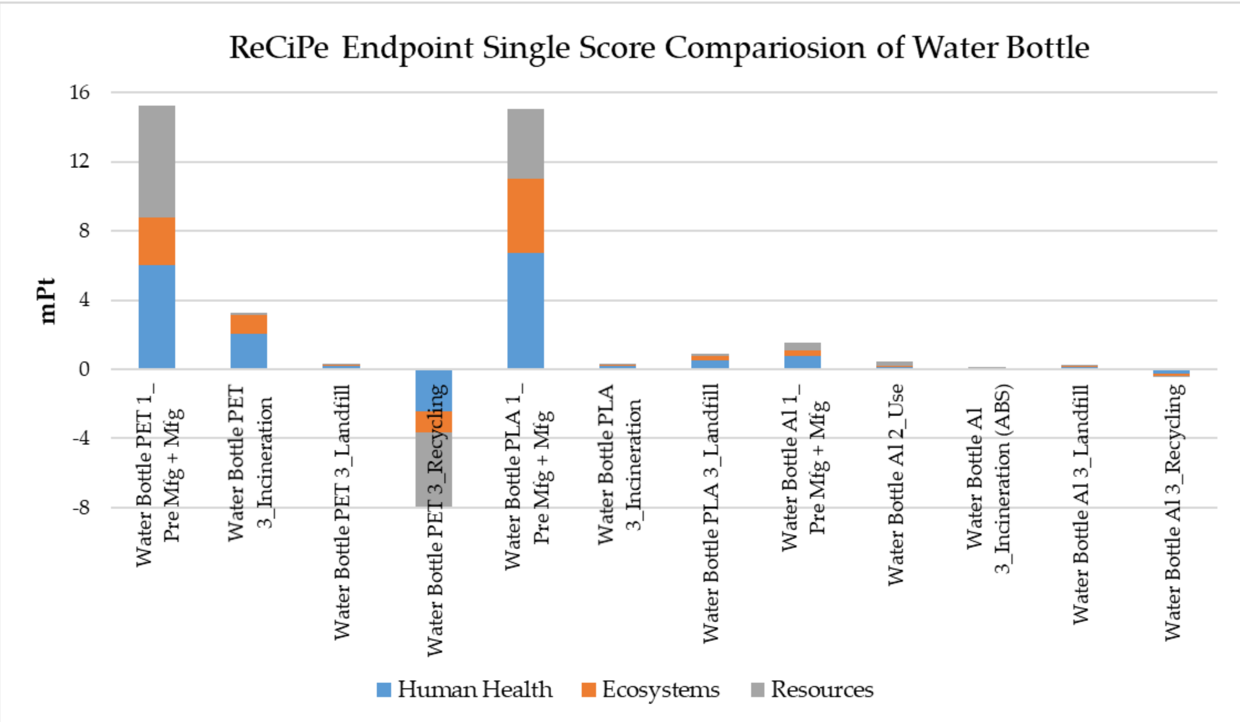


Figure 24: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – endpoint impact assessment using ReCiPe V1.13

Figure 25 describes the ReCiPe midpoint analysis of all three Water bottle alternatives: PET, PLA and Aluminum. Only pre manufacturing and manufacturing phases prior to midpoint comparison are considered. The midpoint analysis of the Water bottle emphasized that PLA production was the most impactful for all midpoint impact categories except fossil depletion. It is due to PLA resin production that contributes significantly in all impact categories. Notably, PLA Water bottles offer savings for fossil fuels resource use but lead to higher impacts for other impact categories while PET production plays a significant role in fossil depletion. Moreover, literature highlighted that PLA bottle production has generally higher impacts than PET bottle production, globally or regionally depending on the categories.

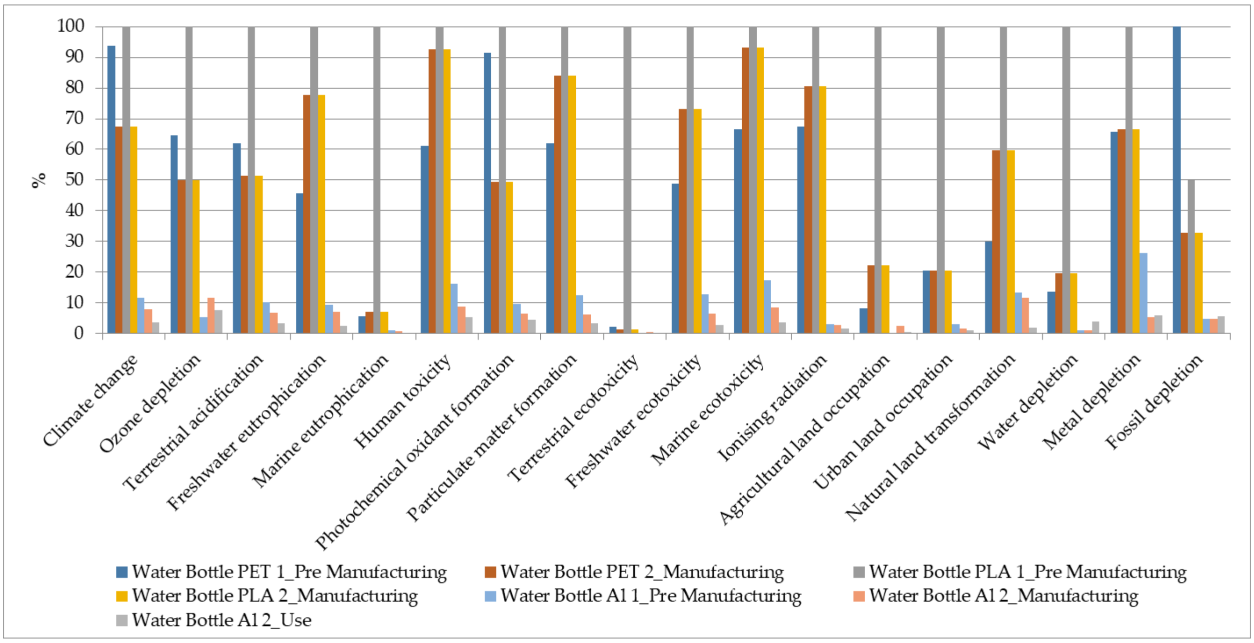


Figure 25: LCIA of SUP water bottles vs. aluminum (MU) and PLA-based (SU) alternatives – midpoint impact assessment using ReCiPe V1.1

3. Making science-based decisions to regulate SUPPs to mitigate the adverse environmental impacts

Plastics are used in a diverse range of products, from packaging for food and other consumable products, to toys and cutlery. However, the negative environmental impacts of plastic pollution, especially in marine environments, are widely recognized (Bucci et al., 2020; Isobe & Iwasaki, 2022; Prata et al., 2020). The focus on reducing the different types of pollution from SUPPs is now shifting from minimizing 'end-of-life' disposal and clean-up solutions to both upstream and downstream oriented measures (GPML, 2021) which include consideration of the full life cycle of plastics and their alternatives. Moreover, the recently adopted resolution to end plastic pollution, realised at UNEA 5.2, highlights the importance of considering the full life cycle impacts in making related decisions (UNEA 5.2, 2022). Upstream measures include the regulation of plastics as well as promotion of related alternative products. This creates a challenge for regulating SUPPs due to the numerous SUP categories – some are difficult to replace and in some cases the alternatives can be more harmful. Hence, guidelines to help determine the screening process in order to set regulatory steps are very useful for policymakers. While there are a range of related factors (e.g., environmental, financial, and social) to consider in decision making, this chapter's scope covers solely the environmental impact-related considerations. In terms of screening itself, the methods proposed by various organizations include simple question-based screening to detailed meta-analysis data-based approaches. To provide an overview, the UNCTAD (UNCTAD, 2021) approach and the UNEP-LCI recommendations are discussed here (a series of publications summarising SUP LCA studies for various products is available from UNEP-LCI (UNEP-LCI, 2022)).

3.1. SUPP screening for regulation

As the initial step of the screening process, the SUPPs under consideration can be pre-evaluated using two questions proposed by UNCTAD (UNCTAD, 2021). These questions consider both the advantages and negative environmental impacts of plastics and explore the available options for promoting substitutes for SUPPs, along with the issues, challenges, and considerations that policymakers are likely to face – particularly from trade and sustainable development perspectives.

a. Is the use of plastics for a particular application useful, justified, and appropriate?
b. Is the use of plastic for a particular application useful and convenient, but inappropriate?

Apart from the environmental aspects, the scope of these two questions can be expanded into the other two pillars of the sustainability, economic and social aspects. Hence the initial screening process considering sustainability aspects the SUPPs relevance to the economic and social impacts can be considered. Following four steps (Table 5) helps to conduct a screening process considering the SUPPs and their substitute products sustainability. This screening process could recommend certain policies even the initial stage. The potential policy instruments and the appropriate choices are given in the section 3.4.

Table 5: Analysis of process steps for forming SUPPs regulations (modified from UNCTAD, 2021)

Step	Content
1	Categorization of SUPPs
2	Categorization of plastic substitutes
3	Conceptual and definitional issues, particularly concerning the concept of biodegradability, recyclability, etc., to set out some key criteria that could be used to evaluate the merits and demerits of various types of plastic substitutes.
4	Situational analysis and intervention predictions (including science-based measures through available tools such as LCA, Social impact assessment, Material flow analysis, Cost-benefit analysis).

Life cycle thinking and sustainable design

Forming a consensus on sustainable design principles is important for the screening process, tool selection, and decision-making. In particular, the tool selection needs to consider whether the solution fits the purpose, and tools already exist for measuring various aspects of sustainability, including LCA, risk assessment, and exposure assessment. However, as each of these tools only evaluates one or a few sustainability attributes (OECD, 2018), interpreting results from one tool against another without having a basic consensus on overall sustainability would be challenging. In this respect, the following three points were derived based on green chemistry and engineering principles, and provide insights into how to approach holistic interpretation (ACS-GCI, 2015).

A. **Life cycle thinking and holistic approach:** SUPPs are not sustainable; however, sustainability is connected with the purpose, the alternatives, and the material flow.
B. **Maximize resource efficiency**: Resource efficiency includes preserving natural capital; for example, renewable resources should not be used faster than they can be regenerated. Similarly, waste is a sign of inefficiency in a system.
C. **Eliminate and minimize hazards and pollution**: Avoiding both the hazard and potential exposure is the best way to reduce the hazard.

3.2. Categorization of SUPPs

By categorizing SUPPs, the regulating process becomes much more convenient to set out. Detailed categorizations need to focus on all the life cycle stage-related aspects, such as chemical composition, human material interaction, and degradation mechanism. However, if the policymaker's perspective is known, provided scientific information is available, the categorization can be narrowed down. Section 3.2.1 provides detailed information related to plastics that need to be considered. Section 3.2.2 narrows down the detailed information-based classifications into more pragmatic sections which support the policymaking process.

3.2.1. Composition-based categorization

Plastic polymer properties, additives, and the other constituent aspects associated with each life cycle stage of SUPPs can be listed, as indicated in Table 6. Having this inventory information available is essential for generating information to form science-based policy. Moreover, the availability of this information would progressively support improving the accuracy of the outputs of sustainability assessment tools such as LCA studies.

Table 6: Types of chemicals to inventory based on life cycle stage and function (Source: OECD, 2021)

Pre-manufacturing and manufacturing Stage	User phase	End-of-life
• **Raw materials** • **Monomers and oligomers** • **Catalysts** • **Polymers** • **Performance additives (flame-retardants, stabilizers, UV stabilizers, colorants, fillers, etc.)** • **Manufacturing and processing aids (solvents, auxiliaries, lubricants, cross-linkers)**	• Monomers and oligomers • Polymers • Additives • Catalysts • Residual performance additives and manufacturing process aids • Other known or potential impurities	• Chemical degradation products • Combustion degradation products • Mechanical degradation products • Bio-degradation products

3.2.2. Three types of SUPPs to be identified for regulation (GPML, 2021)

A. **Avoidable:** The item meets an essential need but does not need to be made of plastic; thus the plastic can be avoided if a suitable alternative is available.

B. **Problematic:** This might also be a case where the plastic material is meeting a need, but that need is overshadowed by problems with the material use or management itself. Such problems may be chemical or biological issues related to the material (or a global issue), or might be physical (in the local context, a capacity to collect, sort, recycle or dispose of appropriately).

C. **Unnecessary:** Plastic that is “not needed” or “non-essential.” This refers to a superfluous product or use of plastics. Defining what is “unnecessary” may require socio-economic studies to determine how products are used or reused (particularly informal reuse) and if they provide for an essential need.

3.3. Plastic substitutes

3.3.1. Categorization of plastic substitutes

Many categories of possible substitutes exist for fossil fuel-based conventional SUPPs. For the screening process, these substitutes can be categorized into the following three:

A. **Products made from recycled plastics:** SUPPs that can be produced using recycled plastics instead of virgin plastics. However, the limitations of closed loop recycling and the quality-based limitations of recycled plastics need to be considered.

B. **Traditional materials**: These are based on naturally occurring polymers found in animals and plants (renewable), such as cellulose, chitin, and lignin as well as non-renewable mineral substances or elements found in nature such as clay, mica, and aluminum.

C. **Synthetic or semi-synthetic bio-based polymers**: These are derived from natural polymers of renewable origin, but undergo extensive physical, thermal, or mechanical processing or chemical treatment (in the case of semi-synthetic bio-based polymers), or transformation of polymers using chemical abiotic routes (in the case of synthetic bio-based polymers).

Figure 26 illustrates the materials used for conventional fossil fuel-based plastics and their alternative products. The inventory information mentioned in Table 6 i.e., the raw materials, additives, etc. needs to be created and maintained for the substitute products as well.

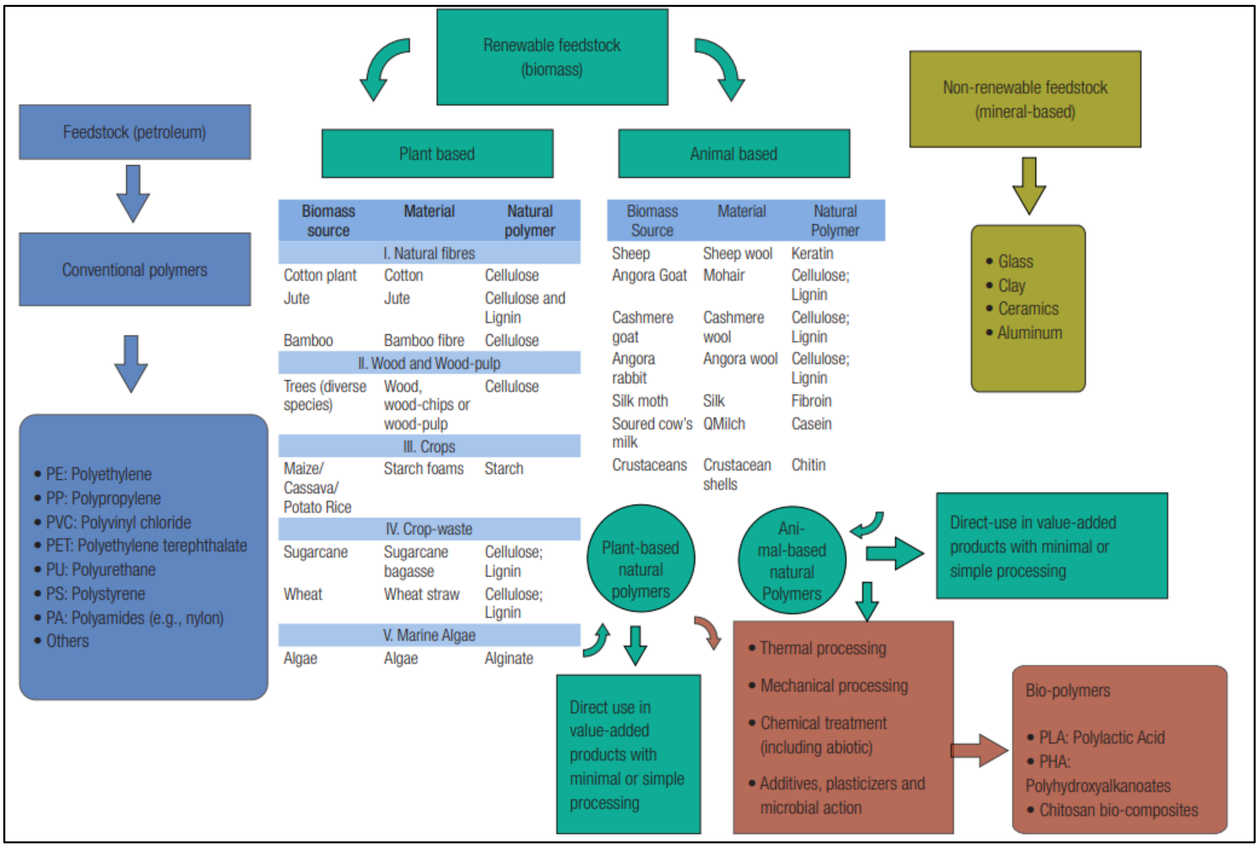


Figure 26: Conventional polymers and substitute materials (UNCTAD, 2021)

Canada has published a report on guidance for selecting alternatives to single-use plastics for business and organizations that are providing single use plastics for reduction of single use plastic and its pollution (Ministry of Climate and Environment, 2022).

3.3.2. Plastic related conceptual and definitional issues

The definitions of terms listed in the Table 7 are useful for recognizing some of the alternatives categorized under biodegradable plastics. Figure illustrates the plastic polymers and products under four categories based on their source and biodegradability.

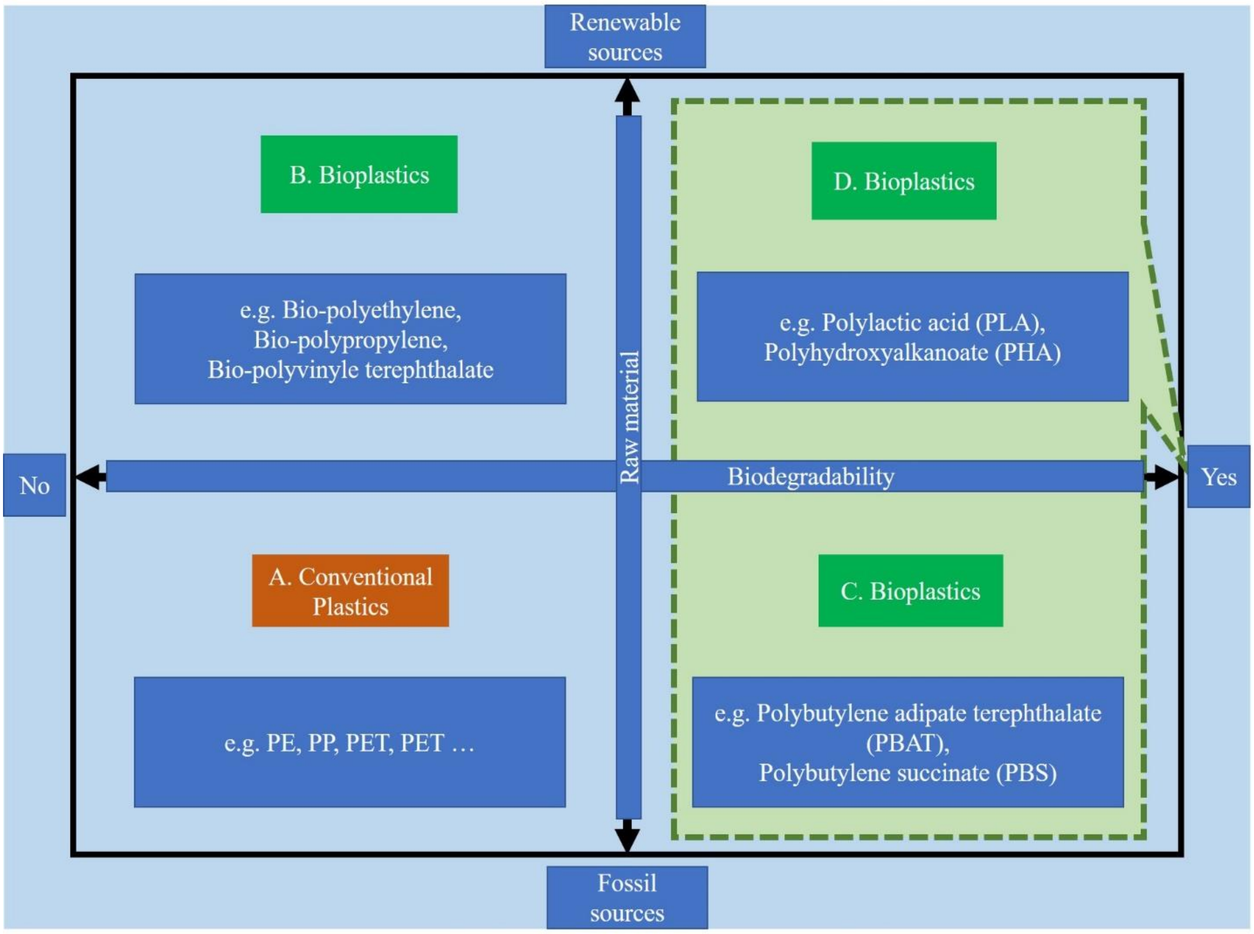


Figure 27: Conventional plastics and bio-plastics, further divided into bio-based plastics and biodegradable plastics (modified from Lackner, 2015; Abeynayaka et al., 2022)

The biodegradability of the plastics needs to be precisely designed since some biodegradable plastics are not degraded under normal conditions. Table 7 clarifies the definitions of degradation. This means that biodegradable plastics need to be classified as to whether they are biodegradable under domestic composting or require industrial composting. In the latter case, the alternative product collection and facilities for degrading them are essential when considering what to recommend as replacements for SUPPs. Moreover, these alternatives need to be assessed in terms of their constituents (listed in Table 7) and impacts.

Table 7: Clarification of terms related to degradation and biodegradation UNEP (2017)

Term	Definition
Degradation	Partial or complete breakdown of a polymer due to combination of ultraviolet radiation, oxygen attack, biological attack, and temperature. This implies alternation of the properties, such as discoloration, surface cracking, and fragmentation.
Biodegradation	A biologically mediated process involving the complete or partial conversion to water, carbon dioxide/methane, energy, and new biomass by microorganisms.
Industrial Composting	Capable of being biodegraded at elevated temperatures under specified conditions and time scales, usually only encountered in an industrial composter.
Domestic Composting	Capable of being biodegraded at low to moderate temperatures typically found in domestic household compost systems.

3.4. Policy Instruments

Policy instruments can be categorised into four main groups such as, regulatory, market-based (economic instruments), informational, and voluntary agreements (Akenji et al., 2020; Bengtsson et al., 2010). Regulatory instruments are the basis for national environmental policies and these mandates or prohibit specific actions or the use of a certain technology, define a level of achieving environmental performance, etc. Usually regulatory measures are combined with a mechanism to monitor the regulated entities and a sanction for non-compliance. Environmental quality standards, technical/emission standards, and restrictions and bans are the three main categories. Restrictions and bans, one of the most common regulatory instruments used to mitigate the environmental impacts of SUPPs, refer to the direct limitation of producing, importing of undesirable product or restrictions on the sale or use of certain products with detrimental environmental and health impacts.

Encouraging certain behaviors and practices through economic incentives is the basic rule of the economic instruments. However, the resource and product prices governed by the market may not reflect environmental performance. Therefore, economic instruments intervene the market through policy measures (Bennear and Stavins, 2007).

It can be identified two basic groups of informational policy instruments. The first group is where the government provides information to some actor group while the second group is where the government requires some actor to provide certain information (i.e. information disclosure). Generally, these are intended to provide information about the environmental performance of certain products in a standardized manner, which helps the consumers investors, etc. to make decisions (Jordon et al. 2003, Howlett 2019).

Voluntary agreements are another instrument to promote environmental improvements through voluntary action by the stakeholders. Some firms make commitments to improve their environmental performance beyond legal requirement. A well-known example is the some of the Japanese cosmetic industry big players voluntary avoiding the microbeads in their products (Hasegawa, 2020).

Table 8: Strengths and limitations of four main groups of policy instruments

Policy Instrument	Strengths	Limitations
Regulatory instruments	• The setting of targets/standards is inexpensive and the goals for policy achievement are clear. • Regulatory measures have proven to be effective for addressing directly visible damages and hotspots of pollution.	• Industry tends to be reluctant to submit to command and control regulation. Such resistances may hinder the effective implementation regulations. • These only require compliance with certain targets and therefore provide no incentives for improvements beyond those targets. • The monitoring costs can be excessive and there can be technical limitations.
Economic instruments	• Ability to provide incentives for innovation and improvement beyond a certain level of performance. • Cost effective.	• Require institutions to implement and enforce them. • Effects are less predictable. • Assessments of effects need to be undertaken and frequent revisions may require.
Informational instruments	• Comparatively low implementation costs • Stakeholder awareness	• Without adequate knowledge and sustainability values among the key actors, information on environmental performance is not likely to generate changes in behavior. • Economic factors pulling in the opposite direction
Voluntary agreements	• More flexible and compliance can be less burdensome. • More effective in situations where there is a high possibility of regulations or economic instruments • being used.	• May provide benefits to large market-leading companies by promoting their business.

Criteria for policy instrument selection can be divided into three categories (US Congress, 1995). Table 9 provides the criteria narrowing the choice of policy instruments.

- Environmental results: The likelihood that the objectives of the policy will actually be achieved.
- Costs and burdens: The costs associated with the policy for society as a whole (including costs for governments and public authorities, for regulated entities, and for others affected by the policy in question), as well as how these costs are distributed. These criteria also include the administrative burden on governmental institutions to ensure policy compliance.
- Change: The adaptability of the policy and to what extent it provides incentives for technological innovation and diffusion.

Table 9: Criteria narrowing the choice of policy instruments (adapted from US Congress, 1995). 1: Effective, 2: Average, 3: It depends, 4: Use with caution

	Environmental Results			Costs & Burdens		Change	
	Assurance of meeting galls	Pollution prevention	Equity and justice	Cost effectiveness and fairness	Demands on government	Adaptability	Technology innovation & diffusion
Tools without fixed targets							
Technical assistance	-	4	1	1	2	1	2
Subsidies	-	4	2	2	4	2	2
Information reporting	--	3	2	2	4	2	2
Liability	2	3		2	2	1	2
Pollution charges	2	2	4	2	2	2	1
Tools with fixed targets							
Challenge regulations	2	2	2	1	1	3	3
Product bans	1	3	-	2	4	2	4
Design standards	1	3	2	2	2	2	2
Harm based standards	1		2	2	4		2
Technology specifications	1	1	1	2	4	2	

Apart from the choosing appropriate policy instruments, the building institutional/policy coherence associated with promoting sustainable SUPPs alternatives need to be supported with governance structural arrangements such as vertical/horizontal coordination, multi-ministerial planning, involvement of key stakeholders, engagement with local communities, etc.

3.5. UNEP-LCI meta-analyses of LCA studies on SUPPs and their substitutes (UNEP-LCI, 2022)

Figure 28 summarizes the UNEP-LCI recommendations. The meta-analyses of the LCA studies on SUPPs and substitutes indicate that the re-usable product substitutes in general have lower environmental impact. The more the product can be re-used, the lower the environmental impact becomes. Substitutes made from different materials (i.e., paper, biodegradable plastic), tend to shift the impact rather than reduce the environmental impact considerably. Therefore, it is important to reconsider the usage of single use products (both SUPPs and substitute single use products). Further, the geographical issues also need to be considered when selecting the substitutes, i.e., the state of the waste management systems, the energy mix in use in a particular country, the end-of-life scenario, consumer awareness and participation, etc. This is because the environmental impacts greatly depend on the above-mentioned factors. Hence, policymakers considering the LCA inputs for their policy recommendations need to consider the relevance of all studies to their contexts. The following points were mentioned as recommendations:

- Product design oriented for resource efficiency. Lighter and durable materials reduce the impacts (i.e., lower transportation-related footprint). Convenience for the end-of-life management (i.e., composite or multi-layered products are difficult to accommodate in recycling systems).
- Reduce the environmental footprint of the production process, since the production process accounts for a significant portion of the lifecycle impact.

- Selecting a low-impact end of life scenario helps minimize the impacts, thus requiring careful consideration of end-of-life scenarios. Keeping the product within the economy while avoiding or delaying the end-of-life stage also helps.
- Consideration of potential future scenarios is also important. A country's energy mix, transportation options, and changes in material supply chain could greatly impact on the comparative impacts of SUPPs and their substitutes.
- Need for combining LCA information with other robust information. LCA provides insights, yet needs to be supported and cross-checked with other scientific information such as marine litter, microplastics, social factors and gender aspects.

Figure 28: UNEP-LCI SUPPs summary of recommendations (UNEP-LCI, 2022)

3.6. Constructive policymaking initiatives on plastic substitutes

The following seven points are to be considered for the short, medium, and long-term substitution of SUPPs through policy measures:

1. In-depth review of SUPPs (information on manufacturing and data collection), and the substitute products and material, to have greater clarity of products within the harmonized system (in most situations single-step complete replacements may not occur; instead, a gradual and/or time bound phaseout or co-existence of SUPPs and substitutes may suffice).
2. Value chain-associated initiatives on plastics recovery, recycling, and compositing.
3. Attracting local and foreign investment for plastic substitutes manufacturing within the country.
4. Technical and technology cooperation, assistance, and capacity-building measures to cooperate with the full life cycle of the substitute products.
5. At national context, the clear definitions of SUPPs and their substitutes need be provided in accordance with the international definitions.
6. Requirement of registration of SUPPs importers, distributers and manufacturers need to be regularized and published.
7. Addressing the difficult to identify Imports/Exports of most of the SUPPs, the customs entry provisions can be improved (i.e. clear definition of HS codes for SUPSs and frequent statistics updates and evaluation).

However, the gaps in scientific information such as LCI databases, and chemical compositions need to be addressed to assist science-based-policymaking enabled with a plastic substitution function. These include the following three key areas (adapted and modified from UNCTAD (2021):

A. Substitute materials within the system need to be clarified in specific terms, in order to assist relevant governing organizations (such as CEA) during negotiations, as well as the officials (CEA, customs), researchers, and other key players in the decision-making and monitoring system.

B. A need for regulatory and infrastructure support, to mechanize the harmonized system (with the substitutes), while addressing:
   - Do SUPP pollution hotspots have access to adequate recovery, recycling, and disposal facilities for conventional polymers?
   - What lessons or best practices can be learned from specific country experiences?
   - Are there regulations and infrastructure (such as industrial composting facilities) available for bio-based polymers across the country?

Mobilization of local/foreign investment for the country, in order to enable access to technologies and knowledge required for effective management of plastic wastes as well as to handle substitutes; and, related to this, how the governance, intellectual property, copyright protection regimes, and licensing issues fit into this.

4. Lessons learned from other countries: A review of existing policies and legal instruments on single-use plastic product management in selected countries

4.1. Common policies in countries

For many SUPPs, the most commonly used policy instruments are regulations by which specific products are restricted and/or banned from the manufacture, distribution and use, and market-based instruments, in which certain charges and taxes are applied to products (UN Environment, 2018). According to studies carried out by UNEP, these regulations apply to products that are identified to be most burdensome in particular regions; for example, food packaging and SUP utensils, due to their prevalence. In some cases, regulations may stretch to cover polymer materials such as PS and EPS as well. Another targeted category is plastic beverage bottles and beverage cans; however, exceptions are commonly applied to products that are used for medical and scientific purposes. As a region, Europe has enacted the highest number of regulations against SUPPs, in which 17 countries include taxation systems for SUPPs, while countries in West Asia and the US have the lowest rate of regulations against SUPPs (UN Environment, 2018).

Market-based policy instruments used to curb SUPPs include EPR, deposit-refund schemes, and recycling requirements, with the former mainly applied to manufacturers and retailers. Most of such EPR mandates, deposit-refund schemes, and recycling rules can be seen in European countries' legal systems, which can be attributed to the fact that EU directives require such steps in their directives. Recycling requirements are the most common type of policy used, and are usually accompanied by solid waste management rules or EPR schemes. These regulations also include imposing recycling targets, monetary incentives on stakeholders, and government mandates.

Table 10: Policy instruments used to control SUPPs

Policy Type	Number of Countries	Description
Legal: Bans and Restrictions		
1. Bans on manufacture, distribution, and use of SUPPs	27	Various bans on the manufacture, importation, distribution, use, and sale of SUPPs
2. Bans on certain product types	22	Product types such as plates, straws, cups, etc.
3. Bans on certain polymer types	16	Specific polymer types include PS and EPS
Market-Based Instruments		
1. Taxes on manufacturers, importers, and traders	29	Environmental tax, excise taxes or charges on waste disposal
2. Extended Producer Responsibility (EPR)	63	In place in 38 countries in Europe; 9 countries in Asia
3. Deposit-refund schemes	23	In place in 15 countries in Europe; 5 countries in Asia-Pacific region; frequently used for plastic beverage bottles
4. Recycling requirements	51	Explicit regulations on recycling

In the following sections, governmental policies, legal measures and initiatives in selected regions (EU as a global leader of plastic measures) and some Asian countries, which may have similar consumption patterns and issues with Sri Lanka, are discussed.

Table 11: The GDP of the selected countries

GDP	Millions USD in 2021
Sri Lanka	84,518
France	2,937,472
India	3,173,397
Thailand	505,981
Japan	4,937,421
Canada	1,990,761

Source: World Bank

4.2. European Union (EU) policies and actions

Governmental approach to industry and consumers

The European Union has introduced several legal instruments and guidelines to their member states to reduce plastic waste, including SUPP waste and marine litter (Watson, 2021). The European Parliament and Council Directive (1994) primarily aims at reducing plastic packaging waste while taking measures to enhance the reuse and recycling norms. An amendment introduced in 2018 further targets identification of the chief sources of marine litter, whilst addressing enhanced prevention and clean-up of existing sources of waste (Watson, 2021).

In the 2019 Directive, the guidelines on SUPP waste reduction and management were further elaborated and made more comprehensive. The Directive explicitly categorizes several types of SUPPs that needed to be restricted or prohibited from use, including SUP cutlery, plates, straws, stirrers, food and beverage containers made of EPS and products made of oxo-degradable plastics (Watson, 2021). Likewise, it recommends member states to adapt EPR schemes to enable efficient collection of such waste and sets related targets for them. Upon the introduction of these proposals, the European Commission led campaigns to raise awareness among stakeholder groups on the impacts of SUPPs and how to reduce these via changing behaviour patterns, particularly focusing on young consumers (Watson, 2021). To cater for the ever-growing consumer demand for plastic products, circular economy concepts have been introduced to improve product efficiency and value recovery rates. These include material design requirements that enable separation and recycling properties while encouraging reuse. In addition, to improve the overall circularity, it is also important to improve the lifetime of plastic products while allowing for their potential maintenance as well. Table 12 and 13 illustrate the regulations regarding SUPP waste management in the EU, and policy development processes of directives on SUPPs in the EU, respectively.

Regulations regarding SUPPs waste management in the EU

Table 12: Regulations in EU

Year	Strategy
2008	• Revision of Waste Framework Directive (WFD) • Introduction of the 'Waste Hierarchy' concept and binding recycling targets • Inclusion of 'Polluter Pays Principle' and 'Extended Producer Responsibility (EPR)' concepts
2015	**Introduction of European directive on lightweight plastic carrier bags** • A levy imposed on plastic bags by the Government of Ireland helped to reduce plastic bag usage from 328 to 14 per capita in 2014. • A number of member states introduced similar fees on lightweight plastic carrier bags, including Germany, the UK, Spain and Netherlands, while countries such as Denmark announced bans. **EU action plan for the circular economy** • Plastics were identified to be one of the five priority areas to be addressed. • EC committed to the preparation of a strategy that addressed the challenges posed by plastics throughout the value chain.
January 2017	Publication of a roadmap **Roadmap for a Strategy on Plastics in a Circular Economy including action on marine litter; aimed at:** • Decoupling plastic production from virgin fossil feedstock • Improving the economics, quality and uptake of plastic recycling and reuse • Reducing plastic leakage to the environment This strategy further aligned EU policy with UN sustainable development agenda 2030
July 2019	**EU Directive on single-use plastic products** The top 10 SUPPs having the largest negative impact on the environment were identified, and their sustainable alternatives were promoted by the Directive on single-use plastic products which went into force on 2 July 2019. The 10 items addressed in the Directive are: 1) Cotton bud sticks; 2) Cutlery, plates, straws and stirrers, 3) Balloons and sticks for balloons; 4) Food containers; 5) Cups for beverages; 6) Beverage containers; 7) Cigarette butts; 8) Plastic bags; 9) Packets and wrappers; 10) Wet wipes and sanitary items.
From 2021	Ban on SUPPs such as straws, forks and knives

Source: Elliott et al., 2020

Table 13: Summary of policy development processes related to Directive on single-use plastics

Date	Legal measures
16 January 2018	The EU plastics strategy was published, which states the necessity of a legislative proposal on SUPPs.
28 May 2018	Commission-level working document on the impact assessment on SUPPs and fishing gear was published.
2 July 2019	Directive on single-use plastic products went into force.
31 May 2021	1) The guidelines on SUPPs and 2) implementation of the decision on reporting on fishing gear were adopted by the EU Commission.
3 July 2021	Designated SUPPs are banned from being placed on Member States' markets, and marking requirements went into force.
1 October 2021	Implementing Decision 2021/1752 was adopted by the EU Commission, which stipulates rules for the calculation, verification and reporting of data on the separate collection of waste SUPP beverage bottles.
4 February 2022	Implementing Decision 2022/162 was adopted by the Commission, which stipulates rules for the calculation, verification and reporting on the reduction in consumption of SUP food containers and beverage cups.

Source: European Commission, 2019

Among the SUPP policies in place in the EU, those of France are explained below as an example of curbing the use of SUPPs and the related environmental pollution.

4.3. Policies and actions in France

Beginning on 1 January 2020, three SUPPs were banned in France, namely plastic plates, cups and cotton bud sticks (single-use plastic products were phased out from January 1, 2019). More SUPPs are planned to be banned in the coming years in accordance with the government's goal to phase out SUPPs nationally by 2040 (single-use plastic products were phased out from January 1, 2019). A ban on plastic straws, disposable cutlery, stirrers, takeaway cup lids, confetti, PS containers and plastic packaging for fruits and vegetables weighing less than 1.5 kg went into effect in 2021 (single-use plastic products were phased out from January 1, 2019). Also in the same year, a penalty was imposed on usage of excessive plastic wrapping (single-use plastic products were phased out from January 1, 2019). By 2022, additional restrictions on plastic tea bags and toys as well as distribution of free plastic bottles are to be imposed. These bans are to be imposed in accordance with the EU directive guidelines, which provide for a six-month transition period for retailers (single-use plastic products were phased out from January 1, 2019). Table 14 shows the regulations on SUPPs in France.

Table 14: SUPPs regulations in France

Year	SUPPs	Policy
2015	EPR schemes	• In response to the EU directives on packaging and packaging waste (Directive 94/62/ EC and Directive (EU) 2015/720) • Applied to household packaging, among other types.
2016	SUPPs ban	• Manufacture, retail distribution, and importation are banned for lightweight plastic bags of 50 microns or less in width • Ban does not apply for compostable bags made of bio-sourced materials. • Minimum bio-sourced content of SUPPs to gradually increase from 30% on 1 January 2017 to 60% on 1 January 2025. • Production, distribution, and sale and the use of packaging or bags made, in whole or in part, from oxo-fragmentable plastic
2017	Marine SUPPs waste	Alongside member states representing G7 summit and EU, launched the Ocean Plastics Charter to reduce plastic pollution and support sustainable consumption.
2020	SUPPs	• By January 1 2020, production, distribution of kitchen plastic plates, cups and cotton bud sticks with plastic sticks is prohibited. (Energy Transition for Green Growth Act) • By 2021, plastic straws, disposable cutlery, stirrers, takeaway cup lids, confetti, PS containers and plastic packaging for fruit and vegetables weighing less than 1.5 kg will be banned. • By 2022, plastic tea bags and toys as well as distribution of free plastic bottles will be prohibited.

Source: UNEP - Legal Limits on Single-Use Plastic Products and Microplastics: A Global Review of National Laws and Regulations (2018)

Consequences by the policies

The EU's plastic strategy includes the following components. (ec.europa.eu, n.d.)

i. Cost-effective reuse and recycling of all plastic containers and packaging by 2030
ii. Pledge-based campaigns by companies to use recycled materials (e.g., PepsiCo)
iii. Setting of quality standards for recycled plastics
iv. Issuance of guidelines for collection and sorting

In response to these, for example, the beverage giant, PepsiCo Europe has announced plans to eliminate virgin plastic from bags for potato chips and other snack products by 2030, and instead use recycled or renewable plastic. The first trial will be rolled out in the market in France in the first half of 2022, followed by the UK. The company estimates that the switch to non-fossil-based materials will reduce greenhouse gas emissions by up to 40% per tonne of packaging. (PepsiCo, Inc. Official Website, n.d.)

Another example is Tesco, the UK's leading retailer, which committed to using recycled product packaging in 2021 based on their 4Rs principle (Remove, Reduce, Reuse and Recycle), to reduce the use of single-use plastic products. To date, the company has improved the packaging of more than 1,600 products, saving over 6,000 tonnes of material in the process. The company also published a list of preferable materials for use and encourages its suppliers to use them for their products. (Tesco PLC, n.d)

One of the key policies that drives producers to shift toward recycling is introduction of a plastic tax. The EU, for example, introduced a plastic tax regulation that imposes a tax on non-recycled plastics, which has meant recycled plastic is becoming more cost-effective than virgin plastic, which is incentivising producers to employ more recycled plastic rather than using virgin plastic.

The EU plastic tax is allocated to member countries as a levy based on the amount of plastic waste they generate, as shown in Figure 29. France, Germany and Italy are ranked in the top three.

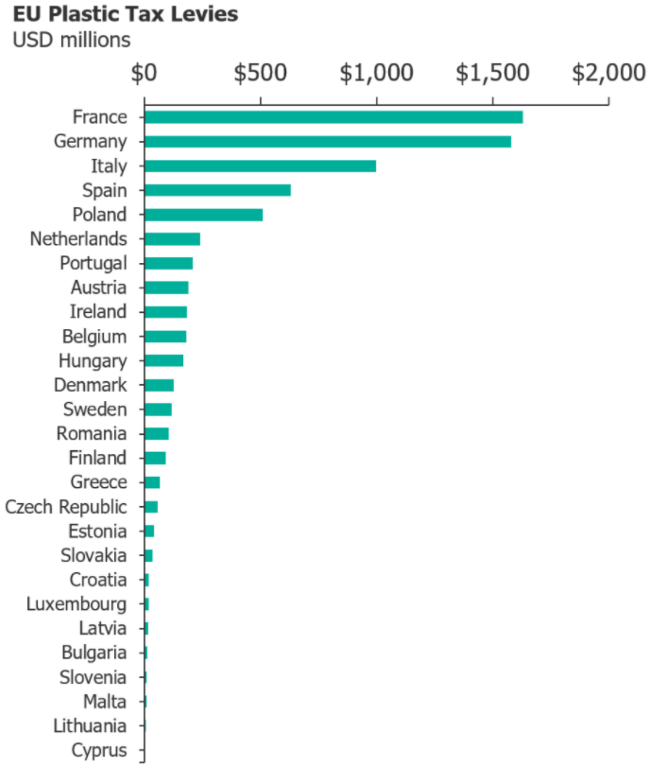


Figure 29: EU plastic tax levies (European Commission, 2021)

4.4. Policies and actions in India

Governmental approach to industry and consumers

Together with China, India is one of the biggest consumers of plastics in the South Asia region (Giacovelli, 2018) and by consequence is also one of the highest consumers of plastics additives globally (Giacovelli, 2018). Studies show that the growth rate of plastic consumption in India has even surpassed that of China and nearly equals that of developed countries like the UK (Giacovelli, 2018).

The plastic packaging industry has been identified as the largest consumer of plastics in India, and several studies indicate it is responsible for around 42–52% of total plastic usage (Giacovelli, 2018). Lower costs and high durability have made polymers such as PE, PP PVC and PS the front runners of total plastic consumption (Giacovelli, 2018). The average per capita consumption of plastics is estimated at 11 kg in 2020, and is predicted to climb to 20 kg by 2022 (Banerjee, 2014).

To manage the plastic waste problem, in 2011, the Plastic Waste (Management and Handling) Rules were introduced, which were then amended in 2016 and 2018 (Banerjee, 2014). Under these regulations, each local body is responsible for developing and implementing infrastructure for the collection, segregation, storage, transportation and processing or disposal of plastic waste (Plastic Waste Management Rules, 2016). The waste generator is responsible for minimizing the waste generated, segregating it prior to handing over to local bodies and is obliged to pay the fee specified by the local authority responsible for waste management services (Plastic Waste Management Rules, 2016). Further, the law requires the registration of manufacturers and recyclers through the State Pollution Control Board or the Pollution Control Committee of the Union Territory concerned and appropriate renewal of their licenses over the course of time (Plastic Waste Management Rules, 2016). Table 15 shows the regulations in India on SUPPs.

Table 15: Regulations regarding SUPP waste management in India

Year	Item/Function	Policy
2016 (Plastic Waste Management Rules, 2016)	SUPB and plastic packaging	• SUPB made of virgin or recycled plastic should not be less than 50 microns in thickness. • Carrier bags made of recycled plastic shall not be used for storing, carrying, dispensing, or packaging ready-to-eat or drink foodstuffs. • A tax is charged on the manufacturing of plastic bags. • Exceptions are made for bags made of compostable plastics. • Manufacturers or sellers of compostable plastic carry bags shall obtain a certificate from the Central Pollution Control Board before marketing or selling such. • Should either be in natural colour shades and not contain any added pigments, or be made using only pigments and colorants in conformity with Indian Standard: IS 9833:1981, which relates to contact with foodstuffs, pharmaceuticals and drinking water. • Manufacture of non-recyclable multilayered plastic shall be phased out within two years.
	Recycled plastics and products	• Shall not be used for storing, carrying, dispensing or packaging ready-to-eat or drink foodstuffs. • Shall conform to Indian Standard: IS 14534:1998, *Guidelines for Recycling of Plastics.*

Year	Item/Function	Policy
	Compostable plastics	• Degree of degradability and degree of disintegration shall be determined as per the protocols of the Indian Standards.
	Plastic sachets	• Shall not be used for storing, packing or selling any type of tobacco and pan masala. • Primary responsibility for collection of used multi-layered plastic sachet or pouches or packaging lies with producers, importers, and brand owners (EPR). • Required to establish a system for return of their product waste, which is be submitted to the State Pollution Control Board while applying for Consent to Establish or Operate or Renewal.
	Specific polymers	• Plastic material, in any form including vinyl acetate, maleic acid, vinyl chloride copolymer, shall not be used in any package for packaging pan masala and tobacco in any form.
	Marketing and labelling	• Name, registration number of the manufacturer, thickness (for carrier bags) and certificate number (carrier bags made of compostable plastic) should be printed in English in SUPB and multilayered packaging. • Recycled carrier bags should bear a label or a mark "recycled" according to the Resin identification code and should conform to Indian Standard: IS 14534: 1998. • Compostable plastics shall bear a label "Compostable" and shall conform to the Indian Standard: IS or ISO 17088:2008, titled Specifications for "Compostable Plastics".
	Waste management	• Shall be delivered to registered plastic waste recyclers and recycling shall conform to Indian Standard: IS 14534:1998 titled Guidelines for Recycling of Plastics. • Plastic waste which cannot be further recycled shall be used in road construction, energy recovery or waste to oil, etc. following standards, guidelines, and pollution control norms specified by relevant authorities. • Thermoset plastic waste shall be processed and disposed of as per the guidelines issued by Central Pollution Control Board.
2017	Marine SUPPs waste	In 2017, made a high-profile commitment to the United Nations #CleanSeas campaign.
2017	Taxation	Excise tax at higher rates for plastic packaging and single-use products including tableware and kitchenware (Integrated Goods and Services Tax Act, 2017)
2018	Proposed SUPPs ban	• The Government of India announced that by 2022 it shall eliminate SUPPs from the country. • Based on state-specific bans on the manufacture, supply, storage and use of plastics that are already in place in at least 25 of the country's 29 states • Recently, the Indian state Maharashtra implemented a complete ban on the manufacture, usage, distribution, sale, storage and import of SUPPs from plastic bags to bottles and cutlery exempting use for medical, agricultural, retail packaging, trash can liners and take-away packaging.

Year	Item/Function	Policy
2022	Ban on identified SUPP	• The Ministry of Environment, Forest and Climate Change announced the ban. The list of banned items includes -ear buds with plastic sticks, plastic sticks for balloons, plastic flags, candy sticks, ice- cream sticks, polystyrene (Thermocol) for decoration, plastic plates, cups, glasses, cutlery such as forks, spoons, knives, straw, trays, wrapping or packing films around sweet boxes, invitation cards, cigarette packets, plastic or PVC banners less than 100 micron, stirrers. (Ministry of Environment, Forest and Climate Change., 2022).

Source: UN Environment, 2018

Consequences by the policies

While policies have been introduced, India still mainly lacks proper implementation methods. Many of the cities lack the necessary waste collection and separation facilities and it is reported that only a small portion of the collected waste receives the appropriate treatment (Banerjee T. S., 2014), while the rest is landfilled or openly dumped. A large portion of the population still lacks proper awareness on the issue of SUPPs, and the absence of strict regulatory measures has weakened the actual implementation.

In order to strengthen policy implementation, the Ministry of Environment, Forest and Climate Change of India has issued guidelines on Extended Producer Responsibility (EPR) for plastic packaging under the Plastic Waste Management Rules (2016). The guidelines aim to enhance recycling of plastic packaging waste and help companies transition to sustainable plastic packaging. In order to reduce the use of new plastic materials, the guidelines mandate, among other things, the reuse of rigid plastic packaging, and also stipulate that producers, importers and brand owners will be subject to the collection of environmental compensation under the polluter pays principle if they fail meet the set targets. India's ban on certain disposable plastic items of low utility and high littering potential will come into force on 1 July 2022, and together with this ban, the guidelines on EPRs are an important step towards reducing environmental pollution caused by littering of plastic waste in the country.

4.5. Policies and actions in Thailand

Governmental approach to industry and consumers

The key government bodies responsible for developing plastic waste management plans, legislation and provision of technical guidance include three main ministries: Ministry of natural Resources and Environment (MONRE) and the Pollution Control Department (PCD), Ministry of Interior, and Ministry of Industry (Akenji et al., 2020; Wichai-utcha & Chavalparit, 2019). In 2016, the government developed a master plan on solid waste management (Akenji et al., 2020) which aims to reduce solid waste by half and appropriately manage 75% of such by 2021 (Akenji et al., 2020). Further, in 2018, a municipal solid waste management action plan was formulated to set up targets for proper waste disposal and upgrading of disposal sites and methods, including recycling (Akenji et al., 2020). For plastic and plastic waste management, Thailand has specifically developed a 10-year plan to reduce plastic products and SUP packaging while promoting sustainable alternatives and to reduce marine plastic waste pollution (Akenji et al., 2020). Moreover, a campaign launched by the government and retailers towards a complete ban in 2021 to reduce waste and debris in the sea resulted in imposing a ban on SUPB in major stores in Thailand (Chankaew, 2020). Table 16 shows the regulations on SUPPs in Thailand.

Table 16: Regulations regarding SUP in Thailand

Year	Item/Function	Policy
2009-2014	National 3R strategy	• Recycle 60% of plastic waste generated by 2021. • Promotion of eco-friendly products and reuse and recycling to improve resource efficiency. • Promotion of public-private partnerships including waste recycling businesses. • Issuing guidelines and standards for waste disposal.
2016-2021	National Master Plan on Solid Waste Management	• Over 75% of total MSW properly managed by 2021. • Ensure waste segregation at source by more than 50% of local authorities by 2021. • Waste recovery and disposal by applying integrated technologies (WTF, biogas, RDF).
2017-2021	Plastic Debris Management plan/ Plastic waste management plan	• Establishing frameworks for systematic plastic waste management; development of a guideline for integrated plastic waste management (IWM) through cooperation between public and private sectors. • Increase the number of environmentally friendly designs and manufactures for plastic products. • Plastic waste is to be recycled by at least 60% before disposal to facilities by the end of 2021.
2018-2020	SUPP ban	• Effective from 2018, use of plastic bags was completely phased out in 30 hospitals under the supervision of Department of medical services in Thailand. • As of 2019, the government announced a plan under discussion to apply a tax and levies on SUPPs. • Ban on SUPB on major stores. • To date, only regulations have been implemented at the national level. • A process is being carried out to ban SUPB and foam containers from national marine parks.
2019-2025	SUPPs	• Plans to ban seven types of SUPPs by 2025. • In 2019, oxo-degradable plastics were targeted to be banned. • In 2022, plastic carrier bags and foam food containers are aimed to be banned. • By 2025, SUP cups and plastic straws are planned to be banned.

Source: Akenji, 2020; UN Environment, 2018; Wichai-utcha, 2019

Consequences by the policies

In terms of the main obstacles to SUPP waste management, these include the behavioral aspects of the Thai population, including higher rates of plastic bag usage, mainly in food packaging, and the lack of proper knowledge on waste sorting, reusing and recycling, etc. (Wichai-utcha, 2019). Moreover, the situation surrounding recycling has worsened due to the lack of identification of such waste plastic packaging in terms of the names of the resin types (Wichai-utcha, 2019) and the fact that most of these recycling facilities face financing problems in their businesses. Further, the regulatory bodies responsible for waste management often lack the manpower, monetary resources and facilities to render the services, and the majority of current employees do not possess up-to-date knowledge on waste treatment practices (Wichai-utcha, 2019).

Hence, the first step for successful implementation of policies should be to raise public awareness among reduce, reuse and recycling practices as well as educating the public on accurate waste sorting and disposal practices. It is also important to introduce use of the Resin Identification Code (RIC) system (Wichai-utcha, 2019) such that the waste sorting, recycling and other treatment methods can be equitably implemented. Moreover, the employment of EPR schemes, taxes and levies on SUPPs can help raise capital for the regulatory bodies for waste management while also discouraging SUPP usage. In addition, studies indicate that proper enactment of policies as well as introduction of sustainable alternatives can further assist in managing current issues surrounding the usage of plastics.

4.6. Policies and actions in Japan

Governmental approach to industry and consumers

Japan is one of the major manufacturers of plastic resins used in SUPPs, alongside other key manufacturing nations such as China, Taiwan and the Republic of Korea (UN Environment, 2018) The country is also the second largest plastic packaging waste generator on a per capita basis following the EU (Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations, 2018).

The total plastic waste generated in Japan is estimated at 9 million tonnes per year, of which the amount of SUPB accounts for only a relatively low figure of 200,000 tons per year (Johnston, 2020). According to the Plastic Waste Management Institute (Inagaki, 2020), in 2018 Japan recycled 84% of the total plastic waste generated that year, with a portion of such plastic waste being used for energy co-generation during the incineration (Inagaki, 2020). In the same year it was also announced that the Japan Soft Drink Association aimed to increase its recycling rate to 100% by 2030. Currently around 85% of PET bottles used are recycled (Johnston, 2020). A study by the Japanese Environment ministry shows that about 10% of the total plastic waste is estimated to be exported from Japan to other countries, while 60,000 tons eventually end up in ocean (Inagaki, 2020). In 2019, the Japanese government announced a goal to reduce plastic waste by 25% by 2030 (Johnston, 2020).

In Japan, since the economic value of plastic as a recyclable resource is lower than metal or paper, plastic reduction and recycling has not been much progressed except some specific products targeted by recycling regulations, such as the Containers and Packaging Recycling Law and the Home Appliance Recycling Law. The bottleneck for accelerating plastic reduction is that there has not existed legal or economic system to create strong incentives for producers and consumers toward better use of plastic materials. However, the new law on plastic recycling, “Act on Promotion of Plastic Resources Recycling” which came into force in April 2022, aiming at supporting more advanced initiatives by the public sector and businesses, would be the legal system to create such incentives.

Research has shown that most of the public is aware of the SUPP waste problem, and among them most are willing to switch to sustainable alternatives (Johnston, 2020). Moreover, it has been indicated that public opinion favors the phasing out of SUP cutlery and straws as well (Johnston, 2020). Japan’s national policies regarding SUP waste management comprise a combination of legislative measures promoting recycling and voluntary measures to discourage the use of SUPPs while further improving rates of recycling (Johnston, 2020), as shown in Table 17.

Table 17: Regulations regarding SUPPs in Japan

Year	Item/Function	Policy
Act No. 102 of June 16, 1995	SUPB	• Restrictions on importation of SUPB • Recycling plan instituted by law
	Recycling waste	• Restricted to specified businesses by law due to their use of large volumes of packaging • Recycling of plastic bags is required by national laws
	EPR schemes	• Designated businesses shall reduce the disposal of waste containers and packaging through the use of recycled containers and packaging and reducing the use of excess packaging
2019	Adopted the policy “Resource Circulating Strategy for Plastics”	• Promotes overall circularity of plastics, reduction of disposable containers and packaging, improving collection and recycling rates for plastics and promotion of bio-plastics and alternatives • Targets a 25% reduction in SUPPs waste generation by 2030; 60% of containers and packaging to be made reusable or recyclable by 2030 • Aims at 100% utilization of used plastics by 2035
2020	SUPB	• All retail outlets are required to charge consumers for using SUP bags • Encouraged the use of complimentary reusable carrier bags

Source: (UNEP, 2018; Johnston, 2020)

In recent years, in response to the urgency of the plastic pollution issue, the government is drafting more progressive policies. In 2019, it formulated the Plastic Resource Circular Strategy, which includes the following milestones: (Ministry of Environment Japan, 2019)

1. By 2030, 25% reduction in SUP waste generation
2. By 2025, plastic containers, packaging and products shall be designed to allow easy reuse and recycling
3. By 2030, reuse or recycling of all plastic containers and packaging at a rate of 60%
4. By 2035, reuse or recycling of all used plastic

Based on the above strategy some new laws have been introduced, as below:

1) Since 2020, plastic bags have become charged items at retail shops, etc. (Ministry of Environment Japan, n.d.)

2) In 2021, the government approved a bill to promote the recycling of plastic resources, aiming at reducing plastic waste and its recycling. This new law, titled 'Act on the Promotion of Resource Recycling for Plastics', came into force in April 2022 and as such is the first law focusing on plastic. It includes the following components:

1. Production and design

   The government has established new guidelines on the ecological design of plastic products for manufacturers, and certifies products which use less plastic or embody designs suitable for recycling. Further, government and public agencies will purchase such products through the Green Procurement Law.

2. Requirements on business entities:
    i. To reduce SUPPs.

       Targeting of 12 SUPPs: Forks, spoons, knives, muddler, straws, hair brushes, combs, razors, shower caps, tooth brushes, clothes hangers, and clothes covers
    ii. Business entities, including retailers, restaurants and convenience stores are to be prohibited from providing SUPPs such as plastic straws and spoons for free to customers.

Failure to comply with the above will incur a penalty comprising a fine of up to around 5,000 USD.

Consequences by the policies

In response to the above act, a number of major Japanese companies have initiated actions.

For example, a major Japanese trading company plans to pilot a project monitoring the collection of plastic containers from households and improve the efficiency of collection and transportation using Internet of Things (IoT) and other technologies. (Sojitz Corporation, n.d.) Another example relates to the fact that in order to utilize recycled plastic materials in the circular economy it is necessary to accurately trace materials throughout the entire value chain, and make information on such sharable. In order to visualize plastic product information, some major companies have started selling recycled plastic with traceability information using blockchain technology, which aims at promoting the use of recycled materials through the supply chain. (IBM Japan, n.d.)

Further, following the New Plastics Economy Global Commitment (involving participation from over 250 companies from various countries), which sets targets for solving the plastics challenge by 2025, in February 2022 the World Wildlife Fund for Nature Japan (WWF Japan) launched a new initiative, the 'New Plastics Economy Global Commitment', which aims to reduce the use of plastics by 2025 through The Plastic Circular Challenge 2025. Participating companies include major beverage manufacturers such as Kirin, Suntory and Coca-Cola, as well as Lion, Unilever and JAL, which have announced comprehensive commitments to achieving the above-mentioned 2025 target. (WWF Japan, n.d.)

4.7. Recent actions in Canada

In North America, besides some environmentally advanced states in U.S., Canada has been also making effort to progress its plastic policies. In June 2022, the government of Canada announced regulations banning SUPP, including plastic bags, cutlery, food packaging made from hard-to-recycle plastics, muddlers and straws. The ban on the manufacture and import of these SUPP will come into force in December 2022, with a further transition period for sales to take effect from December 2023. A ban on the export of six types of plastic products is also planned by the end of 2025. With 15 billion plastic bags/year and 16 million straws/day used in Canada, these measures are estimated to reduce over 22,000 tonnes of plastic in the environment and over 1.3 million tonnes of hard-to-recycle plastic waste over the next 10 years. (Environment and Climate Change Canada, 2022)

5. Conclusion and recommendations

SUPs are used in a vast diversity of products, ranging from packaging for food and other consumable items to toys, etc. However, the negative environmental impacts of plastic pollution, especially in marine environments, are widely recognized and acknowledged. The focus of efforts to reduce plastic pollution is now moving from 'end-of-life' disposal and clean-up solutions to full life-cycle impact considerations. The upstream measures include the regulation of plastics and related alternative product promotion. The screening of SUPPs for regulation is a challenging process owing to the different categories of SUPPs. Some are difficult to replace, and in some cases the alternatives can be more harmful. Hence, guidelines for a screening process would be beneficial for policymakers, for which the following key steps have been identified: a) categorization of SUPPs; b) categorization of the plastic substitutes; c) conceptual and definitional issues, particularly around the concept of biodegradability, and setting key criteria for evaluating the merits and demerits of various types of plastic substitutes; and d) situation analysis and intervention predictions, including science-based measures through available tools such as LCA, social impact assessment, material flow analysis, and cost-benefit analysis.

In many countries, regulations apply to the plastic items that are identified as the most burdensome to the countries or regions based on government assessments, and globally, food packaging and SUP utensils are the most common items to be regulated. Among the policy instruments employed by countries, many governments have introduced market-based policy instruments such as EPR, deposit-refund schemes, and recycling requirements, which utilize economic incentives and transfer responsibility to business entities. Through these policies, it has been observed that businesses have modified their operations by shifting toward more recycling- and environmentally-oriented production and distribution, especially in the EU. On the other hand, some Asian countries such as India have been making efforts to introduce ambitious policy targets; however, due to insufficient means of implementation these policies and regulations have not been fully implemented as expected by the government, which has reduced their efficacy. In order to overcome this drawback, India's government recently published detailed implementation guidelines for its EPR schemes, thus any policy measures introduced would need to be accompanied by effective implementation methods, including penalties, to achieve the targets.

Similarly, Sri Lanka has imposed a ban on four SUPPs and expects to target more, as highlighted in chapter 1, due to the pressing need for management of plastic pollution and marine litter in line with "The National Plastic Action Plan". The Plan highlights the priority actions needed to phase out selected SUPPs by 2021 and achieve an 80% reduction in their production and consumption by 2025 in Sri Lanka. Hence, chapter 2 of this report presents a life cycle assessment based on scientific findings on the environmental performances of selected SUPPs, as well as some alternatives for the ones that are either under consideration for banning or already banned in Sri Lanka. On a general note, while similar studies conducted in other regions and different contexts do exist, this study represents a first to conduct such an analysis. ISO 14040 (2006) and ISO 14044 (2006) guidelines were referenced for the LCA, and modelling was conducted based on four main life cycle stages, namely pre-manufacturing, manufacturing, usage (negligible impact owing to their single-use nature), and disposal. The modeling utilized commercial software, SimaPro, along with the Ecoinvent LCI database. In order to complete the LCI a number of methods were used, including lab tests, experiments, field data collection and reference to secondary sources. The study analysis revealed that PLA has a greater potential to replace some of the SUPP materials, based on its lower impact in the disposal stage. Cotton bud stems, Joss-Stick wrapping, cloth wick wrapping, grocery bags, and straws are the main SUPP applications that can be substituted through use of PLA in the manufacturing process. However, the pre-manufacturing phase of PLA showed higher environmental impact due to its dependence on agricultural crops, which in turn would have multiple impacts on the environment during their cultivation. Moreover, since the choice of PLA highly depends on agricultural crops, the related social impacts, mainly food security would need to be duly considered. Moreover, the government of Sri Lanka due to difficulties in the monitoring of PLA chemical content, consider it as not a good alternative for SUPPs in Sri Lanka. Therefore, considering the current situation of Sri Lanka, PLA cannot be a suitable alternative for SUPPs in Sri Lanka.

In the context of pesticide bottles, considering overall environmental performance, HDPE is the standout candidate; however, when considering the disposal scenario, PLA-based material shows potential as well. For water bottles, according to the overall environmental performance and disposal scenario, aluminum is the best candidate out of Al, PET, and PLA. Furthermore, when we consider the recycling and landfilling scenarios of PET water bottles, recycling exhibits a higher performance compared to landfilling. The reason behind this was due to additional post-processing. However, if we consider a second cycle that uses the recycled content (62% in this analysis), the impact from pre-manufacturing drops, and further, the total environmental impact is reduced for scenario 02 PET water bottles.

Similar comparisons could be carried out for alternative products provided adequate information and data are available to prepare the LCI for the LCIA model. However, the overall level of accuracy of LCA is ultimately determined by the availability of data, as well as the approximations and assumptions made for modeling all the LCA stages and related logistics, etc. These results show that conducting LCA will facilitate scientific decision-making for policy interventions as regards SUPPs. Furthermore, it is essential to consider the socio-economic aspects in parallel with the environmental aspects before making a final decision, as was evident for some of the results for alternative SUPPs. In this regard, the authors plan to address the socio-economic impacts of SUPPs in future research. Moreover, due to the lack of data availability and limited time, the LCA study for Environmental Impact Assessment (EIA) for alternatives to SUPPs was limited, thus the authors plan to conduct an LCA analysis for other alternatives (i.e., paper and other bio-based alternatives) for each of the selected eight SUPPs in future research. In addition, the unavailability of primary inventory data (in the Sri Lanka context) and the limitation of LCA regarding end-of-life mismanaged plastic impacts (on a global scale) limited the accuracy of the observations in certain cases. Hence, primary life cycle inventory (LCI) databases for Sri Lanka need to be developed.

Regarding LCA, policymakers need to be aware that they have the potential to provide science-based evidence that embraces the full life cycle of plastic products and alternatives to support decision-making. However, it is equally important to consider the social and economic aspects when making decisions. Therefore, the future research should consider the study of SUPPs and various alternatives other than PLA to estimate not only the environmental impact but also the social and economic impact of selected SUPPs and their alternatives. On this regard, IGES-CCET in future research in collaboration with the Ministry of Environment (MOE), Sri Lanka, and Peradeniya University will consider the study of selected SUPPs and their alternatives excluding PLA to estimate environmental, social and economic impact of selected SUPPs and their alternatives in Sri Lanka so that the most suitable alternatives for SUPPs could be used to replace the SUPPs.

Further, Policymakers need to note that while market-based policy instruments such as EPR, deposit-refund schemes, and recycling requirements are common policies, the key prerequisite to making such policies functional to create favourable economic conditions to ensure recycled plastic materials are competitive in the market, otherwise manufacturers, retailers, and others will have no incentive or motivation to employ recycle-oriented production and distribution. One of the most effective policies to create such a business environment, or market shift, is a taxation. Regarding the tax with the aim of the environmental protection, several efforts were made by the Sri Lankan government. For instance, the government attempted in 2008 to enact Environmental Conservation Levy Act on specific items and services which are considered to have high risk to give the negative impact on the environment. However, this attempt by the government was filed by consumers at the Supreme Court (Environment Foundation (Guarantee) Limited., 2020). As such, taxation has a number of challenges bothering consumers and manufacturers, and the comprehensive study is needed to design the functional system. On the other hand, it should be noted that successful cases have been observed in some counties. In the EU, for example, introduction of plastic tax regulations, which impose a tax on non-recycled plastics, has resulted in recycled plastic becoming more cost-effective than virgin plastic, thus producers, distributors and others have started replacing use of virgin plastic with recycled plastic. The plastic taxation applied to EU member states is based on their plastic waste generation, thus it would also function as an incentive for other countries to reduce their plastic waste. In addition to the banning of specific plastic items, consideration of how the market context can be optimized by policies for business entities to shift toward circular economy-based business is of prime concern, thus it is of critical importance not only to have the policies but also proper implementation plans in place to ensure policy is faithfully executed on the ground, as might be learned from the cases of India and Thailand mentioned above. Therefore, high public awareness coupled with EPR, schemes, taxes, and levies on SUPPs could assist regulatory bodies to implement the policies with economic incentives, as in the case of Japan and other EU countries.

References

ACS-GCI., 2015. Design Principles for Sustainable Green Chemistry & Engineering. American Chemical Society (ACS) Green Chemistry Institute (GCI). https://www.acs.org/content/dam/acsorg/greenchemistry/resources/2015-gci-design-principles.pdf

AIT & UNEP, 2021. COVID-19 & PLACTIC PLIGHT. A REFELECTION FROM ONE YEAR OF THE PANDEMIC. [online] Available at: http://www.circular-economy.ait.ac.th/downloads/COVID-19%20&%20Plastic%20Plight%20Report.pdf

Akenji, L., Bengtsson, M., Hotta, Y., Kato, M., & Hengesbaugh, M., 2020. Policy responses to plastic pollution in Asia. In *Plastic Waste and Recycling* (pp. 531–567). Elsevier. https://doi.org/10.1016/B978-0-12-817880-5.00021-9

Banerjee, T., Srivastava, R.K., Hung, Y.T., 2013. Plastics waste management in India: An integrated solid waste management approach. World Scientific Publishing Co. Pte. Ltd., DOI: 10.1142/9789814449175_0017

Banerjee, T., Srivastava, RK., and Hung, Y T, 2014. "Plastics Waste Management In India: An Integrated Solid Waste Management Approach". *Civil and Environmental Engineering Faculty Publications*. 114.

Boucher, J., Faure, F., Pompini, O., Plummer, Z., Wieser, O., Felippe de Alencastro., L., 2019. (Micro) plastic fluxes and stocks in Lake Geneva basin. TrAC Trend. Anal. Chem., 112 (2019), pp. 66-74

Briassoulis, D., Babou, E., Hiskakis, M., Kyrikou, I., 2015. Analysis of long-term degradation behaviour of polyethylene mulching films with pro-oxidants under real cultivation and soil burial conditions. Environ. Sci. Pollut. R., 22 (4) (2015), pp. 2584-2598

Bucci, K., Tulio, M., & Rochman, C. M., 2020. What is known and unknown about the effects of plastic pollution: A meta-analysis and systematic review. Ecological Applications, 30(2) doi:10.1002/eap.2044

Cartraud, A.E., Le Corre, M., Turquet, J., Tourmetz, J., 2019. Plastic ingestion in seabirds of the western Indian Ocean. Mar. Pollut. Bull., 14 (2019), pp. 308-314

Chankaew, P., 2020. Thailand kicks off 2020 with plastic bag ban. *Reuters*. https://www.reuters.com/article/us-thailand-environment-plastic-idUSKBN1Z01TR

Elliott et al., 2020. European Union's plastic strategy and an impact as.pdf. (n.d.).

Environment, U. N., 2018. *Legal limits on single-use plastics and microplastics*. UNEP - UN Environment Programme. http://www.unenvironment.org/resources/report/legal-limits-single-use-plastics-and-microplastics

EU, 2018. A European Strategy for plastics in the circular economy Local and regional dimension. European Committee of the Regions. ISBN: 978-92-895-0964-0; doi:10.2863/734820. https://cor.europa.eu/en/engage/studies/Documents/Plastic-Strategy.pdf

EUR-Lex, 2019. An Official website of the European Union. [online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=en (accessed on 15 July 2022)

European Commission., 2019. Single-use Plastics. [online] ec.europa.eu. Available at: https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en.

Ferrara, C., De Feo, G., Picone, V., 2021. LCA of Glass Versus PET Mineral Water Bottles: An Italian Case Study. Recycling 2021, 6, 50. https://doi.org/10.3390/recycling6030050.

France to phase out single-use plastics starting January 1., 2019. France 24. https://www.france24.com/en/20191231-france-begins-phasing-out-single-use-plastics

Giacovelli, C., 2018. Single-Use Plastics: A Roadmap for Sustainability. United Nations Environment Programme. ISBN: 978-92-807-3705-9. Single-use plastics: A roadmap for sustainability | UNEP - UN Environment Programme

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J. and Van Zelm, R., 2009. ReCiPe 2008. *A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level*, *1*, pp.1-126.

GPML., 2021. Global Marine Litter and Plastic Pollution: Unnecessary, avoidable, and problematic (UAP) plastic products and polymers. Global Marine Litter and Plastic Pollution Issue Brief 2. https://digital.gpmarinelitter.org/

GREENPEACE, 2022. The Myth of Single-use Plastic Recycling. [online] Available at: https://www.greenpeace.org/usa/the-myth-of-single-use-plastic-and-recycling/ (accessed on 15 July 2022)

Ilyas, R.A., Sapuan, S.M., Harussani, M.M., Hakimi, M.Y.A.Y., Haziq, M.Z.M., Atikah, M.S.N., Asyraf, M.R.M., Ishak, M.R., Razman, M.R., Nurazzi, N.M. and Norrrahim, M.N.F., 2021. Polylactic acid (PLA) biocomposite: Processing, additive manufacturing and advanced applications. Polymers, 13(8), p.1326.

Inagaki, K., 2020. *Japan faces up to its plastic problem*. https://www.ft.com/content/5cf68c84-afeb-11ea-94fc-9a676a727e5a

Isobe, A., & Iwasaki, S., 2022. The fate of missing ocean plastics: Are they just a marine environmental problem? Science of the Total Environment, 825 doi:10.1016/j.scitotenv.2022.153935

Janairo, 2021. Unsustainable plastic consumption associated with online food delivery services in the new normal. Cleaner and Responsible Consumption, 2, 100014. https://doi.org/10.1016/j.clrc.2021.100014

Johnston, E., 2020. *Japan's new plastic bag charge: What it means for consumers and the environment*. The Japan Times. https://www.japantimes.co.jp/news/2020/07/01/national/japan-plastic-bag-charge-consumers-environment/

Kosior, E., Mitchell, J., 2020. Chapter 6-Current industry position on plastic production and recycling. Plastic Waste and Recycling. Environmental Impact, Societal Issues, Prevention and Solutions.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J., Reddy, C.M., 2010. Plastic accumulation in the North Atlantic Subtropical Gyre. Science, 329 (2010), pp. 1185-1188

Lindwall, C., 2020. Single-Use Plastics 101. Natural Resources Defense Council (NRDC). [online] Available at: https://www.nrdc.org/stories/single-use-plastics-101 (accessed on 15 July 2022)

Ministry of Environment and Climate Change., 2022. Guidance for Selecting Alternatives to Single-use Plastics-as defined in the Single-use Plastics Prohibition Regulations. [online] Available at: https://www.canada.ca/content/dam/eccc/documents/pdf/managing-plastic-waste/reducing-plastic-waste/Guidance%20for%20Selecting%20Alternatives%20to%20Single-use%20Plastics_EN.pdf (accessed on 10 Aug 2022)

Ministry of Environment Japan., 2019. *環境省_「プラスチック資源循環戦略」の策定について.* [online] Available at: https://www.env.go.jp/press/106866.html [Accessed 5 Aug. 2019].

Ministry of Environment, 2021. National Action Plan on Plastic Waste Management 2021-2030. “Sobadam Piyasa”, Robert Gunawardana Mawatha, Battaramulla, Sri Lanka

Moretti, C., Hamelin, L., Jakobsen, L.G., Junginger, M.H., Steingrimsdottir, M.M., Høibye, L. and Shen, L., 2021. Cradle-to-grave life cycle assessment of single-use cups made from PLA, PP and PET. Resources, Conservation and Recycling, 169, p.105508.

Mourshed, M., Masud, M.H., Rashid, F., Joardder, M.U.H., 2017. Towards the effective plastic waste management in Bangladesh: a review. Environmental Science and Pollution Research, 24, 207021-27046. https://doi.org/10.1007/s11356-017-0429-9

Mulla, M.Z., Rahman, M.R.T., Marcos, B., Tiwari, B. and Pathania, S., 2021. Poly lactic acid (Pla) nanocomposites: Effect of inorganic nanoparticles reinforcement on its performance and food packaging applications. Molecules, 26(7), p.1967.

Müller, D.P. and Hiete, M., 2021. Visualization supported corporate decision making for life cycle sustainability assessment–Illustrated using a case study for selecting a sustainable packaging system for self-leveling compounds. Journal of Cleaner Production, 313, p.127768.

OECD., 2018. Considerations and Criteria for Sustainable Plastics from a Chemicals Perspective. https://www.oecd.org/environment/waste/background-paper-sustainable-plastics-from-a-chemicals-perspective-considerations-and-criteria.pdf

Pati, S.N., 2022. Life Cycle Assessment: Future Challenges. CRC Press.

Plastic Waste Management Rules, 2016 English.pdf. (n.d.). Retrieved January 16, 2021, from http://www.mppcb.nic.in/proc/Plastic%20Waste%20Management%20Rules,%202016%20English.pdf

PlasticOceans (Plastic Oceans International), 2020, PlasticOceans (Plastic Oceans International), The facts “more than 8 million tons of plastic are dumped in our oceans every year” https://plasticoceans.org/the-facts/ (2020)

PlasticsEurope, 2019. PlasticEurope. Plastics – The Facts 2016: An Analysis of European Plastics Production, Demand and Waste Data PlasticsEurope (2016)

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C., & Rocha-Santos, T., 2020. Environmental exposure to microplastics: An overview on possible human health effects. Science of the Total Environment, 702 doi:10.1016/j.scitotenv.2019.134455

Rizzi, M., Rodrigues, F.L., Medeiros, L., Ortega, I., Rodrigues, L., Monteiro, D.S., Kessler, F., Proietti, M.C., 2019. Ingestion of plastic marine litter by sea turtles in southern Brazil: abundance, characteristics and potential selectivity. Mar. Pollut. Bull., 140 (2019), pp. 536-548

Shantha, A.A. and Samarakoon, A., 2019. Cost Benefit Analysis for the National Post Consumer Plastic Waste Management Project.

Sojitz Corporation., n.d. *双日、使用済みプラスチック容器の効率的な回収・リサイクルの実現に向け、川崎市内マンションにて検証プロジェクト『POOL PROJECT KAWASAKI』を開始 | 双日株式会社*. [online] Available at: https://www.sojitz.com/jp/news/2022/02/20220208-02.php [Accessed 27 May 2022].

Tesco PLC. (n.d.). Reuse is the way to unlock the shackles of single use. [online] Available at: https://www.tescoplc.com/news/2022/reuse-is-the-way-to-unlock-the-shackles-of-single-use/ [Accessed 27 May 2022]

UNCTAD. 2021. Material Substitutes to Address Marine Plastic Pollution and Support a Circular Economy: Issues and Options for Policymakers. Geneva: United Nations Environment Management Group, Available online: https://unctad.org/webflyer/material-substitutes-address-marine-plastic-pollution-and-support-circular-economy (accessed on 15 June 2021).

UNEA 5.2., 2022. 5/14. End plastic pollution: towards an international legally binding instrument. Resolution adopted by the United Nations Environment Assembly on 2 March 2022.

UNEP SETAC Life Cycle Initiative, 2015. Guidance on organizational life cycle assessment. United Nations Environment Programme (UNEP).

UNEP, 2014. Marine Plastic Waste and Microplastics Established by Resolution 1/6 (2014), pp. 1-4

UNEP, 2016. Marine Plastic Debris and Microplastics Established by Resolution 2/11 (2016), pp. 1-4

UNEP, 2017. Marine Plastic Debris and Microplastics Established by Resolution 3/7 (2017), pp. 1-4

UNEP, 2019. Marine Plastic Litter and Microplastics Established by Resolution 4/7 (2019), pp. 1-4

UNEP., 2017. Exploring the potential for adopting alternative materials to reduce marine plastic litter. Available at https://www.unenvironment.org/resources/report/exploring-potential-adopting-alternative-materialsreduce-marine-plastic-litter

UNEP-LCI., 2022. Single-Use Plastic Products Studies - Life Cycle Initiative.https://www.lifecycleinitiative.org/activities/key-programme-areas/technical-policy-advice/single-use-plastic-products-studies/

United Nations Environment Programme (2011). Towards a life cycle sustainability assessment: making informed choices on products. https://wedocs.unep.org/20.500.11822/8001.

Wang, J.J., Zheng, L.X., Li, J.H., 2018a. A critical review on the sources and instruments of marine microplastics and prospects on the relevant management in China. Waste Manage. Res., 36 (10) (2018), pp. 898-911.

Wang, J.J., Zheng, L.X., Li, J.H., 2018a. A critical review on the sources and instruments of marine microplastics and prospects on the relevant management in China. Waste Manage. Res., 36 (10) (2018), pp. 898-911

Wang, L., Lin, T., Yan, C., He, W., Wang, J., Tang, Q., 2018b. Effects of different film residue and irrigation quota on nutrient and water use efficiency of cotton under drip irrigation. J. Plant Nutr. Fertitizer, 24 (1) (2018), pp. 122-133

Wang, L., Lin, T., Yan, C., He, W., Wang, J., Tang, Q., 2018b.Effects of different film residue and irrigation quota on nutrient and water use efficiency of cotton under drip irrigation. J. Plant Nutr. Fertitizer, 24 (1) (2018), pp. 122-133

Watson, A., 2021. Addressing the Single Use plastic products pollution using a life cycle approach, United nation Environment Programme, ISBN: 978-92-807-3841-4

Wichai-utcha, N., & Chavalparit, O., 2019. 3Rs Policy and plastic waste management in Thailand. *Journal of Material Cycles and Waste Management*, *21*(1), 10–22. https://doi.org/10.1007/s10163-018-0781-y

Appendix

	Product	Parts	Weight of product (g)	Raw Material	Imported country	Imported distance AVG (km)	Local transportation to factory (km)	Manufacturing Process	Disposal transportation (tkm)		Consumer transportation distance (km)
									Recycling (%)	Landfilling (%)	
1	Cutlery-Fork	N/A	6	Polystyrene (PS)	China, India, UAE	4,726	50	Injection moulding		100	100
	Knife	N/A	6	Polystyrene (PS)	China, India, UAE	4,726	50	Injection moulding		100	100
	Spoon	N/A	4.5	Polystyrene (PS)	China, India, UAE	4,726	50	Injection moulding		100	100
2	Cotton buds with plastic stem	N/A	0.237	Polypropylene (PP)	China, India, UAE	4,726	50	Extrusion		100	100
3	Joss-Stick wrappers	N/A	0.994	Low Density Poly Ethylene (LDPE)	China, India, UAE	4,726	50	Extrusion, Blow moulding		100	100
4	Wrappers for cloth wicks	N/A	0.476	Low Density Poly Ethylene (LDPE)	China, India, UAE	4,726	50	Extrusion		100	100
6	PET/PVC pesticide bottles<= 750ml	Bottle	25.777	High Density Poly Ethylene (HDPE)	China, India, UAE	4,726	50	Blow moulding	62	38	100
		Inne Lid	0.979	Polypropylene (PP)	China, India, UAE	4,726	50	Injection moulding	62	38	100
		Outer lid	5.070	Polypropylene (PP)	China, India, UAE	4,726	50	Injection moulding	62	38	100
7	Grocery bags/shopping bags	N/A	1.233	Low Density Poly Ethylene (LDPE)	China, India, UAE	4,726	50	Extrusion, Blow moulding		100	100
8	Straws	N/A	0.304	Polypropylene (PP)	China, India, UAE	4,726	50	Extrusion		100	100
9	PET bottles	Cap cover	0.213	Polyethylene (PE)	China, India, UAE	4,726	50	Extrusion	62	38	100
		Cap	1.769	High Density Poly Ethylene (HDPE)	China, India, UAE	4,726	50	Injection moulding	62	38	100
		Ring	0.285	High Density Poly Ethylene (HDPE)	China, India, UAE	4,726	50	Injection moulding	62	38	100
		Bottle	25.773	Polyethylene terephthalate (PET)	China, India, UAE	4,726	50	Blow moulding	62	38	100
		Label	1.248	Polyethylene (PE)	China, India, UAE	4,726	50	Extrusion	62	38	100

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