Journal of Cleaner Production 417 (2023) 138018

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Quantifying plastic use and waste footprints in SIDS: Application to Seychelles

Patrice Guillotreau [a,*], Sharif Antoine [b], Fatime Kante [c], Katrin Perchat [d]

[a] MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Sète, France
[b] Seychelles Fishing Authority (SFA), Victoria, Seychelles
[c] Ministry of Fisheries and Blue Economy, Victoria, Seychelles
[d] Yes Consulting, Victoria, Seychelles

ARTICLE INFO

Handling Editor: Giovanni Baiocchi

*JEL classification:*
D57
N57
Q25
R15

*Keywords:*
Plastics
Footprint
SIDS
Input-output analysis

ABSTRACT

Small Island Developing States (SIDS) are the most vulnerable territories to marine litter and plastic waste pollution. The magnitude of the issue and ways of action can only be known if the material flows and their origins are correctly estimated. Unfortunately, small territories are often left outside the global ecological footprint databases and models. The present research aims at quantifying the plastic footprint of Seychelles through a standard Environmentally-Extended Input-Output Analysis (EEIOA) and multi-regional input-output (MRIO) approach combining international and domestic data in the south-west Indian Ocean region. The results of several model specifications and industrial classifications are compared to the literature findings and show that SIDS may display the same level of plastic use and waste per capita as high-income countries, without the same infrastructure of waste treatment. A few services and exporting sectors concentrate the bulk of the territorial quantity of plastics used throughout the economy. The multi-regional Indian Ocean context helps to foresee potential joint actions in order to reduce the plastic footprint of SIDS.

## 1. Introduction

Small Island Developing States (SIDS) are vulnerable to the negative effects of plastic pollution due to their limited land and water resources, as well as their reliance on tourism as a source of income (Pratt, 2015). The plastic footprint of these states has become an important issue in the realm of environmental sustainability. It can be defined as the quantity of plastics used in a country for the direct and indirect consumptions of the resident end users along the industrial supply chains, whether located domestically or abroad.

Studies have shown that SIDS are disproportionately impacted by plastic pollution, with plastic waste often ending up in their marine and coastal environments, threatening their biodiversity and impacting their tourism industry (Owens et al., 2011). Research has found that the main sources of plastic waste in SIDS are domestic waste and tourism activities, littering and improper waste management practices (Monsanto et al., 2022).

Nearly 400 Mt of plastics are produced in the word annually (Plastics Europe, 2022). Plastic waste represents 60% of this yearly output and the volume of waste is expected to almost triple by 2060 (OECD, 2022). Because of waste mismanagement, leakages into the environment were estimated at 9.2 Mt per year (Ryberg et al., 2019). The cumulated stock in aquatic environments reached 139 Mt in 2019 (OECD, 2022). Long-term projections do not foresee any “peak waste” before the end of the 21st century, and the stock of marine litter issue will keep on growing with human population, urbanization, and consumption per capita (Jambeck et al., 2015). It becomes therefore urgent to identify the industrial sources of plastic consumption and waste in order to select effective abatement policies (Duchin, 2009).

Life-Cycle Analysis (LCA), Material Flow Analysis (MFA) and Environmentally-Extended Input-Output Analysis (EEIOA) represent useful approaches to estimate plastic footprints of countries, but are rarely developed by SIDS because of a data-deficiency context. In particular, the Plastic Use Intensity (PUI) and waste by monetary unit of output remain unknown and most estimates take place at the landfill or end-use stage (Meylan et al., 2018). This is why the current research proposes to transfer the international plastic use rates by industry to the industrial classification used commonly by some island territories pertaining to the Indian Ocean Commission (IOC) alliance (Seychelles, Madagascar, Mauritius, Comoros, Réunion). On the basis of European

* Corresponding author.
*E-mail address:* patrice.guillotreau@ird.fr (P. Guillotreau).

https://doi.org/10.1016/j.jclepro.2023.138018
Received 17 March 2023; Received in revised form 2 July 2023; Accepted 6 July 2023
Available online 10 July 2023

data, PUI and waste rates are defined by industry, re-scaled and converted into the local industrial classification and currency, assuming similar production technologies by type of output.

The EEIOA and physical models are being developed to distinguish Seychelles' consumption-based footprint from production-based territorial use directed towards exports and identify the plastic content of imports for intermediate and end uses. Various industrial classifications and methods (industry-by-industry *vs* product-by-product data, full input-output table *vs* separate domestic and import tables, single country EEIOA *vs* multi-regional models at the IOC level) are compared to help selecting the most suitable approaches and provide more accurate estimations of SIDS plastic footprint in a data-poor context. Plastic wastes are also considered and compared to what we know about the solid waste management in these island territories. Some policy recommendations follow the discussion of the findings to support efforts already undertaken by SIDS to phase out single-use plastics and reduce plastic uses and waste of plastic material.

The following section reviews the literature about the conventional methods in use to estimate plastic footprints. Section 3 develops several types of EEIOA and MFA models. Section 4 introduces the key data sources to define PUI coefficients by output. The fifth section compares various estimations of the plastic footprint of Seychelles with regard to the aggregation level of industrial classifications and the type of model. Finally a last section discusses the results to characterize the use and waste of plastics in Seychelles relatively to comparable countries in terms of income. Some key sectors are particularly concerned by the territorial use of plastics. They must be identified to design effective policies aiming at reducing their use.

## 2. Literature review

Studies about plastic footprints are divided between resource-based and emission-based footprint assessments, consumption-based vs production based territorial use, bottom-up vs top-down, or between LCA and EEIOA approaches (Boucher et al., 2019). From a large number of published articles, Chen et al. (2020) suggested to classify them into four categories: MFA, emissions and pollution papers, LCA, and studies of public attitude, human behaviour and policymaking. All of them are complementary and respond to different needs. For instance, LCA is more adapted to the production process all along the life of a good in order to consider input requirements in terms of materials, energy, water, $CO_2$ emissions, etc., but it fails to consider the plastic itself as a contaminant (Boucher et al., 2019). In particular, a meta-analysis of 31 LCA studies regretted the absence of unauthorized disposals in all LCA assessments, as though all the residuals were collected in landfills or subject to waste treatment which is far from being the case (Schweitzer et al., 2018). The impacts of marine plastic debris on biodiversity remain unknown at scales greater than individual organisms and not spatially distributed when using such methods (Woods et al., 2016). The transport of mismanaged plastic waste and its fate in the environment remain poorly documented, some authors simply assuming a fractional factor between 15% and 40% of mismanaged plastic waste leaking out to the marine environment (Jambeck et al., 2015). With LCA methods relying on a great amount of details for each product, there is also a need for harmonized standards (Boucher et al., 2019). This is why plastic footprints based on LCA methodologies are usually applied to a specific product, industry or company. For instance, a footprint of 1949 tonnes of plastic packaging (nearly 20g for each garment, or 0.25 kg per USD 10,000 of revenue) was estimated for a single clothing company in China (Liu et al., 2023). Comparisons are made difficult with such firm-specific and product-specific assessments. However, LCA approaches enable the selection of adapted waste management systems for certain industries like food or electrical and electronic equipment (Abejón et al., 2020).

EEIOA is more looking at environmental impacts along the supply chain throughout trade, overlooking the entire life cycle of a product or service (Miller and Blair, 2009). The LCA approach is more linked with materiality and EEIOA with circularity, but synergies and cross fertilization must be found to improve the metrics of environmental footprint, thus reducing the impacts and increasing circularity (Boucher et al., 2019). Input-Output models are interesting approaches to separate the plastic content of imported products from that embodied in exports, reflecting more accurately what is consumed domestically (*Ibid.*). Production-based assessments are distinguished from consumption-based footprints, the latter being usually deemed higher than the former (Towa et al., 2020). Baeta-Humanes (2021) found little evidence of this gap when she compared consumption-based and production-based plastic waste footprints by EEIOA methods for 48 countries. EEIOA studies are commonly applied at a national or multi-national scale, as illustrated by the complete supply-use tables published by the Danish Statistics institute (Gravgård et al., 2021). Such models provide a more holistic and general overview of plastic use as it encompasses direct and indirect uses throughout the whole supply chains, but they are perhaps not as accurate as LCA studies on a case by case product level. This is illustrated by the gap between the literature-based estimates of plastic footprints for EU citizens (84 kg per capita on average) and the assessment relying on product statistics and LCA methods not even including imports of raw materials and intermediate products along the value chain of plastics (129 kg per capita) (Amadei et al., 2022). However, some other authors concluded to similar results between EEIOA and LCA approaches applied to carbon footprints at city levels (Rama et al., 2021), or even slightly higher values from EEIOA because of under-reported services in the case of processed-based LCA analyses (Núñez-Cárdenas et al., 2022). LCA values would dominate EEIOA estimates at the early stages of the value chain, but an opposite domination would be observed at final stages (*Ibid.*).

The term footprint refers to "metrics that capture the direct effects of an activity as well as the indirect effects that are transferred along a supply chain" (Marques et al., 2017). When this concept is applied to environment, it aims at measuring all emission pollutants, resource inputs, energy or water, whether direct or indirect, associated with the consumption or the production of a good or service (Brunner and Rechberger, 2017). Material flow analysis (MFA) attempts to capture physical flows while reconciling materiality and circularity concepts (Hsu et al., 2021), borrowing to both LCA and EE-IOA approaches to establish a mass balance of traded goods (Geyer et al., 2017).

Such approaches (LCA, EEIOA, MFA) are nonetheless highly data consuming and rely on sector-consistent databases. Publicly available databases are gradually improving to encompass all physical inputs and outputs of the plastic supply chain. Material flows are connected to trade flows between industries and countries within hybrid frameworks mixing up physical (tonnes) and monetary units (Merciai and Schmidt, 2018). Environmental satellite accounts have been developed to allow for either waste (WIO), physical (PIO), and hybrid (HIO) input-output models, particularly in Europe (e.g. Exiobase project[1]). The latest version of the latter (Exiobase 3) is able to provide detailed information for multi-regional hybrid input-output (MRHIO) tables encompassing 164 product categories across 43 countries (Stadler et al., 2018). This explains the success of EEIOA methods relying on a thorough theoretical framework pioneered by Wassili Leontief more than fifty years ago (Leontief, 1970). However, the footprint estimations by EEIOA, PIO and MRHIO concern mainly the carbon and waste emissions of plastics, and more rarely the plastic materials flowing throughout trade and economies down to the marine environment (Cabernard et al., 2022). Out of 78 publications reviewed about IO models applied to waste management between 1990 and 2018, only a minority (less than 10%) refers to PIO and HIO models (Towa et al., 2020), although such models are the most relevant to circularity policies (Aguilar-Hernandez et al., 2018).

Another problem lies in the lack of available information regarding

[1] https://www.exiobase.eu/.

material flows and solid waste data in SIDS. Small island territories are unfortunately left outside most data collection efforts and merged into a "rest of world" category, making difficult the assessment of their own footprint (Guillotreau and Bistoquet, 2022). Such territories are nonetheless the most impacted by plastic pollution because they are surrounded by marine plastic litter and do not have the capacity to handle the fast growing amount of waste associated with plastic uses (Lachmann et al., 2017). The key economic sectors of SIDS are usually primary sectors (including fishing) and tourism (incl. hotel construction, food and accommodation services), which may result in a heavy use and discard of plastics (Issifu and Sumaila, 2020).

New approaches need to be created to fill this gap and extend conventional LCA, MFA and EEIOA models to estimate the plastic footprint of small territories and identify the industries and end uses responsible for generating plastic along supply chains, whether located inside or outside the country. Such an assessment would allow to implement appropriate abatement policies and promote a more circular economy. This is why this research suggests a way of combining available international data in terms of plastic use intensity by industry and input-output tables developed at the most relevant level in a small country like Seychelles, and in connection with trade partners. Several models using different levels of aggregation, industry-by industry *vs* product-by-product tables, single-country HIO and PIO models, and an original MRHIO framework at the Indian Ocean country level, are compared to propose a broad range of possible values of consumption-based plastic footprint and production-based territorial use. We hypothesize that the Seychelles footprint per capita is in line with levels reported in high-income countries, that export-directed industries play a major role in plastic territorial use and waste, and also that this footprint is concentrated in a few industries but not necessarily re-allocated away from primary and secondary sectors (Baeta-Humanes, 2021).

## 3. Method

### 3.1. An environmentally-extended input-output analysis (EEIOA) framework

In any Environmentally-Extended Input-Output analysis (EEIOA), the indirect plastic uses resulting from the inter-industry linkages along the supply chains are considered in addition to the direct utilization by each industry and end user (households, government, firms and rest of the world). A symmetric input-output table is therefore needed to calculate the input coefficients and the impact multipliers through the classical Leontief model:

$$X = (I - A)^{-1}.F \tag{1}$$

Where $X$ is a column-vector of outputs for all industries, $A$ is the matrix of technical (or input) coefficients (the industry's requirements in every input to produce one unit of output in monetary terms), $I$ is the identity matrix and $F$ is a column vector of final uses (internal and external, see below).

The impact factors are expressed as intensity rates in physical terms (e.g. tonnes of plastic) per monetary unit of output $z_j = Z_j/X_j$, where $Z_j$ denotes the industry $j$'s plastic consumption and $z_j$ the intensity (or direct impact) coefficient, i.e. the amount of plastic materials per unit of industry $j$'s output value.[2] The industry $j$'s plastic utilization is therefore $Z_j = z_j X_j$. Now substituting $X_j$ by its value in (1) gives the quantity of plastics directly and indirectly resulting from the demand level:

$$Z = z(I - A)^{-1}F \tag{2}$$

[2] Note that we can use other impact factors in the case of plastics, such as $w_j = W_j/X_j$, where $W_j$ is the industry $j$'s plastic waste and $w_j$ the plastic waste per unit of output.

The interpretation is easy: any change by one unit of final demand for commodity $j$ in vector $F$ will result in a $z\,(I - A)^{-1}$ shift of direct (the industry itself and its first suppliers) and indirect plastic uses (the suppliers' suppliers in a chain of cascading effects). What matters now is to separate the plastic use resulting from the sole domestic production from those embodied in inputs imported by the industries and in imports of final goods and services by end users. To do so, we followed the OECD stepwise method used to calculate the environmental footprint (Pasquier, 2018). Let's try first to measure the domestic emissions

$$Z_j^d = \widehat{z_j^d}\,\left(I - A^d\right)^{-1}\widehat{F^d} \tag{3a}$$

The capital letters denote the column-vectors, the hat symbol stands for an operator transforming a column-vector into a diagonal square matrix, the superscript $d$ means domestic.

Most of the time, symmetric industry-by-industry IO tables are used to estimate footprints, with a weak assumption on the structure of inputs, i.e. based on the sales structure of secondary products. This is why some authors suggest to start the EEIOA model by a non-symmetric Supply-Use Table, where a $V$ rectangle matrix represents the commodities supplied by all industries in rows, and $U$ the matrix of intermediate consumption of commodities used as inputs by each industry in columns (Jander, 2021). Let note $B$ the technology matrix ($B = U/_{x'}$), where $x'$ is the transpose vector of domestic industrial outputs, and $D$ the market share matrix ($D = V/_{q'}$), where $q'$ is the transpose vector of commodity supply at market prices, including both domestic and import products. Equation (3)now writes as:

$$Z_j^d = \widehat{z_j^d}\,(I - BD)^{-1}\widehat{F^d} \tag{3b}$$

Where the order of the new Leontief square matrix $(I - BD)^{-1}$ in Eq. (3′), based on a product-by-product table, is greater than that of $A$ in Eq. (3). For the simplicity of the presentation, we shall keep the former script $A$ in the following equations, even though we refer to the BD (product-by-product) matrix at the most disaggregated level of industries.

The import vector of the country must be split into the matrix of imported inputs ($A^m$) used by the domestic industries and the vector of imported commodities and services for final uses ($F^m$):

$$M = A^m X + F^m \tag{4}$$

Substituting $X$ by its value in (1), we obtain:

$$M = A^m\left(I - A^d\right)^{-1}F^d + F^m \tag{5}$$

The plastic use embodied in imports from a country $c$ will depend both on the market share of this exporting country in the local demand, on its own PUI coefficients by industry, but also on the technology (combination of inputs) used to produce a commodity. For instance, producing manufactured goods through bio-based or plastic-based inputs will not result in the same quantity of fossil-fuel plastic materials (Jander, 2021). Consequently, the plastic used embodied in imports can be written:

$$Z^{m,c} = \widehat{z^c}\,\left(I - A^c\right)^{-1}\widehat{M} \tag{6}$$

We can replace $M$ in Eq. (6) by its value in (5):

$$Z^{m,c} = \widehat{z^c}\left(I - A^c\right)^{-1}\left[A^m\left(I - A^d\right)^{-1}\widehat{F^d} + \widehat{F^m}\right] \tag{7}$$

By doing so, we can isolate the plastic materials embodied in imports of intermediate inputs by the domestic industries $Z_{IC}^{m,c} = \widehat{z^c}\,(I - A^c)^{-1}\,[A^m(I - A^d)^{-1}\widehat{F^d}]$, and the plastic embodied in imports of commodities for final uses, $Z_F^{m,c} = \widehat{z^c}\,(I - A^c)^{-1}\,\widehat{F^m}$

Assuming a certain stability of input coefficients throughout time, both for domestic or imported input requirements of industries, we can estimate the current level of plastic use for the year of reference, but also calculate the percent change of plastic after an economic shock by substituting $(\widehat{\Delta F^d} + \widehat{\Delta F^m})$ for $(\widehat{F^d} + \widehat{F^m})$.

In addition of Eq. (3)measuring domestic emissions, Eq. (7) represents the import content of the consumption-based plastic footprint, i.e. including the domestic demand in $\widehat{F^d}$ but excluding the foreign demand (exports) of domestically-produced goods and services. It can be distinguished from a territorial use inventory of production-based plastics, where the column-vector of exports will be re-integrated into $\widehat{F^d}$ but where $\widehat{F^m}$ will not be considered in Eq. (7).

### 3.2. Mapping the physical flows of plastics in the domestic economy

In Eq. (3) and (6), we used a mixed framework of environmental and economic linkages but it remains possible to look at the mere physical flows of plastics (in tonnes) by substituting the plastic equivalent of all monetary flows included in the IOT, whether they concern intermediate or final uses.

If we consider the quantity of plastics $\omega_i^d$ required to produce good $i$ as the sum of plastic requirements for intermediate ($\omega_{ij}$) and final plastic uses ($\omega_i^Y$), then we can define the technical (and physical) coefficients of plastic contents ($q_{ij} = \omega_{ij}/\omega_i^d$) which represent the share of plastics used to produce each intermediate consumption of products $i$ in the total use of plastics by industry $j$. We can use these ratios in the following equations:

$$\sum_j q_{ij} \times \omega_j^d + \omega_i^Y = \omega_i^d \tag{8a}$$

And in the matrix form:

$$Q\Omega^D + \Omega^Y = \Omega^D \tag{8b}$$

Where Q is the matrix of technical (physical) coefficients, $\Omega^Y$ is the column-vector of plastics for final uses and $\Omega^D$ is the column-vector of total plastic uses. We can therefore simplify:

$$(I - Q)^{-1}\Omega^Y = \Omega^D \tag{9}$$

This last formula indicates the tonnage of plastics used by the whole territorial economy as a function of plastic tonnage used to meet the final demand.[3] Note that the latter could be well split into several components, like a domestic and foreign final use of plastics ($\Omega^D = \Omega^{DOM} + \Omega^{EX}$) or by institutions (households, firms, government, exports). This Physical Input-Output (PIO) model helps to identify the sources and sinks of plastic uses, the material flows between industries, and those between industries and institutional agents. It can be represented through a Sankey (flow diagram) of plastics in circulation, either at the territorial level or in a multi-regional framework (Peters et al., 2011).

### 3.3. Towards a multi-regional IO approach in the Indian Ocean

Although foreign trade data in Seychelles are poorly detailed by commodity, origin and destination, it remains possible to use a simple MRIO model such as the one introduced by Miller and Blair (2009, p. 264), where more than one country would be considered:

$$Z = \hat{z}(I - CA)^{-1}C\widehat{F} \tag{10}$$

Where $Z$ represents the matrix of plastic materials by origin ($N$ industries x $K$ countries) resulting from the diagonal vector of final demand ($\widehat{F}$), wherever the goods are produced, $\hat{z}$ denotes a diagonal vector of PUI per output unit in the domestic and trade partner countries, the two matrices $A$ and $C$ are, respectively:

$$A = \begin{bmatrix} A^r & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & A^s \end{bmatrix} C = \begin{bmatrix} \widehat{c^{rr}} & \cdots & \widehat{c^{rs}} \\ \vdots & \ddots & \vdots \\ \widehat{c^{sr}} & \cdots & \widehat{c^{ss}} \end{bmatrix} \tag{11}$$

A is a block diagonal matrix whose submatrices represent regional technology structures (technical coefficient matrices). Matrix C represents trade flows within and between regions as a proportion (i.e. market share) of total trade for every commodity, including the trade from regions *r to s* (i.e. the sum in every column is equal to 1, i.e. 100% of a regional market *r*). Finally, $\widehat{F}$ is the demand from exogenous institutions (household consumption, firms' investment, government expenditure, etc.), both from the domestic country and trade partners (exports). The multipliers obtained by $[\hat{z}(I - CA)^{-1}C]$ would give not only the direct and indirect uses of plastics due to a level or a change of exogenous final demand in the country, but would allocate the effects across supplying regions according to the percentages embodied in the components of block matrix C (Miller and Blair, 2009).

## 4. Data: plastic use intensity (PUI) and waste by industry

The first step aims at looking for plastic use intensity coefficients, industry by industry, to obtain the $z_j$ vector. To this end, we used the plastic unit value of EU-28 imports in 2019 (World Bank data[4]), hence a unit price of 3783 euros per tonne. We assumed in a first approach that this average price was the same whatever the type of plastic inputs consumed by each industry. Secondly, we divided the industrial intermediate consumptions of 'Plastic & rubber' products recorded in the EU-28 IO Table by this average price to obtain a quantity (in tonnes) of intermediate use of plastics for each of the 65 industries. Dividing this quantity by the output value of each industry, we obtained the PUI co-

**Table 1**
PUI 2019 adjusted to the Seychelles Industrial Classification ($z_j$ vector).

| | t.M€$^{-1}$ | t.MSCR$^{-1}$ | t.MUSD$^{-1}$ |
|---|---|---|---|
| *Agriculture* | 1.59 | 0.10 | 1.42 |
| *Fishing* | 1.70 | 0.11 | 1.52 |
| *Manuf. of fishery products* | 3.82 | 0.25 | 3.41 |
| *Manufacture of other food* | 3.82 | 0.25 | 3.41 |
| *Beverage & tobacco* | 3.82 | 0.25 | 3.41 |
| *Manufacturing, other* | 4.22 | 0.27 | 3.77 |
| *Plastics & rubber* | 32.27 | 2.08 | 28.82 |
| *Electricity, gas, steam* | 0.42 | 0.03 | 0.37 |
| *Water-sewerage-waste* | 1.08 | 0.07 | 0.97 |
| *Construction* | 5.01 | 0.32 | 4.48 |
| *Wholesale & retail trade* | 2.24 | 0.14 | 2.00 |
| *Transportation and storage* | 0.79 | 0.05 | 0.71 |
| *Accommod. & food service* | 0.73 | 0.05 | 0.66 |
| *Info. & communication* | 0.55 | 0.04 | 0.49 |
| *Financial & insurance* | 0.16 | 0.01 | 0.15 |
| *Real estate activities* | 0.00 | 0.00 | 0.00 |
| *Owner occupied dwellings* | 0.29 | 0.02 | 0.26 |
| *Professional, sci. & techn.* | 1.31 | 0.08 | 1.17 |
| *Admin. and support service* | 0.89 | 0.06 | 0.80 |
| *Public admin. and defence* | 0.20 | 0.01 | 0.18 |
| *Education* | 0.12 | 0.01 | 0.11 |
| *Human health & social work* | 0.48 | 0.03 | 0.43 |
| *Arts, entertain. & recreation* | 0.47 | 0.03 | 0.42 |
| *Other service activities* | 0.81 | 0.05 | 0.72 |

Note: The 2019 exchange rates were €1 = SCR15.51 = USD 1.12 (ECB, 2022).

[3] Note that the plastic footprints are equivalent in the formulas: $\hat{z}(I - A)^{-1}\widehat{F^d} = (I - Q)^{-1}\hat{z}\widehat{F^d} = (I - Q)^{-1}\Omega^Y$, [Cf. Eq. (3) and (9)]. The first two sides of the equality combine physical and economic elements, while the last model relies only on physical materials.

[4] World Integrated Trade Solution (WITS), World Bank trade statistics HS6, Product code 392190 (Plastics; plates, sheets, film, foil and strip, other than cellular imports by country in 2019). https://wits.worldbank.org/trade/comtrade/en/country/EUN/year/2019/tradeflow/Imports/partner/ALL/product/392190.

efficients, i.e. the quantity of plastics required per M€ of output (Table 1). The average value was 2.29 t.M€$^{-1}$, the second maximum value (after the 'Plastic and rubber industry' with 32 t.M€$^{-1}$) being reached by the car industry with 10.3 tonnes per M€, the minimum being observed in the service industries, for instance in 'legal and financial services' (0.4 t).

In a third step, the PUIs were converted into tonnes of plastics per million of Seychelles rupees (SCR) for the 23 industries of the Seychelles Industrial Classification (SIC). Some of the 65 PUI coefficients of the EU industrial classification had therefore to be averaged to fit with the SIC. For instance, the PUI coefficient used for the Seychelles industry called '*Manufacturing, other'* was the weighted average PUI of 18 different EU manufacturing industries. Conversely, for those industries more detailed in Seychelles (e.g. *Manuf. of fishery products, Manuf. of beverage & tobacco, Manuf. of other food),* the unique EU coefficient available was used for the three local ones.

The $z_j$ vector was diagonalized into a matrix $\widehat{z_j^d}$ and the calculus described in the previous section can begin to disentangle the content of plastics in domestic production and trade (imports or exports). Another impact vector ($w_j$) regarding the quantity of plastic waste generated by every industry (Nakamura and Kondo, 2009) can be extracted from Eurostat data.[5] Fifty-nine categories of waste are available for 22 NACE categories (and another category for household direct waste) since 2004. The category 'Plastic wastes (w074)' was selected at the EU-27 level in 2019, along with the EU-27 IOT data to divide the waste by the industrial output. Previously, the 22 NACE had to be adjusted to the Seychelles Industrial Classification (23 industries and 35 products) by a weighted average method based on the local structure of output, like for PUIs.

The application of the EEIOA model requires different types of data: intermediate and final uses, PUI, plastic waste by industry … All these data are not available yet for the Republic of Seychelles. For the industrial production technology, we used the Supply and Use Table (SUT) released by the National Bureau of Statistics (NBS) in 2021 for the year 2019, with a selection of 23 key industries and 35 products for the domestic economy (NBS, 2021). On that basis, an input-output table was constructed but with no distinction between domestic and imported inputs. Consequently, we had to estimate first the import (interindustry) matrix ($A^m$) by allocating the vector of imports $M$ proportionately to the distribution of intermediate and final output (see Miller and Blair, 2009 for an explanation of the method, p. 151). From that point, we were in a position to calculate both $A^d$ and $A^m$ matrices, the sum of which representing the total technical coefficient matrix ($A = A^d + A^m$). The $A$-matrix was used as a proxy of the foreign country technology structure, assuming that both national and foreign technologies were identical. This is not unrealistic because the biggest domestic industries in Seychelles (such as the fish cannery, *Indian Ocean Ltd*) are owned by foreign holding companies, compete internationally and export most of their output to EU countries (France, UK, Italy, Germany …), hence having the highest technology and environmental standards to export their products.

The matrices $A^d$, $A^m$ and $A^c$, represent the technology matrix of Seychelles, the technology of using imported inputs in Seychelles, and the technology of partner country C, respectively. We assumed that the technology of country C was equivalent to the total matrix A, considering that the technology is the same for Seychelles and its trade partners in a first approximation (otherwise, we would need more information about IOT structures for each trade partner).

First, we ran the models described in Equations (3) and (7)by using the final use diagonal vectors $\widehat{F^d}$ and $\widehat{F^m}$ corresponding to the final use of 2019 (columns Household consumption + Government expenditure + Investment for domestic products, not including the Export column) and the final demand for imported goods, respectively. Then we ran the model for the export vector (but not accounting for embodied imports this time) to estimate the territorial use of plastics for both domestic and foreign final consumptions.

## 5. Results

### 5.1. A first estimation of the Seychelles plastic footprint

Let's first display the results obtained by the consumption-based plastic footprint, whatever the country where the materials originate from, estimated with the 23-indutry Seychelles classification (without a specific plastic industry). The results are given in Fig. 1a and calculated from Equations (3) and (7)with a 23-industry by industry symmetric input-output table.

The total consumption-based footprint exceeds 6500 tonnes (66.8 kg per capita) and the production-based territorial use is slightly lower at 6200 t (63.1 kg p.c.). The red box in Fig. 1 (3790 t) measures the plastic use of local industries for the final demand of Seychellois residents (Eq. 3). The yellow rectangle of the right chart (1709 t) refers to the amount of plastic materials embodied in imports of final products for domestic consumers ($Z_F^{m,c}$) and the orange rectangle (1023 t) to the plastics embodied in imports of intermediate products used by the local industries ($Z_{IC}^{m,c}$). For instance, whenever the wholesale industry imports products that are wrapped in plastic films, it will be accounted for in this industrial category.

On the right-hand side (Fig. 2b), we estimated the use of plastics by domestic industries, whatever the destination of products (domestic or export). Eq. (3)was used but the $F$-vector now includes export. The green

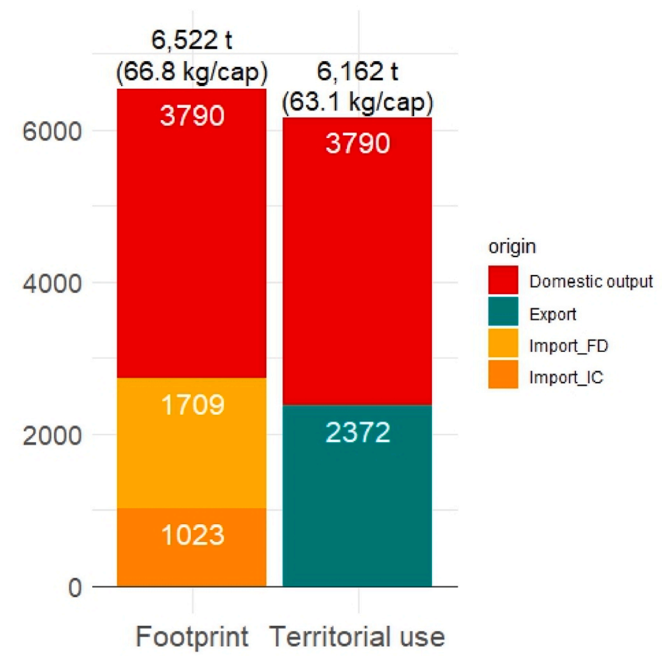


**Fig. 1.** Annual consumption-based plastic footprint (a) and production-based territorial use (b) (in tonnes and kg per capita).
**Note:** own elaboration. Domestic = plastics used by territorial industries for domestic use, Import_IC = plastics embodied in imports for intermediate consumption, Import_FD = plastics embodied in imports for final domestic demand, Export = Plastics used by territorial industries for foreign demand. The Seychelles Industrial Classification (SIC) with 23 industries was used. The Seychelles population was 97,625 inhabitants in 2019 (NBS, 2022).

[5] On the Eurostat portal, the database [ENV_WASGEN_custom_4721070] supplies the 'Generation of waste by waste category, hazardousness and NACE Rev. 2 activity'. https://ec.europa.eu/eurostat/web/products-datasets/product?code=ENV_WASGEN. See Table A1 of waste coefficients $w_j$ in Appendix.

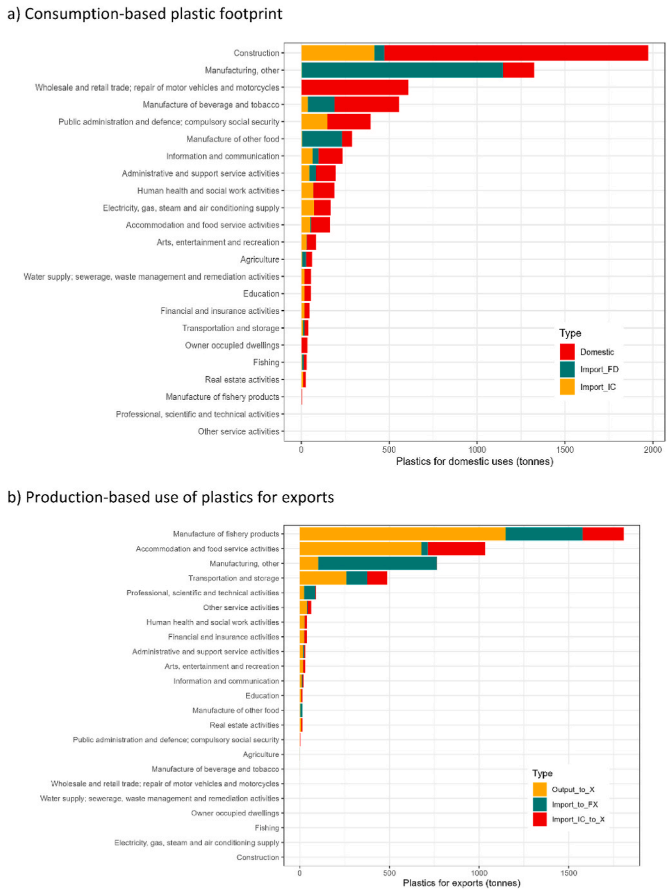


**Fig. 2.** Plastic footprint (a) and use of plastics for exports by industry (b) [in tonnes, 2019].
Note: Own elaboration. *Domestic = plastics used by territorial industries for domestic use, Import_IC = plastics embodied in imports of intermediate products, Import_FD = plastics embodied in imports of final products, Output_to_X = Plastics used by territorial industries for foreign demand, Import_to_FX = Plastics embodied in imported final products for re-exports, Import_IC_to_X = plastics embodied in imported intermediate products for re-exports.*

rectangle (2372 t) represents the plastic content of exports in 2019. These effects can be studied by industry for both consumption-based footprint (Fig. 2a) and production-based use for exports (Fig. 2b).

As far as domestic final consumptions are concerned, construction and manufactured good (such as automotive, electric house devices or mobile phones) industries represent more than half of the plastic use in Seychelles, followed by wholesale & retail, manufacturing of beverage & tobacco, public administration and the manufacture of other food products (Fig. 2a). Any national effort aiming at reducing the plastic footprint should put the emphasis on these six industries. We note that 87% of plastic materials embodied in manufactured goods are imported to meet the domestic final demand (e.g. cars, smartphones, appliances, etc).

When it comes to the territorial use of plastics for exports (Fig. 2b), the manufacturing of fishery products, the food and accommodation services, other manufacturing industries and transportation & storage are the top four industries. Although mostly sold in metal cans, processed fish also utilizes a great quantity of plastics as inputs (wrapping films, Styrofoam boxes, PVC containers, etc.).

This preliminary study was a first estimation of the plastic in use in the country, but it ought to be complemented by industry-specific or consumption surveys near households and companies to better understand the domestic behaviours and levers in order to look for incentives that could reduce or re-use this amount of plastics throughout the economy. Moreover, there is no specific industry of plastics considered thus far.

#### 5.1.1. *Risk analysis with a Monte Carlo approach*

Because the nature and average price of plastic can be different from one industry to another, we carried out a probabilistic analysis (Kawecki et al., 2018) where the unit price of intermediate consumption of plastics purchased by each industry could vary from €3200 to €4200 per tonne (below and above the reference price of €3,783, see Section 4), which would represent a percentage change of −15% and +11% from the initial average price. Consequently, the PUI of each industry could fluctuate randomly within a range determined by a uniform law set between the minimum and maximum values, and result in an output set of 5000 footprint values (in kg per capita) combining randomly the PUI coefficients. Some statistics were computed out of the distribution, showing a median footprint of 77 kg per capita, with a minimum value of 71 kg and a maximum value of 83 kg. The table of results and two diagrams showing the histogram and cumulative probability of footprint values are shown in Appendix A1.

### 5.2. *New estimation after including a distinct industry of plastics*

Although no plastic industry exists in Seychelles, this industry was separated from other manufactured products because the physical requirements of polymer inputs by the plastic industry itself is far greater than for any other industry (*29 t.MUSD*$^{-1}$ for the plastic industry vs *3.8 t.MUSD*$^{-1}$ for all other manufactured goods). A weighted average (by output) is used to aggregate the 23-industry coefficients into a 5-industry $z_i$-vector to simplify the symmetric IOT and adjust it to other countries in a multi-regional model (Table 2).

The upper blue-green section of Table 2 is the usual monetary IOT including an additional industry of plastic products. If the latter are purchased as inputs by all industries, they are entirely imported from overseas for a total value of 80 MUSD, hence with a null GVA for the domestic economy. The domestic services (including transportation and storage, wholesale and retail sectors, accommodation and food services …) buy a great share of plastic inputs, before the manufacturing industry.

The lower (yellow and brown) section of Table 2 displays the converted monetary values in physical terms, i.e. the quantity of plastic embodied in products used by each industry and final use. Between the two tables are the impact factors, $z_i$ for the plastic use intensity coefficient for each product category and $w_i$ for the waste per output unit, both being measured in tonnes per MUSD. The picture is different because we can see now the higher quantity of plastics used by the manufacturing and plastic industry and by households' final consumption, most of this tonnage being embodied in imports (e.g. cars, appliance, textile, etc.). Using the same methodology (Eq. 3 and 7), the estimated plastic footprint with five industries is now 7238 t (i.e. 74.1 kg per capita). This consumption-based footprint is significantly higher than the previous estimation of 6522 t (66.8 kg p.c.). The introduction of a specific plastic industry with a higher technical coefficient explains the difference. The production-based territorial use of plastics is slightly lower (5326 t, i.e. 54.6 kg p.c.) because it now excludes the imported content of exports, of which 40% is for foreign demand.

A more accurate analysis could be obtained with a more detailed industrial classification (Boucher et al., 2019). Therefore we applied Eq. (3') and Eq. (7) to a product-by-product Supply-Use Table (SUT with 35 product categories, including an industry of chemicals, rubber and plastics) (AfDB, 2021). This time, the estimated consumption-based footprint is 7232 t (74.1 kg p.c.), i.e. very close to the previous 5-industry model. The production-based territorial use is 6038 t (61.8 kg p.c.), of which 2190 t (22.4 kg p.c.) for the mere plastics embodied in exported products.

**Table 2**
The Seychelles EE-IOT 2019 with 5 industries (MUSD and tonnes).

| 2019 | Industries | | | | | Final uses | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MUSD | Fish | Food | Manuf | Plastic | Services | Household | Government | Investment | Exports | Trade margins | TOTAL USES |
| Fish | 90 | 0 | 0 | 0 | 9 | 12 | 0 | 0 | 306 | 0 | 417 |
| Food | 6 | 16 | 1 | 0 | 87 | 231 | 0 | 0 | 4 | 0 | 345 |
| Manufactured | 31 | 12 | 209 | 1 | 232 | 187 | 0 | 409 | 191 | 0 | 1 272 |
| Plastics | 14 | 6 | 19 | 0 | 34 | 16 | 0 | 0 | 0 | 0 | 90 |
| Services | 43 | 15 | 32 | 0 | 642 | 478 | 349 | 0 | 779 | 185 | 2 522 |
| TOTAL domestic IC | 184 | 48 | 262 | 1 | 1 004 | | | | | | |
| Imports | 122 | 179 | 793 | 80 | 382 | | | | | | |
| Taxes on products | 2 | 69 | 95 | 9 | 92 | GDP at market prices | | | | | |
| GVA | 109 | 49 | 123 | 0 | 1 043 | | MUSD *1590* | | US$ 1 = SCR 14,49 | | |
| Output | 417 | 345 | 1 272 | 90 | 2 522 | | | | | | |
| $Z_i$ (tonnes/MUSD) | 3,154 | 3,045 | 3,623 | 28,824 | 0,654 | | | | | | |
| $W_i$ (tonnes/MUSD) | 0,781 | 0,790 | 0,813 | 1,742 | 0,166 | | | | | | |
| Fish (t) | 284 | 0 | 0 | 0 | 28 | 37 | 0 | 0 | 966 | 0 | 1 315 |
| Food (t) | 19 | 48 | 3 | 0 | 265 | 703 | 0 | 0 | 12 | 0 | 1 049 |
| Manufactured (t) | 112 | 43 | 757 | 4 | 841 | 679 | 0 | 1 481 | 691 | 0 | 4 609 |
| Plastics (t) | 401 | 168 | 561 | 0 | 994 | 475 | 0 | 0 | 0 | 0 | 2 599 |
| Services (t) | 28 | 10 | 21 | 0 | 420 | 313 | 228 | 0 | 509 | 121 | 1 649 |

Sources: NBS and AfDB (2021).

### 5.3. Physical flows of plastics throughout the Seychelles economy

On the basis of model (9), we can restrict the analysis to the sole physical flows of plastic materials circulating in the Seychelles economy, as shown in the lower section of Table 3, so as to build a Physical Input-Output (PIO) model (Towa et al., 2020). With the mere stimulation of the domestic final demand, the physical multipliers included in the inverse matrix $(I - Q)^{-1}$ would generate 6664 t (59%) out of the 11,222 t circulating directly and indirectly in the whole territory for intermediate and final uses, meaning that a large share is also embodied in exports (41%). Three quarters of these material flows stem from the manufacturing and plastic sectors, but the food industry would also represent a significant share (13%) and services too (14%). The picture is different when the local economy is only stimulated by exports because the fish processing industry would then play a substantial role (27% of exported plastics), as shown by the following flow diagram (Fig. 3):

Own elaboration. All plastics circulating in Seychelles are imported. Blue flows represent plastic materials circulating between industries. All the waste (black flows) is produced by final uses but can be traced back to the responsible industries, along with a direct waste from household consumption.

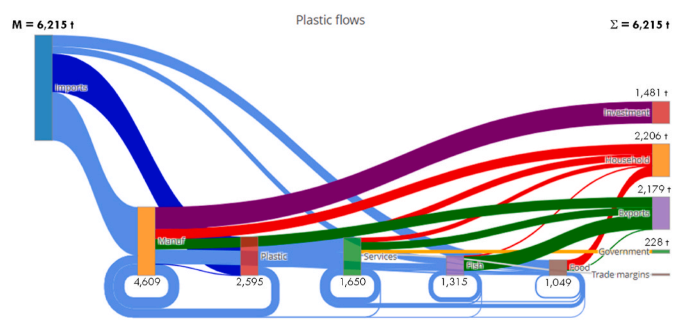


**Fig. 3.** Sankey diagram of plastic material flows (in tonnes)
Own elaboration. All plastics circulating in Seychelles are imported. Blue flows represent plastic materials circulating between industries. All the waste (black flows) is produced by final uses but can be traced back to the responsible industries, along with a direct waste from household consumption. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3, derived from the PIO model, shows the mass balance between supply (i.e. all coming from imports) and end uses of plastics (total = 6215 t). The blue flows represent the intermediate uses of plastics (including imports), all other colours symbolizing the plastic embodied in final uses. Household consumption is a major driver of plastic flows through the purchase of manufactured and food products (35%), but exports are also responsible for more than one third of plastic flows through sub-sectors like canned fish, transportation, food and accommodation services, etc. Firms only consume plastics through manufactured goods. The flow chart also shows how plastic flows circulate between industries through intermediate goods and services, with several important loops of intra-consumption.

**Table 3**
The Plastic footprint of Seychelles in 2019 from various EEIOA models.

| 2019 | Distinct plastic industry included | Consumption-based footprint (tonnes) | Footprint per capita (kg/cap.) | Production-based use for export (PBX) (tonnes) | PBX per capita (kg/cap.) |
|---|---|---|---|---|---|
| **EEIO_4** | No | 5078 | 52.0 | 3539 | 36.3 |
| **EEIO_5a** | Yes | 6506 | 66.6 | 4449 | 45.6 |
| **EEIO_5b** | Yes | 7238 | 74.1 | 2096 | 21.5 |
| **MRIO_5** | Yes | 7109 | 72.8 | 4009 | 41.1 |
| **EEIO_23a** | No | 5499 | 56.3 | 3703 | 37.9 |
| **EEIO_23b** | No | 6522 | 66.8 | 2372 | 24.3 |
| **EEIO_35a** | Yes | 6396 | 65.5 | 3158 | 32.3 |
| **EEIO_35b** | Yes | 7232 | 74.1 | 2190 | 22.4 |

Note: EEIO_4, EEIO_5a and EEIO_23a models correspond to Eq. (2) with 4 (without plastics industry), 5 (with plastics industry) and 23 industries (without), respectively. EEIO_5b, 23b and 35b follow Eq. (3)or (3′) to (7) with the respective number of industries or product categories (EEIO_35 relies on a product-by-product table including the plastics industry). MRIO_5 applies Eq. (1) with five industries in the Seychelles and four other Indian Ocean island countries and the rest of the world. The population of Seychelles in 2019 was 97,625 inhabitants.

### 5.4. Plastics circulating in the south-west Indian Ocean territories

The previous results concern a single country, but it seems also interesting to include several trade partners belonging to the Indian Ocean Commission (Comoros, Mauritius, Madagascar, Seychelles and La Réunion). The data collection process is made more complex because only Seychelles and Mauritius have developed their own IOT. The French territory of La Réunion reports some data by industry (output, total intermediate consumption, gross value added). Other developing states such as Madagascar or Comoros release very few public economic statistics. In such a data deficient context, we assumed in a first attempt that the economic specialization of Madagascar looked like an agricultural economy (e.g. Jamaica) and referred to the technology (Leontief) structure of this country. In the same way, we shall assume that the industry structure in Comoros behaves like the Seychelles one, La Réunion like Mauritius and the rest of the world like the EU-28 group. This framework can be improved by any further statistical information made available by a country. As far as the trade structure is concerned, we used the UN Com Trade database of goods and services by origin and destination for the five major product categories (fish products, food products, manufactured goods, plastics and services). The available supply tables gave the breakdown between domestic and imports by product category for the IOC members and their trade partners. When the information was missing for services, we assumed that all services were domestically produced.

We applied Model (10) to the vector of final uses in Seychelles (domestic uses and exports). The results are displayed in Fig. 4 below:

The total requirements of plastics by Seychelles, mixing up those for domestic (two thirds) and foreign uses (one third), are now reaching 8844 t. It is worth noting that half of the footprint is due to the manufacturing industry (e.g. plastic embodied in vehicles, electric or electronic equipment, etc.). On the left-hand side chart in Fig. 4, we observe that most plastics are imported from outside the Indian Ocean region (China, EU, South-Africa, USA, etc.). A smaller proportion is passing through Seychelles-based manufacturing activities (furniture, repair and maintenance of equipment, etc.). Interestingly, services are the second most important sector of plastic consumption, with 22%. A lot of services like wholesaling and retailing, transportation and storage, accommodation and food services, information and communication … are themselves containing a lot of plastic materials. Then comes the food industry (e.g. PET bottles, yoghurt pots, styrofoam boxes …) with 18%.

On the export side (right graph of Fig. 4), the fish industry leads in the quantities of plastics sent abroad, accounting for 41% of materials, followed equally by services and manufactured products (29% each). This is not surprising since the fish processing industry is the country's main export industry and accounts for 8–15% of GDP (Guillotreau and Bistoquet, 2022). Services such as tourism (airlines, hotels and restaurants, car rental, yachting and recreational activities, …) are of crucial importance for the domestic trade balance and foreign exchange revenues. For these two macro-sectors (fish industry and services), the origin of plastics comes equally from domestic industries after intermediate use and re-processing, hence value-adding, and from the plastic and other manufactured goods industries located in the rest of the world. Madagascar and Mauritius contribute for a small fringe to the use of plastics by Seychelles for the sake of domestic and export consumptions, mainly by supplying manufactured or plastic products used by the fish product industry. However, it appears quite clearly that the Indian Ocean island territories are poorly connected by international trade and more turning to the rest of the world for their supply (Levin et al., 2018).

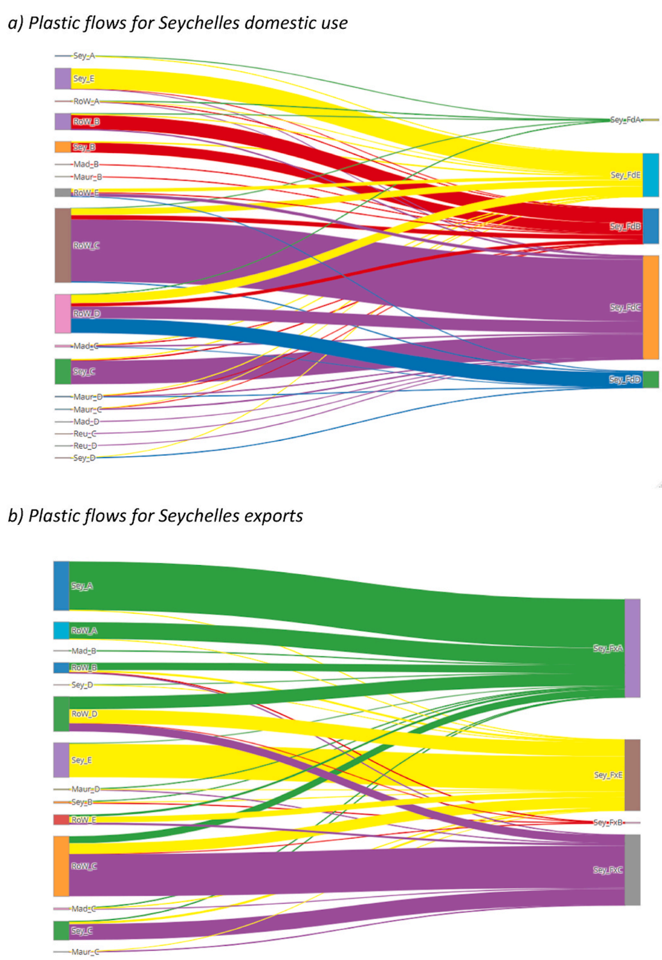


**Fig. 4.** Origin of plastic materials used by Seychelles activities for domestic (a) and foreign (b) uses.
*Note*: Flows in tonnes. *Sey* = Seychelles, *Mad* = Madagascar, *Maur* = Mauritius, *Reu* = Réunion, *Row* = Rest of World. *A* = Fish products (green), *B* = Food products (red), *C* = Manufactured goods (purple), *D* = Plastics (blue), *E* = Services (yellow). *Sey_Fd(i)* = Seychelles final domestic uses of plastics embodied in product *i*, *Sey_Fx(i)* = Foreign uses (= Seychelles exports) of plastics embodied in product *i*. Only flows > 1t were kept in the diagram.

### 5.5. Estimation of the Seychelles plastic waste

Finally, we can develop the same analysis as in Section 5.2 to look at plastic waste as impact factor (Table A2 in Appendix). Based on a 35 × 35 product-by-product table and equations (3') to (7), we obtained a consumption-based *Plastic Waste Footprint (PWF)* of 1622 t (16.6 kg p.c.). The production-based territorial waste amounts to 1682 t (17.2 kg p.c.) after including production waste for exports. When dividing these quantities by the tonnage of plastic materials found in Section 5.2, the discard rates would lie between 22% for domestic consumers and 28% for resident producers. These amounts look pretty much in line with other rates found in the literature (Baeta-Humanes, 2021; OECD, 2022). The question now becomes: which proportion of the waste leaks out to the environment as marine litter?

In absence of any specific study, we can only refer to the literature assessing marine litter from the percentage of mismanaged waste adjusted to the population within 50 km of the coast (Jambeck et al., 2015). In the supplementary materials of the latter study, the Seychelles mismanaged waste rate is 39%, thus potentially 633 t of plastic marine debris per year when applied to the 1622 t of plastic waste. The total quantity of mismanaged waste in 2010 was estimated at 4619 t for Seychelles in the Jambeck et al. (2015) study, which is seven times more than our own estimation. Presumably, the waste coefficients derived from the Eurostat database under-estimate the quantity of waste disposal in Seychelles.

## 6. Discussion

Although first countries hit by marine pollution, SIDS have a low capacity to handle the growing amount of plastic waste generated by their domestic consumption (Mata-Lima et al., 2021). Some studies showed that marine litter is dominated (more than half) by plastics and that sixty percent are issued from local land-based catchment (Verlis and Wilson, 2020). This is why it is so important for SIDS to identify the sources of plastic pollution and contain them by taking mitigation measures. The LCA, MFA and EEIOA approaches have made significant improvements for the last decade and databases are now available in a great number of countries (Towa et al., 2020). Unfortunately, small island territories are often left outside the scope of such studies because of their size and lack of survey data (Guillotreau and Bistoquet, 2022).

### 6.1. Comparison between various EEIOA models to calculate the plastic footprint of Seychelles

In the present study, we suggest to use the plastic use and waste coefficients from international databases coupled with supply and use tables to create single-country or multi-regional PIO and EEIOA models for SIDS and thus estimate their plastic use and plastic waste footprints. Such an approach was made possible by the estimation of PUI coefficients derived from World Bank trade data and Eurostat data on plastic waste by industry (NACE2). Because the National Bureau of Statistics in Seychelles released its first Supply and Use Tables (SUT) in 2019 with 23 industries and 35 product categories, we could create several EEIOA models with various levels of aggregation, including or not a specific Plastic industry, and testing for several model specifications. The results are synthesized in Table 3.

Even though Seychelles has no domestic plastic industry and imports all plastic materials (PVC or PE for wrap, PET for bottles, styrofoam boxes, …), adding a separate plastic industry with a specific PUI coefficient distinct from manufactured goods increased significantly the plastic footprint which was found probably closer to the actual value. In overall, a Seychellois resident would be responsible of 75 kg of plastic use per year because of her own consumption. Interestingly, either a selected classification of 5 or 35 activities does not affect the final result around 7235 t. It is admitted that the accuracy decreases with the level of aggregation (Boucher et al., 2020) but in the present case the single country EEIO model with five industries confirmed the outcome of the more complete model. This result is important to further extend the estimation in the Indian Ocean multi-regional context where the industrial classifications need to be harmonized between heterogeneous countries in terms of income per capita and national account statistics. In spite of incomplete information about the technology structure and final uses for several IOC countries, the MRIO was able to replicate precisely the consumption-based footprint resulting from the best single-country EEIOA models (~7100 t).

Another important result of Table 3 lies in the model specification itself. In EEIO_4, _5a, _23a and _35a models, Eq. (2) in Section 3 was used with a technical input matrix cumulating domestic and imported intermediate consumptions, unlike EEIO models 5b, 23b and 35b separating domestic and imported inputs in Eq. (3) to (7) (Section 3), as recommended by the standard environmental footprint methodology (Wiebe and Yamano, 2016). The first approach significantly under-estimates the weight of plastic use embodied in imports for both intermediate and final uses. The second approach demands a first step to estimate the proportion of imports used for intermediate and final consumptions, with a method suggested by Miller and Blair (2009), but gives a more reliable and responsible idea of what a consumption-based ecological footprint should be, whatever the origin of goods and services purchased by local consumers (Marques et al., 2017). The second model enhanced the footprint by 7.5–21.8%, depending on the level of aggregation and inclusion of a plastic industry. We strongly recommend to use this second approach for a more accurate assessment. In Table 3, we can also observe discrepancies between a-type and b-type models regarding the territorial use of plastics for exports. Once again, the b-type models separating the plastic content of imports for intermediate and final uses must be preferred to the a-type model relying on a single matrix of technical coefficients (Miller and Blair, 2009). Let's remind that the territorial use considers only input requirements for domestic or foreign final uses, but should not include imported materials for a fair estimation. Consequently, in the Seychelles, the plastic content of exports is rather found in the range between 2100 and 2400 t.

### 6.2. A plastic footprint per capita of a high-income country

How does Seychelles, considered a high-income country by the World Bank,[6] compare to footprint levels in other similar developed countries? Amadei et al. (2022) compared the literature-based EU plastic footprint with the consumption statistics-based footprint (using the database PRODCOM). The literature-based footprint of EU citizens was 84 kg of plastic per capita in 2014, but the statistics-based amount was deemed much higher, at 129 kg per capita (Amadei et al., 2022). The latter approach relies on the apparent consumption by product (for 590 product categories) multiplied by the unitary weight of products and the plastic share of each product. This method is therefore more comprehensive than the former one but requires a great deal of product-wise information that most SIDS do not have, hence the useful EEIOA models for small island territories until they can upgrade their data collection system. With 74 kg per capita, i.e. the value estimated for 2019 in the present study, the Seychelles seems to behave like a high-income country, but without the returns to scale and facilities needed to manage a too high waste tonnage. Seychelles introduced a landfill lately, in the first quarter of 2015, letting behind its previous dumping practices.[7]

When it comes to the Plastic Waste Footprint (PWF), we found a value of 1622 t (16.6 kg per capita) in Seychelles. This is in the range of values observed in countries involved in the worldwide EXIOBASE 3 project (Baeta-Humanes, 2021). The magnitude of Seychelles' PWF would then be closer to upper middle-income countries such as Romania (11.5 kg per capita), South Africa (13.7), Hungary (17.8), but quite far from the high-income biggest waste producers: South-Korea (60.1), Switzerland (61.6), Finland (63.4), Croatia (68.3), Australia (123.7), Luxembourg (125.6) and Canada (159.6) (*Ibid.*). However, in 2016, the total landfill solid waste in Mahé amounted to 71,841 t (Lai et al., 2016) and the share of plastics represented 7.5% of the total tonnage of solid waste between 2003 and 2010 (Talma and Martin, 2013). If the composition had not changed, plastic wastes would then represent some 5388 tonnes in 2016 (55 kg p.c.), meaning that our estimation is significantly under-valued by a factor 3. The gap could be explained by a decreasing generation of plastic waste since 2010, which is unlikely, or most probably by a selection of too low coefficients of waste by product ($w_j$) from Eurostat data. More accurate waste coefficients by activity should therefore be searched for. An evidence is given by the Jambeck et al. (2015) study which estimated 11,800 tonnes of plastic waste in Seychelles in 2010, of which 4631 tonnes (and 5478 forecast in 2025) would be mismanaged and likely to end up in the ocean as marine litter. A study about the origins of marine debris emphasized that mismanagement was a major cause of pollution and that the negative impacts were felt on very remote areas (Duhec et al., 2015). At least 38% of marine debris collected on a small Seychelles island (Alphonse island) were coming from land (beach sandals, foam sheets, plastic caps …) and more specifically from South-East Asia and Somalia, 19% from ocean-based sources (cruise ships, cargo ships, fishing vessels …), the remaining share being made of small plastic fragments impossible to associate to any origin (Duhec et al., 2015).

### 6.3. Which industries are responsible for the plastic footprint?

Our analysis emphasized the key role of the construction industry (24% of the Seychelles plastic footprint), followed by the machinery and transport equipment sector (20%), the beverage and tobacco industry (8%), the wholesale-retail trade and repair industry (6%), health sector (5%) and public administration (4%). Such an industrial structure fits

[6] With a GDP per capita at USD 13,306 in 2021, the highest in Africa, Seychelles is considered high-income country (https://data.worldbank.org/).

[7] https://www.nation.sc/archive/243396/new-modern-landfill-to-be-operational-soon.

with others from the literature, where construction has a 29% contribution to the EU consumption-based plastic footprint, packaging coming next with 24%, electrical and electronic equipment (EEE, 11%), transport (6%), clothing (4%), etc. (Amadei et al., 2022). There is no such category as 'packaging' or 'clothing' in the Seychelles industrial classification, but these activities are probably included in the 'wholesale-retail' + plastic-rubber' categories, as well as EEE which is certainly integrated in 'machinery equipment'. We believe that an introduction of separate categories for such plastic-intensive outputs in the Seychelles industrial classification could be useful to help public policies reducing the use of plastics.

At the worldwide level, the most impacting sectors in terms of carbon footprint from plastics are fairly similar: construction (14%), electronics and machinery (14%), automotive industry (14%), textile and furniture (7%), food industry (6%), etc. (Cabernard et al., 2022). However, in the latter study, services altogether represent the most polluting sector with 18% (*Ibid.*). With EXIOBASE and a global MRIO model, other authors found a high plastic waste footprint for public services, in particular for health and social services' (7.2%) and 'public administration and defence services' (3%) (Baeta Humanes, 2021). This is the case too in our own estimation of the plastic footprint, where the cumulated contribution of services reaches 19%, of which health and social services and other public services play a major role. Tourism-based activities play a quasi-null part in the consumption-based footprint, but are the second largest contributors (24%) to the production-based territorial use of plastics, just after the fish processing industry (49%). As illustration, the local tuna cannery delivers specifically to the UK market (TESCO) PP plastic cups of 20 g each, where else other markets in the EU get tin cans.

We conclude that the industrial origin of the Seychelles footprint looks like many other developed countries around the world but with several specificities related to SIDS (importance of fisheries and tourism), and that a substantial proportion of this material footprint is somehow reallocated away from primary and secondary sectors and driven by a few services.

### 6.4. How to reduce the plastic footprint?

Plastics are so convenient that it seems difficult to avoid them completely. Two policy levers could be actionable to mitigate the use of plastics: 1) Decreasing consumptions by households and industries. 2) Decoupling economic growth and plastic use by lower PUI per unit of output through innovating technology and material substitution.

In the present study, we can only predict changes in the first lever because PUI, based on coefficients derived from EU data, are fixed by definition in EEIOA models. The EU production of plastics has not changed much in a decade, stabilizing around 60 million tonnes (Plastics Europe, 2022). In France, the average input coefficient of 65 industries has nonetheless increased by 62% over the past decade, but the EU one has been quite stable at slightly less than 1%. A specific measurement of the plastic content of productions in Seychelles would be necessary to achieve a more reliable look at such changes.

There are issues of a socio-economic nature, concerning the willingness and the infrastructural capacity for separating waste streams at source, or even to act earlier in the hierarchy of a virtual chain, which would consist of refusing, reducing, recovering or repair recyclable plastics. Seychelles is a small island state, which triggers competition for land use, i.e. land for tourism or for trade against allocation for waste management facilities. The economies of scale are another challenge for Seychelles with less than 100,000 inhabitants. Investment and cooperation should be envisaged at the region-wide level, other small island countries in the vicinity of the Seychelles (Comoros, Mauritius, Mayotte, La Réunion, Madagascar …) being in a similar situation with various infrastructures: network economies may be found to cope jointly with the issue of plastic waste. Investors face uncertainty when it comes to planning for collection and recycling and any forecast will be risky in view of economic viability. The establishment of EPR, Extended Producer Responsibility, recovery systems for plastic products and packaging, could fill this gap. Several initiatives have been implemented, including waste management systems, reduction in single-use plastics, and increased public awareness and education programs (Barrowclough and Vivas-Eugui, 2021). However, the implementation of these initiatives is often hindered by a lack of resources and capacity, and the need for increased international support. Despite the creation in 2014 of the new landfill in Mahé already mentioned, 150,000 tonnes of waste had been dumped over the first two years of its existence, comprising some 40% of the landfill capacity (Krütli et al., 2018). This is why alternative of solid waste management to landfills have to be considered, such as anaerobic digestion and incineration (*Ibid.*).

There has been a significant progress in WTO notifications of related trade measures for plastics since 2015, particularly regarding plastic-selective measures. Of about 127 measures notified to the WTO (up to 2018) that were relevant to plastics, nine have been notified by two Indian Ocean SIDS, Mauritius and Seychelles: bans on import, sales and manufacture of certain plastic bags, straws, tableware and kitchenware, foam boxes and other containers (Barrowclough and Vivas-Eugui, 2021). However, there is also a lack of enforcement capacity for bans on certain plastics, i.e. polystyrene food trays which still arrive through certain imported products, such as vegetables. For instance, plastic bags are still commonly used in the Seychelles main island market. On the plastic ban in Seychelles, the Landscape and Waste Management Agency (LWMA) wrote: "in 2017 the initiative was to restrict the manufacturing, importation, sales and distribution of single use plastic items such as cups, bags, utensils and Styrofoam boxes. The next step in 2019 was the restriction on single use plastic straws and they are one of the plastic items causing a major nuisance to global ecology and environment as a whole. They are very light and small, therefore are easily carried out at sea and other water bodies by wind and surface water run-off." (https://macce.gov.sc/waste-management/).

Such measures will certainly reduce the plastic footprint of SIDS in the short run, but not to the extent of the issue regarding some specific sectors like construction, machinery and equipment, beverage and tobacco, fish processing, food and accommodation services, where more specific actions need to be implemented. For instance, campaigning against industrial food would avoid imports of plastic-wrapped food products towards more healthy and environmental-friendly diets. Looking for substitutes to plastics may also represent profitable business opportunities for the entrepreneurship of SIDS, such as the use of biomaterials (Barrowclough and Vivas-Eugui, 2021). Whenever the amount of plastics cannot be reduced due to Seychelles' dependence on fossil fuels, physical waste treatment and recycling solutions should be promoted for a more circular economy (Meylan et al., 2018). This could be done by merging the plastic waste disposal and treatment efforts at the regional level and intensify trade within the Indian Ocean Commission so as to reach the economies of scale and network economies that are still missing for a country alone (Monsanto et al., 2022).

### 6.5. Limitations and possible extensions of the study

The present study attempted to estimate the plastic footprint of SIDS with international data when local monitoring systems are missing. Obviously, this is far from being accurate as seen by the discrepancy with other empirical studies (Jambeck et al., 2015). Surveys near private companies and public agencies would give a better idea of the plastic content of output and consumption, as well as counting surveys in landfills or at household places. More bottom-up (e.g. LCA and MFA) studies converting the plastic embodied in thousands of products currently consumed in SIDS would complement usefully the EEIOA and PIO approaches which are likely to under-estimate the magnitude of plastic accumulation in the environment. A MRHIO model would deserve further information about the technology structure of trade partners and their technology and waste management policy with regard to plastics. The theoretical framework requires to be extended by splitting up some industrial and product categories into more specific ones (packaging, clothing, bio-based vs fossil fuel-based plastics, etc.) and, as far as possible, by type of polymers (PE, PP, PVC, PS …) (Jander, 2021). The physical supply-use tables could be coupled to an integrated Computable General Equilibrium Model (AfDB, 2021) in order to simulate the effects of public policies on the material footprint and circularity of the Indian Ocean SIDS economies (ban measures, tax on plastic-based products, subsidy of green sectors, new waste treatment facilities, etc.) (Masui, 2005).

## 7. Conclusion

Marine litter in the ocean affects particularly small island developing states (SIDS) which rely on sustainable marine ecosystems for their fishery- or tourism-based economies. Political action against plastic pollution starts with a quantitative assessment of the problem. The present study adapts conventional MFA and EEIOA approaches to estimate the plastic material footprint of SIDS with a particular focus on the Seychelles and the Indian Ocean region. The plastic consumed by each inhabitant is estimated to be within the range of other high-income countries, however the available waste treatment capacity is not comparable to that of SIDS. The origins and circulation of plastic flows are identified and point out the key role of some specific exporting industries and services.

This type of approach is meant to assist policy makers by a better understanding of products and sectors on which efforts should be made to reduce the domestic plastic footprint, but also how to select the most effective measures with regard to their cost-effective effects along the supply chains. EEIOA can improve the roadmap towards more circularity within small island territories and less reliance on harmful trade for the environment. Situating the analysis within a multi-regional hybrid input-output framework clearly shows how loosely connected the island territories of the South West Indian Ocean region are. Some potential joint efforts could be made to scale up not only the exchanges between them, but also the economies of scale necessary to deal with such a massive problem for their marine environment and their blue economy.

## CRediT authorship contribution statement

**Patrice Guillotreau:** Methodology, Software, Formal analysis, Writing – review & editing. **Sharif Antoine:** Formal analysis, Writing – review & editing. **Fatime Kante:** Formal analysis, Writing – review & editing. **Katrin Perchat:** Formal analysis, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Appendix

**Table A1**
Statistics of the footprint values with a Monte Carlo approach

| *Statitics* | *Value* |
|---|---|
| Mean | 77.18 |
| St. Dev. | 1.81 |
| Mean St. Error | 0.03 |
| Minimum | 71.28 |
| First Quartile | 75.92 |
| Median | 77.17 |
| Third Quartile | 78.42 |
| Maximum | 83.08 |
| Skewness | 0.0108 |
| Kurtosis | −0.1933 |

Note: Footprint values (in kg per capita) are obtained from a sample of 5000 trials combining randomly industrial PUIs where the average price of plastics varies between €3200 and €4200 for each industry.

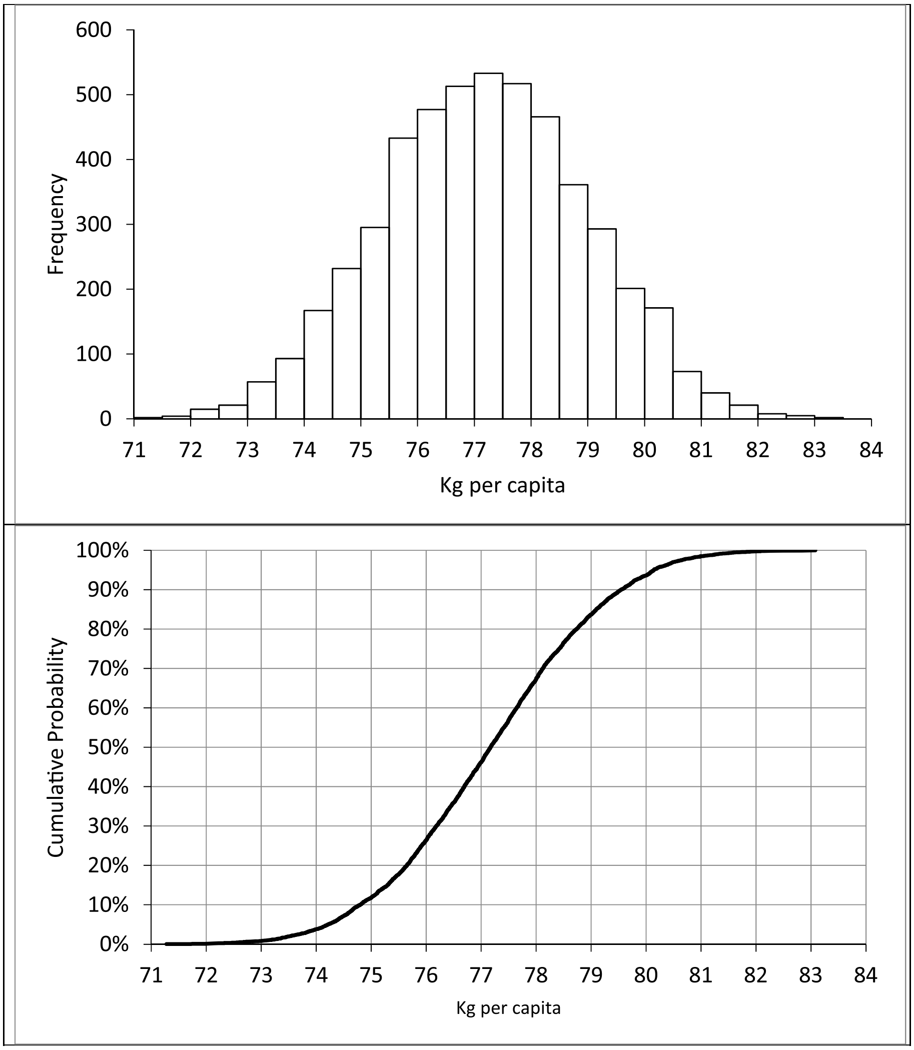


**Fig. A1.** Histogram and cumulative probability of footprint values (in kg per capita) from the Monte Carlo analysis (sample of 5000 trials) where the average price of plastics fluctuates between €3200 and €4200 per tonne within a uniform law distribution.

**Table A2**
Waste coefficients in tonnes per unit value of output in 2018

| Seychelles classification of 35 products | t/M€ | t/MSCR | t/MUSD |
|---|---|---|---|
| Agricultural products | 1.060 | 0.064 | 0.897 |
| Fish & aquatic products | 1.060 | 0.064 | 0.897 |
| Quarry products | 0.080 | 0.005 | 0.068 |
| Processed fish | 0.845 | 0.051 | 0.715 |
| Other food products | 0.845 | 0.051 | 0.715 |
| Beverages and tobacco | 0.845 | 0.051 | 0.715 |
| Textiles, clothing, footwear & leather products | 0.709 | 0.043 | 0.600 |
| Wood, paper and printed products | 0.458 | 0.028 | 0.387 |
| Petroleum products | 0.053 | 0.003 | 0.045 |
| Chemicals, rubber and plastic products | 1.951 | 0.119 | 1.651 |
| Non-metallic mineral products | 0.793 | 0.048 | 0.671 |
| Metal products except machinery and equipment | 0.288 | 0.017 | 0.243 |
| Machinery & equipment and parts except transport | 0.286 | 0.017 | 0.242 |
| Transport equipment and parts | 0.286 | 0.017 | 0.242 |
| Furniture and other products nes | 0.373 | 0.023 | 0.316 |
| Repair & installation serv. except for motor vehicles | 0.373 | 0.023 | 0.316 |
| Electricity, gas, steam and air conditioning supply | 0.071 | 0.004 | 0.060 |
| Water supply; sewerage, waste mgt & remediation | 19.458 | 1.184 | 16.469 |
| Construction | 0.510 | 0.031 | 0.432 |
| Wholesale and retail trade | 0.215 | 0.013 | 0.182 |
| Repair of motor vehicles and motorcycles | 0.240 | 0.015 | 0.203 |
| Transportation and storage | 0.190 | 0.012 | 0.161 |
| Accommodation services | 0.190 | 0.012 | 0.161 |

(*continued on next page*)

**Table A2** (*continued*)

| Seychelles classification of 35 products | t/M€ | t/MSCR | t/MUSD |
|---|---|---|---|
| Food and bar services | 0.190 | 0.012 | 0.161 |
| Information and communication | 0.190 | 0.012 | 0.161 |
| Financial and insurance services | 0,190 | 0012 | 0,161 |
| Real estate services | 0,000 | 0000 | 0,000 |
| Owner occupied dwellings | 0,190 | 0012 | 0,161 |
| Professional, scientific and technical services | 0,190 | 0012 | 0,161 |
| Administrative and support services | 0,190 | 0012 | 0,161 |
| Public admin. & defence; compulsory social security | 0,190 | 0012 | 0,161 |
| Education | 0,190 | 0012 | 0,161 |
| Human health and social work | 0,190 | 0012 | 0,161 |
| Arts, entertainment and recreation | 0,190 | 0012 | 0,161 |
| Other services | 0,126 | 0008 | 0,107 |

Note: Own elaboration from Eurostat data [ENV_WASGEN_custom_4721070], 'Generation of waste by waste category, hazardousness and NACE Rev. 2 activity' + EU-27 IOT for outputs by industry https://ec.europa.eu/eurostat/web/products-datasets/product?code=ENV_WASGEN.

## References


Abejón, R., Bala, A., Vazquez-Rowe, I., Aldaco, R., Fullana-i-Palmer, P., 2020. When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the Spanish peninsular market. Resour. Conserv. Recycl. 155, 104666.

AfDB, 2021. Economic Impacts of COVID-19 and Policy Options in the Seychelles. African Development Bank Group, p. 84pp.. + Appendices, 13pp.

Aguilar-Hernandez, G.A., Sigüenza-Sanchez, C.P., Donati, F., Rodrigues, J.F., Tukker, A., 2018. Assessing circularity interventions: a review of EEIOA-based studies. J. Econ. Struct. 7 (1), 1–24.

Amadei, A.M., Sanyé-Mengual, E., Sala, S., 2022. Modeling the EU plastic footprint: exploring data sources and littering potential. Resour. Conserv. Recycl. 178, 106086.

Baeta Humanes, J., 2021. Closing the Plastic Tap—Global Plastic Waste and the Circular Economy. A Multi-Regional Hybrid Input-Output Analysis of Plastic Waste Footprints, Master Dissertation. Lund University, p. 77.

Barrowclough, D., Vivas-Eugui, D., 2021. Plastic production and trade in small States and SIDS: the shift towards a circular economy. In: International Trade Working Paper 2021/01. Commonwealth Secretariat, p. 18.

Boucher, J., Dubois, C., Kounina, A., Puydarrieux, P., 2019. Review of Plastic Footprint Methodologies: Laying the Foundation for the Development of a Standardised Plastic Footprint Measurement Tool. UICN *Report No. 2831719909*. UICN, Gland, Switzerland, p. x+82.

Boucher, J., Billard, G., Simeone, E., Sousa, J., 2020. The Marine Plastic Footprint. Towards a Science-Based Metric for Measuring Marine Plastic Leakage and Increasing the Materiality and Circularity of Plastic. UICN, Gland, Switzerland viii+69.

Brunner, P.H., Rechberger, H., 2017. Handbook of Material Flow Analysis, second ed. CRC Press, p. 435.

Cabernard, L., Pfister, S., Oberschelp, C., Hellweg, S., 2022. Growing environmental footprint of plastics driven by coal combustion. Nat. Sustain. 5 (2), 139–148.

Chen, W.Q., Ciacci, L., Sun, N.N., Yoshioka, T., 2020. Sustainable cycles and management of plastics: a brief review of RCR publications in 2019 and early 2020. Resour. Conserv. Recycl. 159, 104822.

Duchin, F., 2009. Input-output economics and material flows. In: Handbook of Input-Output Economics in Industrial Ecology. Springer, Dordrecht, pp. 23–41.

Duhec, A.V., Jeanne, R.F., Maximenko, N., Hafner, J., 2015. Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. Mar. Pollut. Bull. 96 (1), 76–86.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3 (7), e1700782.

Gravgård, O., Kristensen, S., Svantesson, S., Urhammer, E., 2021. Accounts and indicators for Danish plastic flows. In: Physical Supply-Use Tables for Plastics 2016. Circular Material Use Rates for Plastics 2011-2019. https://www.dst.dk.

Guillotreau, P., Bistoquet, K., 2022. An estimation of the Seychelles CO2 footprint using Eurostat data. Eurostat Rev. Natl. Acc. Macroecon. Indicat. (EURONA) 15, 47–75 art. 3.

Hsu, W.T., Domenech, T., McDowall, W., 2021. How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity. Clean. Environ. Syst. 2, 100004.

Issifu, I., Sumaila, U.R., 2020. A review of the production, recycling and management of marine plastic pollution. J. Mar. Sci. Eng. 8 (11), 945.

Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., et al., 2015. Plastic waste inputs from land into the ocean. Science 347 (6223), 768–771.

Jander, W., 2021. An extended hybrid input-output model applied to fossil-and bio-based plastics. MethodsX 8, 101525.

Kawecki, D., Scheeder, P.R., Nowack, B., 2018. Probabilistic material flow analysis of seven commodity plastics in Europe. Environ. Sci. Technol. 52 (17), 9874–9888.

Krütli, P., Nef, D., Zumwald, M., Haupt, M., Harlay, J., Stauffacher (Eds.), 2018. Waste Management in the Seychelles – Pathways for Systemic Change, USYS TdLab Transdisciplinary Case Study 2018. ETH Zürich (USYS TdLab).

Lachmann, F., Almroth, B.C., Baumann, H., Broström, G., Corvellec, H., Gipperth, L., Hassellov, M., Karlsson, T., Nilsson, P., 2017. Marine Plastic Litter on Small Island Developing States (SIDS): Impacts and Measures. Swedish Institute for the Marine Environment, University of Gothenburg.

Lai, A., Hensley, J., Krütli, P., Stauffacher, M. (Eds.), 2016. *Solid Waste Management In the Seychelles*. USYS TdLab Transdisciplinary Case Study 2016. ETH Zürich, USYS TdLab.

Leontief, W., 1970. Environmental repercussions and the economic structure: an input-output approach. Rev. Econ. Stat. 262–271.

Levin, N., Beger, M., Maina, J., McClanahan, T., Kark, S., 2018. Evaluating the potential for transboundary management of marine biodiversity in the Western Indian Ocean. Australas. J. Environ. Manag. 25 (1), 62–85.

Liu, Y., Lai, J., Ma, S., Feng, Q., Yang, G., Zhao, Z., Yang, J., Zhou, C., 2023. Supply Chain Plastic Footprint Analysis. *Circular Economy*, Art, 100037.

Marques, A., Verones, F., Kok, M.T.J., Huijbregts, M.A.J., Pereira, H.M., 2017. How to quantify biodiversity footprints of consumption? A review of multi-regional input–output analysis and life cycle assessment. Curr. Opin. Environ. Sustain. 29, 75–81.

Masui, T., 2005. Policy evaluations under environmental constraints using a computable general equilibrium model. Eur. J. Oper. Res. 166 (3), 843–855.

Mata-Lima, H., Silva, D.W., Nardi, D.C., Klering, S.A., de Oliveira, T.C.F., Morgado-Dias, F., 2021. Waste-to-Energy: an opportunity to increase renewable energy share and reduce ecological footprint in small island developing states (SIDS). Energies 14 (22), 7586.

Merciai, S., Schmidt, J., 2018. Methodology for the construction of global multi-regional hybrid supply and use tables for the EXIOBASE v3 database. J. Ind. Ecol. 22 (3), 516–531.

Meylan, G., Lai, A., Hensley, J., Stauffacher, M., Krütli, P., 2018. Solid waste management of small island developing states—the case of the Seychelles: a systemic and collaborative study of Swiss and Seychellois students to support policy. Environ. Sci. Pollut. Control Ser. 25 (36), 35791–35804.

Miller, R.E., Blair, P.D., 2009. Input-Output Analysis, Foundations and Extensions, second ed. Cambridge University Press, Cambridge, p. 750 pp.

Monsanto, M., Kohler, P., Binetti, U., Silburn, B., Russell, J., Corbin, C., et al., 2022. A Blue Future: developing a national marine litter action plan in SIDS—lessons learnt in Belize. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. https://doi.org/10.1093/icesjms/fsac206.

Nakamura, S., Kondo, Y., 2009. Waste Input–Output Analysis: Concepts and Application to Industrial Ecology. Springer, Heidelberg.

NBS, 2021. Supply and use table 2014, annual national accounts, employment & earnings. www.nbs.gov.sc.

Núñez-Cárdenas, P., San Miguel, G., Báñales, B., Álvarez, S., Diezma, B., Correa, E.C., 2022. The carbon footprint of stone fruit production: comparing process-based life cycle assessment and environmentally extended input-output analysis. J. Clean. Prod. 381, 135130.

OECD, 2022. Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options. OECD Publishing, Paris. https://doi.org/10.1787/c2744069-en. www.oecd.org.

Owens, E.L., Zhang, Q., Mihelcic, J.R., 2011. Material flow analysis applied to household solid waste and marine litter on a small island developing state. J. Environ. Eng. 137 (10), 937–944.

Pasquier, J.-L., 2018. Méthodologie de calcul de l'empreinte carbone de la demande finale intérieure française. Commissariat Général au Développement Durable, SDES-SDIE, Document de Travail, p. 25.

Peters, G.P., Andrew, R., Lennox, J., 2011. Constructing an environmentally-extended multi-regional input–output table using the GTAP database. Econ. Syst. Res. 23 (2), 131–152.

Plastics Europe, 2022. Plastics – the Facts 2022, p. 81. www.plasticseurope.org. October 2022.

Pratt, S., 2015. The economic impact of tourism in SIDS. Ann. Tourism Res. 52, 148–160.

Rama, M., Entrena-Barbero, E., Dias, A.C., Moreira, M.T., Feijoo, G., Gonzalez-Garcia, S., 2021. Evaluating the carbon footprint of a Spanish city through environmentally extended input output analysis and comparison with life cycle assessment. Sci. Total Environ. 762, 143133.

Ryberg, M.W., Hauschild, M.Z., Wang, F., Averous-Monnery, S., Laurent, A., 2019. Global environmental losses of plastics across their value chains. Resour. Conserv. Recycl. 151, 104459.
Schweitzer, J.P., Gionfra, S., Pantzar, M., Mottershead, D., Watkins, E., Petsinaris, F., et al., 2018. Unwrapped: How Throwaway Plastic Is Failing to Solve Europe's Food Waste Problem (And what We Need to Do Instead). Institute for European Environmental Policy.
Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.J., Simas, M., Schmidt, S., et al., 2018. Exiobase 3: developing a time series of detailed environmentally extended multi-regional input-output tables. J. Ind. Ecol. 22 (3), 502–515.
Talma, E., Martin, M., 2013. The Status of Waste Management in Seychelles, p. 20. GEF/SGP Strategic Project Proposal for "engaging civil society in sustainable waste management" 2013-2015. http://www.s4seychelles.com.
Towa, E., Zeller, V., Achten, W.M., 2020. Input-output models and waste management analysis: a critical review. J. Clean. Prod. 249, 119359.
Verlis, K.M., Wilson, S.P., 2020. Paradise trashed: sources and solutions to marine litter in a small island developing state. Waste Manag. 103, 128–136.
Wiebe, K., Yamano, N., 2016. Estimating CO2 Emissions Embodied in Final Demand and Trade Using the OECD ICIO 2015: Methodology and Results. OECD Science, Paris. Technology and Industry WP 2016/05, OECD.
Woods, J.S., Veltman, K., Huijbregts, M.A., Verones, F., Hertwich, E.G., 2016. Towards a meaningful assessment of marine ecological impacts in life cycle assessment (LCA). Environ. Int. 89, 48–61.