E-waste in the Caribbean: Is there a potential for a circular economy?

by

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AUTHOR'S DECLARATION

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

A total of two scientific journal articles have been produced during this master's project. Therefore, this thesis is built around these two papers, included in chapters 3 and 4. Introduction and conclusion of these papers are contained within Chapters 1 and 4, for the purpose of this research.

Paper I. Electronic waste in the Caribbean: An impending environmental disaster or an opportunity for a circular economy?
Chapter 2 contains material from a paper accepted by the International Journal of Resources, Conservation & Recycling (https://www.journals.elsevier.com/resources-conservation-and-recycling). I am the lead author on this article, joined by co-authors Simron J. Singh and Komal Habib.
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Paper II. How big is circular economy potential on Caribbean islands considering e-waste?
Chapter 3 also contains material from a manuscript submitted to the International Journal of Resources, Conservation & Recycling. I am the lead author on the manuscript, joined by co-authors Simron J. Singh and Komal Habib.

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Abstract

Islands are bounded systems, often plagued with several sustainability challenges of limited land and resource availability, as well as pressing waste management issues. Small island economies import most of their resource needs, which ends up as waste on the island at the end of the life cycle, representing a one-way material flow. Despite these known problems, research aiming to help develop waste management systems for small island nations is scarce, let alone for e-waste. Focusing on five Caribbean island states, this study provides the first comprehensive view of e-waste generation trends in an island context and explores the potential for a circular economy (CE).

This study has two primary objectives: a) to quantify e-waste flows and accumulated stocks on the five Caribbean SIDS and b) to conduct an analysis on the economic value of e-waste being generated and the potential for a circular economy. As part of the first objective, the study estimated Electrical and Electronic Equipment (EEE) flows for the five island cases over a period of 60 years (1965-2025), including e-waste that these flows have and will generate. A dynamic material flow analysis (MFA) is used to estimate these flows and stocks for 206 product types. Then, the quantity of secondary resources within e-waste is estimated that is likely to be generated between 2020 to 2025, using the available data on material composition from the literature.

In the next step, the economic value of the materials embedded in end-of-life (EoL) products is estimated. The results show that the five Caribbean islands produced significantly higher e-waste per capita per year compared to the global average of 6.1 kg/cap/year in 2016. The aggregated amount of e-waste generated per year on these five islands seems to significantly rise in the future: from 27,500 tonnes in 2010 to an estimated amount of 59,000 tonnes in 2025. This considerable estimated e-waste generation rate, when not properly managed, is not only harmful to the local environment, but also translates into considerable health impacts and loss of valuable resources.

In pursuit of the second objective, closing material loops through a CE was considered to limit waste generation as well as reliance on the supply of virgin materials from outside. To test the feasibility of a CE, an analysis of the economics of e-waste on the five islands was conducted. The results reveal that, between 2020 and 2025, more than 317.4 kt of secondary materials could be recovered from EoL products. However, if these islands had started the recovery of resources in early 2001, they could gain approximately \$1,430 million of economic value by the end of 2025. The economic convenience coming from the recovery of the materials embedded into the e-waste is estimated to be more than \$546 million, equivalent to nearly 1% of the annual GDP of all Caribbean Community (CARICOM) countries. Different types of base, precious and rare metals can be recovered from the EoL products including: Fe (106.7 kt), Al (21.6 kt), Cu (16.7 kt), Ag (0.028 kt), Au (0.005 kt), Pd (0.001 kt); as well as plastics (84.9 kt), glasses (14.7 kt) and other materials (72.6 kt). Around 54% of the economic value would come from precious metals (Pd, Au, and Ag). For a shift towards a CE, circularity thinking will need to be embedded in policies that support efficient e-waste management systems. Planned eco-industrial parks for industrial symbiosis and resource flows among the sectors of the economy could be of great benefit. Due to economies of scale that limit smaller nations, regional co-operations would be essential for island nations that are desirous to shift to a CE.

Keywords: E-waste, Material flow analysis, Weibull distribution, Circular economy, Resource recovery, Caribbean islands, Industrial symbiosis

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List of Abbreviations

Ag: Silver

Al: Aluminum

Au: Gold

BCRC: Basel Convention Regional Centre

CARICOM: The Caribbean Community

CE: Circular Economy

Cu: Copper

EEE: Electrical and Electronic Equipment

EoL: End-of-Life

EU: European Union

Fe: Iron

GDP: Gross Domestic Product

HDI: Human Development Index

HS: Harmonised System

IS: Industrial Symbiosis

kt: kiloton

LCA: Life Cycle Assessment

MFA: Material Flow Analysis

Pd: Palladium

PoM: Put-on-Market

SIDS: Small Island Developing States

UN: United Nations

UNU: United Nations University

Chapter 1: Introduction

Electronic waste (e-waste) is one of the emerging problems worldwide and its mismanagement results in serious environmental pollution and human contamination (Silva et al., 2017). Discarding large and growing volumes of electronics can have lasting consequences due to the pollution caused by landfilling and improper recycling (Chen et al., 2015). The e-waste problem is more acute in island nations as the dumping in a limited land area causes pollution of ground and surface water and degradation of coastal and marine resources (Phillips & Thorne, 2013). This is especially the case for Caribbean islands that do not have the recycling facilities or financial capacity to provide e-waste related services or to ship them elsewhere (BCRC, 2016; UNEP, 2019). Therefore, studying the e-waste problem in the Caribbean and providing solutions for a proper management system would be of great benefit for these nations.

The Caribbean is one of the most resource-insecure regions in the world, importing up to 80-90% of their food, energy, manufactured products, and construction materials. Not only is their heavy reliance on goods an acute problem, but also the waste generated at the end-of-life of products is a critical issue. Tourism, new cultures, and new lifestyles influence the consumption patterns in the islands, intensifying the environmental burdens (Shah et al., 2019). Lack of proper disposal facilities, limited land area for enough landfills, and financial constraints to recycle or reexport waste are huge sustainability challenges for the islands (Camilleri-Fenech et al., 2018, Fuldauer et al., 2019). Besides these issues, the Human Development Index (HDI) is relatively high for the Caribbean countries. HDI is a measure of the standard of living, which positively correlates with consumption amounts, and consequently, waste generation rates (Mohee et al., 2015). The average HDI is 0.70 for the Caribbean SIDS, exceeding the HDI for AIMS (Atlantic, Indian Ocean, Mediterranean and South China) and Pacific SIDS (ibid). With the Caribbean region as one of the world's major biodiversity hotspots (UN-OHRLLS 2015), the significance of the e-waste management issue is of major concern.

Policies, regulations, and data on the amount of e-waste are the essential ingredients of proper management in all countries. Data on the quantity of e-waste generation and material composition helps to plan effective management strategies (Zeng et al., 2015). However, merely 20 percent of countries in the world collect statistics on e-waste (Balde et al., 2015) and the Caribbean countries do not have data on the amount of e-waste being generated. Moreover, despite the significant consequences of e-waste mismanagement in the Caribbean (BCRC, 2016), none of the countries have required policies and rules addressing e-waste (BCRC, 2016, Balde et al., 2017). Therefore, there is a substantial need to quantify e-waste in the Caribbean to provide a foundation for a proper e-waste management system and policy formulation.

Applying the approach of circular economy (CE) to Electrical and Electronic Equipment (EEE) is essential, given the growing volumes of these products and the challenges they pose (Ellen MacArthur Foundation, 2015). The 3R concept (Reduce, Reuse, and Recycle), is the most common how-to conceptualization of CE (Kirchherr et al., 2017), and it prioritizes reduce and reuse over recycling due to economic and environmental reasons (Kirchherr et al., 2017; Step Initiative, 2016; Truttmann & Rechberger, 2006). However, recycling is also considered one of the important aspects of CE aiming to reduce the reliance on virgin materials as well as to minimize waste. Mining different kinds of materials for manufacturing short-lived EEE has lasting consequences on our planet (Balde et al., 2015). Moreover, available materials in e-waste and the corresponding revenue they carry highlight the opportunities for the recycling aspect of CE (Parajuly et al., 2017; Cucchiella et al., 2015). There is still little involvement in the recycling industry in islands due to the relatively smaller population and fewer sensitization of the decision-makers on the matter (Kumar et al., 2007). Therefore, e-waste recycling in the Caribbean region is an issue of prime importance, which has been largely ignored, both by the governments and scholars.

This Master thesis research aims at exploring the potentials for a CE for e-waste in the Caribbean, focusing on five island nations: Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago. This study has two interrelated objectives and are dealt with as separate chapters in this thesis:

I. To quantify e-waste flows and accumulated stocks on the five Caribbean SIDS (Chapter 2):

In this chapter, the volume of e-waste flows and stocks is estimated on the five islands from 2001 to 2025. The analysis starts with tracking the trade of EEE published by custom organizations and/or national statistical institutes. Material Flow Analysis is applied to estimate the amount of EEE consumed in these islands. Then, the calculated EEE consumption is modelled using MATLAB software and Weibull distribution function to determine the e-waste amount.

II. To conduct an analysis on the economic value of e-waste being generated and the potential for a circular economy, using the estimates obtained under Objective 1 (Chapter 3):

In this chapter, the amount of recoverable secondary resources from e-waste are estimated on the five island cases, from 2020 to 2025, and the potential for a regional circular economy is explored. Since different kinds of materials are used in each type of EEE, the percentage of the materials within

EEE are identified from related literature. Using the average material market value, the worth of resource composition is quantified. The e-waste amounts are then translated into secondary resources available for recovery and the associated economic potential. Based on the results, the chapter discusses if there is an opportunity for a CE in the region.

1.1 Map and table of characteristics

Figure 1. Map of location of the five Caribbean islands.

Table 1. Characteristics of the five Caribbean islands.

Country	Population[1] (2017)	GDP per capita[1] (2017)	HDI[2] (2017)	Surface area[3] (km^2)
Aruba	105,366	$25,630	0.908*	180
Barbados	286,233	$16,328	0.8	431
Grenada	110,874	$10,164	0.772	345
Jamaica	2,920,853	$5,061	0.732	10,990
Trinidad and Tobago	1,384,072	$16,076	0.784	5,127

1. The World Bank, 2019
2. UNDP, 2018
3. UN data

* The human development index for Aruba last measured in 2009

Chapter 2: Electronic waste in the Caribbean: An impending environmental disaster or an opportunity for a circular economy?

In 2019, approximately 53.6 million metric tonnes (Mt) of electrical and electronic waste (e-waste) was generated globally, however, only 17.4% was recycled properly (Forti et al., 2020). Thus, the majority of the valuable resources consumed in Electrical and Electronic Equipment (EEE) are lost, ending up as e-waste (Schluep et al., 2009). E-waste is defined as any end-of-life (EoL) piece of equipment that depends on electric currents or electromagnetic fields to function properly and includes all components, sub-assemblies and consumables that constituted the product at the time of discarding (The Council of the European Union, 2012). The increasing number of electronic products, the swift evolution of technology, low initialization cost, improved purchasing power, and planned obsolescence are among the main causes for the significant rise in e-waste (Luhar & Luhar, 2019). In 2006, the European Commission reported that e-waste was growing by 3-5% per year in the European Union, around three times faster than solid waste (Savage et al., 2006). A recent UN report still highlights e-waste as one of the fastest-growing solid waste streams in the world, which is estimated to grow from 75 million tonnes in 2030 to 111 million tonnes by 2050 (Parajuly et al., 2019).

E-waste is not only one of the fastest-escalating waste streams in the world with respect to quantity, it is also a significant contributor to toxicity (Chung et al., 2011). Discarding this large and growing quantity of electronics will have lasting consequences on our planet due to the pollution caused by landfilling and artisanal recycling (Chen et al., 2015). Artisanal recycling is an informal recycling method in which manual sorting, dismantling and open burning of e-waste is performed mainly without safety precautions (Ilankoon et al., 2018). Different EEE contain various hazardous materials that are harmful to human health and also to the environment. Huge quantities of e-waste retain toxic substances such as copper, lead, chromium, and cadmium (Kumar et al., 2017); consequently, illegal or improper recycling of e-waste may cause serious health issues. For example, when some e-waste recycling areas in China were studied, approximately 35% to 39% of children living in these areas were found to have above 10 $\mu g\ L^{-1}$ blood lead levels (Wang et al., 2012), which is considered harmful limit by the World Health Organization (World Health Organization, 2010).

Managing this fast-escalating and hazardous waste stream requires data and statistics on the quantities of e-waste being generated. However, merely 20 percent of countries in the world collect international data on e-waste, and only Europe has regular and harmonized statistics. Recently, the

United Nations University (UNU) developed a comprehensive overview of the global e-waste for the year 2016 to help countries establish their e-waste statistics (Balde et al., 2017). A year later, in 2018, UNU published a guideline document of the methodological steps (Forti et al. 2018) to help future researchers to apply the model in their e-waste estimations. The UNU model followed the methodology developed by Wang et al. (2013), who first proposed to use the Weibull distribution and sales-stock-lifespan method for e-waste generation estimation (Islam & Huda, 2019). This method was later applied in other researches, such as the study by Johnson et al. (2018) for Ireland and Parajuly et al. (2017) in Denmark.

Based on the Basel Convention Regional Centre (BCRC) report in 2016, improper e-waste discarding and processing in the Caribbean islands results in a severe decline in environmental quality, causes biodiversity loss, and a decrease in the natural population. Despite this assertion, none of the Caribbean countries have laws and regulations addressing e-waste (BCRC, 2016, Balde et al., 2017). Very few non-governmental stakeholders, like the International Telecommunications Union (ITU) (ECLAC, 2018) and the BCRC (BCRC, 2016) in the Caribbean, have embraced the e-waste challenge and are addressing the related concerns (Riquelme et al., 2016). A report on the e-waste management policy framework was published for Jamaica by Telecommunications Management Group in 2017 (Roldan, 2017), focusing on very few product types. Earlier a study by the BCRC (2016) identified the local stakeholders involved in e-waste management in Suriname. A comprehensive overview of the global e-waste (2016) by UNU contains a very limited number of SIDS, only providing the e-waste amount for the year of 2016. There is still quite limited information on the generated e-waste amount in this region (BCRC, 2016) and there is no holistic overview of the problem and recommended solutions. Therefore, research on e-waste in Small Island Developing States (SIDS) is very scarce.

To address the gap in e-waste evaluation studies for islands and especially for the Caribbean, the e-waste generation amount is estimated in this study, focusing on five island nations: Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago. The main objective of this study is to estimate the EEE Put-on-Market (PoM) amount from 1965 to 2025, and the resulting e-waste flows and stocks on these islands from 2000 to 2025. To gain insights into the drivers behind these trends, the e-waste generation amount over time is correlated with GDP, total population and level of affluence. It is expected that a better understanding of e-waste patterns, types and pressures generated will help reevaluate the appropriateness of existing policies, and asses the necessity for a transformation in legislative and infrastructure requirements.

2.1 The challenge of waste management on small islands

Simply described, islands are landmasses surrounded by water and often characterized as closed and bounded systems. Islands make up 3% of the Earth's land area, harbour 20% of all plant, bird and reptile species. The Caribbean is classified as one of the world's most biodiverse regions (Myers et al., 2000). It provisions about 13,000 species of endemic plants, 469 reptiles, 170 amphibians (UN-OHRLLS, 2015), 148 birds, and 49 mammals (Kairo et al., 2003). A major threat to these hotspots of biodiversity is hazardous waste that is often poorly managed and ends up in terrestrial and marine ecosystems.

Small Island Developing States (SIDS) around the world are struggling with an increasing rate of waste (Mohee et al., 2015), including the 16 SIDS in the Caribbean region. SIDS are a distinct group of 38 UN and 20 Non-UN Member states sharing unique vulnerabilities to social, economic, and environmental issues (UN-OHRLLS, 2015). The average waste generation of SIDS is around 2.30 kg/cap/day (includes waste generated by tourists), which is much higher compared to the global average of 1.55 kg/cap/day (UNEP, 2019b). Shortcomings in the waste collection, transfer, and transport, namely outdated collection vehicles and narrow- inaccessible roads (Mohee et al., 2015), makes it more challenging to manage the high waste generation rate in these islands. Moreover, three out of the world's 50 largest dumpsites are located in SIDS, however the generated waste mainly ends up in marine areas and dumpsites (UNEP, 2019b).

Waste management is a global problem. According to Haas et al. (2015), the planet currently generates 41 Gt of waste annually, which is 66% of total materials entering the economy each year. On a global scale, recycling is very modest, amounting to only 4% of the inflows (ibid). The severity of waste generation and management is much higher in SIDS, given their unique vulnerabilities such as narrow resource-base economies (UN-OHRLLS, 2015) and restricted ability to metabolize the generated waste streams (Shah et al., 2019). These limitations can be also coupled with the restricted geographical, ecological, and social capacity of the island systems (ibid). Focusing on waste-related issues, some documented impacts of waste mismanagement on small islands are damage to the marine and environment, resource loss, increasing greenhouse gas emissions (GHGs), in addition to the continuous nuisances of littering and treatment facilities (Camilleri-Fenech et al., 2018).

Moreover, inadequate waste management in small island states can have severe impacts on human health, atmospheric, terrestrial, freshwater, and coastal environments, as well as having severe effects on different economic sectors such as tourism, fishing and agriculture (UNEP, 2019b).

Different studies have emphasized the constraints causing the mismanagement of the waste in island nations. As described by Eckelman et. al. (2014), islands confront six common obstacles setting up waste management systems: lack of available land and financing resources, vulnerability to extreme weather events, higher operational expenditures, small market sizes, and changing community norms. Fortuitously, rehabilitation of landfills and dumpsites is feasible for island nations, and it has proved successful. One of the examples often quoted as an effective climate-resilient landfill is the Namara site in Fiji (UNEP, 2019b). However, recycling and recovery of materials is challenging in islands due to the lack of available market for recycled resources and the distance from larger markets (Zsigraiová et al., 2009). Moreover, in densely populated and tourist dependent islands, it is challenging to find a suitable location for waste treatment (Agamuthu and Herat, 2014) and landfill sites often exposed to the view of tourists (Eckelman et al., 2014).

The field industrial ecology applied to islands offers several useful practices for tracking and planning of waste management (Eckelman et al. 2014), that can be used by islands. The threats of waste can also be opportunities following a transition from linear to a circular economy to achieve the UN Sustainable Development Goals (UNEP, 2019b). However, from a material stock and flow perspective, only a handful of studies have been conducted on island waste to date: the material, energy and waste flows of tourist sector for Grenada (Telesford 2014; Telesford & Strachan 2017); material flow analysis of waste management in Oahu (Eckelman and Chertow, 2009); and material flow and carbon footprint analysis of municipal waste management in the Maltese (Camilleri-Fenech et al., 2018). Recently a study by Noll et. al. (2019) used a dynamic stock-driven model for different infrastructures and buildings on Samothraki from 1971 to 2016 to provides a systematic view of construction and demolition waste on this island.

2.2 The study area: Five island nations in the Caribbean

Five Caribbean Small Island Developing States (SIDS), namely Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago, were selected for this study. Together, they represent diverse profiles in the region such as size, location spread, economic prosperity, population density, and geography. These five SIDS comprise 11% of the Caribbean population and 7% of the Caribbean land area, while being geographically spread across the Caribbean crescent, from east to the west.

Jamaica and Aruba are the most and least populated countries, among these five island cases, with 2,920,853 and 105,366 residents respectively in 2017 (The World Bank, 2019). Jamaica's land area is around 10,991 km2 whereas Aruba only lies on 180 km2. Barbados has the highest population density, with 665 people per km2, and Jamaica and Trinidad and Tobago are least densely populated, with 270 people per km2. Comparing these countries based on economic and development performances, it is notable that Aruba has the highest GDP per capita of $25,630 (in 2017) and also the highest Human Development Index (HDI) of 0.908, which is last measured in 2009 (Hastings, 2009). On the other hand, in 2017 Jamaica has the lowest HDI of 0.732 between these cases (The World Bank, 2019). In the Caribbean, the service sector that mainly corresponds to tourism, transport, government, and financial sectors has the highest share in national GDP (The world bank, 2019). However, the contribution of these countries to the regional tourism sectors varies. In 2014, Trinidad and Tobago was the main contributor to CARICOM's GDP in service sector with an approximate share of 30%, and Grenada had the lowest share of 1.5% (Regional Statistics Programme Caribbean Community Secretariat, 2016). These economic and demographic differences might influence the EEE consumption pattern of these five countries that will be discussed further.

2.3 Methods and data sources

Currently, the Caribbean lacks any baseline data related to the annual quantity of Electrical and Electronic Equipment (EEE) consumption and the corresponding e-waste amount generated. Therefore, it is crucial to evaluate the past and prospective regional levels of e-waste generation over time.

In order to quantify the current and future e-waste generation on the Caribbean islands, dynamic Material Flow Analysis (MFA) is applied as method, using the Weibull distribution function that is also known as Sales-Stock-Lifespan model (Wang et al., 2013). MFA is a systematic assessment of the material flows and stocks, based on the mass balance principle, within space and time boundaries (Brunner & Rechberger, 2004). This method had been applied in several studies for analysis and evaluation of e-waste management systems formerly (Streicher-Porte et al., 2005; Gurauskiene & Stasiškiene, 2011; Steubing et al., 2010; Habib et al., 2015; Parajuly et al., 2016, 2017). For MFA modeling, static or dynamic approaches can be used for quantifying the e-waste volume. Static MFA model is within a time scale of one year, however dynamic model assesses past, present, and future stocks and flows (Müller et al., 2014). Dynamic MFA is capable of providing a more in-depth understanding of the e-waste system by taking into account the actual EEE sales statistics and then coupling the data with product lifespan distribution (Islam & Huda, 2019). Wang et al. (2013) utilized the Weibull distribution function in dynamic MFA for e-waste estimation in the Netherlands. Thereafter, this method was applied by other researchers for other countries (Balde et al., 2017; Parajuly et al., 2017; Song et al., 2017).

The categorization of e-waste in this study is based on the methodological principles and guidelines set by the Sustainable Cycles (SCYCLE) Programme of the United Nations University (2018) and the study by Forti et al. (2018). The EEE corresponding to 206 Harmonised System (HS) codes as per UN COMTRADE database were first aggregated to 54 product categories to allow using the available lifetime distribution data for these 54 categories. As the next step, these 54 categories were aggregated into 10 main e-waste categories (EU-10) to show the results in clear and consistent manner. The EU-10 classification of e-waste is based on the directive 2012/19/EU of the European Parliament on e-waste (European Union, 2012). These categories include: large household appliances (LHA), small household appliances (SHA), IT and telecommunications equipment (ITE), consumer equipment excluding photovoltaic panels (CE), lighting equipment (LE), electrical and electronic tools (EET), toys, leisure and sports equipment (TLSE), medical devices (MD), monitoring and control instruments (MCE), and automatic dispensers (AD).

2.3.1 Estimating the annual EEE Put-on-Market (PoM)

The amount of EEE products sold to a consumer or Put-on-Market (PoM) is estimated using MFA for 54 EEE types on five island nations from 1965 to 2025. PoM is defined as "any supply of a product for distribution, consumption or use on the market in the course of a commercial activity, whether in return for payment or free of charge" (Forti et al., 2018, p. 37). Intended for these estimations, the trade data for different EEE were retrieved from published import and export statistics (UN COMTRADE, 2019). At the time of this research, the annual trade data had been only published for 2001 to 2017. Two lifetimes have been considered for EEE products to calculate the PoM amount (from 1965 to 2025). The maximum lifespan of a product is considered to be 30 years, within which the probability of all products becoming absolute is approximately more than 98% for the given α and β values. The PoM growth rate for each island has been used to back-cast the historic data for 1965 to 2001. Moreover, to forecast the PoM amount, the EEE market is assumed to be saturated where PoM quantities are expected to remain largely unchanged from 2017 to 2025.

The material flows for islands logically fall into two main categories: (1) imports from other countries, and (2) export or re-export to other nations. UN Comtrade (2019) defined re-export as "exports of foreign goods in the same state as previously imported", and it was mentioned that the re-exports are to be included in the country exports. Therefore, re-exports are taken into consideration in the export statistics. There are no major domestic EEE production, resale, reuse, or official recycling strategies in these islands up to this date. Thus, it is assumed that PoM is approximately equal to the physical trade balance, which is (PoM = Import – Export). The export amount in the same year is deducted from the imports to estimate the amount of PoM that stays in the island for a specific residence time and then reaches its end-of-life.

2.3.2 Calculating annual e-waste generated amounts

The e-waste generation estimation in this study has been conducted based on dynamic MFA model, using the Weibull distribution function. The lifespan profile of the products in this model are defined by the shape (α) and scale (β) parameters. Forti et al. (2018) have made available α and β values for 54 categories of EEE products in different EU countries. Due to the lack of specific product lifespan data in the Caribbean region, the lifetime parameters are obtained from the study by Baldé et al. (2018). The calculated PoM of different EEE categories across their lifespans is modeled by Weibull distribution function using MATLAB software and Microsoft Excel. The Weibull function is widely used to estimate e-waste generation for all EEE product types.

The amount of e-waste generated for each year is calculated using the following equation. The estimated e-waste amount using this model is in tonnes and has been converted into the number of units as well.

$$E\_WASTE_{(y)} = \sum_{n=1}^{206} P_{n(1965)} * f_{n(y-1965)} + P_{n(1966)} * f_{n(y-1966)} + \ldots + P_{n(y-1)} * f_{n(y-1)}$$

Where

$E\_WASTE_{(y)}$ = amount of e-waste generated in year y

n = categories of e-waste according to 206 Harmonized System (HS) codes

$P_{\mathrm{n(y)}}$ = amount of EEE Put-on-Market for category n in year y

f = failure rate using α and β

2.3.3 E-waste generation in number of units

The EEE sales, import and export data are usually provided in the number of units of products. Therefore, the estimated amount of e-waste generation in metric tonnes has been converted into the number of pieces using the weight of 54 EEE categories provided by Forti et al. (2018). Forti's report listed the weight of the 54 product types for EU-28 countries over six different years: 1995, 2000, 2005, 2010, 2015 and 2016. The average weight for each category has been calculated and used in this research assuming that the EEE weights are not significantly different between EU and Caribbean countries.

2.3.4 Data collection

To capture the trade data for EEE, the published import and export statistics are obtained from the United Nations commodity trade statistics database and/or national statistical institutes. Trade data for five islands is retrieved from UN COMTRADE (2019) and for Grenada, the quantities are triangulated with the data received from the statistics department of this island. These EEE trade data are obtainable from 2001 to 2017, while the data for previous and subsequent years is not available. At the time of this study, the data for Aruba and Trinidad and Tobago is available only for 2005 to 2017 and 2001 to 2015. For the years, where the trade data is not available, the PoM growth rate is used to estimate the EEE amount. Moreover, at the time of conducting this research, the trade data for three out of 54 UNU Keys: 0002 (Photovoltaic Panels), 0502 (Compact Fluorescent Lamps), and 0505 (Led Lamps), were not available in UN COMTRADE database and therefore were not included in calculations.

2.3.5 Sensitivity analysis

To test the sensitivity of the results to the assumptions made, sensitivity analysis is conducted to visualize the impact of changing a variable on actual results. An important assumption made in this study is regarding the PoM volume, where the EEE market is assumed to be saturated and expected to remain largely unchanged from 2017 to 2025.To demonstrate the sensitivity of the model to this assumption (saturation assumption of PoM quantity from 2017 to 2025), the annual put-on-market is forecasted for 2017 to 2025 using the PoM growth rate for each island. Then the Weibull function is used again to estimate the e-waste generation, considering the new scenario. Comparing the new e-waste quantification results with the initial results expresses the sensitivity of the model to the market saturation assumption.

2.4 Results

The annual amounts of Put-on-Market (PoM) for Electrical and Electronic Equipment (EEE) under 10 categories have been estimated and provided below for each island from 1965 to 2025. The results have been presented by country, highlighting through each figure the electrical and electronic equipment's PoM (shown in grey areas) and the corresponding e-waste (shown in bars). The trade data is not still available on the UN COMTRADE database for 2018 and later, therefore these estimates are based on the saturation assumption. Here the saturation assumption indicates that PoM will not change significantly from 2017 to 2025. Detailed annual quantities of EEE's PoM and generated e-waste under the 10 categories for each island case is provided in the supplementary material (SM), along with the total distribution of e-waste under different category types.

2.4.1 Aruba

It is estimated that the total electrical and electronic equipment's PoM in Aruba is around 84,856 tonnes over the years of 1965 to 2025. Figure 2 shows an increasing PoM trend from 2000 to 2009 in which the annual put-on-market quadrupled in 2009 in comparison to 2000. Then it fluctuated for 4 years due to two recessions in 2009-10, followed by another recession in 2012. The PoM reached the highest point of 4,492 tonnes in 2014 and declined again in 2015. This fall was due to the financial recession of the country which weighed on the fiscal position (IMF, 2019). The electronic equipment's PoM in the last 9 years (2017- 2025) assumed to remain steady at the level of 3,680 tonnes. Accordingly, the corresponding annual accumulation of e-waste in Aruba ranges from 196 tonnes in 2000 to 3,256 tonnes in 2025. The e-waste generation growth rate on this island is estimated to have an upward trend in upcoming years. This trend will slow down from a growth rate of 24% in 2000 to one of 1.5% in 2025. The quantity of annual e-waste generation is expected to rise from 2,845 tonnes to 3,256 tonnes between 2019 and 2025. Besides, around 36.5 kt of electronics is estimated to remain as in-use stock on these islands by the end of 2025, which will be discarded by the user in future years.

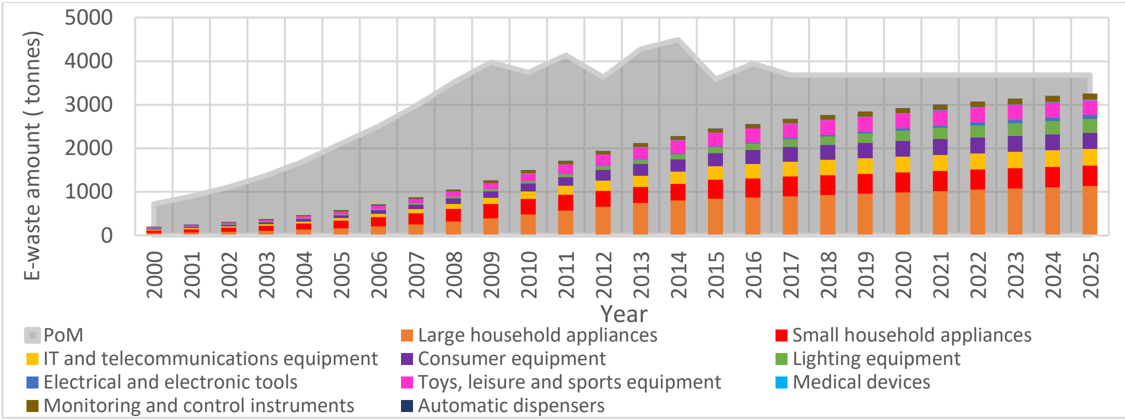


Figure 2. Quantifying electrical and electronic equipment's Put-on-Market (grey area) and the corresponding e-waste (bars) for Aruba from 2000 to 2025.

2.4.2 Barbados

Figure 3 shows the quantity of EEE's PoM and the resultant total e-waste in Barbados from 2000 to 2025. The annual put-on-market amount on this island is raised from 3,824 tonnes in 2000 to 6,467 tonnes in 2016. PoM quantity reached the highest volume of 7,879 tonnes in 2006 and then fluctuated for 10 years. It is assumed that the PoM amount maintains the same level of 6,467 tonnes after 2016 for the next 9 years. The corresponding e-waste generation on this island had a surge at the beginning of the 21st century when it had an annual growth rate of 32%. It is estimated that the yearly e-waste generation on Barbados will increase from 5,341 tonnes in 2019 to 5,780 tonnes in 2025. During this period, the growth rate will have an increasing trend, which is projected to slow down by half to around 1% in 2025. More than 70 kt of in-use stock will remain on this island by the end of 2025.

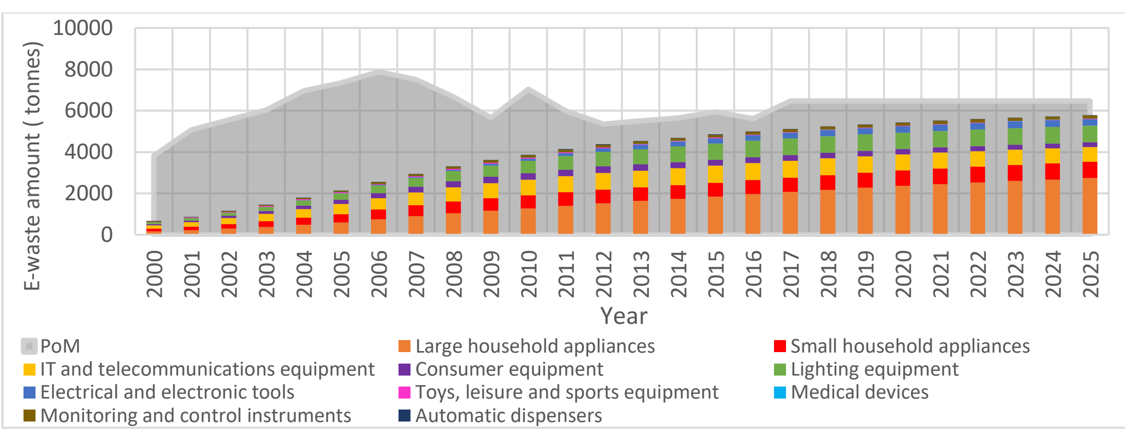


Figure 3. Quantifying electrical and electronic equipment's Put-on-Market (grey area) and the corresponding e-waste (bars) for Barbados from 2000 to 2025.

2.4.3 Grenada

The estimated quantity of total electrical and electronic equipment's PoM in Grenada is about 44,657 tonnes for the years of 1965 to 2025. Figure 4 shows the PoM volumes for each category and the projected corresponding e-waste amount for the period between 2000 and 2025. As shown below, the EEE trade balance or put-on-market dipped in 2005 with a total of 437 tonnes and peaked in 2017 with a total of 2,939 tonnes. The dramatic PoM fall in 2005 was due to Hurricane Ivan, which caused widespread damage in Grenada in 2004 (The World Bank, 2005). The estimations show that the PoM had an upsurge in the beginning of the 20th century, with over 130% annual growth rate. The put-on-market is assumed to stay static at the volume of 2,939 tonnes from 2017 to 2025. These evaluations show that the annual e-waste generation will increase from 18 to 1,909 tonnes during the years of 2000 to 2025. Although the e-waste generation growth rate will slow down from 15% in 2018 to around 6% in 2025, it still will have an upward trend. By the end of 2025, more than 25.5 kt of in-use stock will remain on this island.

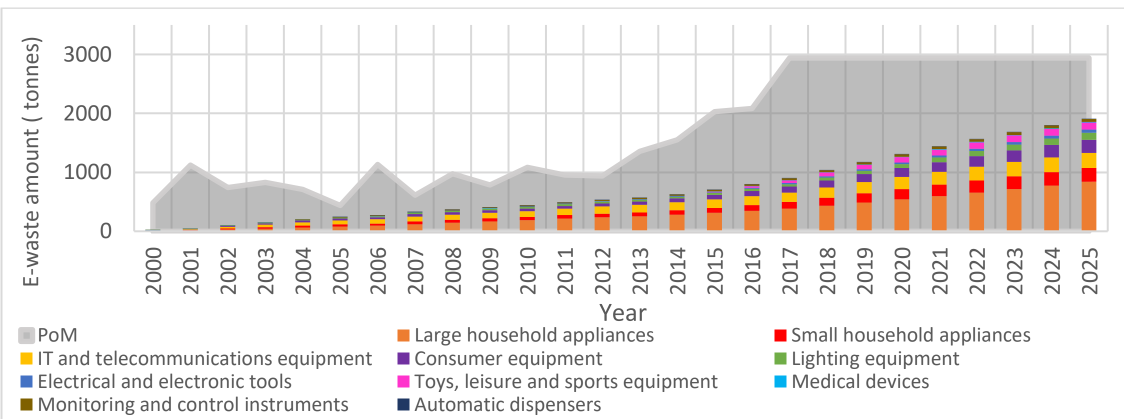


Figure 4. Quantifying electrical and electronic equipment's Put-on-Market (grey area) and the corresponding e-waste (bars) -Grenada - 2000 to 2025.

2.4.4 Jamaica

It is estimated that the total electrical and electronic equipment's consumption in Jamaica is about 507,624 tonnes between 1965 and 2025. Figure 5 shows an increasing trend from 2000 to 2008 when the put-on-market tripled. In 2009 due to the great global recession, the EEE consumption decreased by around 25% from 20,988 tonnes to 15,705 tonnes and it decreased steadily for three years, reaching a low of 14,548 tonnes in 2011. There was a dramatic increase in 2016 and the PoM grew by more than 50% and peaked at 26,885 tonnes. The electrical and electronic equipment's PoM in the last 9 years (from 2016 to 2025) assumed to remain steady. Our evaluations show that the corresponding annual e-waste generation amount increased from 563 to 19,775 tonnes between 2000 and 2025. The e-waste generation growth rate in Jamaica is estimated to slow down from 54% in 2000 to around 3.5% in 2025. While the quantity of waste of Electrical and Electronic Equipment in this island is still going to increase from 14,818 tonnes to 19,775 tonnes between 2019 and 2025. It is estimated that by the end of 2025, around 256 kt of in-use stock will remain on this island.

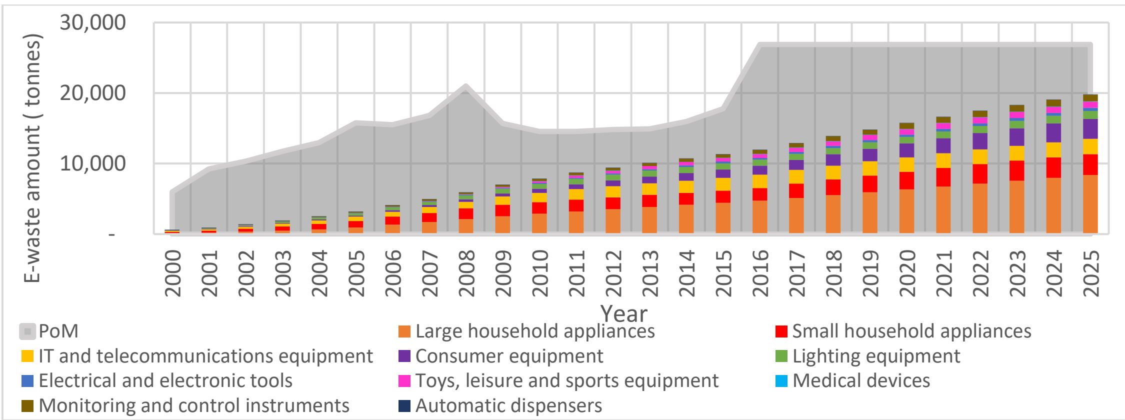


Figure 5. Quantifying electrical and electronic equipment's Put-on-Market (grey area) and the corresponding e-waste (bars) -Jamaica - 2000 to 2025.

2.4.5 Trinidad & Tobago

Figure 6 illustrates the quantity of electrical and electronic equipment's PoM and the corresponding e-waste amount in Trinidad and Tobago from 2000 to 2025. The annual EEE consumption amount on this island nation increases from 9,423 tonnes in 2000 to 29,917 tonnes in 2015. The PoM quantity reached the highest volume of 31,034 tonnes in 2008 and then declined by 25% in the following year and reached 29,917 tonnes in 2015. The trade data for Trinidad and Tobago is only available until 2015, therefore, the EEE's put-on-market amount for the years of 2016 to 2025 is forecasted based on the average PoM growth rate. It is assumed that the PoM amount will maintain the same level of 29,917 tonnes from 2016 to 2025. The commensurate e-waste generation on this island had a surge in the first two years of the 21st century and still has an ascending trend. It is estimated that the yearly e-waste generation on this island will increase from 22,271 tonnes in 2019 to around 26,133 tonnes in 2025. During this period, the e-waste generation rate of growth will still have an upward trend but will be only 1.5% in 2025 compared to 4.5% in 2019. In 2025, the estimated in-use stock on this island will be around 295 kt.

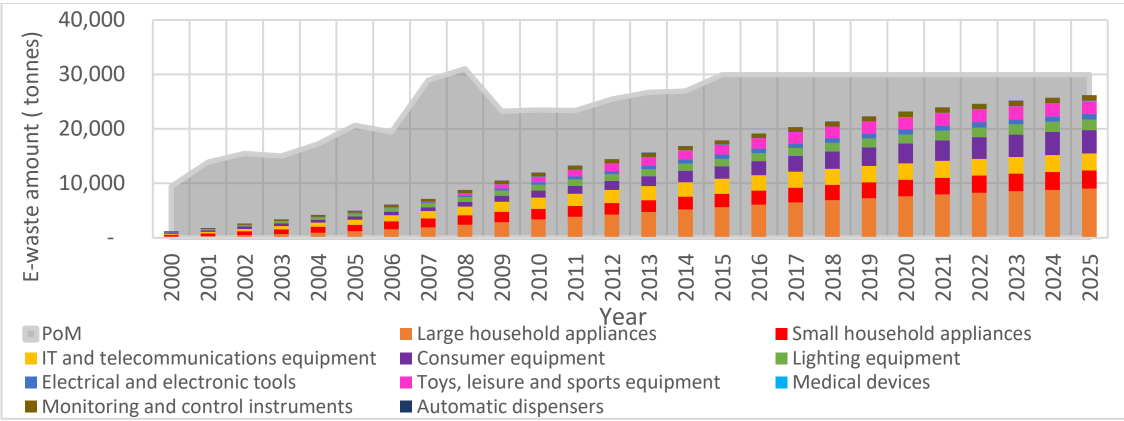


Figure 6. Quantifying electrical and electronic equipment's Put-on-Market (grey area) and the corresponding e-waste (bars) –Trinidad &Tobago - 2000 to 2025.

2.4.6 Results of the sensitivity analysis

The trade data for these islands is mainly available until 2017, and it is assumed that the EEE market can be expected to remain largely unchanged and saturated from 2017 to 2025. As mentioned in section 4.5 to demonstrate the sensitivity of the model to the saturation (plateaued) assumption of PoM, the annual e-waste generation is forecasted for a second time based on the growing trend assumption. Table 2 shows the estimated amount of e-waste using plateaued assumption versus the growing trend assumption, from 2017 to 2025. Considering the plateaued assumption, the estimated e-waste generation will gradually increase and in 2025 it is estimated to only rise by 1% to 6% on these islands. However, replacing the assumption with the growing flow of EEE consumption, the yearly rate of e-waste generation may rise much higher; for instance, in 2025 the rate is estimated to rise by 14%, 16%, 53%, 32% and 29% in Aruba, Barbados, Grenada, Jamaica and Trinidad and Tobago islands respectively. The sensitivity analysis indicates that if the EEE market or PoM continues to expand, the corresponding e-waste amount will rise exponentially in the upcoming years.

Table 2. Comparing the estimated e-waste amount (tonnes) in five Caribbean islands from 2017 to 2025, considering the plateaued assumption versus increasing trend assumption.

Country	Assumption	2017	2018	2019	2020	2021	2022	2023	2024	2025	Total (tonnes)	Difference (tonnes)
Aruba	Saturated	2,671	2,760	2,845	2,926	3,003	3,075	3,141	3,202	3,256	**21,448**	**5,129**
	Increasing trend	2,671	2,760	2,887	3,066	3,306	3,621	4,022	4,526	5,150	**26,577**	
Barbados	Saturated	5,120	5,238	5,330	5,422	5,504	5,579	5,648	5,712	5,772	**38,967**	**10,279**
	Increasing trend	5,120	5,238	5,406	5,677	6,070	6,623	7,377	8,385	9,709	**49,246**	
Grenada	Saturated	901	1,039	1,176	1,310	1,441	1,567	1,687	1,801	1,909	**10,890**	**19,570**
	Increasing trend	901	1,039	1,260	1,620	2,200	3,131	4,613	6,962	10,674	**30,461**	
Jamaica	Saturated	12,905	13,874	14,818	15,732	16,614	17,462	18,273	19,045	19,775	**121,720**	**121,050**
	Increasing trend	12,905	14,357	16,474	19,515	23,820	29,839	38,174	49,635	65,314	**242,769**	
Trinidad & Tobago	Saturated	20,269	21,321	22,271	23,123	23,882	24,555	25,150	25,673	26,133	**170,787**	**202,696**
	Increasing trend	20,836	23,261	26,671	31,413	37,937	46,828	58,859	75,045	96,730	**373,483**	

2.5 Discussion

For a cross country comparison, the cumulative amounts of e-waste generation on these islands and the generated e-waste per capita have been demonstrated. It is estimated that Trinidad and Tobago generates the largest e-waste quantity, whereas Grenada produces the lowest amount. Including the population data, Aruba and Jamaica are the biggest and smallest generators of e-waste per capita respectively. To better understand the e-waste generation pattern, data has been compiled with statistical testing on factors of influence. The hypothesis that relatively faster-growing population countries or more economically progressive islands would have higher e-waste generation rates. GDP per capita (in purchasing power parity [PPP]) has also been included to test for affluence, to see if it is a significant driver of e-waste generation.

2.5.1 Total e-waste generated on the five island nations

Between 2019 and 2025, it is estimated that at least 363 kt of new e-waste will be generated cumulatively in these five islands, bringing the total in-use e-waste stock to 683 kt. Getting rid of the newly generated e-waste (of 363 kt) alone would require a total of 14,600 containers, each 20-ft in size (or 6.6 containers a day) leaving these islands. Considering that this amount is generated by only 11% of the Caribbean population, the total e-waste amount from the region is several times fold. Exporting the e-waste imposes two types of costs to an island's economy: 1) collection, handling and shipping costs and 2) the lost opportunity in terms of revenue and income that could potentially be generated from material recycling. There is yet another cost (in terms of social and environmental externalities) that would be borne by countries receiving this e-waste, in most cases the less developing countries.

The e-waste generation distribution (flow) over the five islands is illustrated in figure 7 for the period of 2019 to 2025. Trinidad and Tobago will have the highest e-waste generation quantity, while the population and available land area of this island country is less than half that of Jamaica. Therefore, it is expected that Trinidad and Tobago will experience higher pressure to deal with the e-waste generation situation. Aruba has the lowest population and land area, but it's e-waste generation potential is estimated to be more than double that of Grenada, with their population size being similar. Considering that the total in-use stock will be more than 683 kt by the end of 2025, that will gradually be discarded, the e-waste situation will remain acute until after 2025.

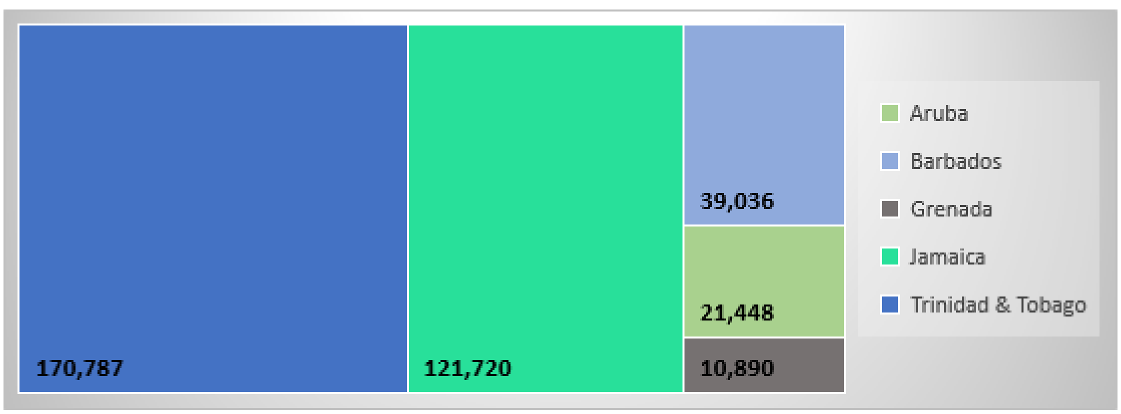


Figure 7. Estimated volume of e-waste generation (in tonnes) in each island from 2019 to 2025.

2.5.2 E-waste generation rate per inhabitant

The generated e-waste per inhabitant quantity helps to make a cross-country comparison between these five islands. Therefore, to calculate the material flux or e-waste per inhabitant, population data were taken into account from the World Bank (2019). The highest e-waste discarding rate (kg/year per cap) is observed in Aruba with 30 kg per capita for 2025. Barbados, Trinidad and Tobago and

Grenada will have 20, 18, and 17 kg e-waste generation per capita in 2025, respectively. Compared to the other four islands, the amount of e-waste per capita is expected to be lowest in Jamaica with 7 kg per person by the end of 2025. Figure 8 reveals that the e-waste discarding rates profoundly differ across these island nations which can be described by different factors such as economic conditions or population growth. The average e-waste generation rate in these five island nations was over 13 kg/cap in 2016, which is more than two times higher than the average global rate (6.1 kg/cap), which has been estimated by Baldé et al. (2017) for the same year.

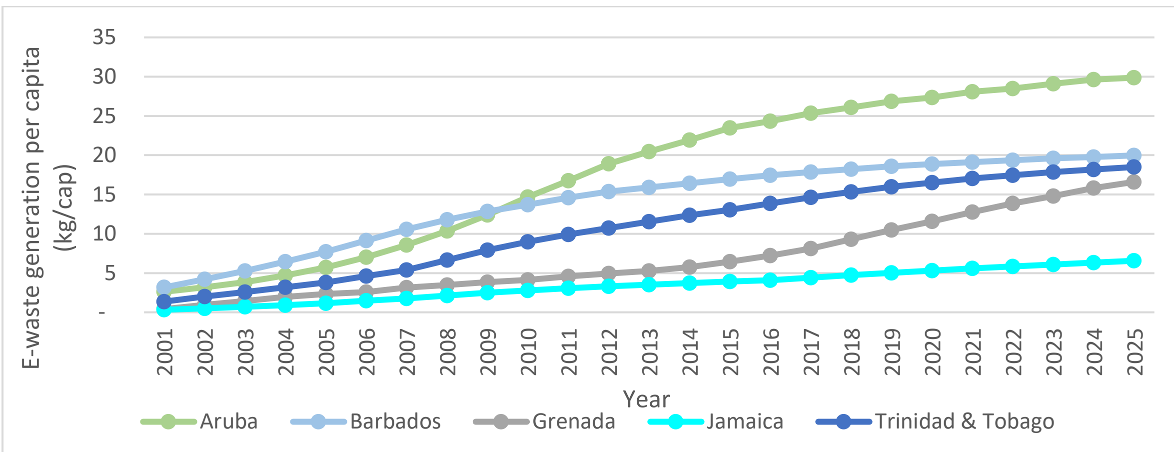


Figure 8. Comparing the e-waste generation per capita amount on the five Caribbean islands from 2001 to 2025.

2.5.3 E-waste, GDP and Population

The difference between the e-waste generation patterns in these islands can be explained by their population size and the level of affluence (using Gross Domestic Product or GDP per capita as a proxy). Correlation coefficients were calculated to test the relationship between e-waste volumes with population and GDP measures (Table 3). To determine the Pearson correlation coefficient, the estimated e-waste data are used along with the GDP and population data from the World Bank database (2019). E-waste generation amount shows a significant correlation with population and GDP in all SIDS. Contrarily to what reported in a study by Kumar et al. (2017), there is a robust relationship between the amount of e-waste generation per capita and population growth. Kumar and colleagues (2017) stated that there is no significant correlation between the population and the e-waste generation amount. Their study considered the population data for different countries in a specific point of time and was not taken the population growth into consideration. Therefore, it is more reasonable to conclude that the e-waste generation amount has a significant correlation with the population growth rate but not substantially with the population size.

Table 3. The correlation coefficient (r) for the relationship between per capita generation of e-waste with the population and the GDP per capita in five SIDS from 2001 to 2017.

Country	r value (Population and e-waste generation per capita)	r value (GDP per capita and e-waste generation per capita)
Aruba	0.888	0.704
Barbados	0.998	0.862
Grenada	0.987	0.971
Jamaica	0.994	0.887
Trinidad and Tobago	0.995	0.760

Figure 9 demonstrates a trend or a pattern of relationship between the GDP and the amount of e-waste generated in these countries from 2000 to 2017 (or 2018 in case actual GDP value is available). The distribution of data around the linear regression line is the lowest for Grenada and demonstrates the limited variability around the regression line (R^2=0.963), while in Aruba, the data are more spread around the fitted regression line (R^2= 0.545). The plot displays that, for most data points, increasing the GPD per capita value causes higher e-waste generation. Therefore, it can be concluded that GDP value is positively linked to the flow of the e-waste in these islands.

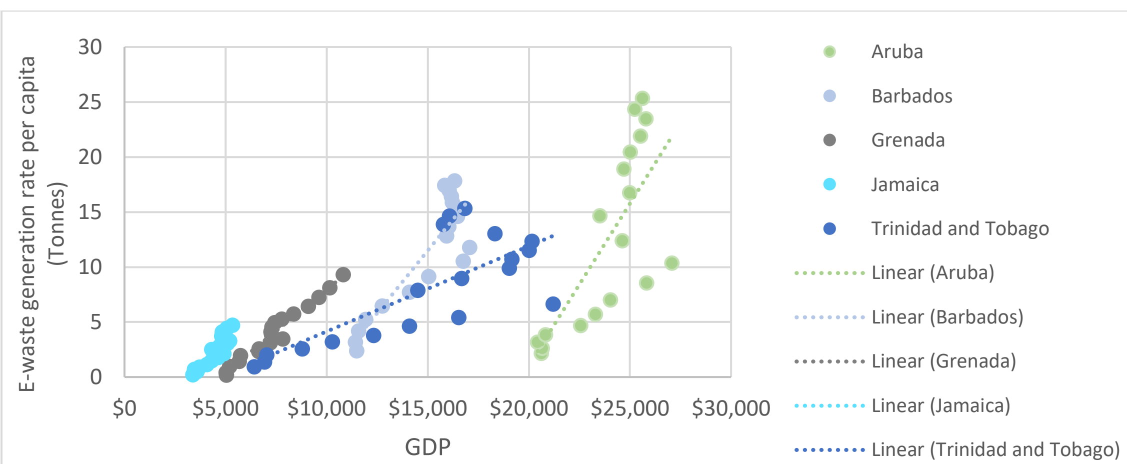


Figure 9. Scatter plot of e-waste generation per capita versus GDP per capita in five Caribbean islands from 2000 to 2017.

A more comprehensive comparison is conducted, that is to look at the effect of GDP per capita and population growth on e-waste generation for each island (Figure 10). The distinguished positive relationship between population growth and e-waste generation rate suggests that slowing down the purchasing power, and the fall in GDP, can decrease e-waste growth rate. The GDP per capita has been peaked in 2008 and then dropped dramatically; this pattern has been the same for all five countries because of the negative influence of the global financial recession in 2008. The key economic indicators in the Caribbean SIDS were affected by the great recession and especially in the countries which were heavily dependent on tourism (ECLAC, 2010). The worst affected countries by this recession were Trinidad and Tobago and Jamaica, with a sharp decline in their GDP (32% and 12%) from 2008 to 2009. This decline took a toll on the average income of the people and caused a falling demand for electrical and electronic equipment. As an example, in Trinidad and Tobago, with the highest fall in GDP, e-waste generation rate was decreased from 23% (2008) to 19% (2009) and then 14% (2010). Other factors, such as environmental disasters and financial institutions, also affected the GDP. For instance, GDP per capita has declined in Trinidad and Tobago from 2014 to 2016 due to the sharp decline in oil and gas prices (Grigoli et al., 2019).

In lower-affluence countries with less GDP or declined GDP, such as Grenada and Jamaica, the slope of the e-waste generation line is considerably steeper. Whereas, the slope of the e-waste generation line is more moderate in higher- affluence countries with consistent GDP value, such as Aruba. A higher standard of living in affluent nations results in producing more e-waste whereas, at the same time, the annual e-waste generation growth rate decreases year by year. Decreasing the e-waste generation growth rate is due to reaching the saturation volume and will only shift if products with new technologies emerge in the market. Besides these factors, specific circumstances of islands may influence the e-waste generation rate or change the strength of the relationships, which needs to be studied further in future studies.

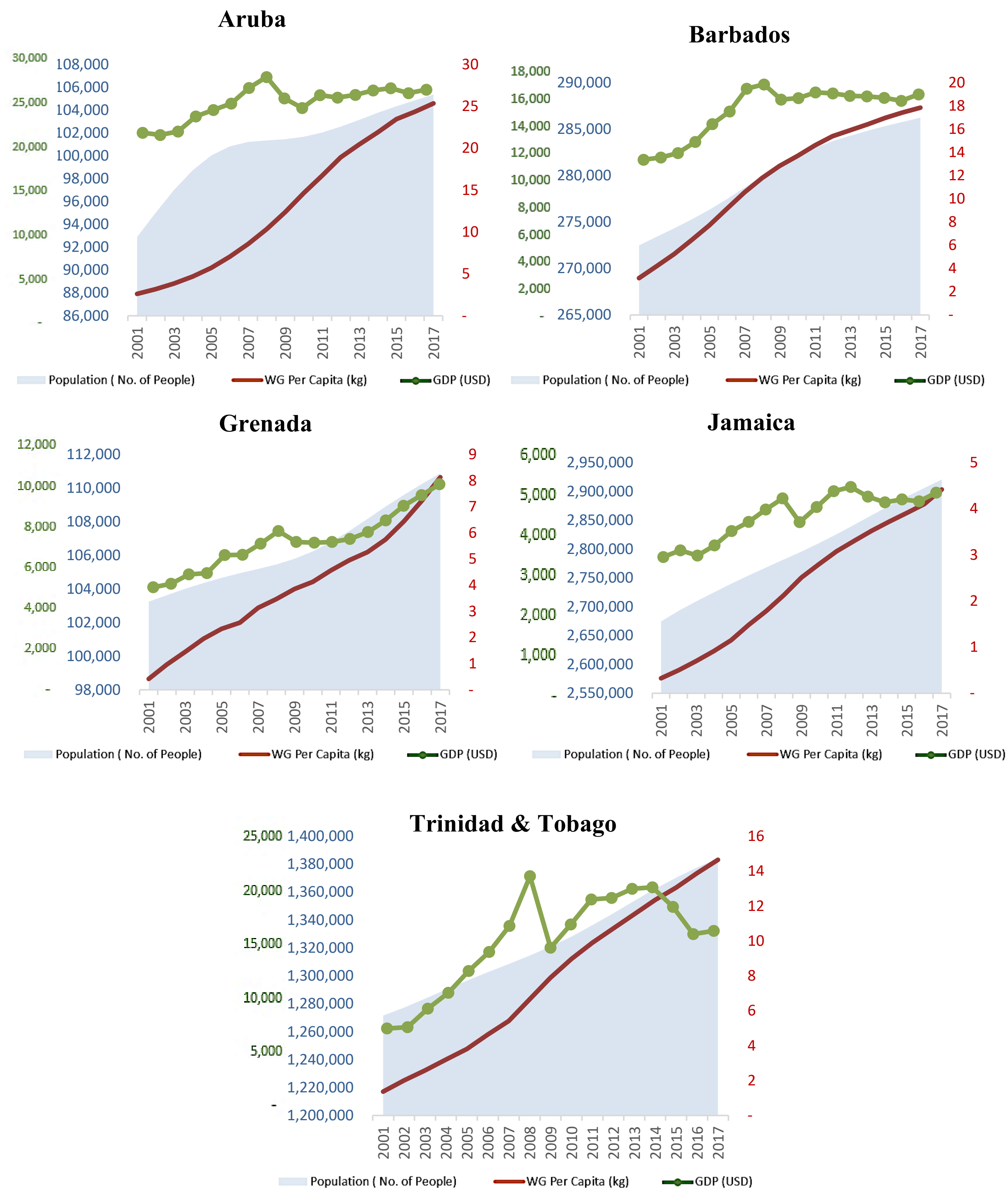


Figure 10. The relationship between GDP per capita (USD) (in green), population (in blue), and generated e-waste (kg) (in red) in each island.

2.5.4 Quantifying e-waste across the ten categories

Recognizing the quantity of each e-waste category is of particular importance for developing e-waste recycling strategies. Therefore, to show the e-waste amount in the number of units, the weight of 54 product categories for six years is retrieved from a report by Forti et al. (2018). Then, the average weight of the years is calculated and used to determine the quantity of e-waste generated in the number of units. Figure 11 determines e-waste distribution at the category level (based on weight) from the date of this study (2019) up to 2025 on five Caribbean islands. The weight of generated e-waste at the large household appliances category level will be the highest, with approximately 38% of the total. The small household appliances and IT and telecommunications equipment categories are the next most cumbersome types, with almost 14% and 13% shares, respectively. Translating estimated e-waste generation volume into the number of units, Figure 12 shows e-waste distribution at each category level from 2019 to 2025. The lighting equipment category has the highest proportion, with around 152 million pieces over the six years. IT and telecommunication equipment has the second main share with around 65 million pieces. Medical devices and automatic dispensers have the lowest share in either of both calculation models. This information will be useful for the identification of the material recovery, and revenue potential assessments intended for the current or future recycling practices.

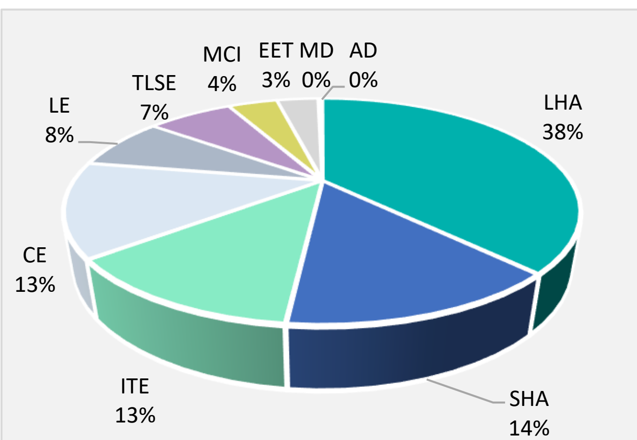


Figure 11. Categorization of the total e-waste generated (based on weight) into ten categories (EU-10) from 2019 to 2025 on five Caribbean islands.

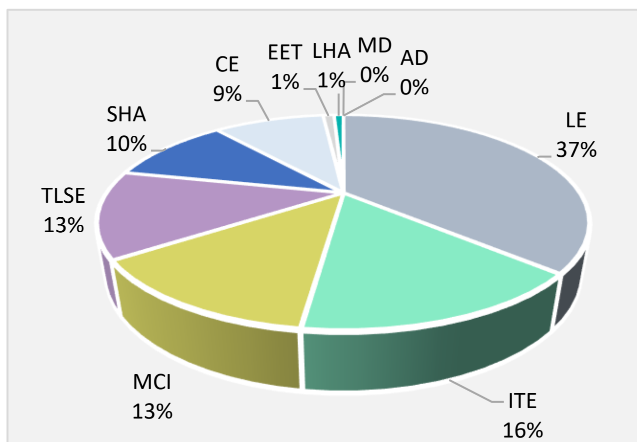


Figure 12. Categorization of the total e-waste generated (based on number of units) into ten categories (EU-10) from 2019 to 2025 on five Caribbean islands.

(Large household appliances (LHA), small household appliances (SHA), IT and telecommunications equipment (ITE), consumer equipment excluding photovoltaic panels (CE), lighting equipment (LE), electrical and electronic tools (EET), toys, leisure and sports equipment (TLSE), medical devices (MD), monitoring and control instruments (MCE), and automatic dispensers(AD))

2.5.5 Plateaued versus growing trend assumption: What does the sensitivity analysis tell us?

The results of the sensitivity analysis emphasize that a higher EEE consumption growth rate yields an exponential increasing effect on the amount of e-waste generated in upcoming years. Considering the plateaued assumption, when the consumption achieves the saturation point, the annual e-waste generation rate gradually declines from 2% - 15% in 2017 to 1% - 6% in 2025. However, the e-waste generation amount sharply increases on these islands using the growing trend assumption; the annual growth rate experiences a dramatic upsurge from 2% - 15% in 2017 to 14% - 53% in 2025. This considerable difference between the results of the two scenarios reveal the need for proper strategies aimed at reducing EEE consumption at source. Reducing the amount of consumption will significantly lead to the reduction of waste generation in upcoming years.

The sensitivity results for Grenada shows the highest difference between the plateaued assumption versus the growing trend assumption. The dashed line displays the slight changing trend concerning the former assumption, while the trend changes with a steeper slope (blue line) in the latter assumption (Figure 13). E-waste generation in Grenada is estimated to rise from 901 tonnes in 2017 to 1,909 tonnes in 2025 if the consumption remains steady over this period. However, assuming the EEE consumption continuously grow by the existing average rate, the e-waste amount will increase sequentially to reach to 10,674 tonnes in 2025. The reason behind this dramatic change in the e-waste generation amount can be explained by the sensitivity of the model to the amount of PoM. In case such substantial increase in consumption occurs, there would be a more crucial need for e-waste management purposes. If the e-waste is not managed properly, it would lead to serious environmental problems in the region. This exponential growth can have wider and more complex repercussions on these islands, due to their limited land and resource availability.

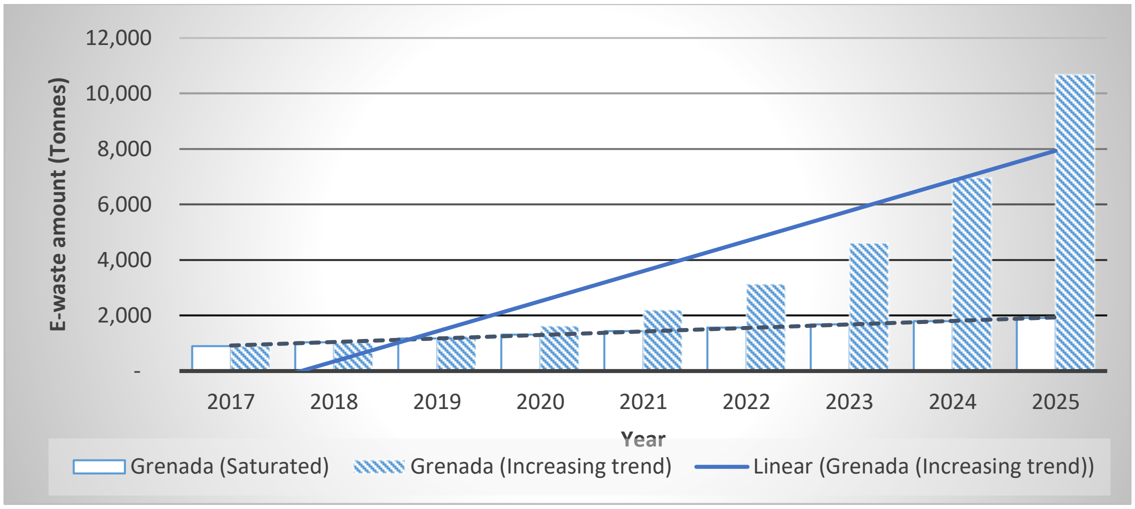


Figure 13. Estimated e-waste amount in Grenada considering plateaued assumption (white bars) versus growing trend amount assumption (diagonal bars) between 2017 and 2025.

2.6 Will e-waste in the Caribbean become an environmental disaster or an opportunity for a circular economy?

By 2025, it is estimated that our five island cases will have an e-waste in-use stock of 683 kt. Considering that this represents only 11% of the Caribbean population, it can be expected that at least 10 times this amount being generated throughout the Caribbean. The presence of harmful substances as copper, lead, chromium and cadmium in the discarded materials not only threatens human health through improper management but is also a source of toxic pollution to the vulnerable (is)land and marine ecosystems. These pressures will likely impact other critical sectors on which islands depend, such as tourism and local food security. The recent generous financing from the World Bank's Global Environment Facility (GEF) to reduce toxic waste and chemicals on island environments already sends signals of alarm on this issue (UNEP, 2019a).

Given that the Caribbean region is a hotspot of biodiversity and highly vulnerable to internal and external shocks, individual governments, national and international organizations need put greater efforts to tackle e-waste challenges. The significant amount of e-waste volume relative to island size as well higher per capita as compared to global averages, suggests that urgent attention is given to proper e-waste management in terms of infrastructure, laws and regulations. The e-waste pressure in more populated and affluent SIDS is higher such as in Trinidad and Tobago, but one would expect that they can afford better waste management systems. Due to several limitations, building partnerships would be a crucial ingredient to the successful end of life management in the region to also help smaller and less affluent islands. Because of significantly high e-waste generation rates on these islands, building environmentally sound e-waste dismantling and recycling facilities should be more feasible on a regional level to achieve economies of scale. Starting these facilities will help to reduce the side effects of illegal or improper recycling of e-waste, and it will be an effective mid-to-long-term strategy to move towards a circular economy (CE).

Decreasing the environmental effects of e-waste, a transition from the current linear take- make-waste economy to CE will be beneficial for these islands. A linear economy is defined as one where resources are extracted, turned into products and after a short lifetime discarded as waste. Whereas, the CE minimizes wastes by closing the loops through recycling, reuse, refurbishment, and remanufacturing (Stahel, 2016). The e-waste management strategy in the region should involve the development of a plan to maximize the reduction of EEE consumption, reusing electronics, and recycling end of life products in an economically viable and environmentally feasible manner. This strategy must consist of a set of guiding principles and action plans for development of policies, financial systems, technologies and skills.

Recycling is a labor- and capital-intensive industry that needs considerable funding and diverse skills for collection, sorting, and processing activities. Despite the financial limitations of SIDS, recycling may provide an economically viable, and ecologically sustainable solution for e-waste management in mid-to-long-term. A profitable regional industry can be developed from recovery of precious and rare metals within e-waste. These islands will require to set up human resource training and development beforehand, expecting the recycling industry to provide different job opportunities in future. The potential for a CE in the Caribbean is the subject of our next chapter assessing the economic feasibility of recycling rare and precious materials from e-waste.

To transition to a more sustainable e-waste management systems, robust data and information systems need to be created by national governments. There is a lack of clarity among different stakeholders on their role and format of reporting data. To keep track of the resource flows more precisely and transparently, harmonization of data sources and reporting method is crucial. Apparent documentation and categorization of the data on EEE sales and consumption, e-waste generation volume, import and export of used EEE and e-waste flows, will help to set the targets and to improve the overall planning and resource recovery from e-waste. Manufacturers and companies should also be encouraged to launch take-back programs to reduce the amount of discarded EEE dumped into the landfills. Moreover, different stakeholders need to take the initiative to increase local community awareness on the issue of e-waste. Effective behavioral change through public awareness about e-waste is of crucial importance. Considering all these aspects, establishing proper e-waste management systems will have a significant impact on decreasing environmental and subsequent public health burdens in long term.

This article is an attempt to offer the first comprehensive estimates on the electronic and electric products' Put-on-Market (PoM), and the resulting e-waste generated in five Caribbean nations. While more reliable data on the PoM amount and lifetime parameters of electronic products may help refine some of our estimates, we believe that this would not change our overall conclusion and concern around e-waste on small islands. Nonetheless, these gaps provide future research opportunities for conducting regional projects to gather more information and establish a harmonized database addressing these needs. Measuring lifetime parameters and the actual PoM amounts not only for these five island cases but for all Caribbean nations will serve to highlight the importance in establishing a robust regional e-waste management system, and a catalyst for a CE.

Chapter 3: How big is circular economy potential on Caribbean islands considering e-waste?

The development and widespread use of Electrical and Electronic Equipment (EEE) have enabled technological, social, educational, and communicational advances; however, they have also raised new sustainability challenges. Several impacts occur over the entire lifecycle of electronic products, such as resource depletion, human toxicity, and pollution risks (Kohler & Erdmann, 2004; Song et al., 2012; Biganzoli et al., 2017). Extraction and primary production of metals usually require considerable energy (Oguchi et al., 2011) and lead to significant upstream emissions (Dutta et al., 2016). Electronics are composed of a mix of materials, mainly plastics and common metals (Nowakowski & Mrówczyńska, 2018), as well as precious and rare earth elements (Cucchiella et al., 2015; Oguchi et al., 2011; Tansel, 2017). The geopolitical distribution of natural resources, such as the rare elements, used in different EEE raises concerns about scarcity, supply disruption or increasing price of these materials (Habib, 2015). Moreover, electronics may contain hazardous materials like lead and mercury, which can cause harmful environmental and health impacts at products' end-of-life (EoL) (Chen et al., 2011; Kiddee et al., 2013). The swift evolution of technology and planned obsolescence are amongst the main causes for the significant rise in material consumption in the EEE industries, as well as the escalation of corresponding e-waste generation (Bakker et al., 2014; Luhar & Luhar, 2019).

Waste management is a significant challenge in Small Island Developing States (SIDS) (Fuldauer et al., 2019). Several studies of different geographic locations have addressed the waste problem on islands (Noll et al., 2019; Shah et al., 2019; Fuldauer et al., 2019; Camilleri-Fenech et al., 2018; Mohee et al., 2015; Telesford 2020; Saito, 2013; Eckelman & Chertow, 2009; Skordilis, 2004). Since sustainability challenges are often more immediate in islands than other landmasses (Deschenes & Chertow, 2004), waste mismanagement issues can be more intense and develop more rapidly for these nations. Boundedness, isolation from markets, limited land area, and higher costs of infrastructure are some of the main characteristics that restrict sustainable development in many SIDS (Deschenes and Chertow, 2004; Eckelman & Chertow, 2009; Briguglio, 1995; Eckelman et al., 2013, 2014; UNEP, 2008; IPCC, 2014). In addition to these characteristics, limitations in recycling and resale opportunities, lack of policies, and barriers to exporting waste to other countries are some of the challenges confronting SIDS (Camilleri-Fenech et al., 2018, Fuldauer et al., 2019). These characteristics and challenges exacerbate the rising problem of e-waste management for these nations, thereby prompting calls for innovative solutions (UNEP, 2019). Despite the importance of e-waste management, none of the existing studies have addressed the issue on islands.

The lack of effective waste management systems on most SIDS, and by extension, the availability of reliable data, restricts meaningful planning and sustainable action (Simpson, 2012; Eckelman et al. 2014). To address the data gap for proper e-waste management in the Caribbean, the previous chapter provided the first comprehensive estimates of e-waste quantities in five SIDS. The results of the study highlighted the importance of e-waste management for these islands. The average estimated e-waste generation rate in the five studied islands was over 13 kg/cap in 2016, twice higher than the average global rate (i.e. 6.1 kg/cap) estimated for the same year (Baldé et al., 2017).

This chapter aims to estimate the amount of recoverable secondary resources from e-waste, and their economic value, for these five island cases, from 2020 to 2025. Based on the data from the literature, the amount of secondary resources available for recycling is estimated using the material composition of different EEE categories. Next, the economic value of embedded materials is calculated on the basis of material composition at the category level and the average market price of each material. Identifying the material composition of the e-waste and the associated resale values, the potential for sustainability practices to promote a circular economy (CE) will be articulated. This chapter will provide the first SIDS-specific perspective to assist decision-makers in managing e-waste flows, integrating regional participatory CE implementation strategies. The recommended solutions are sufficiently generic and flexible to be adapted in another SIDS.

To perform the present study, five Caribbean SIDS are selected: Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago. Together these cases represent around 11% of the Caribbean population, 7% of the land area, and exhibit diverse portfolios such as human and economic development, key economic sectors, and geographical spread in the Caribbean Sea (The World Bank, 2019). According to the previous estimations (chapter 2), among these islands, Aruba has the highest e-waste generation rate per capita of 26 kg/cap, followed by Barbados (18.2 kg/cap), Trinidad and Tobago (15.3 kg/cap), Grenada (9.3 kg/cap), and Jamaica (4.7 kg/cap). From 2020 to 2025, the estimated volume of generated e-waste would around 148.5 (kt) in Trinidad and Tobago, 106.9 (kt) in Jamaica, 33.6 (kt) in Barbados, 18.6 (kt) in Aruba, and 9.7 (kt) in Grenada. The significant amount of e-waste on these small islands would result in different impacts on ecosystems and the economy, depending on the way of treatment.

3.1 Recent developments with respect to e-waste and circular economy

Circular economy (CE) is seen as an effective strategy to promote sustainable development. There is no single definition of the CE concept (Kirchherr et al., 2017) or no clear indication of when and who initiated it (Winans et al., 2017). It has been mentioned that the primary school of thoughts referring to ‘closed loops’ and ‘cradle to cradle’; were used as early as 1976 by Walter Stahel (Stahel, 1981; Preston, 2012; EMF, 2015). A widely cited definition is from Ellen MacArthur Foundation (2016) where CE is conceived as a restorative or regenerative system, which aims to maintain products and their materials and components at their highest efficiency and value at all times, while “distinguishing between technical and biological cycles”. While the goal of CE is on achieving sustainability on a system level, existing CE research and practice is mostly at the level of products and eco-industrial parks to minimize raw material intake, design eco-friendly goods that are easy to dismantle and reuse, utilize recyclable materials in products, lengthen the lifecycle of products through repair, and recycling or recovery of waste (Van Buren et al., 2016). In other words, the CE concept has been highly considered by scholars and practitioners at micro-system level, usually considering products and individual enterprises (Sauve et al. 2016; Kirchherr et al., 2017).

The strong applicability of CE has been highlighted for electronic goods given their increasing volumes (e.g., EMF, 2013, 2015, 2016; Nowakowski & Mrówczyńska, 2018; Ongondo et al., 2010) and the importance of critical and precious materials exist in e-waste (e.g., Chancerel et al. 2009; Coughlan et al., 2018). The necessity for the transformation of EEE through the CE has been emphasized, to minimize resource consumption, and to prolong product lifespan through reuse, repair, and remanufacturing (e.g. Bakker et al., 2014; Reike et al., 2018; Zlamparet et al., 2017). The recovery of secondary raw materials from EoL Electrical and Electronic Equipment (EEE) has become of high interest (Cossu and Williams, 2015); however, attempts for reduction of e-waste volumes, repair, and reuse of EEE has been limited globally (Forti et al., 2020).

The Global E-waste Monitor in 2020 has discussed the e-waste challenge and elaborated solutions for creating a CE, emphasizing global e-waste collection and recycling (Forti et al., 2020). Few studies have assessed the e-waste sector from a CE perspective in different countries, evaluating the material composition and potential revenues. These studies have aimed to help the optimization of the EoL products’ collection for a CE. For instance, a study by Cesaro et al. (2018) has assessed the elemental composition of e-waste and has overviewed the e-waste management systems in some EU and non-EU countries. Another study in Denmark has mapped the EEE flows and examined the economic viability of prioritizing reuse (Angouria et al., 2018). Parajuly and Wenzel (2017) have also investigated the potential for a CE of e-waste in Denmark and identified the potential revenues from reuse and recycling of the EoL electronics. The study by Islam & Huda (2019) and Cucchiella et al. (2015) have also evaluated the material composition and economic value of e-waste for different products in non-island nations. Despite the potential benefits of the CE in e-waste management that have been recognized in the previous studies, relevant studies remain limited in the macro-level, specifically for the island nations.

3.2 Methodology

In this chapter, the amount of recoverable materials and their economic value will be estimated for five Caribbean islands. Then, the potential for recycling and other aspects of CE (reduce and reuse) will be discussed based on the interview findings. The method consists of three steps: first, estimate the quantity of secondary resources available for recycling from 2020 to 2025. The estimated values demonstrate the potential amount of the secondary materials which would be available for recycling on these islands in the upcoming years. Second, estimate the potential economic value carried by the secondary resources, considering the current market values. Third, conduct semi-structured interviews with professionals in solid waste management in these five islands to gain further knowledge of current policies, practices, and probable challenges of e-waste management. Finally, three sensitivity analyses are performed to examine the uncertainty.

The material composition and economic assessment covers all Electrical and Electronic Equipment (EEE) types: 1) temperature exchange equipment, 2) screens and monitors, 3) lamps, 4) large equipment, 5) small equipment, and 6) small IT and telecommunication equipment. The amounts of e-waste generation were estimated in the previous chapter for five island cases, and this section is built upon the e-waste generation amounts from 2020 to 2025. Based on the interview findings, it is assumed that no e-waste stock is available on these islands for recovery from previous years up to 2020. Any e-waste generated prior to that had been mainly dumped into the landfills. Subsequently, this assumption will be tested using three sensitivity analyses to evaluate what could happen in alternative contexts, where stocked e-waste could be recovered.

3.2.1 Quantifying e-waste material composition

The estimated e-waste generation amounts in the previous chapter were classified based on EU-10 categories, which are first converted to EU-6 categories for the purpose of our analysis. This categorization would help compare the results with other studies conducted in several countries based on the European Union guidelines. Then, the amount of secondary resources available for recycling in each e-waste category was estimated using the average material composition, retrieved from Magalini et al. (2015). The quantity of secondary materials within EoL EEE is estimated for five resource types: base metals (Aluminum (Al), Copper (Cu), Iron (Fe)), precious metals (Silver (Ag), Gold (Au), Palladium (Pd)), plastics, glass, and other materials. The availability of secondary materials from each e-waste category in a given year is calculated using the following equation:

$$M_{j\,(t)} = \sum_{i=1}^{6} E_{i\,(t)} \, . \, C_{ij}$$

$M_{j\,(t)}$= *The total secondary material resource "j" available in e- waste in the year t*
$E_{i\,(t)}$= *The e-waste amount of the "i" category in the year "t"*
C_{ij}= *The composition of secondary material resource "j" in the "i" e-waste category*

3.2.2 Economic Value of Embedded Materials

The economic value of recyclable resources within e-waste can be represented using the amount of embedded materials and related market prices. Market prices are consistently changing, and it is not possible to consider a fixed value for each material type. Therefore, the historical trend of prices has been retrieved for 2019 from dedicated websites (the London Metal Exchange and Comext). Still, the latest reliable prices for plastics and glass are only available for 2018. The average yearly prices of embedded materials of different grades are calculated using the historical data demonstrated in Table 4. The highest average market value is related to palladium, whereas glass has the lowest value. The economic value for the category of 'other materials' is not evaluated in this step, as this category contains very different material types and identifying the quantity and market value of these materials is not feasible at the time of this study.

In the previous step, the mass content of secondary materials (base metals, precious metals, plastics, glass, and other materials) was estimated for each e-waste category (EU-6). In this step, the accumulated materials' amount of similar product categories is calculated for the period of 2020 to 2025, for each island. Then, the materials' amount is multiplied by the average unit price of embedded materials to identify the total material value per tonne for each product category. The economic value of each product category (P) is calculated using the below equation, considering the mass content (weight) of the category multiplied by the unit price of the primary material (USD/t):

$$P = \sum_{i=1}^{n} p_i \,.\, M_i$$

P = The total material value per tonne for each product category (USD/t)
M_i = The weight of the material "i" in the product category in tonnes
p_i = The unit price of primary material "i" (USD/t)
n = The total number of materials in a product category

Table 4. The average market values of the embedded materials within e-waste.

MATERIAL	AVERAGE ANNUAL MARKET VALUE (USD/T)	YEAR
IRON (FE)	275	2019
COPPER (CU)	5,308	2019
ALUMINUM (AL)	1,504	2019
SILVER (AG)	557,660	2019
GOLD (AU)	48,290,385	2019
PALLADIUM (PD)	61,729,387	2019
PLASTICS	1,200	2018
GLASS	50	2018

3.2.3 Interviews

A series of remote expert interviews were undertaken with academics and professionals in the solid waste management sector in five islands to understand how reduce, reuse, and recycling of EEE are nationally facilitated. The information obtained from these interviews would help better understand the current situation in islands and provide practical recommendations for developing proper e-waste management systems. Interviewees were selected based on their expertise, ensuring that they had high enough levels of knowledge and experience to provide information about the current CE and e-waste management strategies in their countries. All interviewees had at least three years of experience in the solid waste sector as an academic, e-waste broker, or manager in waste management companies or non-governmental organizations (NGOs).

Eight semi-structured interviews were conducted, and a set of seven open-ended questions were used for each interview. The initial questions posed to them allowed the interviewees to lead the discussions around the CE of e-waste on each island, providing them with the flexibility to share information they considered relevant. The key questions were; 1) Are there any national e-waste management policies in place?; 2) Are people aware of their role in the CE practices (focusing on e-waste)?; 3) Are any companies or organizations operating in the e-waste dismantling sector?; 4) What are the major e-waste recycling activities?; 5) What are the major e-waste reduce and reuse activities in the island?; 6) Is there any co-operation with other countries for recycling operations?; and 7) Are there any significant difficulties in implementing a CE approach on the island (focusing on e-waste)? The results of the interviews were organized around the core questions. Further details provided by interviewees about the existing e-waste management systems are elaborated in the discussion section to offer recommendations to the small islands.

3.2.4 Sensitivity analysis

In the sensitivity analysis, three other possible scenarios have been considered and analyzed. Due to the lack of proper e-waste management on these islands, it was assumed that people might have kept at least part of their EoL EEE. For the small IT and telecommunication equipment category, the retained amount could be much higher as people tend to keep old devices for a longer time. Thus, to test the sensitivity of our model to other probable scenarios, the analysis has been repeated by a) adding the 20% hoarded e-waste comprising all categories from 2001 to 2019, b) adding the 50% retained e-waste for Small IT and Telecommunication Equipment category and 20% hoarded e-waste for the other five categories. Finally, the third sensitivity analysis was performed considering 100% of the e-waste generated on these islands, from 2001 to 2019, available for materials recovery. This comparison helped demonstrate approximately how much resources these nations have lost by neglecting the recovery of secondary resources from EoL EEE.

3.3 Results

The material composition and quantities of secondary materials are demonstrated for each island, for all six EEE categories: 1) temperature exchange equipment, 2) screens and monitors, 3) lamps, 4) large equipment, 5) small equipment, and 6) small IT and telecommunication equipment. The potential economic value of embedded materials is also specified and current practices, challenges, and implications of a CE are explained based on the information obtained during interviews.

3.3.1 Material composition

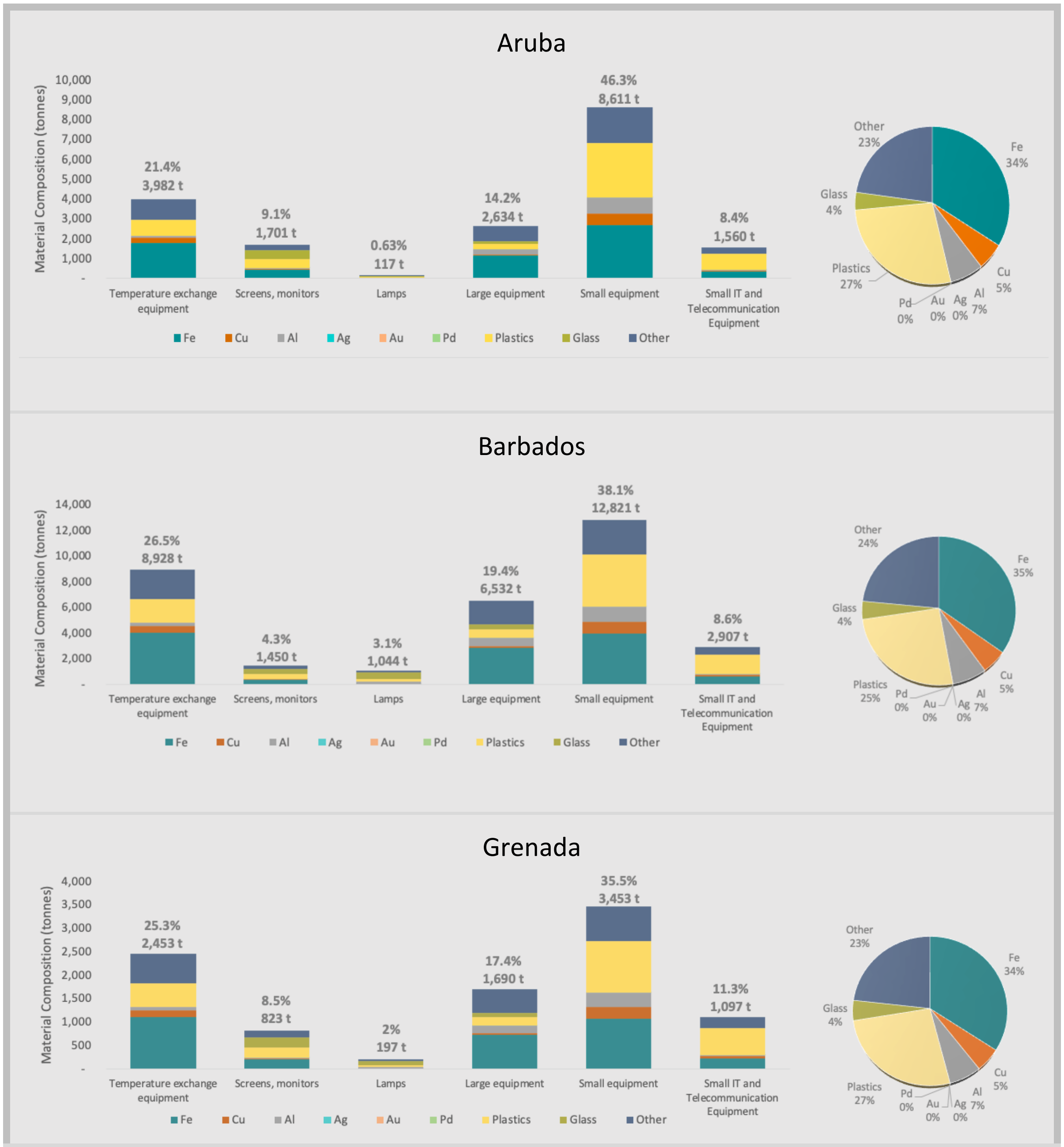
The material composition of EoL EEE in our five cases is shown in Figure 14 for the period 2020 to 2025. The total quantity of recoverable materials from e-waste in these islands is around: 148.5 kt for Trinidad and Tobago, 106.9 kt for Jamaica, 33.6 kt for Barbados, 18.6 kt for Aruba, and 9.7 kt for Grenada. The distribution of secondary resources embedded in different product types follows mostly the same pattern in all island cases. The small equipment is the largest category, comprising 35.5% to

46.3% of the total materials. For Aruba, the small equipment category (46.3%) contributes the largest share of the total, while for Grenada (35.5%) this category contributes the lowest compared to other islands. The small equipment category is mostly comprised of plastics (32%) and Fe (31%), while the glass amount is estimated to be around zero. The quantity of Ag and Au in this category would be approximately 0.007 (kt) and 0.001 (kt).

The temperature exchange equipment makes up the second largest category, including 18.6% to 26.5% of secondary resources. The share of the aggregated material composition of temperature exchange equipment category is 26.5% for Barbados and is 18.6% for Trinidad and Tobago. The temperature exchange equipment is mostly composed of Fe (31.8 kt) and plastics (14.1 kt) and does not embed any quantity of precious metals and glass. The third largest category is large equipment, comprising 14.2% to 19.4% of the total. The share of recoverable materials from large equipment in total is largest for Barbados (19.4%), while it is the lowest for Aruba (14.2%). This category mainly contains Fe (21.3 kt), Al (4.9 kt), and plastics (4.9 kt). Around 0.011 kt of Ag can also be recovered from this product category in the five islands.

The next category is the small IT and telecommunication equipment, in which the share of recoverable materials in total is highest for Grenada (11.3%) and lowest for Aruba (8.4%). The major recoverable components from this category (considering the weight) are plastics (15.5 kt) and Fe (6 kt). Based on our estimations, around 0.008 (kt) of Ag, 0.002 (kt) of Au, and 0.001 (kt) of Pd can be recovered from this category. The screens and monitors category comprises 4.3% to 9.9% of the secondary resources. The share of the accumulated material composition of this category in total amount is largest for Trinidad and Tobago (9.9%) and is the smallest for Barbados (4.3%). Plastics (7.4 kt) and Fe (6.8 kt) are the heaviest components of this category. Besides, approximately 0.002 (kt) of Ag, 0.0009 (kt) of Au, and 0.0003 (kt) of Pd can be recovered from this product category. Lamps constitute the lowest share of embedded materials, with the highest amount in Barbados (3.1%) and the lowest in Aruba (0.63%). Glass is the heaviest material (4 kt) contained in this category, followed by Al (1.3 kt), and plastics (1.2 kt).

Overall, Fe and plastics are the weightiest materials contained in different types of EEE, whereas precious metals (Ag, Au, and Pd) are the lightest embedded materials. The majority of precious metals are concentrated in small IT and telecommunication equipment, small equipment, and screens and monitors.


Aruba
Material Composition (tonnes)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
-
21.4%
3,982 t
9.1%
1,701 t
0.63%
117 t
14.2%
2,634 t
46.3%
8,611 t
8.4%
1,560 t
Temperature exchange equipment
Screens, monitors
Lamps
Large equipment
Small equipment
Small IT and Telecommunication Equipment
Fe
Cu
Al
Ag
Au
Pd
Plastics
Glass
Other
Other 23%
Fe 34%
Glass 4%
Plastics 27%
Cu 5%
Al 7%
Pd 0%
Au 0%
Ag 0%
Barbados
Material Composition (tonnes)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
26.5%
8,928 t
4.3%
1,450 t
3.1%
1,044 t
19.4%
6,532 t
38.1%
12,821 t
8.6%
2,907 t
Temperature exchange equipment
Screens, monitors
Lamps
Large equipment
Small equipment
Small IT and Telecommunication Equipment
Fe
Cu
Al
Ag
Au
Pd
Plastics
Glass
Other
Other 24%
Fe 35%
Glass 4%
Plastics 25%
Cu 5%
Al 7%
Pd 0%
Au 0%
Ag 0%
Grenada
Material Composition (tonnes)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
25.3%
2,453 t
8.5%
823 t
2%
197 t
17.4%
1,690 t
35.5%
3,453 t
11.3%
1,097 t
Temperature exchange equipment
Screens, monitors
Lamps
Large equipment
Small equipment
Small IT and Telecommunication Equipment
Fe
Cu
Al
Ag
Au
Pd
Plastics
Glass
Other
Other 23%
Fe 34%
Glass 4%
Plastics 27%
Cu 5%
Al 7%
Pd 0%
Au 0%
Ag 0%

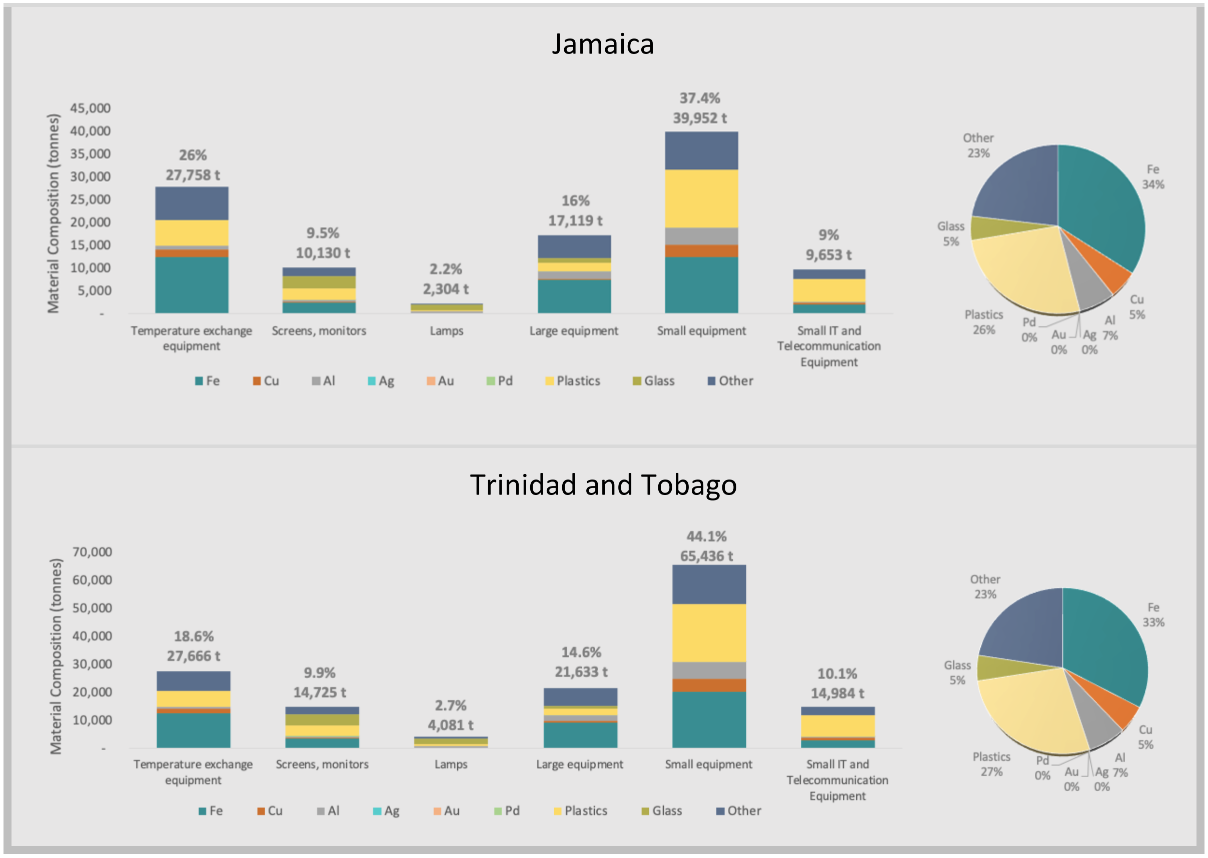


Figure 14. Material composition of generated e-waste in each island from 2020 to 2025.

3.3.2 Potential economic value

The estimated economic value of different secondary materials embedded in the six categories of e-waste is presented in Figure 15, for 2020 to 2025. The total economic value of the recoverable secondary resources is more than \$546 million, and around 40% of this value would come from Au. The main economic values are associated with the recovery of Au (40%), plastic (19%), and Cu (16%). Au is mainly contained in small IT and telecommunication equipment (2 tonnes), small equipment (0.0013 kt), and screens and monitors (0.0009 kt). Plastics are contained in all categories (10% to 51%), while mostly embedded in small equipment (41.6 kt), small IT and telecommunication equipment (15.5 kt), and temperature exchange equipment (14.1 kt). Here, the estimated plastic composition can be recovered if it can come out as a clean fraction. Plastics have meagre recycling rates (Habib et al., 2015; Parajuly et al., 2016) due to a number of factors such as type of polymers used in plastics and contamination to impurities (e.g. Hahladakis and Iacovidou, 2019). Therefore, separation and purification methods can impact the estimated recycling amounts and costs.

Cu is the third-largest contributor to the economic value, which is mainly contained in small equipment (9.1 kt), temperature exchange equipment (4.2 kt), and small IT and telecommunication equipment (1.5 kt). Another interesting contribution to the economic value could come from Pd (10%), mostly concentrated in small IT and telecommunication equipment, and screens and monitors. The economic value of recoverable Al is around $33 million, which can be found in all categories but is mainly contained in small (11.7 kt) and large equipment (4.9 kt). Fe is also a common material widely used in all EEE categories; however, the most substantial quantity of this base metal can be recovered from small equipment (40.3 kt), temperature exchange equipment (31.8 kt), and large equipment (21.3 kt). The potential value from the recovery of glass is very low compared to other materials ($1 million).

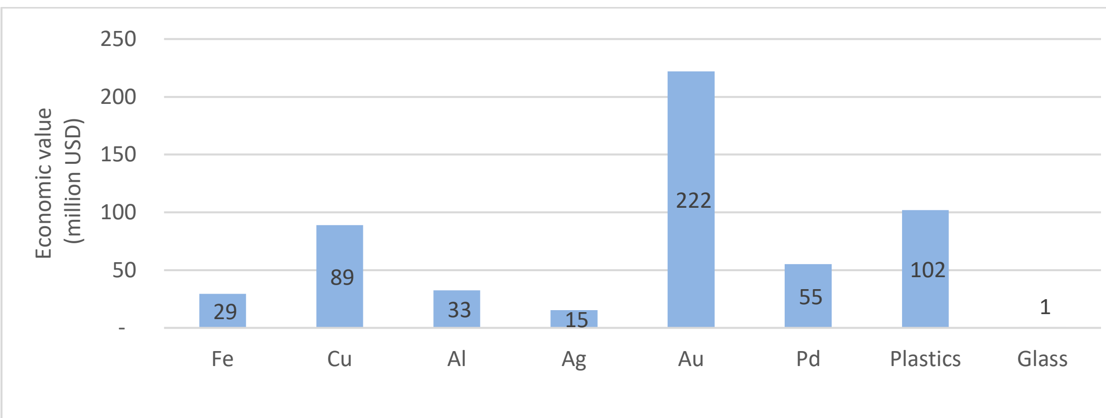


Figure 15. Estimated economic value of the accumulated secondary materials embedded in e-waste for all five islands (from 2020 to 2025).

3.3.3 Recovery and economic value potential

The overall recovery and economic potential related to the entire amount of e-waste from the five cases is demonstrated in Figure 16. Converting the e-waste quantities into secondary resources, from 2020 to 2025 alone, these five islands can earn around $546 million. The exploitable materials from e-waste and the economic value can significantly vary depending on the type of product, the EoL management system, and the available technology (Parajuly et al., 2017). Among these islands, the e-waste generated in Trinidad and Tobago is the largest and contains the highest amount of secondary resources (148.5 kt). The economic value of these resources can be up to $266 million. Jamaica has the second largest amount of materials (106.9 kt) and associated economic value ($179 million). Barbados and Aruba can also recover around 33.6 kt and 18.6 kt of secondary resources, with the economic value of $52 million and $32 million, respectively. Grenada, which has the lowest population, can recover 9.7 kt of materials from e-waste with a value of roughly $17 million.

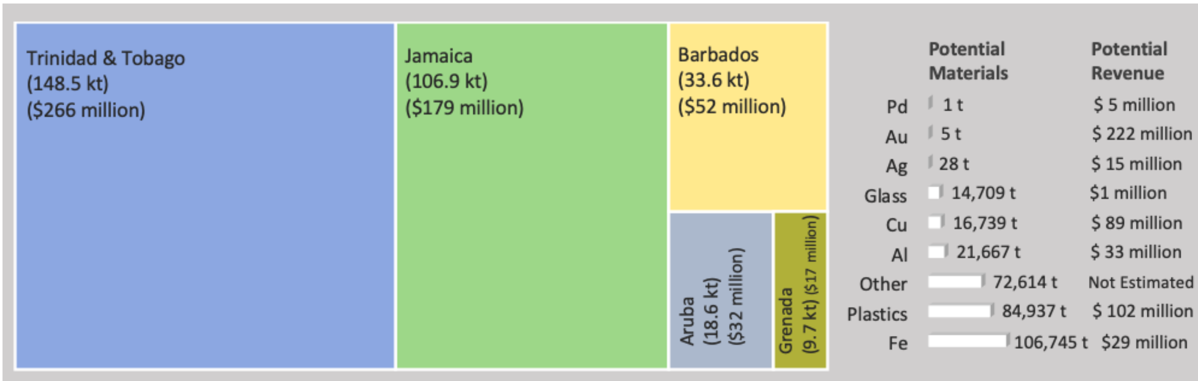


Figure 16. The weight of accumulated secondary resources in e-waste and the associated economic value of these materials from 2020 to 2025 (in tonnes and million USD).

The amount of embedded precious metals (Pd, Au, and Ag) within e-waste is around 0.034 (kt), only comprising 1% of the total volume. However, more than half of the economic value ($242 million) can come from the recovery of these precious metals. The precious metals are concentrated in printed circuit boards (PCBs). Therefore, proper dismantling and handling of PCBs would require efficient recycling and recovery of these resources (Ardente et al., 2014). To plan for a successful dismantling and recycling strategy, these results would help distinguish among different EEE types and focus on categories with the highest economic and environmental benefits.

We have compared the results of this research with a study in Denmark (Parajuly et al., 2017). The estimated population of Denmark is around 5,792 thousand people for 2020, and the estimated total population of these five islands is around 4,867 thousand people in the same year. It was estimated that in Denmark, from 2020 to 2025, around 486 (kt) of material could be recovered from e-waste, with approximately $816 million (or €720 million) economic value. Our estimation reveals that over the same period, 317 (kt) of materials can be recovered in these five SIDS with a total value of $546 million. This comparison shows that the average economic value of each kilo tonne of material in Denmark was $1.68 million (at the time of the study in 2017), and now it is around $1.72 million in the Caribbean. The difference between these two values can be explained by the significant increase in gold prices in recent years. The study in Denmark indicates that Au and plastic carry more than half of the total economic value, which is also true for the Caribbean case. In both studies, the next key metal is Cu representing around 15% of the potential value for Denmark and 16% for the Caribbean.

3.3.4 Results of the sensitivity analysis

Figure 17 compares the estimated values and material composition of the generated e-waste (excluding the category of other materials) in three sensitivity analyses. In the first sensitivity analysis, it was assumed that 20% of the e-waste generated from 2001 to 2019 is still stocked on islands and available for materials recovery. Adding this 20% hoarded e-waste, the economic value can increase from \$546 to around \$723 million. In the second sensitivity analysis, it was assumed that 50% of the e-waste for small IT and telecommunication equipment, as well as the 20% of e-waste for the other five categories, are still retained. The second sensitivity analysis shows that economic value can increase to around \$1,124 million (up by around 205% compared to the base scenario). However, if these islands had started the recovery of secondary resources in early 2001 (the third sensitivity analysis), they could gain around \$1,430 million of economic value by the end of 2025. It is worth noting that the aggregated material composition in Figure 17 is not a hundred percent. The category of 'other materials' is excluded from the economic value estimation (further discussed in section 3.2).

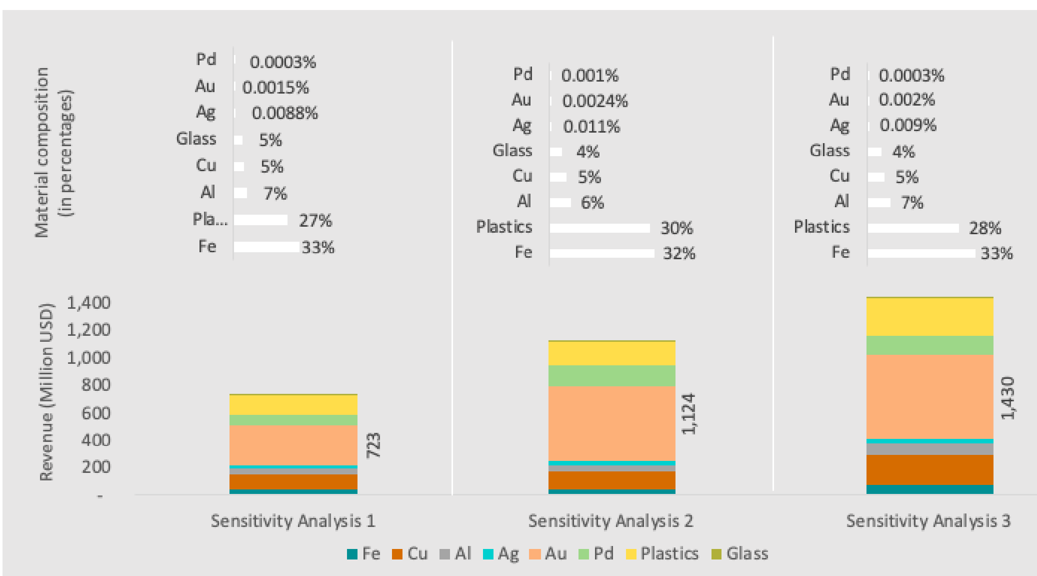


Figure 17. The comparison of estimated material composition of the generated e-waste (excluding the category of 'other materials') and the corresponding economic value in the case of three sensitivity analyses.

Due to the lack of proper e-waste management system, around 470 (kt) of materials and $883 million of economic value was ignored in these islands, between 2001 and 2019. Some old stockpiled e-waste might still be available for recycling in some islands. The sensitivity analyses reveal that recovery of the hoarded secondary resources can considerably increase material and value benefits. Regional and national authorities would require taking on-time actions through planning, funding, and constructing the necessary facilities to avoid more material and value loss. The later the island nations start to recover these materials, the lower is the economic value that can be recovered. Over time, the opportunities from the hoarded e-waste would be lost due to improper stocking, discarding, or handling.

3.4 Discussion

Considering the amount of embedded materials within e-waste, the economic value of these materials, and the interview results, this section will identify whether there is a potential for a circular economy (CE) in small islands. Potential CE strategies will be articulated, showing the current status of e-waste recycling and management systems in the five cases. Based on the literature review, quantitative estimations, and interview findings, recommendations such as establishing policies and developing industrial symbiosis are proposed for developing e-waste management systems in SIDS.

3.4.1 Current situation on islands

The summary of the responses of the eight country experts to the core questions are presented in Table 5. Based on their inputs, it could be argued that, currently, there are no specific national practices devoted to achieving the CE of e-waste in these five islands. Barbados and Jamaica's governments have recognized the e-waste problem, and efforts are being made to address the issue by putting in place policies and regulations. In 2015, the National Solid Waste Management Authority in Jamaica launched a pilot project to collect specific e-waste categories to provide the necessary information for Jamaica's e-waste policy. However, no particular progress has been made so far. Besides, all experts mentioned that there is minimal awareness about CE practices for proper e-waste management in these islands. There are some programs for raising public awareness (mainly about plastics and paper wastes), but progress on e-waste still lags.

Currently, no e-waste recycling effort is performed on these five islands. Disaggregating and exporting some materials or parts (mainly computer parts, base metals, and plastics) to other countries, are the only practices that have been implemented in four out of five islands. Two e-waste brokers in Barbados and Trinidad and Tobago try to repair, refurbish or upgrade some types of products, including computers and laptops for reuse, but they are not on a major scale. Some repair activities also happen, but the necessary spare parts are available for a limited range of products, making repairing quite expensive and narrow in scope. People usually buy cheaper electronics with a lower lifetime because products on the market have higher prices than those found in other countries, due to the greater shipping costs and taxes. Currently, there is no specific co-operative program between these islands and other countries to develop a regional e-waste recycling. The ABC Islands (Aruba, Bonaire and Curaçao) have signed a pledge in 2016 to increase co-operation for waste recycling, but there is no particular program for e-waste. According to the interviews, the difficulties confronted by these islands, for implementing the CE practices (focusing on e-waste) can be labelled into three main categories: lack of awareness, economies of scale, and government support.

Table 5. Summary of the findings from the expert interviews

Focus of the core questions	Aruba	Barbados	Grenada	Jamaica	Trinidad & Tobago
Effective e-waste management policy	None	E-waste policy is in progress	None	E-waste policy is in progress	None
Level of awareness about the CE practices	Low	Low	Low	Low	Low
Active companies or organizations in e-waste dismantling	Yes	Yes	No	Yes	Yes
Major e-waste dismantling/ recycling activities	Dismantling circuit boards and metals from large household appliances	Dismantling circuit boards, plastics and some metals	Dismantling copper from copper wirings	Dismantling some metals from e-waste	Dismantling plastics, some metals, and computer parts
Major e-waste reuse and reduce activities	None	Repairing, or refurbishing monitors and computers in small scale	None	Repair in small scale	Reconfiguring computers and laptops for reuse
Co-operation with other countries for e-waste recycling activities	None	None	None	None	None
Major difficulties of implementing the CE approach	-Lack of economies of scale - Lack of awareness	-Lack of economies of scale - Lack of awareness	-Lack of economies of scale - Lack of awareness	-Lack of Government support - Lack of awareness	-Lack of Government support - Lack of awareness

3.4.2 Is there an opportunity for a Circular Economy (CE)?

Our findings reveal that the quantity and value of embedded materials within e-waste could ensure feasible recycling opportunities in the Caribbean; if an island can construct a facility to serve multiple islands. The findings strongly support the recycling aspect of the CE. Iron, plastics, and aluminum represent the majority of the total weight of secondary materials (213 kt) that can be found in e-waste. However, the amount of precious metals (Pd, Au, and Ag) within e-waste is less than 1%, and more than half of the economic value comes from the recovery of these precious metals. Improving e-waste collection and recycling practices in the Caribbean would help decrease the continuous extraction of ecologically valuable raw materials while circulating a considerable amount of secondary materials into the manufacturing processes. Recycling and treating the e-waste in an environmentally sound manner would also help elude the losses of economically valuable materials.

Comparing the results of our study, with the recent $33 million investment by the United Arab Emirates (Pereira, 2019) in an e-waste recycling facility with a capacity of 100 kt per year (Forti et al., 2020), reveals the potential for initiating a recycling project in the Caribbean. Considering that our estimated amounts represent only 11% of the Caribbean population, we can expect at least ten times these quantities being attained throughout the Caribbean. Investing in reduce, and reuse initiatives would be less expensive (Hall et al., 2017). Therefore, the economic convenience coming from recycling materials can also be utilized to move towards the other pillars of CE (reduce and reuse) and support the development of sustainable e-waste management system in the region.

Considering the current limited reuse, repair, and refurbishment actions on islands, establishing these initiatives is essential for moving to a CE. Based on the interview findings, raising public awareness and behavioural change can help reduce EEE consumption in SIDS. Maximizing the reduction of EEE consumption and reuse of electronic products and their components would help sustain more materials, resources and labour inputs. In addition, the remaining functionality of the End-of-Use products and components should be recognized by islands to offer reuse and refurbishment opportunities. To make these improvements, SIDS would need to provide a foundation for a proper e-waste management system, such as developing maintenance and repair facilities, setting up policy requirements, and promoting human resource and technology development. It is worth noting that moving to a CE, a holistic view must be taken into account to ensure the sustainable development (Geissdoerfer et al., 2017) of the EEE sector in SIDS. Appropriate plans should ensure economic performance, social, and environmental inclusiveness.

The CE as an umbrella concept (Blomsma & Brennan, 2017) is interwoven with several other concepts, like Industrial Symbiosis (IS) (Chertow & Ehrenfeld, 2012). It can be claimed that the success story of IS in other geographies, like Kalundborg in Denmark, can be repeated in the Caribbean if the IS could be implemented efficiently. IS takes into account the co-operation between industries that are located in close proximity, and conventionally performed separately (Chertow, 2000). The implementation of IS can have a significant impact on reducing environmental burdens and costs in e-waste management in SIDS. Co-operation between different industries can occur in the form of exchanging utilities, materials, by-products, waste, water, energy, information, or joined marketing efforts.

IS can engender a broad range of opportunities in SIDS, sharing limited available resources and improving industrial sustainability. The islands can plan to construct other industries close to the recycling plants, to share resources or to use recovered material as raw materials. IS has proven feasible to use a variety of carbon-rich waste streams (such as waste plastic) as an alternative fuel in cement production (Lamas et al., 2013; Rahman et al., 2013; Rahman et al., 2015). Trinidad &Tobago has a cement plant, called Trinidad Cement Limited (TCL), with an annual production capacity of 1.2 million metric tons (Millette et al., 2019). IS could make it possible to divert plastic waste from e-waste for use as feedstock in a local cement plant. Moreover, recycled secondary resources can be used to produce value-added products. Manufacturing and trading value-added products would be much more profitable for SIDS than exporting raw materials; it would create more job opportunities and ripple through the economy.

3.4.3 Importance of Relevant Policies

Appropriate policies and regulations can inevitably play a significant role in e-waste management systems focused on building CE. According to the latest Global E-waste Monitor (2020), 78 countries in the world have policies or legislation governing e-waste. Almost no policies needed to drive e-waste management exist in the Caribbean, either for the islands or the region as a whole, and few nations are currently trying to introduce them. National and regional authorities need to develop consistent e-waste policies and legislation to manage e-waste.

The e-waste policies should target all stakeholders from manufacturers and governments to the public. Legislations should aim to establish and improve all aspects of the CE and not only the efficiency of the recycling chain. However, recycling activities should be carefully designed according to specific local conditions and situations. To stop importing low-quality products, imported EEE must meet the quality standards, and they should be disassembled easily for repair and recycling purposes. Imported electronic products also need to be updatable and reconfigurable. It would be especially crucial for SIDS to monitor and control the transition to a CE, setting the collection and recycling targets. Robust data and information systems need to be created by national and regional governments to support planning for a shift to a CE.

It is essential to move away from a policy where all materials are treated equally, to an alternate method for specifying collection targets for different waste streams, specifically different EEE types (Althaf et al., 2019). These targets can be identified based on various factors. Wang and Gaustad (2012) proposed prioritizing electronics with higher economic value, energy-saving potentials, and lower eco-toxicity. Policies emphasizing on Extended Producer Responsibility (EPR) should also be developed to manage e-wastes. EPR was introduced based on the polluter-pays principles (Widmer et al., 2005). According to this environmental policy approach, extended responsibility should be attributed to manufacturers at all stages of the product's life cycle, including disposal at their EoL (OECD, 2001). Even when the policies and legislations are enacted in SIDS, enforcement is of high importance to achieve CE.

3.4.4 Enabling Environment

Figure 18 sets out potential collaborations, stakeholders, and critical steps for developing efficient e-waste management systems in small island states, based on the literature review, estimations and expert interviews. Actions and collaborations are required at four different levels: a) regional authorities (such as CARICOM or the Basel Convention Regional Centre for the Caribbean Region), b) national governance, c) businesses, and d) the public. These steps are interrelated and could occur simultaneously or in a different order, prioritizing policy instruments, as previously discussed.

Moving to a CE of e-waste depends on extensive co-operation and raised awareness among governments, businesses, and the public. Co-operative business models would provide opportunities to combine resources, increase the quantities of recyclable products, and expand business opportunities. Consultation with experts confirm that educational outreach is minimal, involving only a few non-governmental organizations and campaigns focused on plastics and paper, not on e-waste. Increased public, governmental, and stakeholder awareness is needed, with stress placed on behavioural change towards reducing and reusing EEE, as well as proper e-waste disposal.

Some other steps are also required to be taken by islands to develop an efficient e-waste management system. Based on the expert interviews, harmonized definitions and categories for e-waste are needed, which is a fundamental requirement for co-operative management. The EU reports and guidelines on e-waste can be useful as a benchmark. Previous experiences in other waste sectors have shown that external financing at initial stages would be necessary to support the growth of a CE in the region. Therefore, investment plans and incentive and disincentive financial instruments would help to facilitate a thriving e-waste sector in the region. Compared to other waste streams, e-waste recycling is associated with higher job creation capacity (GreenCape, 2017). Therefore, development of the e-waste recycling sector in islands can create new employment opportunities. However, capacities need to be expanded in the case of human resources and technological development. The most appropriate technology and environmental practices should be identified for the islands' specific requirements and long term economically viable development. According to the interview findings, lightweight and small devices are usually disposed of in waste bins and mixed with organic and municipal waste. Large household appliances are often dumped illegally. Thus, easy access to e-waste collection points and public awareness about the collection services would be advantageous.

It was indicated that no agent or provider currently offers buy-back services in these five islands. Most of the previous efforts to establish take-back services did not succeed because of the high financial burdens, as initiating collection channels and arrangement of reverse logistics require substantial investments. Regional alliances between stakeholders would be the solution to provide buy-back services for all EEE types to the clients across the Caribbean. The experts also mentioned that people are not often getting high-quality EEE due to remoteness and high shipping costs. Therefore, the average lifetime of products might be shorter than other landmasses. There would also be a higher demand for replacement or repair; however, spare parts might be available (at very high costs), or even they might not be available. A strong demand exists for better return and repair services for EEE products. Products supplied in the region should be designed to fit into the CE; they need to be designed for easy disassembly, should be durable, upgradable, and be offered at reasonable costs.

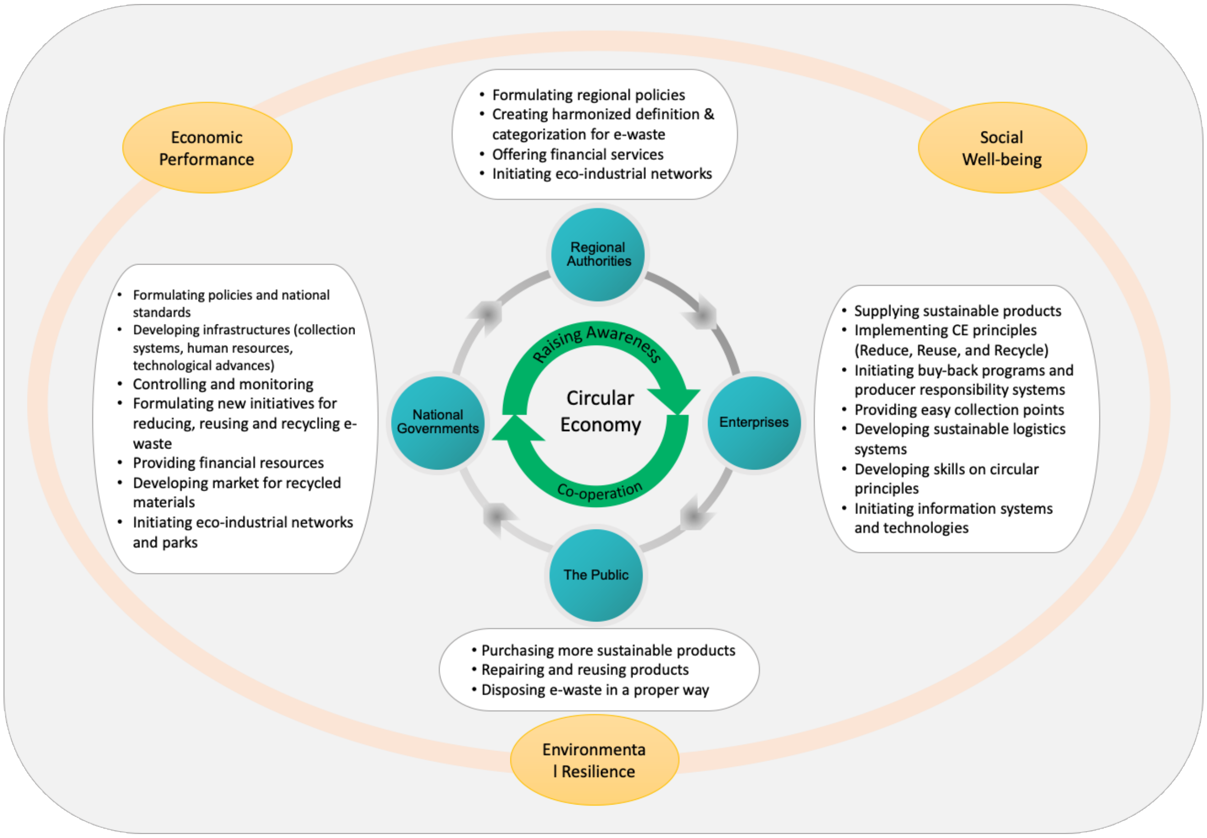


Figure 18. The potential roles and responsibilities for different stakeholders across scale to facilitate a shift towards a CE.

3.5 Outlook and Future Research

Next to the challenges associated with e-waste on islands, promising opportunities exist. E-waste can be considered an extensive source of materials and recycling these materials in the Caribbean can be a valuable opportunity and a significant step towards a system-wide CE. From 2020 to 2025, more than 317 kt of secondary resources can be recovered from EoL products in these five small islands. This quantity is much larger than the annual volume of recoverable materials from generated e-waste in different European countries such as Belgium, Sweden, Austria, and Portugal. However, compared to these countries, the Caribbean lags proper strategies for recovering these resources. The potential economic value of the embedded materials is $546 million, about 1% of the annual CARICOM GDP, which can significantly contribute to the GDP of islands with a small population such as Grenada (around 46%).

Establishing recycling programs and facilities is a small step for islands to meet the full potential of CE. Still, it is a worthwhile step because it can generate businesses and economic opportunities for the islands with small economies. CE for e-waste will help islands diversify their economic situation and alleviate the probable risks associated with narrow economies. Neglecting material recovery would lead to a loss of a considerable volume of secondary resources, as well as the associated economic values. To decrease environmental, health, and social problems that come from e-waste, the islanders need to address different aspects of CE: reduction of e-waste, reuse, and recycling. Recovering recyclable materials, using products with a longer lifetime, and lengthening the lifecycle of products through repair and reuse are the strategies that need to be implemented. CE for e-waste will not only have economic and environmental benefits but will also reduce the burden on public landfills in islands with limited land area.

Lack of governmental support is one of the main challenges of e-waste management in the Caribbean; therefore, national and regional authorities need to develop e-waste policies and legislation to deal with the growing problem of EoL products. It would be essential to establish regional co-operative alliances such as industrial symbiosis or eco-industrial networks to develop a robust e-waste management system. These co-operations will bring several sustainability advantages by minimizing energy and raw materials intake, reducing waste, and building sustainable relationships. Islands would also require a particular effort to promote awareness on all levels: governments, businesses, and the public. Raising awareness and better communication with the public is essential for promoting reduce and reuse strategies.

This is the first study of its kind about the potential for a circular economy (CE) of e-waste in small islands. Regardless of the strong applicability of a CE for electronic goods, utilizing materials from e-waste, either for reuse on the island or for separation and recycling to sell to international markets, has been neglected in previous studies. This research study highlights that the response to the e-waste challenge must be timely to be able to convert the recovery and reuse potential into an opportunity. Each year of bypassing the CE would result in more environmental and health burdens. Achieving the highest level of material recovery and closing the material loop in the region would be reached through successful long-term regional efforts.

Some limitations should be taken into account when considering the results of this study. The material composition of e-waste is highly heterogeneous and may vary in time and space; therefore, the compositions cannot be determined univocally. Moreover, the market value of the secondary resources in e-waste may vary as it depends on fluctuating market conditions, the grade of materials, and geographical locations. This study provides the basis for further cost-benefit or techno-economic evaluations of EoL recycling programs in islands. In the cost-benefit analysis, the costs of neglecting health and environmental burdens should be included because the presence of toxic substances in the discarded materials threatens human health and is a source of pollution to the land and marine ecosystems.

Chapter 4: Conclusion

The importance and urgency of the proper management of End-of-Life electronics are spotlighted in our work. The estimations reveal that from 2020 to 2025, around 317 (kt) of e-waste will be generated on the five island cases. Besides, by 2025, it is expected that they will have the EEE in-use stock of 683 kt. These e-waste and stock volumes correspond only to 11% of the Caribbean population, and it can be expected that at least ten times this amount being generated throughout the Caribbean. The estimated e-waste generation rate for the five island cases is significantly high compared to the global averages. Given that the Caribbean region is a hotspot of biodiversity, the estimated rates suggest urgent attention is required to proper e-waste management in terms of infrastructure, laws and regulations. However, the estimated e-waste quantities also represent a significant potential to move towards a system-wide Circular Economy (CE).

CE can be a multifaceted solution for SIDS. It can bring several social, environmental, health and economic benefits; through creating new employment opportunities, mitigating environmental and health impacts of e-waste, and delivering financial gains. An extensive amount of base, precious and rare metals can be recycled on small islands, and the potential worth of these materials can encourage these nations to take steps towards a CE. However, to meet the full potential of CE, maximizing the reduction of EEE consumption and reuse of electronics is required in a socially feasible, economically viable, and environmentally practicable manner. Considering current limited reuse, repair, and refurbishment activities on islands, establishing these initiatives is essential to sustain more materials, resources and labor inputs. The remaining functionality of the End-of-Use products and components should be recognized to provide reuse and refurbishment opportunities. However, to implement these changes, SIDS would need to provide a foundation for a proper e-waste management system, such as setting up policy requirements and human resource and technology development beforehand.

National and regional authorities need to develop e-waste policies and legislation to deal with the emerging problem of EoL EEE. The e-waste policies should target manufacturers, collectors, brokers, recyclers, governments and the public, to enforce the legislation at different stakeholder levels. Legislations should aim to establish and improve all aspects of the CE and not only the efficiency of the recycling chain. However, the recycling actives should also be promoted in SIDS due to (1) the scarcity of land areas for landfilling, (2) several impacts of discarding hazardous substances, and (3) the economic earnings from the recovery of embedded materials. Currently, a significant amount of

EEE in the Caribbean has a lower lifetime in comparison to other geographies. Therefore, imported products must meet quality standards, and they should be disassembled easily for repair and recycling purposes. Imported electronic products also need to be updatable and reconfigurable. It would be especially crucial for SIDS to monitor and control the transition to a CE, setting the collection and recycling targets at both national and regional levels. Robust data and information systems need to be created by national and regional governments to set the targets and improve planning for a shift towards CE.

Building partnerships, collaborations and co-operations would be a crucial ingredient to a successful EoL management in the region. It would be beneficial for SIDS to establish alliances such as Industrial Symbiosis (IS) or eco-industrial networks to build sustainable relationships. IS can enable synergies within e-waste value chains, by local utilization of wastes, by-products, and energy, as well as shared use of utilities. To encourage reuse and efficient recycling, EEE manufacturers and EoL management systems need to be connected, providing integrated regional buy-back services. Effective behavioral change and increased awareness is needed at all stakeholder levels for proper e-waste disposal, reduction in EEE consumption, and reusing electronic products. Furthermore, developing environmentally sound e-waste dismantling and recycling facilities would be feasible on more populated and affluent islands if they can co-operatively serve multiple islands. Co-operative CE for e-waste will help islands diversify their economic situation and alleviate the probable risks associated with narrow economies.

A holistic view must be taken into account to ensure the sustainable development of the EEE sector in SIDS. Appropriate plans are required to develop sustainability standards and support practices with low energy consumption and low emissions. As an instrument, technological advances should be used to design processes that prioritize resource efficiency (e.g. water and energy). The e-waste collection and transportation systems should be planned considering the specific sustainability and economic requirements of islands. Inefficient in-country or inter-country transportation can significantly contribute to an increase in emissions and a decrease in CE's expected benefits.

This study is the first attempt to evaluate the current condition of the e-waste management system and the potential for a circular economy in SIDS, providing a basis for further studies. Some suggestions have been recommended for future analyses on sustainable e-waste management systems in SIDS. By now, the lifetime parameters (alpha and beta) has not been determined for SIDS. Therefore, measuring these factors for different electrical and electronic products will be helpful for future estimations. In this research, only the economic value of the embedded materials has been estimated; however, a detailed cost-benefit analysis of CE programs will be required in an island context. Techno-economic evaluations would also help to identify proper recycling strategies and practices. Evaluating different business cases for reducing and reusing EEE is also required to recommend appropriate methods, based on specific requirements of these nations.

References

Agamuthu, P., Herat, S. (2014). Sustainable waste management in small islands developing states (SIDS). Waste Management. Res. 32 (8), 681e682. http://dx.doi.org/ 10.1177/0734242x14544869.

Althaf, S., Babbitt, C. W., & Chen, R. (2019). Forecasting electronic waste flows for effective circular economy planning. Resources, Conservation and Recycling, 151, 104362.

Angouria-Tsorochidou, E., Cimpan, C., & Parajuly, K. (2018). Optimized collection of EoL electronic products for Circular economy: A techno-economic assessment. Procedia CIRP, 69, 986-991.

Ardente, F., Mathieux, F., & Recchioni, M. (2014). Recycling of electronic displays: Analysis of pre-processing and potential ecodesign improvements. Resources, Conservation and Recycling, 92, 158-171.

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: exploring product life extension through design. Journal of Cleaner Production, 69, 10-16.

Balde, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The global e-waste monitor 2017. United Nations University. https://doi.org/10.1016/j.proci.2014.05.148.

Balde, C. P., Wang, F., Kuehr, R., & Huisman, J. (2015). The global e-waste monitor 2014: Quantities, flows and resources.

BCRC. (2016). Assessment of Waste Electrical and Electronic Equipment for the Republic of Suriname. Retrieved from http://www.basel.int/Portals/4/download.aspx?d=UNEP-CHW-eWaste-PACE-PilotPoject-Suriname-Report-20160711.English.pdf.

Biganzoli, L. A. U. R. A., Falbo, A. L. I. D. A., Forte, F. E. D. E. R. I. C. A., Grosso, M., & Rigamonti, L. (2015). Mass balance and life cycle assessment of the waste electrical and electronic equipment management system implemented in Lombardia Region (Italy). Science of the Total Environment, 524, 361-375.

Bomsma, F., & Brennan, G. (2017). The emergence of circular economy: A new framing around prolonging resource productivity. Journal of Industrial Ecology, 21(3), 603-614.l.

Briguglio, L. (1995). Small island developing states and their economic vulnerabilities. World development, 23(9), 1615-1632.

Brunner, P. H., & Rechberger, H. (2004). Practical handbook of material flow analysis. https://doi.org/10.1016/B978-1-85617-809-9.10003-9.

Camilleri-Fenech, M., Oliver-Solà, J., Farreny, R., & Gabarrell, X. (2018). Where do islands put their waste? – A material flow and carbon footprint analysis of municipal waste management in the Maltese Islands. Journal of Cleaner Production, 195, 1609–1619. https://doi.org/10.1016/j.jclepro.2017.07.057.

Cesaro, A., Marra, A., Kuchta, K., Belgıorno, V., & Van Hullebusch, E. D. (2018). WEEE management in a circular economy perspective: An overview. Global NEST Journal, 20, 743-750.

Chancerel, P., et al. (2009). "Assessment of precious metal flows during preprocessing of waste electrical and electronic equipment." Journal of Industrial Ecology 13(5): 791-810.

Chen, J., Taylor, J. E., & Wei, H. H. (2011). Toward a building occupant network agent-based model to simulate peer induced energy conservation behavior. In Proceedings of the 2011 Winter Simulation Conference (WSC) (pp. 883-890). IEEE.

Chen, M., Zhang, S., Huang, J., & Chen, H. (2015). Lead during the leaching process of copper from waste printed circuit boards by five typical ionic liquid acids. Journal of Cleaner Production, 95, 142–147. https://doi.org/10.1016/j.jclepro.2015.02.045.

Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. Annual review of energy and the environment, 25(1), 313-337.

Chertow, M. R., & Ehrenfeld, J. (2012). Organizing self-organizing systems: Toward a theory of industrial symbiosis. Journal of industrial ecology, 16(1), 13-27.

Chung, S., Lau, K., & Zhang, C. (2011). Generation of and control measures for, e-waste in Hong Kong. Waste Management, 31(3), 544–554. https://doi.org/10.1016/j.wasman.2010.10.003.

Cossu, R. and Williams, L. (2015). Urban mining: concepts, terminology, challenges. Waste Management. (Oxford) 45, 1–3.

Coughlan, D., Fitzpatrick, C., & McMahon, M. (2018). Repurposing end of life notebook computers from consumer WEEE as thin client computers–a hybrid end of life strategy for the Circular Economy in electronics. Journal of Cleaner Production, 192, 809-820.

Cucchiella, F., D'Adamo, I., Koh, S. L., & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. Renewable and Sustainable Energy Reviews, 51, 263-272.

De Queiroz Lamas, W., Palau, J. C. F., & de Camargo, J. R. (2013). Waste materials co-processing in cement industry: Ecological efficiency of waste reuse. Renewable and Sustainable Energy Reviews, 19, 200-207.

Deschenes, P. J., & Chertow, M. (2004). An Island Approach to Industrial Ecology: Towards Sustainability in the Island Context. 47(2), 201–217. https://doi.org/10.1080/0964056042000209102.

Dutta, T., Kim, K. H., Uchimiya, M., Kwon, E. E., Jeon, B. H., Deep, A., & Yun, S. T. (2016). Global demand for rare earth resources and strategies for green mining. Environmental Research, 150, 182-190.

Eckelman, M. J., & Chertow, M. R. (2009). Using material flow analysis to illuminate Long-Term waste management solutions in Oahu, Hawaii. Journal of Industrial Ecology, 13(5), 758-774.

Eckelman, M. J., Ashton, W., Arakaki, Y., Hanaki, K., Nagashima, S., & Malone-Lee, L. C. (2014). Island waste management systems: Statistics, challenges, and opportunities for applied industrial ecology. Journal of industrial ecology, 18(2), 306-317.

Eckelman, M., & Chertow, M. (2009). Linking Waste and Material Flows on the Island of Oahu, Hawai'i: The Search for Sustainable Solutions. Report Number 21. Yale School of Forestry & Environmental Studies.

Eckelman, M., & Chertow, M. (2013). Life cycle energy and environmental benefits of a US industrial symbiosis. The International Journal of Life Cycle Assessment, 18(8), 1524-1532.

ECLAC. (2010). Economics of Climate Change in Latin America and the Caribbean: Summary 2010.

ECLAC. (2018). Caribbean regional report on the mid-term review of SIDS accelerated modalities of action. Retrieved from https://sustainabledevelopment.un.org/content/documents/20949Caribbean_SAMOA_Pathway_Midterm_report_18_Oct.2018_final_draft1.pdf.

Ellen MacArthur Foundation. (2015). Towards the circular economy: Business Rationale for an Accelerated Transition. https://www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf.

Ellen MacArthur Foundation. (2016). Intelligent Assets: Unlocking the Circular Economy Potential.

EMF-Ellen MacArthur Foundation. (2013). Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition. Cowes, UK.

Forti V., Baldé C.P., Kuehr R., Bel G. (2020). The Global E-waste Monitor 2020. Quantities, flows and the circular economy potential. United Nations University (UNU), United Nations Institute for Training and Research (UNITAR), co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA). Bonn, Geneva, Rotterdam.

Forti, V., Baldé, C., & Kuehr, R. (2018). E-waste Statistics: Guidelines on Classifications, Reporting and Indicators, second edition. Retrieved from http://collections.unu.edu/eserv/UNU:6477/RZ_EWaste_Guidelines_LoRes.pdf.

Fuldauer, L. I., Ives, M. C., Adshead, D., Thacker, S., & Hall, J. W. (2019). Participatory planning of the future of waste management in small island developing states to deliver on the Sustainable Development Goals. Journal of cleaner production, 223, 147-162.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm?. Journal of cleaner production, 143, 757-768.

GreenCape. (2017). Waste Economy - 2017 Market Intelligence Report. http://www.green-cape.co.za/assets/Uploads/GreenCape-Waste-MIR-2017-electronic-FINAL-v2.pdf.

Grigoli, F., Herman, A., & Swiston, A. (2019). A crude shock: Explaining the short-run impact of the 2014–16 oil price decline across exporters. Energy Economics, 78(January 2015), 481–493. https://doi.org/10.1016/j.eneco.2018.11.025.

Gurauskiene, I., & Stasiškiene, Ž. (2011). Application of material flow analysis to estimate the efficiency of e-waste management systems: The case of Lithuania. Waste Management and Research, 29(7), 763–777. https://doi.org/10.1177/0734242X11406171.

Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. Journal of industrial ecology, 19(5), 765-777.

Habib, K. (2015). Critical resources in clean energy technologies and waste flows. Syddansk Universitet. Institut for kemi-, bio- og miljøteknologi.

Habib, K., Parajuly, K., & Wenzel, H. (2015). Tracking the flow of resources in electronic waste-the case of end-of-life computer hard disk drives. Environmental science & technology, 49(20), 12441-12449.

Hahladakis, J. N., & Iacovidou, E. (2019). An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. Journal of hazardous materials, 380, 120887.

Hall, J. W., Thacker, S., Ives, M. C., Cao, Y., Chaudry, M., Blainey, S. P., & Oughton, E. J. (2016). Strategic analysis of the future of national infrastructure. In Proceedings of the Institution of Civil Engineers-Civil Engineering (Vol. 170, No. 1, pp. 39-47). Thomas Telford Ltd.

Hastings, D. A. (2009). Filling Gaps in the Human Development Index: Findings for Asia and the Pacific (Human Development Index No. WP/09/02). Human Development. Retrieved from https://www.unescap.org/sites/default/files/wp-09-02.pdf

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018). E-waste in the international context – A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Management, 82, 258–275. https://doi.org/10.1016/j.wasman.2018.10.018.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Inter- governmental Panel on Climate Change, Geneva. https://doi.org/10.1017/ CBO9781107415379.

Islam, M. T., & Huda, N. (2019). E-waste in Australia: Generation estimation and untapped material recovery and revenue potential. Journal of Cleaner Production, 237, 117787. https://doi.org/10.1016/j.jclepro.2019.117787.

Johnson, M., Fitzpatrick, C., Wagner, M., & Huisman, J. (2018). Modelling the levels of historic waste electrical and electronic equipment in Ireland. Resources, Conservation and Recycling, 131(June 2017), 1–16. https://doi.org/10.1016/j.resconrec.2017.11.029.

Kairo, M., Ali, B., Cheeman, O., Haysom, K., & Murphy, S. (2003). Invasive species threats in the Caribbean Region. Report to the Nature Conservancy.

Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. Waste management, 33(5), 1237-1250.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, conservation and recycling, 127, 221-232.

Köhler, A., & Erdmann, L. (2004). Expected environmental impacts of pervasive computing. Human and Ecological Risk Assessment, 10(5), 831-852.

Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). E-waste: An overview on generation, collection, legislation and recycling practices. Resources, Conservation and Recycling, 122, 32–42. https://doi.org/10.1016/j.resconrec.2017.01.018.

Kumar, S., Mathieux, F., Onwubolu, G., & Chandra, V. (2007). A novel powder metallurgy-based method for the recycling of aluminum adapted to a small island developing state in the Pacific.

Luhar, S., & Luhar, I. (2019). Potential application of E-wastes in construction industry: A review. Construction and Building Materials, 203, 222–240. https://doi.org/10.1016/j.conbuildmat.2019.01.080.

Magalini, F., Wang, F., Huisman, J., Kuehr, R., Baldé, K., Straalen, V., Hestin, M., Lecerf, L., Sayman, U., & Akpulat, O. (2015). Study on WEEE recovery targets, preparation for re-use targets and on the method for calculation of the recovery targets. EU Commission.

Millette, S., Williams, E., & Hull, C. E. (2019). Materials flow analysis in support of circular economy development: Plastics in Trinidad and Tobago. Resources, Conservation and Recycling, 150, 104436.

Mohee, R., Mauthoor, S., Bundhoo, Z. M. A., Somaroo, G., Soobhany, N., & Gunasee, S. (2015). Current status of solid waste management in small island developing states: A review. Waste Management, 43, 539–549. https://doi.org/10.1016/j.wasman.2015.06.012.

Müller, E., Hilty, L.M., Widmer, R., Schluep, M., Faulstich, M., 2014. Modeling metal stocks and flows: a review of dynamic material flow analysis methods. Environ. Sci. Technol. 48, 2102–2113.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Noll, D., Wiedenhofer, D., Miatto, A., & Singh, S. J. (2019). The expansion of the built environment, waste generation and EU recycling targets on Samothraki, Greece: An island's dilemma. Resources, Conservation and Recycling, 150(July 2019), 104405. https://doi.org/10.1016/j.resconrec.2019.104405.

Nowakowski, P., & Mrówczyńska, B. (2018). Towards sustainable WEEE collection and transportation methods in circular economy-Comparative study for rural and urban settlements. Resources, Conservation and Recycling, 135, 93-107.

OECD, 2001. Extended Producer Responsibility: A Guidance Manual for Governments. OECD, Paris, France.

Oguchi, M., Murakami, S., Sakanakura, H., Kida, A., & Kameya, T. (2011). A preliminary categorization of end-of-life electrical and electronic equipment as secondary metal resources. Waste management, 31(9-10), 2150-2160.

Ongondo, F. O., Williams, I. D., & Cherrett, T. J. (2011). How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste management, 31(4), 714-730.

Parajuly, K., & Wenzel, H. (2017). Potential for circular economy in household WEEE management. Journal of Cleaner Production, 151, 272-285.

Parajuly, K., Habib, K., & Liu, G. (2017). Waste electrical and electronic equipment (WEEE) in Denmark: Flows, quantities and management. Resources, Conservation and Recycling, 123, 85-92.

Parajuly, K., Habib, K., Cimpan, C., Liu, G., & Wenzel, H. (2016). End-of-life resource recovery from emerging electronic products–A case study of robotic vacuum cleaners. Journal of cleaner production, 137, 652-666.

Parajuly, K.; Kuehr, R.; Awasthi, A. K.; Fitzpatrick, C.; Lepawsky, J.; Smith E.; Widmer, R.; Zeng, X. (2019). Future e-waste scenarios. StEP (Bonn), UNU ViE-SCYCLE (Bonn) & UNEP IETC (Osaka).

Pereira, N. (2019). Enviroserve launches world's largest e-waste plant in Dubai Industrial Park. https://www.arabianindustry.com/construction/news/2019/mar/21/enviroserve-launches-worlds-largest-e-waste-plant-in-dip-6056986/.

Phillips, W., & Thorne, E. (2013). Municipal solid waste management in the Caribbean: a benefit-cost analysis.

Preston, F. (2012). A global redesign? Shaping the circular economy.

Rahman, A., Rasul, M. G., Khan, M. M. K., & Sharma, S. (2013). Impact of alternative fuels on the cement manufacturing plant performance: an overview. Procedia Engineering, 56, 393-400.

Rahman, A., Rasul, M. G., Khan, M. M. K., & Sharma, S. (2015). Recent development on the uses of alternative fuels in cement manufacturing process. Fuel, 145, 84-99.

Regional statistics programme Caribbean community secretariat. (2016). CARICOM'S Selected Economic Indicators 2005, 2010-2014, A Statistical Profile of the CARICOM Single Market and Economy. Retrieved from www.caricomstats.org.

Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: new or refurbished as CE 3.0?—exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. Resources, Conservation and Recycling, 135, 246-264.

Reuter, M. A., Hudson, C., Van Schaik, A., Heiskanen, K., Meskers, C., & Hagelüken, C. (2013). Metal recycling: Opportunities, limits, infrastructure. A report of the working group on the global metal flows to the international resource panel.

Riquelme, R., Mendez, P., & Smith, I. (2016). Solid Waste Management in the Caribbean: Proceedings from the Caribbean Solid Waste Conference. In Caribbean Solid Waste Conference (p. 61). Inter-American Development Bank. Retrieved from http://www.kpesic.com/sites/default/files/Solid-Waste-Management-in-the-Caribbean-Proceedings-from-the-Caribbean-Solid-Waste-Conference_0.pdf

Roldan, J. M. R. Telecommunications Management Group (2017). E-waste management policy and regulatory framework for Jamaica Phase 1.

Saito, O. (2013). Resource use and waste generation by the tourism industry on the big island of Hawaii. Journal of Industrial Ecology, 17(4), 578-589.

Sauvé, S., Bernard, S., & Sloan, P. (2016). Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environmental Development, 17, 48–56. https://doi.org/10.1016/j.envdev.2015.09.002.

Savage, M., Ogilvie, S., Slezak, J., & Artim, E. (2006). Implementation of Waste Electric and Electronic Equipment Directive in EU 25. Retrieved from http://www.jrc.cec.eu.int.

Schluep, M., Hagelüken, C., Kuehr, R., Magalini, F., Maurer, C., Meskers, C., … Wang, F. (2009). Recycling – From e- waste to resources. In United Nations Environment Programme & United Nations University. Retrieved from http://www.unep.org/PDF/PressReleases/E-Waste_publication_screen_FINALVERSION-sml.pdf

Shah, K. U., Niles, K., Ali, S. H., Surroop, D., & Jaggeshar, D. (2019). Plastics waste metabolism in a Petro-Island state: Towards solving a "wicked problem" in trinidad and tobago. Sustainability (Switzerland), 11(23). https://doi.org/10.3390/su11236580.

Silva, U., & Ludwig, C. (2010). Assessing computer waste generation in Chile using material flow analysis. Waste management, 30(3), 473-482.

Simpson, M.C., (2012). The Caribsave Climate Change Risk Atlas and Climate Change Risk Profile for Saint Lucia. Technical Report. Caribsave, Saint Lucia.

Skordilis, A. (2004). Modelling of integrated solid waste management systems in an island. Resources, Conservation and Recycling, 41(3), 243-254.

Song, Q., Wang, Z., Li, J., & Zeng, X. (2012). Life cycle assessment of TV sets in China: a case study of the impacts of CRT monitors. Waste management, 32(10), 1926-1936.

Song, X., Hu, S., Chen, D., & Zhu, B. (2017). Estimation of Waste Battery Generation and Analysis of the Waste Battery Recycling System in China. Journal of Industrial Ecology, 21(1), 57–69. https://doi.org/10.1111/jiec.12407.

Stahel, W. (1981). Jobs for Tomorrow: The Potential for Substituting Manpower for Energy. New York: Vantage Press.

Stahel, W.R. (2016). Circular economy. Nature 531, 435–438.

Steubing, B., Böni, H., Schluep, M., Silva, U., & Ludwig, C. (2010). Assessing computer waste generation in Chile using material flow analysis. Waste Management, 30(3), 473–482. https://doi.org/10.1016/j.wasman.2009.09.007.

Streicher-Porte, M., Widmer, R., Jain, A., Bader, H. P., Scheidegger, R., & Kytzia, S. (2005). Key drivers of the e-waste recycling system: Assessing and modelling e-waste processing in the informal sector in Delhi. Environmental Impact Assessment Review, 25(5 SPEC. ISS.), 472–491. https://doi.org/10.1016/j.eiar.2005.04.004.

Tansel, B. (2017). From electronic consumer products to e-wastes: Global outlook, waste quantities, recycling challenges. Environment international, 98, 35-45.

Telesford, J. N. (2020). Strategic sustainability and industrial ecology in an island context, with considerations for a green economy roadmap: a study in the tourist accommodation sector, Grenada (Doctoral dissertation).

Telesford, J. N., & Strachan, P. A. (2017). Strategic Sustainability Procedures: Focusing Business Strategic Planning on the Socio-Ecological System in an Island Context. Sustainable Development, 25(1), 35-49.

Telesford, John N. 2014. "Strategic Sustainability and Industrial Ecology in an Island Context, with Considerations for a Green Economy Roadmap: A Study in the Tourist Accommodation Sector, Grenada." https://openair.rgu.ac.uk/handle/10059/1135.

The Council of the European Union. (2012). Directive 2012/19/Eu. Official Journal of the European Union, (June), 38–71. Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN.

THE WORLD BANK. (2005). Grenada: A Nation Rebuilding An assessment of reconstruction and economic. Washington. Retrieved from http://siteresources.worldbank.org/INTLACREGTOPHAZMAN/Resources/grenanda_rebuilding.pdf

The World Bank. (2019). Global population data. Retrieved from https://data.worldbank.org/ (accessed 07 January 2020).

UN COMTRADE. (2019). UN COMTRADE database. Available from. https://comtrade.un. org/ (accessed 13 August 2019).

UN-OHRLLS. (2014). Small Island Developing States in Numbers. Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS).

UN-OHRLLS. (2015). Small Island Developing States In Numbers: Climate Change Edition 2015. Retrieved from http://unohrlls.org/custom-content/uploads/2015/12/SIDS-IN-NUMBERS-CLIMATE-CHANGE-EDITION_2015.pdf

UNEP. (2008). Climate Change in the Caribbean and the Challenge of Adaptation. United Nations Environment Programme Regional Office for Latin America and the Caribbean, Panama City, Panama. Technical Report.

UNEP. (2019a). Taking the fight to the frontline: Island states unite to end pollution. Retrieved from https://www.unenvironment.org/pt-br/node/25085.

UNEP. (2019b). Small Island Developing States Waste Management Outlook. Available online: http://wedocs.unep.org/bitstream/handle/20.500.11822/27683/SIDS_WMO.pdf?sequence=1&isAllowed=y.

Van Buren, N., Demmers, M., Van der Heijden, R., & Witlox, F. (2016). Towards a circular economy: The role of Dutch logistics industries and governments. Sustainability, 8(7), 647.

Wang, F., Huisman, J., Stevels, A., & Baldé, C. P. (2013). Enhancing e-waste estimates: Improving data quality by multivariate Input-Output Analysis. Waste Management, 33(11), 2397–2407. https://doi.org/10.1016/j.wasman.2013.07.005.

Wang, X., & Gaustad, G. (2012). Prioritizing material recovery for end-of-life printed circuit boards. Waste Management, 32(10), 1903-1913.

Wang, X., Miller, G., Ding, G., Lou, X., Cai, D., Chen, Z., Han, J. (2012). Health risk assessment of lead for children in tinfoil manufacturing and e-waste recycling areas of Zhejiang Province, China. Science of the Total Environment, 426, 106–112. https://doi.org/10.1016/j.scitotenv.2012.04.002.

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). Global perspectives on e-waste. Environmental impact assessment review, 25(5), 436-458.

Winans, K., Kendall, A., & Deng, H. (2017). The history and current applications of the circular economy concept. Renewable and Sustainable Energy Reviews, 68, 825-833.

World Health Organization. (2010). Childhood lead poisoning.

Zeng, X., Song, Q., Li, J., Yuan, W., Duan, H., & Liu, L. (2015). Solving e-waste problem using an integrated mobile recycling plant. Journal of cleaner production, 90, 55-59.

Zlamparet, G. I., Ijomah, W., Miao, Y., Awasthi, A. K., Zeng, X., & Li, J. (2017). Remanufacturing strategies: A solution for WEEE problem. Journal of Cleaner Production, 149, 126-136.

Zsigraiová, Z., Tavares, G., Semiao, V., Carvalho, M. d. G. (2009). Integrated waste-to- energy conversion and waste transportation within island communities. Energy 34 (5), 623e635. http://dx.doi.org/10.1016/j.energy.2008.10.015.

Appendix A: Annual amounts of put-on-market, Aruba

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total PoM
1965	0	0	0	0	0	0	0	0	0	0	**0**
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**1**
1968	0	0	0	0	0	0	0	0	0	0	**1**
1969	0	0	0	0	0	0	0	0	0	0	**1**
1970	0	0	0	0	0	0	0	0	0	0	**1**
1971	1	0	0	0	0	0	0	0	0	0	**1**
1972	1	0	0	0	0	0	0	0	0	0	**2**
1973	1	1	0	0	0	0	0	0	0	0	**2**
1974	1	1	0	0	0	0	0	0	0	0	**3**
1975	1	1	0	0	0	0	0	0	0	0	**3**
1976	2	1	0	1	0	0	0	0	0	0	**4**
1977	2	1	0	1	0	0	0	0	0	0	**5**
1978	2	2	1	1	0	0	0	0	0	0	**7**
1979	3	2	1	1	0	0	1	0	0	0	**8**
1980	4	3	1	1	1	0	1	0	0	0	**10**
1981	4	3	1	2	1	0	1	0	0	0	**12**
1982	5	4	1	2	1	0	1	0	0	0	**15**
1983	7	5	2	3	1	0	1	0	1	0	**19**
1984	8	6	2	3	1	0	1	0	1	0	**24**
1985	10	8	3	4	2	0	2	0	1	0	**29**
1986	13	10	3	5	2	0	2	0	1	0	**36**
1987	16	12	4	6	2	0	3	0	1	0	**45**
1988	20	15	5	8	3	0	3	0	2	0	**55**
1989	25	18	6	9	4	1	4	0	2	0	**69**
1990	30	23	7	12	4	1	5	0	2	0	**85**
1991	38	28	9	14	6	1	7	0	3	0	**105**
1992	47	35	11	18	7	1	8	0	4	0	**131**
1993	58	43	14	22	9	1	10	0	5	0	**162**
1994	72	53	17	27	11	2	13	0	6	0	**200**

1995	89	66	22	34	13	2	16	1	7	0	**248**
1996	110	82	27	42	16	3	19	1	9	0	**308**
1997	136	101	33	52	20	3	24	1	11	0	**381**
1998	168	125	41	64	25	4	30	1	13	1	**472**
1999	209	155	51	79	31	5	37	1	17	1	**585**
2000	258	192	63	98	38	6	46	2	21	1	**725**
2001	320	238	78	122	47	8	56	2	25	1	**898**
2002	397	295	96	151	59	10	70	2	31	1	**1,112**
2003	491	366	119	187	73	12	87	3	39	2	**1,377**
2004	608	453	148	231	90	15	107	4	48	2	**1,706**
2005	754	561	183	286	111	18	133	5	60	3	**2,114**
2006	934	591	227	344	138	23	165	6	74	3	**2,504**
2007	1157	649	281	385	171	28	204	7	92	4	**2,978**
2008	1433	649	348	455	211	35	253	9	114	5	**3,511**
2009	1775	434	431	561	262	43	313	11	141	6	**3,977**
2010	1592	436	374	471	320	33	420	12	75	7	**3,740**
2011	1851	376	369	641	340	49	397	14	89	12	**4,138**
2012	1736	376	385	363	300	42	325	14	81	10	**3,632**
2013	1815	538	378	486	478	30	422	24	90	11	**4,272**
2014	1836	831	476	431	391	93	298	18	115	3	**4,492**
2015	1277	567	401	386	377	76	340	16	136	10	**3,586**
2016	1342	659	374	401	545	63	389	18	143	10	**3,944**
2017	1353	533	387	363	363	160	357	14	141	9	**3,680**
2018	1353	533	387	363	363	160	357	14	141	9	**3,680**
2019	1353	533	387	363	363	160	357	14	141	9	**3,680**
2020	1353	533	387	363	363	160	357	14	141	9	**3,680**
2021	1353	533	387	363	363	160	357	14	141	9	**3,680**
2022	1353	533	387	363	363	160	357	14	141	9	**3,680**
2023	1353	533	387	363	363	160	357	14	141	9	**3,680**
2024	1353	533	387	363	363	160	357	14	141	9	**3,680**
2025	1353	533	387	363	363	160	357	14	141	9	**3,680**
Total	32,834	13,813	8,476	9,675	7,377	2,049	7,428	299	2,729	175	84,856

Appendix B: Annual amounts of put-on-market, Barbados

Year \ Cat.	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total PoM
1965	0	0	0	0	0	0	0	0	0	0	**0**
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**1**
1970	0	0	0	0	0	0	0	0	0	0	**1**
1971	0	0	0	0	0	0	0	0	0	0	**1**
1972	1	0	0	0	0	0	0	0	0	0	**1**
1973	1	0	0	0	0	0	0	0	0	0	**2**
1974	1	0	0	0	0	0	0	0	0	0	**2**
1975	1	0	1	0	1	0	0	0	0	0	**3**
1976	2	1	1	0	1	0	0	0	0	0	**4**
1977	2	1	1	0	1	0	0	0	0	0	**6**
1978	3	1	1	1	1	0	0	0	0	0	**8**
1979	4	1	2	1	2	0	0	0	0	0	**10**
1980	5	2	2	1	2	0	0	0	0	0	**13**
1981	7	2	3	1	3	0	0	0	0	0	**18**
1982	9	3	4	2	4	1	0	0	1	0	**24**
1983	12	4	5	2	6	1	0	0	1	0	**31**
1984	16	6	7	3	7	1	0	0	1	0	**42**
1985	21	7	9	4	10	1	1	0	1	0	**55**
1986	28	10	13	5	13	2	1	0	2	0	**73**
1987	37	13	17	7	17	2	1	0	2	0	**97**
1988	50	17	22	9	23	3	1	0	3	1	**129**
1989	66	23	29	13	31	4	2	0	4	1	**171**
1990	87	30	39	17	41	5	3	0	5	1	**227**
1991	116	40	52	22	54	7	3	0	7	1	**301**
1992	153	53	68	29	72	9	4	0	9	2	**399**
1993	203	70	91	39	95	11	6	0	11	2	**529**
1994	270	93	120	52	126	15	8	0	15	3	**702**

1995	358	123	160	68	167	20	10	0	20	4	**931**
1996	475	164	212	91	222	27	14	0	27	5	**1235**
1997	630	217	281	120	294	36	18	0	36	7	**1638**
1998	835	288	372	160	390	47	24	0	47	9	**2173**
1999	1108	382	494	212	517	63	32	0	63	13	**2883**
2000	1470	507	655	281	686	83	42	0	83	17	**3824**
2001	1950	672	869	373	910	110	56	0	110	22	**5072**
2002	2379	655	941	389	857	143	72	1	70	43	**5550**
2003	2626	877	843	509	924	83	53	3	119	2	**6039**
2004	3314	923	800	560	949	186	40	3	156	25	**6956**
2005	3199	1028	910	713	974	292	49	1	143	42	**7351**
2006	3354	1101	1056	536	1013	536	50	26	169	38	**7879**
2007	3259	1048	1012	465	1145	316	59	14	166	20	**7504**
2008	2925	963	912	381	976	299	51	6	142	12	**6667**
2009	2226	845	897	324	917	233	57	12	132	12	**5655**
2010	2743	897	878	307	860	1153	39	1	141	15	**7034**
2011	2709	816	896	321	814	262	26	13	127	3	**5987**
2012	2625	697	698	268	742	228	28	4	61	7	**5358**
2013	2528	760	811	267	741	196	24	9	152	22	**5510**
2014	2692	789	822	205	739	232	23	8	135	9	**5654**
2015	3159	819	731	216	630	212	18	5	141	12	**5943**
2016	2778	859	759	242	544	235	24	6	158	9	**5614**
2017	3257	931	678	223	859	315	27	4	168	5	**6467**
2018	3257	931	678	223	859	315	27	4	168	5	**6467**
2019	3257	931	678	223	859	315	27	4	168	5	**6467**
2020	3257	931	678	223	859	315	27	4	168	5	**6467**
2021	3257	931	678	223	859	315	27	4	168	5	**6467**
2022	3257	931	678	223	859	315	27	4	168	5	**6467**
2023	3257	931	678	223	859	315	27	4	168	5	**6467**
2024	3257	931	678	223	859	315	27	4	168	5	**6467**
2025	3257	931	678	223	859	315	27	4	168	5	**6467**
Total	***79751***	***24186***	***22599***	***9225***	***24253***	***7888***	***1084***	***148***	***3971***	***405***	**173510**

Appendix C: Annual amounts of put-on-market, Grenada

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total PoM
1965	0	0	0	0	0	0	0	0	0	0	**0**
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**0**
1976	0	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	0	0	0	0	0	0	**0**
1981	0	0	0	0	0	0	0	0	0	0	**0**
1982	0	0	0	0	0	0	0	0	0	0	**0**
1983	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	0	0	0	0	0	0	**0**
1985	0	0	0	0	0	0	0	0	0	0	**0**
1986	0	0	0	0	0	0	0	0	0	0	**0**
1987	0	0	0	0	0	0	0	0	0	0	**0**
1988	0	0	0	0	0	0	0	0	0	0	**0**
1989	0	0	0	0	0	0	0	0	0	0	**0**
1990	0	0	0	0	0	0	0	0	0	0	**0**
1991	0	0	0	0	0	0	0	0	0	0	**0**
1992	0	0	0	0	0	0	0	0	0	0	**1**
1993	1	0	0	0	0	0	0	0	0	0	**1**
1994	2	0	1	0	0	0	0	0	0	0	**3**

1995	4	1	1	1	0	0	0	0	0	0	**7**
1996	9	1	3	2	1	0	0	0	0	0	**16**
1997	21	3	7	4	1	1	0	0	1	0	**38**
1998	50	7	16	9	3	2	0	0	2	0	**89**
1999	115	16	37	21	7	6	0	0	4	0	**207**
2000	268	38	87	49	15	13	0	1	9	0	**481**
2001	625	89	202	115	36	31	0	3	21	0	**1120**
2002	350	96	153	59	35	12	0	1	37	0	**743**
2003	462	76	124	110	27	12	0	2	18	0	**831**
2004	371	72	123	61	30	9	0	18	29	0	**713**
2005	232	46	70	44	18	8	0	2	18	0	**437**
2006	619	125	147	125	71	12	0	7	26	1	**1133**
2007	378	52	91	39	24	14	0	2	14	0	**614**
2008	563	107	157	7	60	9	0	31	41	1	**978**
2009	502	87	110	52	7	10	0	3	17	1	**788**
2010	566	118	200	126	32	19	0	3	17	3	**1085**
2011	381	95	216	158	32	36	0	6	30	1	**954**
2012	466	81	154	151	25	18	0	22	19	0	**938**
2013	687	138	184	240	31	44	1	2	19	11	**1357**
2014	651	191	176	228	120	50	79	2	52	2	**1551**
2015	950	210	170	277	227	40	115	6	35	0	**2030**
2016	1085	213	178	270	134	47	108	3	46	2	**2085**
2017	1532	339	288	312	179	80	130	19	56	4	**2939**
2018	1532	339	288	312	179	80	130	19	56	4	**2939**
2019	1532	339	288	312	179	80	130	19	56	4	**2939**
2020	1532	339	288	312	179	80	130	19	56	4	**2939**
2021	1532	339	288	312	179	80	130	19	56	4	**2939**
2022	1532	339	288	312	179	80	130	19	56	4	**2939**
2023	1532	339	288	312	179	80	130	19	56	4	**2939**
2024	1532	339	288	312	179	80	130	19	56	4	**2939**
2025	1532	339	288	312	179	80	130	19	56	4	**2939**
Total	***23,148***	***4,910***	***5,198***	***4,953***	***2,551***	***1,115***	***1,476***	***289***	***964***	***54***	**44,657**

Appendix D: Annual amounts of put-on-market, Jamaica

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total PoM
1965	0	0	0	0	0	0	0	0	0	0	**0**
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**0**
1976	0	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	**1**
1980	1	0	0	0	0	0	0	0	0	0	**1**
1981	1	0	0	0	0	0	0	0	0	0	**2**
1982	1	0	0	0	0	0	0	0	0	0	**2**
1983	2	1	0	0	0	0	0	0	0	0	**4**
1984	3	1	1	0	1	0	0	0	0	0	**6**
1985	5	1	1	0	1	0	0	0	0	0	**9**
1986	7	2	2	1	2	0	0	0	0	0	**14**
1987	11	3	3	1	2	0	0	0	0	0	**21**
1988	17	5	4	1	4	1	0	0	1	0	**33**
1989	26	8	6	2	6	1	0	0	1	0	**51**
1990	41	13	10	3	9	1	0	1	2	0	**79**
1991	63	20	15	5	13	2	1	1	3	0	**121**
1992	97	30	23	7	20	3	1	1	4	0	**187**
1993	149	47	35	11	32	5	2	2	6	0	**288**
1994	231	72	54	17	49	8	3	3	10	0	**445**

1995	356	111	83	25	75	12	4	5	15	0	**686**
1996	548	171	128	39	116	19	6	7	23	1	**1,058**
1997	846	264	197	61	179	29	9	11	36	1	**1,632**
1998	1304	406	304	94	276	45	14	17	55	1	**2,517**
1999	2011	627	470	144	425	69	22	26	85	2	**3,881**
2000	3102	967	724	222	656	106	34	41	130	3	**5,986**
2001	4784	1491	1117	343	1011	164	53	63	201	5	**9,232**
2002	5344	1797	1325	374	962	145	81	61	236	15	**10,340**
2003	6470	2124	1110	438	1065	160	73	64	220	9	**11,733**
2004	7497	2250	1088	608	931	238	62	59	237	6	**12,976**
2005	7760	2947	1475	934	1525	449	76	77	535	13	**15,791**
2006	8423	2663	1618	717	951	538	96	56	430	14	**15,506**
2007	8529	3469	1463	854	1387	458	86	68	501	8	**16,823**
2008	7693	2519	4293	3340	1201	590	732	32	563	25	**20,988**
2009	6957	2063	1943	2541	952	248	569	28	398	6	**15,705**
2010	5512	2291	2341	2349	799	264	563	54	402	3	**14,578**
2011	6459	1868	1608	2394	723	310	633	45	504	4	**14,548**
2012	6951	2198	1481	2093	630	218	659	65	532	7	**14,834**
2013	6643	1838	2232	1897	645	288	631	36	703	8	**14,921**
2014	7589	2203	2217	1682	640	297	552	17	765	23	**15,985**
2015	8644	2450	2107	1875	1091	234	622	25	719	22	**17,789**
2016	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2017	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2018	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2019	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2020	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2021	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2022	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2023	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2024	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
2025	12550	3888	2243	3966	1636	631	934	34	980	23	**26,885**
Total	***239,577***	***75,801***	***51,908***	***62,732***	***32,737***	***11,213***	***14,926***	***1,206***	***17,117***	***407***	**507,624**

Appendix E: Annual amounts of put-on-market, Trinidad and Tobago

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total PoM
1965	0	0	0	0	0	0	0	0	0	0	**0**
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**1**
1976	0	0	0	0	0	0	0	0	0	0	**1**
1977	0	0	0	0	0	0	0	0	0	0	**1**
1978	1	0	0	0	0	0	0	0	0	0	**2**
1979	1	0	0	0	0	0	0	0	0	0	**3**
1980	2	1	0	1	0	0	0	0	0	0	**4**
1981	2	1	1	1	0	0	0	0	0	0	**6**
1982	3	1	1	1	1	0	0	0	0	0	**8**
1983	5	2	1	2	1	0	0	0	0	0	**12**
1984	8	3	2	3	2	0	0	0	1	0	**18**
1985	11	5	3	4	2	1	0	0	1	0	**27**
1986	17	7	4	6	3	1	0	0	2	0	**39**
1987	24	10	7	8	5	1	0	0	2	0	**58**
1988	36	15	10	12	7	2	0	0	4	0	**86**
1989	53	22	15	18	11	2	1	0	5	0	**127**
1990	79	32	22	27	16	4	1	0	8	0	**188**
1991	117	48	32	39	23	5	2	0	11	0	**278**
1992	173	71	47	58	34	8	2	1	17	0	**411**
1993	256	104	70	86	51	12	3	1	25	1	**608**

1994	379	154	103	127	75	17	5	1	37	1	**900**
1995	560	228	152	188	111	25	7	2	55	1	**1,331**
1996	829	338	226	278	165	38	11	2	81	2	**1,968**
1997	1226	500	334	411	244	56	16	4	119	3	**2,911**
1998	1813	739	493	608	361	82	24	5	176	4	**4,307**
1999	2682	1094	730	900	533	122	36	8	261	6	**6,371**
2000	3967	1618	1080	1331	789	180	53	11	386	9	**9,423**
2001	5868	2393	1597	1969	1167	266	78	17	505	13	**13,873**
2002	7291	2100	2371	889	1876	250	122	47	533	13	**15,492**
2003	7152	2763	1981	726	1514	355	79	33	411	7	**15,021**
2004	7819	2400	1870	990	1508	1953	79	27	572	11	**17,229**
2005	9975	3514	2217	1312	1898	936	88	32	680	31	**20,683**
2006	7954	3245	3048	1183	2342	798	101	34	680	27	**19,412**
2007	9868	3450	3286	4346	2335	1452	2586	84	1473	48	**28,928**
2008	12070	2981	4278	5168	2084	1351	1887	46	1131	38	**31,034**
2009	8332	2689	3572	3292	1596	722	2028	31	928	45	**23,235**
2010	9114	2723	2692	3697	1363	1450	1604	55	742	16	**23,456**
2011	8647	2839	2878	3504	1867	837	2071	25	699	15	**23,382**
2012	9633	3454	2956	4156	1631	797	1996	35	770	18	**25,446**
2013	9733	3852	2833	4558	1760	901	2122	51	893	16	**26,719**
2014	9875	3579	2656	4677	2264	911	2199	39	695	27	**26,922**
2015	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2016	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2017	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2018	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2019	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2020	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2021	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2022	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2023	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2024	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
2025	10945	3962	3202	4896	2322	1048	2450	119	946	27	**29,917**
Total	**255,970**	**90,558**	**76,789**	**98,432**	**53,183**	**25,062**	**44,153**	**1,900**	**22,310**	**649**	**669,006**

Appendix F: Annual e-waste generation amount, Aruba

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total e-waste
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**1**
1974	0	0	0	0	0	0	0	0	0	0	**1**
1975	0	0	0	0	0	0	0	0	0	0	**1**
1976	0	0	0	0	0	0	0	0	0	0	**1**
1977	0	0	0	0	0	0	0	0	0	0	**1**
1978	0	1	0	0	0	0	0	0	0	0	**2**
1979	1	1	0	0	0	0	0	0	0	0	**2**
1980	1	1	0	0	0	0	0	0	0	0	**3**
1981	1	1	0	0	0	0	0	0	0	0	**3**
1982	1	1	0	1	0	0	0	0	0	0	**4**
1983	1	2	1	1	0	0	1	0	0	0	**5**
1984	2	2	1	1	0	0	1	0	0	0	**6**
1985	2	2	1	1	0	0	1	0	0	0	**8**
1986	3	3	1	1	0	0	1	0	0	0	**10**
1987	4	4	1	1	0	0	1	0	0	0	**12**
1988	4	5	2	2	0	0	2	0	1	0	**15**
1989	5	6	2	2	1	0	2	0	1	0	**19**
1990	7	7	2	3	1	0	2	0	1	0	**23**
1991	8	9	3	3	1	0	3	0	1	0	**29**
1992	10	11	4	4	1	0	4	0	1	0	**35**
1993	13	13	5	5	1	0	4	0	2	0	**44**
1994	16	16	6	7	2	0	5	0	2	0	**54**
1995	19	20	7	8	2	0	7	0	3	0	**67**

1996	24	25	9	10	3	0	8	0	3	0	**83**
1997	30	31	11	13	3	1	10	0	4	0	**103**
1998	37	39	13	16	4	1	13	0	5	0	**128**
1999	46	48	16	19	5	1	16	0	6	0	**158**
2000	57	59	20	24	6	1	20	0	8	0	**196**
2001	70	74	25	30	8	1	25	0	10	0	**243**
2002	87	91	31	37	10	2	30	0	12	0	**301**
2003	108	113	39	46	12	2	38	0	15	0	**373**
2004	134	140	48	56	15	3	47	0	18	0	**462**
2005	166	174	59	70	19	3	58	1	23	1	**573**
2006	205	215	73	87	23	4	72	1	28	1	**709**
2007	254	256	91	106	29	5	89	1	35	1	**867**
2008	315	298	113	126	36	6	110	1	43	1	**1,050**
2009	390	334	140	149	45	8	136	1	53	1	**1,257**
2010	484	356	173	176	55	10	169	2	66	2	**1,492**
2011	568	369	203	200	67	12	215	2	72	2	**1,709**
2012	656	371	230	253	81	14	254	3	76	3	**1,940**
2013	744	370	256	268	95	17	277	3	79	3	**2,110**
2014	802	385	278	285	111	19	304	4	82	4	**2,275**
2015	842	437	308	306	129	22	312	5	86	4	**2,451**
2016	869	441	328	323	148	26	318	6	91	5	**2,553**
2017	897	458	340	337	172	30	329	7	97	6	**2,671**
2018	927	456	350	347	193	36	335	8	103	6	**2,760**
2019	957	457	358	354	214	43	338	9	108	7	**2,845**
2020	988	459	364	360	234	51	340	10	114	7	**2,926**
2021	1019	462	369	364	253	59	341	11	118	8	**3,003**
2022	1049	464	373	367	271	68	342	12	122	8	**3,075**
2023	1078	467	376	368	287	77	342	12	125	8	**3,141**
2024	1106	469	378	369	302	86	343	13	128	8	**3,202**
2025	1132	471	380	369	315	94	343	13	130	9	**3,256**
Total	**16,143**	**8,894**	**5,786**	**5,876**	**3,155**	**704**	**5,609**	**127**	**1,871**	**96**	**48,262**

Appendix G: Annual e-waste generation amount, Barbados

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total e-waste
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**1**
1976	0	0	0	0	0	0	0	0	0	0	**1**
1977	0	0	0	0	0	0	0	0	0	0	**1**
1978	0	0	0	0	0	0	0	0	0	0	**1**
1979	0	0	0	0	0	0	0	0	0	0	**2**
1980	1	0	1	0	0	0	0	0	0	0	**2**
1981	1	1	1	0	0	0	0	0	0	0	**3**
1982	1	1	1	0	1	0	0	0	0	0	**4**
1983	1	1	1	0	1	0	0	0	0	0	**5**
1984	2	1	2	1	1	0	0	0	0	0	**7**
1985	2	2	2	1	1	0	0	0	0	0	**9**
1986	3	2	3	1	2	0	0	0	0	0	**13**
1987	4	3	4	2	2	0	0	0	1	0	**17**
1988	6	4	6	2	3	0	1	0	1	0	**22**
1989	7	6	7	3	4	0	1	0	1	0	**29**
1990	10	8	10	4	5	0	1	0	1	0	**39**
1991	13	10	13	5	7	0	1	0	2	0	**51**
1992	17	13	17	6	9	1	2	0	2	0	**68**
1993	23	18	23	8	12	1	2	0	3	0	**90**
1994	31	24	30	11	16	1	3	0	4	0	**120**
1995	41	32	40	15	21	2	4	0	5	1	**159**

1996	54	42	53	20	28	2	5	0	7	1	**211**
1997	72	55	70	26	37	3	7	0	10	1	**280**
1998	95	74	93	35	49	4	9	0	13	1	**371**
1999	126	98	123	46	65	5	12	0	17	2	**493**
2000	167	129	163	61	86	6	15	0	22	3	**653**
2001	222	172	217	81	114	8	20	0	30	3	**867**
2002	295	228	288	107	151	11	27	0	39	5	**1,150**
2003	381	273	359	134	196	14	36	0	45	6	**1,445**
2004	478	341	427	170	247	18	41	0	55	8	**1,784**
2005	597	403	485	209	301	23	42	0	69	9	**2,140**
2006	753	470	544	254	359	31	44	0	81	11	**2,546**
2007	896	537	610	283	421	47	45	0	94	14	**2,946**
2008	1036	580	670	302	485	66	47	1	106	16	**3,309**
2009	1162	612	720	311	546	86	48	1	115	17	**3,618**
2010	1274	629	756	313	600	107	49	2	121	19	**3,869**
2011	1403	653	783	312	651	146	48	2	125	19	**4,141**
2012	1528	662	806	311	694	179	44	3	128	20	**4,375**
2013	1637	653	811	306	730	207	40	4	125	19	**4,531**
2014	1739	657	816	299	761	231	36	4	126	19	**4,690**
2015	1852	665	823	290	784	251	33	5	132	19	**4,852**
2016	1971	675	821	280	797	267	29	5	134	18	**4,998**
2017	2073	691	818	272	802	279	27	6	135	17	**5,120**
2018	2177	710	808	265	804	289	26	6	137	16	**5,238**
2019	2275	726	795	258	804	297	26	7	139	15	**5,341**
2020	2366	740	781	253	803	303	25	7	140	14	**5,432**
2021	2451	752	767	248	802	308	25	7	142	13	**5,515**
2022	2530	763	753	243	801	311	26	7	144	12	**5,589**
2023	2604	772	740	239	801	313	26	7	145	11	**5,658**
2024	2672	781	727	236	801	314	26	7	147	10	**5,721**
2025	2734	788	716	233	803	315	26	7	149	9	**5,780**
Total	**39,785**	**15,459**	**17,504**	**6,453**	**15,405**	**4,447**	**924**	**87**	**2,897**	**347**	**103,308**

Appendix H: Annual e-waste generation amount, Grenada

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total e-waste
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**0**
1976	0	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	0	0	0	0	0	0	**0**
1981	0	0	0	0	0	0	0	0	0	0	**0**
1982	0	0	0	0	0	0	0	0	0	0	**0**
1983	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	0	0	0	0	0	0	**0**
1985	0	0	0	0	0	0	0	0	0	0	**0**
1986	0	0	0	0	0	0	0	0	0	0	**0**
1987	0	0	0	0	0	0	0	0	0	0	**0**
1988	0	0	0	0	0	0	0	0	0	0	**0**
1989	0	0	0	0	0	0	0	0	0	0	**0**
1990	0	0	0	0	0	0	0	0	0	0	**0**
1991	0	0	0	0	0	0	0	0	0	0	**0**
1992	0	0	0	0	0	0	0	0	0	0	**0**
1993	0	0	0	0	0	0	0	0	0	0	**0**
1994	0	0	0	0	0	0	0	0	0	0	**0**

1995	0	0	0	0	0	0	0	0	0	0	**0**
1996	0	0	0	0	0	0	0	0	0	0	**1**
1997	0	0	0	0	0	0	0	0	0	0	**1**
1998	1	1	1	1	0	0	0	0	0	0	**3**
1999	2	1	2	1	0	0	0	0	0	0	**8**
2000	6	3	5	3	1	0	0	0	0	0	**18**
2001	13	8	12	7	2	0	0	0	1	0	**43**
2002	30	17	28	16	5	1	0	0	2	0	**100**
2003	44	27	43	22	8	1	0	0	6	0	**150**
2004	66	31	54	31	12	2	0	0	8	0	**203**
2005	82	35	66	34	14	2	0	0	10	0	**244**
2006	96	35	71	36	16	3	0	0	11	0	**270**
2007	121	46	81	43	21	4	0	1	13	0	**330**
2008	148	45	86	43	24	5	0	1	13	0	**366**
2009	169	52	95	42	28	5	0	2	15	0	**408**
2010	188	55	99	43	29	6	0	2	16	0	**438**
2011	215	62	109	45	30	7	0	3	17	0	**487**
2012	236	64	121	50	31	9	0	3	19	0	**532**
2013	257	65	129	54	30	10	0	4	20	0	**570**
2014	283	73	138	63	30	12	0	5	22	1	**626**
2015	312	85	146	75	31	14	11	5	25	1	**705**
2016	344	98	153	89	35	16	28	6	28	1	**798**
2017	386	110	159	103	40	19	45	6	31	1	**901**
2018	435	135	175	118	47	22	63	7	35	2	**1,039**
2019	487	156	191	134	56	25	78	7	39	2	**1,176**
2020	541	174	206	150	66	29	91	8	42	2	**1,310**
2021	598	190	220	166	77	33	101	8	45	2	**1,441**
2022	657	204	231	181	88	37	109	9	47	2	**1,567**
2023	717	216	241	196	99	41	114	9	49	3	**1,687**
2024	778	227	250	209	110	45	118	10	51	3	**1,801**
2025	838	237	256	222	120	49	121	11	52	3	**1,909**
Total	**8,051**	**2,454**	**3,372**	**2,178**	**1,054**	**397**	**880**	**106**	**616**	**24**	**19,133**

Appendix I: Annual e-waste generation amount, Jamaica

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total e-waste
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**0**
1976	0	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	0	0	0	0	0	0	**0**
1981	0	0	0	0	0	0	0	0	0	0	**0**
1982	0	0	0	0	0	0	0	0	0	0	**0**
1983	0	0	0	0	0	0	0	0	0	0	**0**
1984	0	0	0	0	0	0	0	0	0	0	**1**
1985	0	0	0	0	0	0	0	0	0	0	**1**
1986	0	0	0	0	0	0	0	0	0	0	**1**
1987	1	1	0	0	0	0	0	0	0	0	**2**
1988	1	1	1	0	0	0	0	0	0	0	**3**
1989	1	1	1	0	0	0	0	0	0	0	**5**
1990	2	2	2	0	1	0	0	0	0	0	**7**
1991	3	4	2	1	1	0	0	0	0	0	**11**
1992	4	5	4	1	2	0	0	0	1	0	**18**
1993	7	8	6	1	3	0	0	0	1	0	**27**
1994	11	13	9	2	4	0	1	0	2	0	**42**
1995	16	20	14	3	7	0	1	0	2	0	**65**

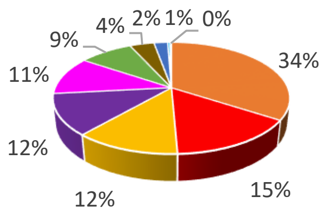
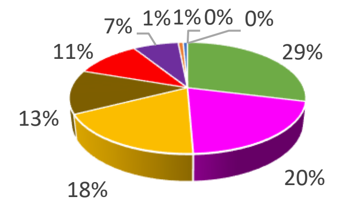
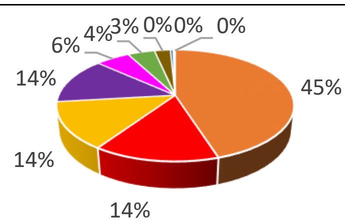
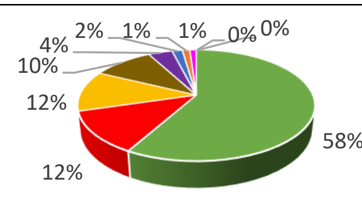
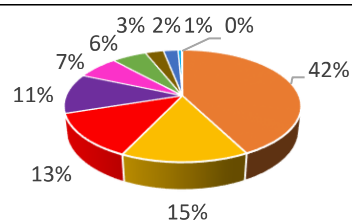
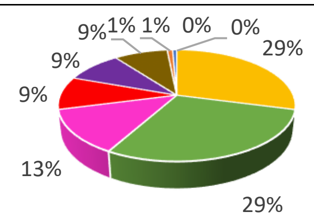
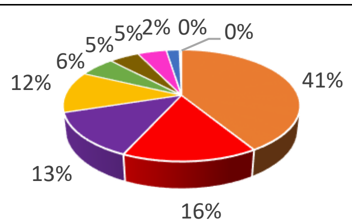
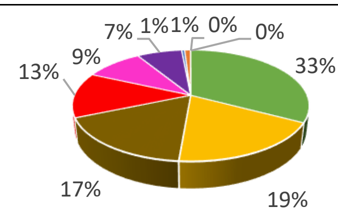
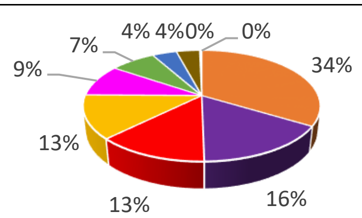
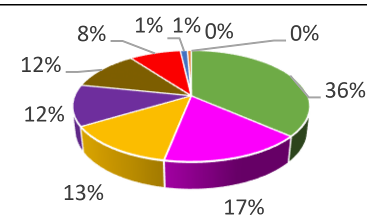
1996	25	31	22	5	10	1	1	0	4	0	**100**
1997	39	48	33	8	16	1	2	0	6	0	**153**
1998	60	73	52	13	24	2	3	1	8	0	**237**
1999	93	113	80	19	37	3	5	1	13	0	**365**
2000	144	175	123	30	57	4	8	1	20	0	**563**
2001	221	269	189	46	89	7	13	2	31	0	**868**
2002	341	416	292	71	137	10	20	3	48	1	**1,339**
2003	492	578	414	97	192	14	31	5	69	1	**1,894**
2004	686	752	513	128	254	19	40	7	91	2	**2,492**
2005	953	914	600	171	317	26	47	10	113	2	**3,153**
2006	1333	1136	706	239	395	39	53	13	158	3	**4,076**
2007	1717	1288	825	286	471	58	61	17	202	4	**4,929**
2008	2142	1533	917	339	561	79	67	21	245	5	**5,909**
2009	2549	1598	1190	439	642	105	161	25	293	6	**7,008**
2010	2908	1623	1325	561	709	130	241	29	325	7	**7,858**
2011	3222	1678	1487	688	769	154	310	33	349	8	**8,698**
2012	3535	1665	1584	826	814	178	376	37	369	8	**9,392**
2013	3846	1707	1644	962	842	200	435	40	390	8	**10,074**
2014	4147	1689	1737	1091	858	221	480	43	429	9	**10,705**
2015	4444	1728	1824	1178	857	241	505	45	475	9	**11,305**
2016	4740	1796	1883	1276	854	257	531	46	519	10	**11,914**
2017	5132	2026	1933	1437	862	275	597	47	587	10	**12,905**
2018	5532	2213	1975	1608	876	294	662	47	657	11	**13,874**
2019	5938	2372	2010	1786	899	312	719	47	722	12	**14,818**
2020	6349	2509	2042	1966	928	331	766	46	781	13	**15,732**
2021	6762	2628	2071	2145	964	351	804	45	830	15	**16,614**
2022	7175	2732	2098	2322	1005	370	832	44	869	16	**17,462**
2023	7585	2823	2121	2493	1049	389	853	43	900	17	**18,273**
2024	7989	2903	2141	2657	1097	409	868	42	923	18	**19,045**
2025	8383	2973	2157	2811	1146	429	878	40	940	19	**19,775**
Total	**98,529**	**44,047**	**36,026**	**27,707**	**17,750**	**4,912**	**10,373**	**784**	**11,372**	**214**	**251,713**

Appendix J: Annual e-waste generation amount, Trinidad and Tobago

Cat. / Year	LHA	SHA	ITE	CE	LE	EET	TLSE	MD	MCI	AD	Total e-waste
1966	0	0	0	0	0	0	0	0	0	0	**0**
1967	0	0	0	0	0	0	0	0	0	0	**0**
1968	0	0	0	0	0	0	0	0	0	0	**0**
1969	0	0	0	0	0	0	0	0	0	0	**0**
1970	0	0	0	0	0	0	0	0	0	0	**0**
1971	0	0	0	0	0	0	0	0	0	0	**0**
1972	0	0	0	0	0	0	0	0	0	0	**0**
1973	0	0	0	0	0	0	0	0	0	0	**0**
1974	0	0	0	0	0	0	0	0	0	0	**0**
1975	0	0	0	0	0	0	0	0	0	0	**0**
1976	0	0	0	0	0	0	0	0	0	0	**0**
1977	0	0	0	0	0	0	0	0	0	0	**0**
1978	0	0	0	0	0	0	0	0	0	0	**0**
1979	0	0	0	0	0	0	0	0	0	0	**0**
1980	0	0	0	0	0	0	0	0	0	0	**0**
1981	0	0	0	0	0	0	0	0	0	0	**1**
1982	0	0	0	0	0	0	0	0	0	0	**1**
1983	0	0	0	0	0	0	0	0	0	0	**2**
1984	0	1	0	0	0	0	0	0	0	0	**2**
1985	1	1	1	1	0	0	0	0	0	0	**3**
1986	1	1	1	1	0	0	0	0	0	0	**5**
1987	1	2	1	1	1	0	0	0	1	0	**7**
1988	2	3	2	2	1	0	0	0	1	0	**11**
1989	3	4	3	3	1	0	0	0	1	0	**16**
1990	5	6	4	4	2	0	0	0	2	0	**23**
1991	7	9	6	6	3	0	0	0	2	0	**35**
1992	10	14	8	10	5	0	1	0	4	0	**51**
1993	15	20	12	14	7	1	1	0	5	0	**76**
1994	22	30	18	21	10	1	1	0	8	0	**112**

1995	33	45	27	31	15	1	2	0	12	0	**166**
1996	48	66	40	46	22	2	3	0	18	0	**245**
1997	71	98	60	67	32	3	4	0	26	0	**363**
1998	105	145	89	100	48	5	7	0	39	0	**537**
1999	156	214	131	148	71	7	10	0	57	1	**794**
2000	231	317	194	218	104	10	14	1	84	1	**1,174**
2001	341	469	286	323	154	15	21	1	125	1	**1,737**
2002	505	694	424	478	228	22	31	1	183	2	**2,568**
2003	705	849	602	528	312	31	46	2	236	3	**3,313**
2004	946	1065	783	553	414	44	52	3	270	3	**4,133**
2005	1207	1197	945	593	515	95	58	4	314	4	**4,932**
2006	1568	1463	1126	661	620	151	64	5	368	5	**6,032**
2007	1937	1637	1349	709	741	211	71	7	409	7	**7,077**
2008	2382	1795	1552	885	873	288	439	9	502	9	**8,735**
2009	2888	1885	1821	1113	994	372	742	12	596	11	**10,434**
2010	3371	1951	2074	1266	1090	449	1029	15	662	14	**11,920**
2011	3830	2016	2251	1479	1164	534	1208	17	704	17	**13,220**
2012	4279	2080	2410	1651	1227	608	1401	20	720	19	**14,415**
2013	4736	2205	2551	1845	1278	671	1548	23	731	21	**15,609**
2014	5191	2373	2659	2071	1325	726	1679	26	751	22	**16,823**
2015	5628	2477	2735	2283	1392	773	1793	29	757	23	**17,888**
2016	6067	2611	2829	2583	1457	815	1919	32	785	23	**19,120**
2017	6489	2730	2905	2869	1521	852	2028	35	816	24	**20,269**
2018	6892	2837	2964	3135	1583	885	2116	38	848	24	**21,321**
2019	7272	2932	3008	3378	1642	913	2184	42	877	25	**22,271**
2020	7628	3016	3041	3596	1698	936	2236	46	901	25	**23,123**
2021	7961	3090	3066	3789	1750	957	2273	51	920	25	**23,882**
2022	8268	3156	3084	3957	1801	973	2300	56	934	25	**24,555**
2023	8551	3214	3097	4102	1848	987	2319	62	943	25	**25,150**
2024	8811	3265	3107	4224	1893	999	2331	68	949	26	**25,673**
2025	9047	3311	3114	4327	1936	1009	2340	73	952	26	**26,133**
Total	**117,212**	**55,298**	**54,380**	**53,072**	**29,777**	**14,344**	**32,272**	**679**	**16,512**	**412**	**373,957**

Appendix K: The distribution of total generated e-waste amount on five islands in different categories (in tonnes versus the number of units)

<table>
<tr><th></th><th>Categorization of the estimated e-waste (weight in tonnes) from 2019 to 2025</th><th>Categorization of the estimated e-waste (number of units) from 2019 to 2025</th></tr>
<tr><td>Aruba</td><td></td><td></td></tr>
<tr><td>Barbados</td><td></td><td></td></tr>
<tr><td>Grenada</td><td></td><td></td></tr>
<tr><td>Jamaica</td><td></td><td></td></tr>
<tr><td>Trinidad & Tobago</td><td></td><td></td></tr>
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- IT and telecommunications equipment
- Lighting equipment
- Toys, leisure and sports equipment
- Small household appliances
- Consumer equipment
- Monitoring and control instruments
- Large household appliances
- Electrical and electronic tools
- Medical devices
- Automatic dispensers