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How Eurostat can assist CO₂ assessment in small island developing states: a post-Covid estimation of the Seychelles carbon footprint.

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Abstract

Small Island Developing States (SIDS) are particularly vulnerable to climate change and ought to pay attention to their own contribution through the CO₂ emissions resulting from the domestic production and consumption levels. Although poorly responsible of the worldwide carbon emissions by the modest level of their domestic demand, they can nonetheless contribute to the problem because of the global demand for their exported commodities. However, the carbon footprint is hardly assessed by SIDS because of a lack of data about greenhouse gas emissions or national account statistics. Taking the opportunity of the Covid-19 pandemic and the resulting economic shock, an environmentally-extended input-output model based on Eurostat data on air emissions is used to disentangle the CO₂ emissions embodied in the domestic production and international trade, respectively, and to clearly identify the origin of emissions by industry. Not surprisingly, the consumption-based carbon footprint of Seychelles is deemed lower (6.79 tCO₂ per capita) than the production-based inventory (9.55 tCO₂ p.c.) for this small open economy relying to a large extent on exports of canned tuna and tourism services, hence a decrease of carbon dioxide emissions (-16%) in 2020 because of the Covid-19 pandemic. Could it be the right time to re-frame the international specialization of Seychelles?

Key-words: Environmentally-Extended Input-Output (EE-IO) model, air emission accounts, carbon footprint, Covid-19, Seychelles economy

Introduction.

It is well acknowledged that Small Island Developing States (SIDS) are amongst the most vulnerable nations regarding global warming (Robinson et al. 2010, Guillotreau et al. 2012, Kelman 2018, Robinson 2020). In particular, the issues of sea-level rising and climate variability for SIDS are under particular scrutiny since the UN Barbados global Conference held in 1994

(www.sustainabledevelopment.un.org). Agriculture lands, populations and infrastructures are often concentrated in the coastal zones, making SIDS highly vulnerable to climatic extreme events. Although poorly responsible of the worldwide carbon emissions by the modest level of their domestic demand, they can nonetheless contribute to the problem because of the global demand for their exported commodities. Assessing the carbon dioxide emissions of SIDS would allow to identify the main sources of emission and to implement targeted abatement policies (“charity begins at home”). The UN international Mauritius programme of action for the sustainable development of SIDS (2005) and the Bali Action Plan (2007) have first defined some Nationally Appropriate Mitigation Actions (NAMAs) to reduce the impact of SIDS and other developing countries on climate change through “common but differentiated responsibilities and respective capabilities” (UNDP 2008). The NAMAs aim at inventing pathways and concrete steps for developing countries to reduce their emission trajectory. Several conditions are required to follow the adopted action plans: the initiatives must be measurable, verifiable and reportable (*Ibid.*). Developing such actions can be seen as a means of meeting sustainable development aspirations. It can also shed new light on particular industries which are vital although overlooked for SIDS economies, such as natural resource-based industries and tourism (Burns and Vishan 2010, Pratt 2015).

Depending to a great extent on foreign trade, the economic benefits of these activities for SIDS in terms of income can be outweighed by the negative environmental consequences of trade liberalization (Sannasse and Seetanah 2016). While developed countries tax more heavily polluting activities, the pollution haven hypothesis would tend to concentrate the most polluting industries in developing countries (Zheng and Shi 2017). Separating the production-based from the consumption-based CO₂ emissions would show the respective responsibilities of developed trade partners and of small developing nations in global emissions (Nath and Madhoo 2021). By reducing the weight of their most emission intensive activities, the SIDS economies can also become less dependent to fossil fuel energy, providing the double dividend of a “no-regret” strategy, i.e. a net gain even if the climate change does not result in too severe consequences (Hallegatte 2009). They can do so by shifting to “green” or “blue” energy sources and deploy defensive strategies to enhance the environmental productivity (Nath and Madhoo 2021).

Today, the emission levels of carbon dioxide are calculated by both the International Energy Agency (IEA) and the Carbon Dioxide Information Analysis Center (CDIAC)¹. However there is no information regarding industry level breakdowns in the data, nor up-to date input-output tables as developed in an environmentally-extended input-output (EE-IO) (Hertwich and Peters 2009, Wiedmann et al. 2011, Moran and Wood 2014, Wiebe and Yamano 2016, Wu et al. 2020, Brown et al. 2021). Therefore we propose in this research to develop EE-IO model for the first time in Seychelles on the basis of Eurostat data on air emissions (Gajos and Prandecki 2016), and to estimate both CO₂ footprint and national inventory before and after the COVID-19 pandemic.

The concept of carbon footprint is defined as a synthetic indicator of ecological sustainability (Boutaud and Gondran 2018). The carbon footprint of a resident population represents the

¹ The CDIAC is a research centre of the US Department of Energy calculating the carbon dioxide footprint through the multi-regional input-output model GTAP (Global Trade and Analysis Project). Their estimations can be found on the World Bank website (Hertwich and Peters 2009).

set of Greenhouse Gas (GHG) emissions, of which CO₂ is a major component, associated with the domestic consumption, whatever the originating country where the goods and services are produced. The national inventory is a domestic production-based assessment, including the demand for exports but excluding the emission content of imports. Since the protocol of Kyoto signed in 1997 and the various Conferences of Parties afterwards, many countries are committed to reduce their emissions of carbon dioxide. Several studies have shown a transfer of emissions between developed countries and emerging or developing countries because of emissions embodied in international trade (Ahmad and Wyckoff 2003, Aichele and Felbermayr 2012, Wiebe and Yamano 2016, Wu et al. 2020). As largely open economies, the SIDS are particularly concerned by the gap between consumption-based and production-based emissions (Robinson 2020). In particular, in many SIDS, the economic pillars are tourism and primary sectors (mining, agriculture and fishing), which may release a great deal of greenhouse gas in the atmosphere (Archer and Fletcher 1996, Chassot et al. 2021). This is why it is of major importance to assess the Seychelles CO₂ footprint and inventory, attempting to disentangle the emissions embodied in trade and domestic production.

Such an assessment is a timely necessity as new challenges are coming along for SIDS like the Republic of Seychelles since the recent pandemic shock. On March 11th 2020, the World Health Organization declared Covid-19 a worldwide pandemic resulting in a wave of lockdowns for many countries. The International Monetary Fund considered that the global economic growth of 2020 would be reduced by 3.5% in their revised estimation of January 2021, before bouncing back to +5.5% in 2021 and +4.2% in 2022 according to projections (IMF 2021). The African Bank of Development (AfdB), in its outlook of March 2021, predicted the worst growth rate (-12% in 2020) of all East-African countries (AfDB 2021). The World Trade Organization predicted that global trade would contract between 13 and 32% in 2020 (WTO 2020). On the basis of autoregressive models and impulse response functions, the UN Department of Economic and Social Affairs predicted a situation for SIDS that should be even worse than the financial crisis of 2008-09 since the length of recovery depends on the magnitude of the initial shock: SIDS are projected to take about four years to return to the baseline forecast path (Kim 2020). Consequently, the level of CO₂ emissions associated with production and consumption should be somehow affected by the trade restrictions imposed by the pandemic.

SIDS rely heavily on foreign trade and supply of commodities for the day-to-day life. In particular, the energy required by the Seychellois households and industries is fossil fuel-based, machinery and transport equipment represent 30% of imports, even the fish canning plant, main private employer of the archipelago, needs a large volume of raw materials like frozen tuna and tin metal cans coming from overseas. A sudden disruption of foreign trade affects dramatically the whole economy (Kontovas and Sooprayen 2020). In Seychelles, a comprehensive report assessing the economic consequences of the COVID-19 pandemic for the country was published by the Government and the United Nations in December 2020 (Rassool et al. 2020). It clearly showed the extent of the social and economic shock caused by the pandemic, with a GDP contraction of 11.5% in 2020 (the IMF 2020 forecast was even higher at -13.8% for 2020). The budget balance as a share of GDP was one of the worst among SIDS at -15.5% in 2020, with a projection of -6% in 2021 (Rassool et al. 2020). Exports decreased by 38.9% in 2020 (IMF 2021), and the actual GDP contraction in 2020 estimated by

the National Bureau of Statistics finally amounted to -11% relatively to previous year (NBS 2021).

The Covid-19 pandemic has deeply affected the whole economy but some industries have suffered more than others, like the tourism sectors bearing a 70% reduction in the number of visitors in 2020. Tourism is considered in this country as the main pillar of the economy and would normally represent one fourth of the Seychelles GDP directly, and two-thirds after including indirect and induced effects (Archer and Fletcher 1996, Valenghi 2004, Pratt 2015). The second most important source of income comes from the fishing and tuna processing industries 10% to 15% of the GDP directly and indirectly (Rassool et al. 2020). A new prevailing role was assigned to fishery-related industries and the “blue economy” after the COVID-19 shock. In the recent years, Seychelles has developed an ambitious and innovating programme for the development of the blue economy (Rep. of Seychelles 2018). The blue economy is hard to define and delineate accurately, though it follows the overarching objective of UN-SDG14 (“Conserve and sustainably use the oceans, seas and marine resources for sustainable development”). However, these two industries (tourism and fishing) are both highly energy-dependent, hence responsible for a great deal of CO₂ emissions in Seychelles. How is the new deal of economic activity after the pandemic changing the rules and re-allocate carbon emissions between industries? Will the economy come back to the current specialization after the shock, or take this opportunity to re-direct its resources to a “greener” (or “bluer”) economy? A thorough analysis of carbon emissions resulting from domestically-produced and imported commodities might help the government to decide what the best options are for the country.

The following article starts in Section 1 with a first glance at Seychelles CO₂ emissions as reported by some international agencies. An original EE-IO model is introduced in the second section, following the international methodological standard used by the EU-27 and OECD countries to allow for comparisons. A numerical application, including the estimated impact of the COVID-19 pandemic on carbon emissions, is proposed in Section 3 on the basis of a Supply-Use Table recently released by the National Bureau of Statistics for the first time. Finally, a last section will discuss the results in terms of international specialization for Seychelles.

1. The overall CO₂ emissions in the Republic of Seychelles

Data about emissions from fuel combustion are made available, among others, by the International Energy Agency (IEA, www.iea.org). Carbon dioxide emissions are calculated using IEA energy databases and the default methods and emission factors given in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories². From IPCC sources, we learn that carbon dioxide emission factors for electricity and heat have been derived as “the ratio of CO₂ emissions from fuel inputs of power plants relative to the electricity and heat delivered” (www.ipcc.ch). The calculation is conducted at the country level, indirect emissions being derived by multiplying the amount of energy and heat consumed by CO₂ emission factors at

² <https://www.worldometers.info/co2-emissions/seychelles-co2-emissions/>

the sectoral level. The Emission Database for Global Atmospheric Research (EDGAR) developed by both the European Commission Joint Research Centre (JRC) and the Dutch environmental assessment agency provides an independent database of atmospheric emissions for all countries in the world since 1970. The calculation of emissions uses a technology based emission factor approach combining data from the International Energy Agency (IEA), the Food and Agricultural Organization (FAO) and additional sources (Crippa et al. 2021)³. The results for Seychelles are presented in the Figure below (Fig. 1).

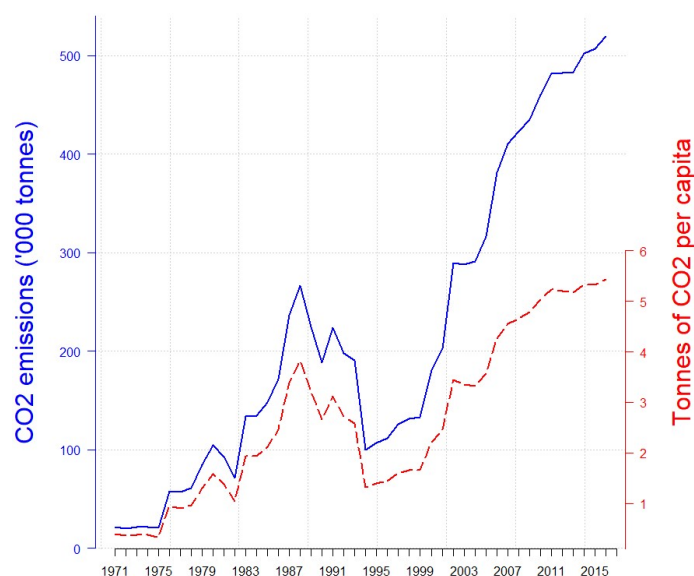


Fig. 1 - CO2 emissions from fuel combustion in Seychelles

Source: Own elaboration from IEA and EDGAR data released by www.worldometers.info (total emissions in thousand tonnes, blue solid line & left axis, and in tonnes per capita, dashed red line & right axis)

The amount of emissions can vary between sources, for instance between the IEA and the World Bank indicators based on data issued by the Carbon Dioxide Information Analysis Center (CDIAC). The IEA appears to be the most cited reference when dealing with CO₂ emissions from heat and energy. The level of air emissions in the Republic of Seychelles has tremendously grown since the early 1970s, from 20,000 tonnes annually to more than 500,000 tonnes in 2016 (Fig. 1). A large proportion (82%) of these emissions is released by the power industry itself, based on fossil fuel, and the remaining part by the other industrial combustions, including transport and buildings. The increasing trend is obviously explained by the growing population but also by the economic development of the country, as illustrated by the steadily increasing level of emissions per capita, from less than half a tonne to more than 5.4 tonnes over the same period of time. We can compare this last figure to the average

³ Emission Database for Global Atmospheric Research EDGARv6.0_GHG websites: https://edgar.jrc.ec.europa.eu/dataset_ghg60; https://data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR; More information about the methodology can be found in Crippa et al. (2021)

worldwide carbon emissions of 1.35 tonnes per capita in 2014, meaning that Seychelles is well above average and very close to the EU-27 level of 5.70 tonnes according to Eurostat⁴.

However, the above figures do not tell anything about the import content of emissions relatively to the domestic production, nor the details by activity. This is why we suggest to use the standard Input-Output approach extended to environment proposed by Leontief in 1970 and introduced in greater details in Suh (2009) or Miller and Blair (2009). In their 10th Chapter, Miller and Blair (2009) explain how to extend the famous Leontief model to deal with energy flows or any environmental factor measured in monetary or physical terms. It can be done in a single-country or multi-regional framework, with respect to the level of available information about emissions, inter-industry transactions and international trade (Hertwich and Peters 2009, Moran and Wood 2014, Wiebe and Yamano 2016, Wu et al. 2020). A good starting point for the Republic of Seychelles would consist in developing a single environmentally-extended input-output (EE-IO) model taking into consideration the import content of emissions. This would further serve for other types of footprint (water, energy, raw materials and waste) that could be helpful to minimize the impact of the economy on the natural environment.

2. The environmentally-extended input-output approach

In an Environmentally-Extended Input-Output model (EE-IO), the indirect emissions resulting from the inter-industry linkages along the supply chains are considered in addition to the direct emissions produced by each industry and by the end users (households, government, investors and rest of the world). A symmetric input-output table is therefore needed to calculate the input coefficients and the multipliers. Starting from the classical Leontief model:

$$X = (I - A)^{-1} \cdot F \quad (1)$$

Where X is a column vector of output, 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 need to be expressed as intensity rates in physical terms (e.g. Gigagrams of CO₂) per monetary unit of output $e_j = E_j / X_j$, where E_j denotes the industry j 's CO₂ emissions and e_j the intensity (or direct impact) coefficient, i.e. the amount of pollutant type per unit of industry j 's output value. The industry j 's CO₂ emission is therefore $E_j = e_j \cdot X_j$. Now substituting X by its value in (1) gives the level of emissions directly and indirectly resulting from industry j 's activity:

$$E = e_j \cdot (I - A)^{-1} \cdot F \quad (2)$$

The interpretation is easy: any change by one unit of final demand for commodity j will result in a $e_j \cdot (I - A)^{-1}$ shift of direct (the industry and its first suppliers) and indirect emissions (the suppliers' suppliers in a chain of cascading effects). What matters then is to separate the

⁴ See the Eurostat portal <https://ec.europa.eu/eurostat/>, including the Air emissions accounts (AEA) by NACE Rev. 2 activity.

emissions caused by the sole domestic production from those linked with the imported inputs used by the industries and those associated with the imports of final goods and services. To do so, we followed the stepwise methodology to calculate the carbon footprint in France and in the rest of Europe or OECD countries (Pasquier 2018, Wiebe and Yamano 2016, Brown et al. 2021). Let's try first to measure the domestic production-based emissions

$$E_j^d = \widehat{e}_j^d \cdot (I - A^d)^{-1} \cdot \widehat{F}^d \quad (3)$$

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.

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):

$$M = A^m X + F^m \quad (4)$$

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

$$M = A^m \cdot (I - A^d)^{-1} \cdot F^d + F^m \quad (5)$$

The CO₂ emissions embodied in imports from a country c will depend both on the share this exporting country holds in the domestic imports, on its own emission intensity coefficients by industry, but also on the technology (combination of inputs) used to produce a commodity. For instance, producing electricity through renewable energy or fossil-based inputs will not result in the same level of carbon dioxide emissions. Consequently, the emissions embodied in imports can be written:

$$E^{m,c} = \widehat{e}^c \cdot (I - A^c)^{-1} \cdot \widehat{M} \quad (6)$$

We can replace \widehat{M} in Eq. (6) by its value in (5):

$$E^{m,c} = \widehat{e}^c \cdot (I - A^c)^{-1} \cdot [A^m \cdot (I - A^d)^{-1} \cdot \widehat{F}^d + \widehat{F}^m] \quad (7)$$

By doing so, we can isolate the emissions embodied in imports of intermediate inputs by the domestic industries: $E_{IC}^{m,c} = \widehat{e}^c \cdot (I - A^c)^{-1} \cdot [A^m \cdot (I - A^d)^{-1} \cdot \widehat{F}^d]$, and the emissions embodied in imports of commodities for final uses, $E_F^{m,c} = \widehat{e}^c \cdot (I - A^c)^{-1} \cdot \widehat{F}^m$

By 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 carbon dioxide emissions for the year of reference, but also calculate the percent change of emissions after an economic shock like the Covid-19 pandemic, by substituting $(\Delta \widehat{F}^d + \Delta \widehat{F}^m)$ for $(\widehat{F}^d + \widehat{F}^m)$.

Eq. (7) represents the footprint which is consumption-based, 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 national inventory of production-based emissions,

where the column-vector of exports will be re-integrated into \widehat{F}^d but where also \widehat{F}^m will not be considered in Eq. (7).

One further objective to improve the estimation is to use a Multi-regional input-output (MRIO) model (Hertwich and Peters 2010). 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 two countries would be considered (e.g. Seychelles and EU-27):

$$E = \hat{e} \cdot (I - CA)^{-1} \cdot CF \quad (8)$$

Where E represents the vector of emissions resulting from the final demand, wherever the goods are produced, \hat{e} denotes a diagonal vector of emission intensity per unit of output in the domestic and trade partner countries, the two matrices A and C are, respectively:

$$A = \begin{bmatrix} A^r & 0 \\ 0 & A^s \end{bmatrix} \quad C = \begin{bmatrix} \widehat{C}^{rr} & \widehat{C}^{rs} \\ \widehat{C}^{sr} & \widehat{C}^{ss} \end{bmatrix} \quad (9)$$

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 domestic region which is considered (i.e. the sum in column is equal to 1). Finally, F is the demand for exogenous sectors in the domestic country and trade partners. The multipliers obtained by $[\hat{e} \cdot (I - CA)^{-1} \cdot C]$ would give not only the direct and indirect emissions due to a level or a change of exogenous final demand in the country, but would distribute the emission effects across supplying regions according to the percentages embodied in the components of block matrix C (Blair and Miller 2009).

3. Application to the Seychelles case

3.1. Data

The application of the EE-IO model requires different types of data: input-output technology, CO₂ emissions by industry, final uses... All data are not available yet for the Republic of Seychelles. However, the National Bureau of Statistics (NBS) has published for the first time in 2020 a Supply and Use Table for the year 2014, with a selection of 23 key industries 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, p. 151, for an explanation of the method). The domestic IOT is shown in Appendix (Table A1).

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 foreign capital-owned, compete internationally and export most of their output to European Union countries (France, UK, Italy, Germany...), hence having the highest technology standards to produce and export commodities.

When it comes to emission intensity coefficients, we used the EU-27 CO₂ emissions, adjusted for African countries⁵. The IEA suggests to apply coefficients of deviation to the EU-27 (air emission accounts) database at Eurostat of air pollutant emissions, with a different coefficient for electricity and non-electricity industries (Pasquier *et al.* 2018). The emission coefficients e_j are expressed in thousand tonnes of CO₂ per million Euro, and thus need to be converted by the exchange rate in thousand tonnes per million SCR (the Central Bank rate was SCR16.96 per Euro in 2014). The coefficients were then averaged for some industries to be adjusted from a 65-row vector to a 23-row vector. Note that a single CO₂ emission coefficient of the Manufacture of food, fishery, beverage and tobacco products from the EU-27 classification in 65 industries was used for the three distinct industrial categories found in the Seychelles industrial classification. The table of emission coefficients by activity of the Seychelles Industry Classification (SIC), corresponding to a selection drawn from the ISIC (UN International Standard Industrial Classification of all economic activities), is left in Appendix (Table A2).

The last missing information concerned the direct emissions released by domestic households: CO₂ emissions resulting from the use of personal vehicles, air-conditioning, cooker and other devices... They are available for the EU countries, such as France (1.76 tonnes of CO₂ equivalent per capita in 2014) or the whole EU-27 (1.59 t CO₂e p.c. in 2014). At the worldwide level, the CDIAC provides the figure of 1.35 tCO₂e p.c., which may be used as a proxy value for the country (Boden *et al.* 2017).

3.2. Results

Beyond the direct emissions of households from combustion (personal vehicles and other equipment) representing 127 kt, the indirect emission content of final demand resulting from domestic production was calculated with Eq. (3). The CO₂ footprint of Seychelles (direct + indirect emissions) reached 640 ktCO₂ in 2014, i.e. 3.67 tonnes per capita. Such a figure may look quite high if we consider that imports represent 25% of final domestic consumption, but the local industry relies mostly on fossil fuel energy which is highly CO₂-emitting.

⁵ Available from the Eurostat portal: <https://ec.europa.eu/eurostat/>, file of air emission accounts for 65 industries + direct emissions [env_ac_ainah_r2]. The coefficient for Africa in 2014 was 2.47 for non-electrical industries, and 2.00 for the electricity industry.

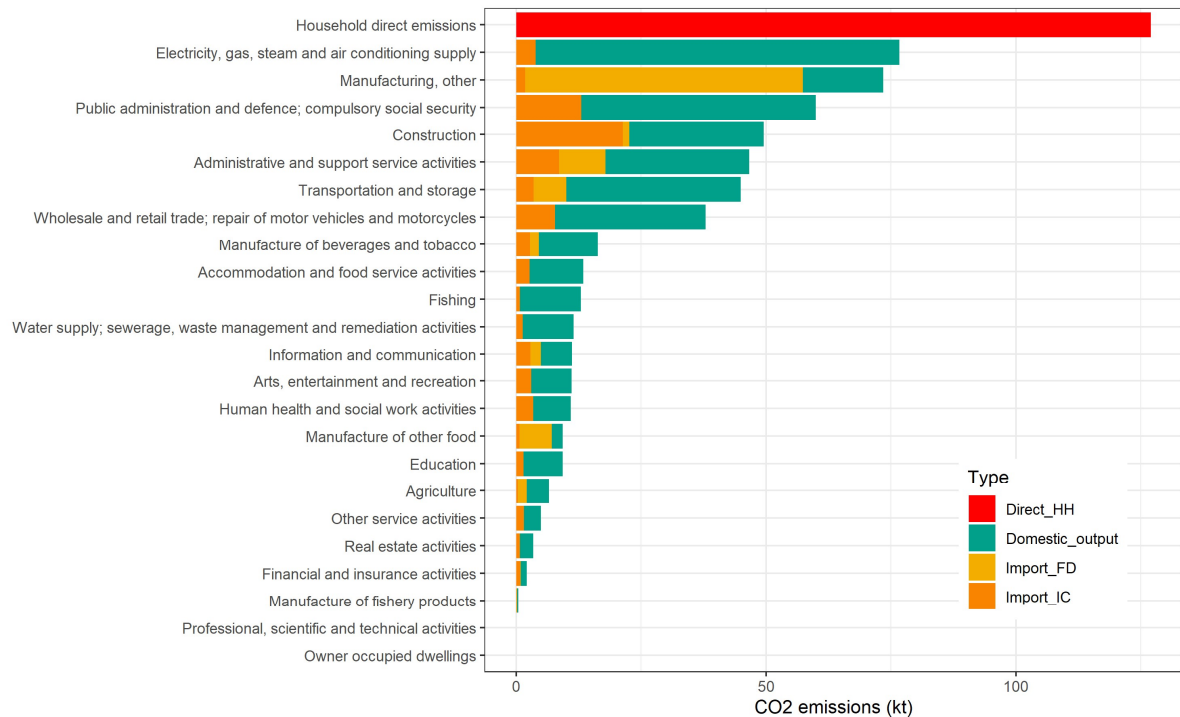


Fig. 2 – CO₂ emissions resulting from domestic demand by industry and direct combustion.

Direct_HH = Direct emissions of households from gas combustion, Domestic_output = emissions resulting from the domestic output process to meet the internal demand, import_FD and import_IC = imports of commodities and services for the final and intermediate domestic demand, respectively.

We can identify the key industries responsible for the highest level of CO₂ emissions with regard to the domestic or foreign origin (Fig. 2). As far as the domestic GHG emissions resulting from the mere domestic demand (households' consumption + firms' investment + government expenditure) are concerned, the domestic output generates two thirds of the CO₂ footprint, and another third is for imports of intermediate and final commodities. A large proportion of the territorial emissions (21%) originates from the electricity & gas sector because of the fossil fuel origin of energy, but the public administration & defence activity stands just behind (14%), followed by Transportation & storage, Wholesale & retail, Administrative & support services, and construction with very close shares (10%, 9%, 8% and 8%, resp.).

The picture is rather different when looking at the import content of emissions associated with the domestic demand (Fig. 2). First, the 'Other Manufacturing' industry produces two thirds of the emissions from final good imports (cars, electric and electronic equipment, etc.), the remaining share resulting mostly from three industries (Administrative & support services, Transportation & storage, and the Manufacturing of other food products). As far as the emissions from imported inputs (intermediate consumption) are concerned, the tonnes of emitted CO₂ stem from a broader variety of industries (Construction, Public administration & defence, Administrative & support services, Wholesale & retail trade, etc.).

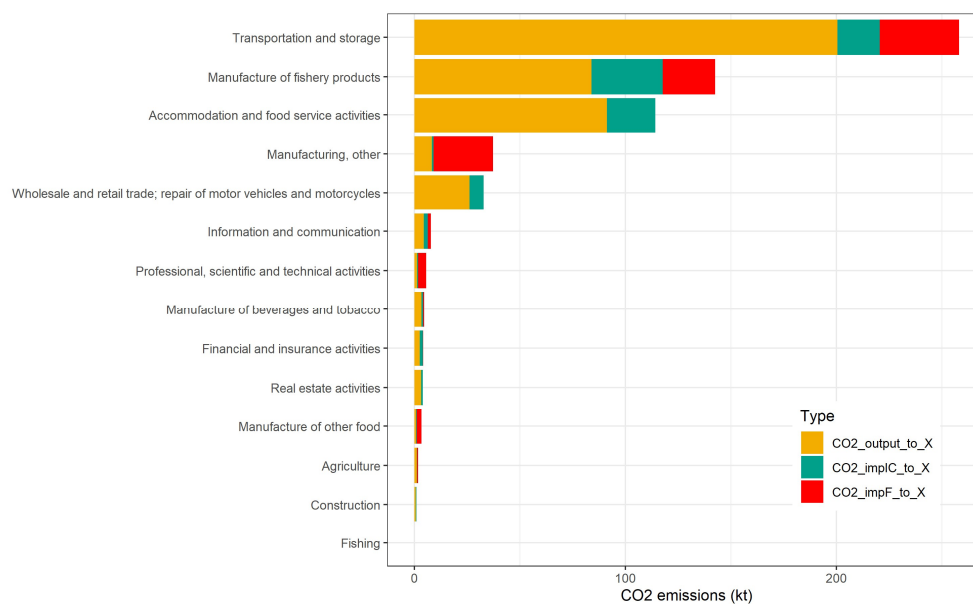


Fig. 3 - CO₂ emissions resulting from Seychelles exports by industry. CO₂_output_to_X = CO₂ emissions resulting from domestic output to meet export demand;_impC_to_X = emissions linked to imported intermediate consumption used for exports; impF_to_X = emissions linked to re-exports of imported final goods and services.

In the national inventory, only the emissions issued by the domestic output to meet the foreign demand for exports is included, for a total amount of 427 kt. However, exported commodities such as canned fish also need imports (e.g. of frozen fish) whose production process is CO₂-emitting. When adding the emissions embodied in imports for external demand served by the Seychellois industries, the cumulative amount of emissions would reach 617 kt. Three industries are particularly involved in CO₂ emissions for exports, reflecting the economic specialization of the country. Transportation and storage is the first one, in particular to meet the external demand for tourism services. The second pillar of the economy, namely the manufacture of fishery products, comes in a second position, and finally, accommodation and food services (still for tourism purposes) is the third most polluting industry.

In order to summarize the previous values, the total CO₂ footprint of Seychelles are displayed in Table 1:

Table 1. CO₂ footprint per capita in the Seychelles in 2014

| | ktCO ₂ | tCO ₂ per capita |
|---|-------------------|-----------------------------|
| Direct emissions of households* | 127 | 1.35 |
| Emissions resulting from domestic output | 346 | 3.67 |
| Emissions embodied in imports for final use | 85 | 0.90 |
| Emissions embodied in imports for intermediate use | 82 | 0.87 |
| TOTAL CO₂ footprint (excl. exports) | 640 | 6.79 |

Note: * the direct emissions per capita were extrapolated from Boden et al. (2017). The size of the Seychelles population was 94,215 inhabitants in 2014 (NBS 2021).

This first assessment of a detailed CO₂ footprint for Seychelles is consumption-based, i.e. not looking at the origin of commodities that are domestically consumed. This means that emissions related to exports are excluded. Re-assessing the national emissions on the mere basis of domestic production, whether the output is consumed internally or in foreign countries, would give a totally different picture. When subtracting the imported emissions for final use and including the CO₂ content of exports, the total CO₂ emissions related to domestic production (i.e. the national inventory) would reach 900 kt (or 9.55 tCO₂ per capita), far above the carbon footprint in Table 1.

One should also note that the total CO₂ footprint per capita is estimated to 6.79 tonnes but this figure encompasses the direct household emissions linked with the gas combustion of personal vehicles, air conditioning and other devices estimated from the total emissions per capita at the worldwide level (Table 1). This latter amount may therefore include also the industrial emissions and be counted twice. When excluding the households' direct emissions, the footprint falls down to 5.44 tCO₂, a level which is quite close to the one estimated by the IEA, 5.33 t CO₂ (worldometers.info). Let's try to figure out why the total footprint in Table 1 is perhaps over-estimated through a sensitivity analysis (sub-section 3.3 below).

We can first compare these results with a different approach based on a MRIO model (Eq. 8 and Eq. 9 in previous section). Because NBS does not provide any details about foreign trade combining commodities and origin or destination, it was not possible to distribute the regional effects between partner countries. We chose to integrate the trade between Seychelles and the EU-27 block for which we know the A-matrix of technical coefficients and the e-vector of emission intensity by sector. We therefore assumed that all Seychelles imports originate from the EU-27 and that all Seychelles exports are directed to EU-27 partners. Such an assumption remains fairly realistic because EU countries supplied 34.4% of Seychelles imports and absorbed 88% of Seychelles exports in 2020 for the sole merchandise goods. The other major suppliers from which Seychelles import commodities are the United Arab Emirates (UAE, 26.5% in 2020), South Africa (6.5%), India (5%), China and Mauritius (3.5% each) (NBS 2021). EU visitors represent also 57% of foreign tourism visits between January 2010 and March 2020 (source: Central Bank of Seychelles). In our estimation, the mere domestic demand (excluding exports) was retained as the exogenous final demand vector. The results obtained are slightly lower than the results of Table 1: the domestic CO₂ emissions resulting directly or indirectly from domestic output amounted to 307 kt (i.e. 3.26 t per capita). The emissions in other countries proxied by the EU-27 block and resulting from the Seychelles final demand reached 187 kt (or 1.98 t p. c.), i.e. 494 kt in overall (5.24 t per c.p.), not including the direct emissions by local households. Consequently, this other way of assessing CO₂ emissions gave decent results, only 4% lower than the previous EE-IO model, though difficult to interpret at the industry-specific level.

3.3 Sensitivity analysis

The previous estimations of CO₂ emissions, resulting from the domestic production for internal final uses, or from CO₂ embodied in imported commodities for final or intermediate domestic uses, were based on UE-27 intensity coefficients adjusted for Africa by the IEA coefficients of deviation (CD). Let's assume now that the technology used by Seychelles to produce goods and services is exactly identical to the EU technology, hence emission coefficients by industry equivalent to the EU-27 ones in Appendix Table A2. The sensitivity of the CO₂ per capita outcome as a function of the CD varying from 1 (equivalent to EU-27 technology) and 2.47 (or 2.00 for the electricity & gas sector) is shown in Fig. 4.

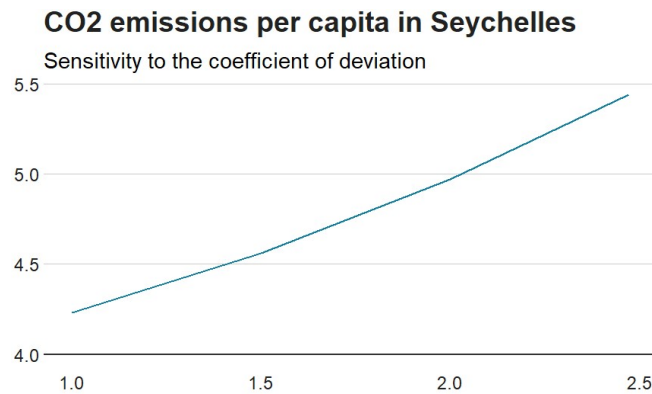


Fig. 4. Emissions in tCO₂ per capita as a function of the coefficient of deviation (CD)

Source: own elaboration with R software (R Core Team, 2021)

A perfect match between the EU-27 and Seychelles emission coefficients (CD=1) would result in a 4.23 tCO₂ level per inhabitant (emissions embodied in [domestic output + imports for final demand + imports for intermediate demand]). Adding this amount to the households' direct emissions of Table 1 would then give a total amount of 5.58 tCO₂, in better connection with the overall IEA estimation of 5.33 tCO₂ in 2014. Let's now estimate the influence of the CD, industry by industry (Fig. 5).

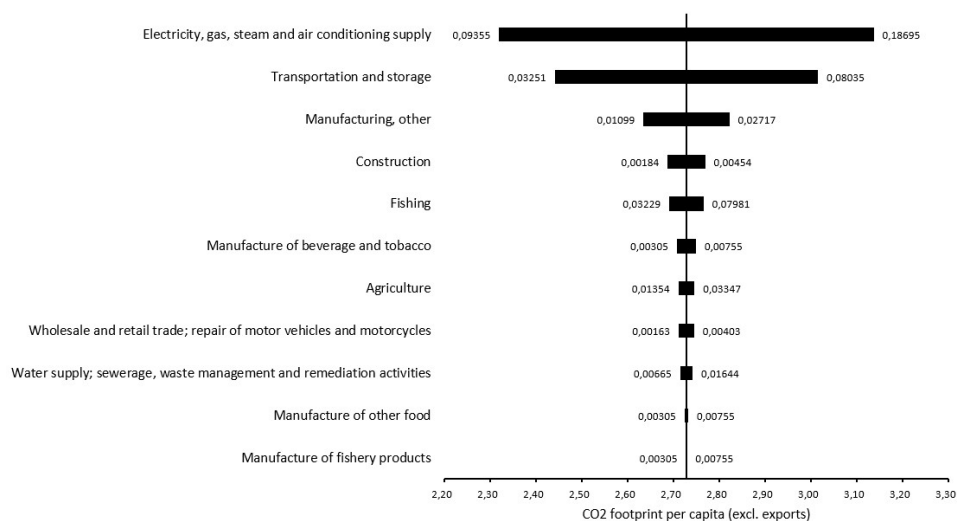


Fig. 5. Sensitivity of CO₂ emissions per capita to the CD by industry

Source: own elaboration with SensIt 1.53 software

In Fig. 5, the individual effect of each industry is calculated by using values of the emission coefficient (CO₂ per unit of output) between the UE-27 (CD=1) and Africa-adjusted emission coefficients (UE-27 rates multiplied by a CD=2.47 for non-electrical industries or 2.00 for the electricity & gas industry) centred on the mean between the lowest and highest values of the intensity ratio by industry. For instance, the Electricity & gas CO₂ coefficient fluctuates between 0.094 and 0.187 with a mean value of 0.140. Consequently the footprint per capita would be found between 2.32 and 3.14 tCO₂, other things being equal (i.e. other ratios sticking to their mid-value). Obviously, the energy sector has the most prominent effect on the CO₂ footprint, followed by the 'Transportation and storage' and 'Manufacturing, other' activities to a lesser extent. The rest of industries have a much smaller influence on the domestic emissions per capita. The impact of each industry is not only explained by the intensity of emissions per unit of output value, but also by the level of final demand for the various commodities and the technology of the country in terms of inputs to produce one unit of output (Leontief matrix). In addition to the intensive use of fossil fuel-based energy, the transport and energy sectors cumulate a high level of demand from all industries and the institutional end users, with strong backward and forward linkages across the economy. As a result, the footprint level is unsurprisingly linked with these two industries.

3.4 Impact of the COVID-19 pandemic

Like many other SIDS, the Republic of Seychelles was particularly affected by the COVID-19 crisis after March 2020, because of trade restrictions and new priorities set for passenger or freight transport (Kontovas & Sooprayen 2020, Rassool *et al.* 2020, IMF 2021, AfDB 2021). A ban on international travel was implemented by the State with effect from 23 March 2020 until 30 July 2021. Cruise ship visits were also suspended indefinitely since February 2020 and extended until 2021 (Rassool *et al.* 2020). The second semester of 2020 was not better than the first one because most foreign countries where tourists originate had implemented a lockdown and restricted travelling abroad. The UNDP report estimated the impact through the decreasing earnings from tourism before and after the pandemic, taking year 2019 as the reference (Rassool *et al.* 2020, p.12).

We assumed that the structure of exports to non-resident tourists followed the contribution of tourism to GDP published by NBS (average 2014-2019, NBS 2021). Four exporting industries would therefore be impacted: Wholesale and retail trade, Transportation and storage, Administrative and support service activities, and Accommodation and food services. We used the NBS survey on the number of visitors and the CBS survey on the estimated earnings from

tourism⁶. The number of visitors fell by 70% in 2020 (114,858) compared to 2019 (384,204), with a corresponding 58% decrease of foreign currency revenues (Fig. 6). Assuming that the shock had exclusively affected the level of exports of the four above-mentioned industries, proportionately to their initial value, the new vector of final uses was introduced to simulate the new levels of CO₂ emissions.

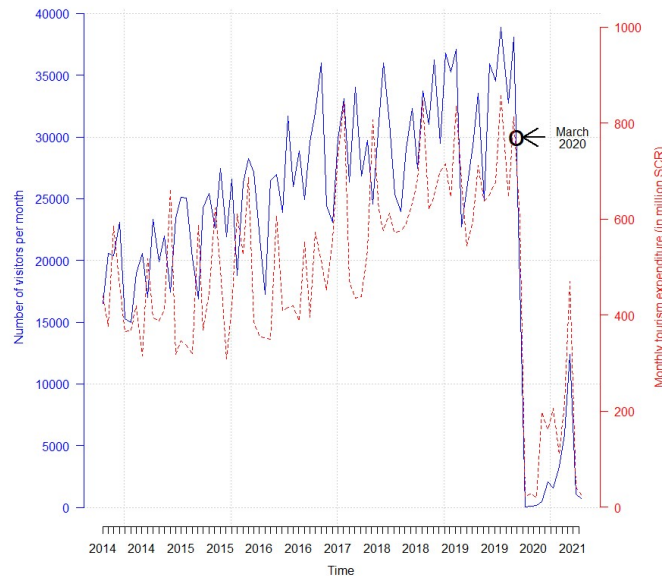


Figure 6. Number of visitors (solid blue and left axis) and estimated tourism expenditure (Million SCR - dashed red and right axis) per month in Seychelles (January 2014 - August 2021)

Source: NBS (number of visitors) & Central Bank of Seychelles (CBS, expenditure)

The total exports fell down by 24%, a bit less than the IMF expectation which considered other affected industries. Obviously, the consumption-based CO₂ footprint did not change because it was assumed that none of the internal institutions had modified their consumption level. The mere emissions of the domestic output directed to exports declined by 35%. In overall, the CO₂ emissions found in the national inventory were reduced by 16%, from 900 kt to 752 kt. As expected, nearly two thirds of the 148 tCO₂ reduction of emissions were due to lower transportation, and 30% to the decreasing use of Accommodation and food services industry. It is important to remind that the external shock concerned only the tourism industry in this simulation, not other sectors affected by the pandemic. However, when looking at the actual figures for 2020, it appears that a few other key industries such as the fish processing activity have been poorly affected by the pandemic, exports even increasing in 2020 both in quantity and value.

⁶ On a monthly basis, the Central Bank of Seychelles collects accurate and comprehensive information about transactions captured from credit card systems in hotels, online bookings, restaurants, tourism-related transactions, destination management companies, ferries, etc.

4. Discussion of the results

4.1 *Why is this CO₂ emission assessment useful for Seychelles?*

Like many SIDS in the world, the Republic of Seychelles is particularly vulnerable to the effects of global warming and very concerned by the international commitments of reduction taken after the protocol of Kyoto in 1997 and the 2007 Bali Action Plan (UNDP 2008, Burns and Vishan 2010, Nath and Madhoo 2021). Considering the long-term effects of climate change as equivalent to an ENSO (El Niño Southern Oscillation) episode, global warming would cost several percent points of GDP in the long run (Robinson et al. 2010). Despite a very small contribution to the global carbon dioxide emissions, the country has to find pathways to reduce its ecological footprint by adapting its own patterns of production and consumption. First of all, this is the only means for the country to shift away from fossil fuel energy and transition to a more sustainable economy. Secondly, SIDS depend to a large extent on foreign trade: exports on the one hand for their foreign exchange income, and imports on the other for their intermediate and final consumptions.

However, the comparative advantages of developing countries tend to concentrate locally the carbon emissions while developed countries can specialize in less polluting activities (Sannasse and Seetanah 2016). Trade openness might be wealth-creating and provide foreign currency resources to a SIDS, but often at the expense of higher environmental costs. For example, it was shown econometrically for Mauritius that “a 1% increase in trade openness is accompanied by an upshot of 0.60% in CO₂ emission” (Sannasse and Seetanah 2016, p. 175). What is the need of exporting processed food products if the spillover effects are few for the country because of foreign shareholders, profits transferred to offshore companies, massive imports of inputs, and employment of foreign workers spending their income overseas? Why should final consumption of domestic households be based on imported processed products rather than local production? Even the steady growth of tourism, pillar of economic development for the Seychelles, is questionable in terms of sustainability (Pratt 2015). The increasing number of visitors (+120% between 2010 and 2019, i.e. an annual growth rate of +9%) results in greater air traffic and emissions, deforestation to build new resorts and accommodation capacity, privatization of land and restricted access to beaches for the local population, foreign investment resulting in outflows of capital income, imports of many intermediate and final goods, more income inequalities, etc. The assessment of carbon emissions may send the right signals to re-direct the country’s international specialization (Sannasse and Seetanah 2016, Roth et al. 2018, Republic of Seychelles 2018).

4.2 *Which methodology for a replicable carbon assessment on a routine basis?*

Two strands of methodology are usually distinguished to calculate CO₂ emissions from human activities. The first one is of microeconomic nature, with detailed information on household consumption and emission factors by type of commodity (Pasquier 2018). The second one is more macroeconomic and combines inter-industrial data with national accounts on air pollutant emissions (Suh 2009, Hertwich and Peters 2009, Boden et al. 2017). The latter are rather based on a multi-regional framework, but can also be developed in a single-country

framework (Miller and Blair 2009, Pasquier 2018, Boutaud and Gondrand 2018). The difference of methodology and the level of details may explain the difference between the two types of approaches. For instance, the World Bank, using the CDIAC approach based on the multiregional GTAP model, found a CO₂ footprint per capita of 6.32 tonnes for Seychelles in 2016 (data.worldbank.org), quite different from the one estimated the same year by the IEA with 5.43 tonnes (worldometers.com). Moreover, the first source provides a time series of CO₂ emissions with a very irregular pattern since 1971, following the booms and busts of the world economy, whereas the second one shows a more regular and increasing trend (see Fig. 1). There is no absolute truth when it comes to the estimation of CO₂ emissions, but the least is to know how the calculus is made in order to simulate the effects resulting from major shocks affecting the economy, such as the Covid-19 pandemic for instance, or trade policy changes, and to reduce the overall level of air emissions.

In that respect, through the present contribution, we suggest to apply a widespread and transparent EE-IO methodology to the CO₂ footprint of Seychelles to serve as a reference basis for the coming years. Because there is no national account of air pollutant emissions yet, we used the European Union air emission accounts database, which has the twofold advantage of being published online on a yearly basis and to cover the wide variety of 27 EU member states across different levels of industrial development and technology. Moreover, the EU is a major trade partner of the country, weighting one third of imports and nearly 80% of merchandise exports, meaning that the technology structure materialized by the Leontief matrix and the air emission intensity could be fairly similar because the same environmental quality standards must be fulfilled by both partners.

4.3 Details about the CO₂ emissions by origin and industry

The results show a carbon dioxide footprint of 513 ktCO₂, not including the direct emissions of households' vehicles and air conditioning personal systems for which we have no specific data yet (640 kt otherwise). This would represent an average amount of 5.44 tCO₂ per capita (6.79 tCO₂, resp. - Fig. 7a). These amounts are quite close to the IEA estimation of 502 kt (i.e. 5.33 tCO₂ p.c.), showing the reliability of the estimated outcome. They are also well above the worldwide average figure of 1.35 tCO₂ p.c., a difference which is consistent with the economic status of Seychelles as high income country, with a GDP per capita of US\$ 14,700 in 2014 (IMF 2021). However the national inventory, which includes the emission content of exports and excludes that embodied in imports, reaches 900 ktCO₂ (i.e. 9.55 tCO₂ p.c., Fig. 7b), exceeding the domestic footprint. As a comparison, the respective levels of national footprint and inventory in France are just opposite, showing a footprint greater than the inventory: 10.6 vs 7.3 tCO₂ p.c., respectively (Boutaud and Gondran 2018). Proportionately, France exports relatively less and imports relatively more industrial commodities than Seychelles.

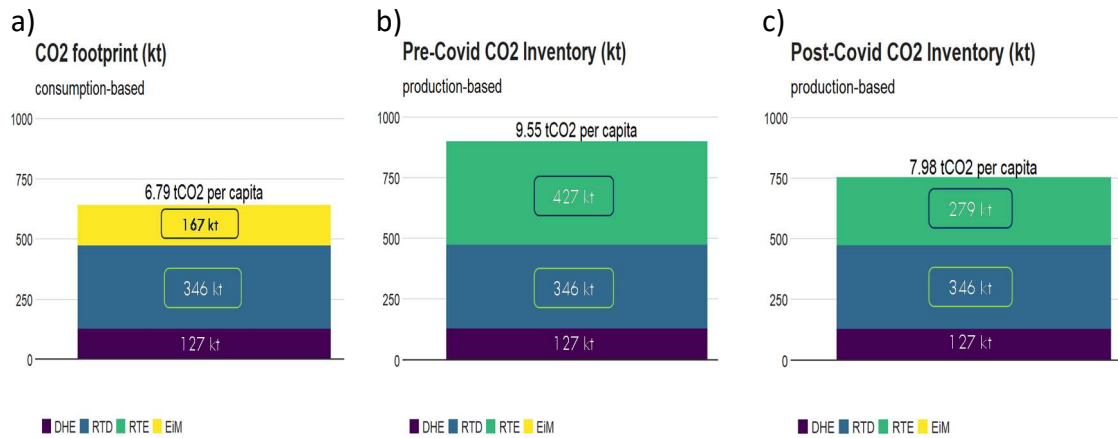


Fig. 7. CO₂ footprint and inventory in the Seychelles (ktCO₂)

Source and notes: own elaboration. *DHE* = Direct household emissions, *RTD* = Emissions related to domestic production for domestic use, *RTE* = Emissions related to exports, *EiM* = Emissions embodied in imports. The emissions related to export (green layer) do not include the import content of production: only the territorial emissions matter in the national inventory. The Seychelles population was 94,215 inhabitants in 2014 (NBS 2021).

Another interest of the study is to disentangle the content of emissions by origin, either from imports or domestic production. This is important to show the gap between a production-based national inventory of CO₂ emissions and a consumption-based footprint where the responsibility of the country extends to the foreign nations where the commodities are produced (Wiebe and Yamano 2016, Boden et al. 2017, Wu et al. 2020). Fig. 7b shows a great deal of carbon dioxide emissions related to exports, explaining that the level of emissions of the national inventory (900 ktCO₂, production-based) exceeds by far the footprint level (640 ktCO₂, consumption-based). The country imports raw materials (e.g. frozen tuna) that are further processed to be re-exported as final goods (canned tuna). The carbon emissions released by the fishing industry are imported but those included in the domestic output of canned fish products are exported, explaining why this important industry for Seychelles, representing 8% of private jobs and 84% of merchandise exports (NBS 2021), does not appear among the most prominent industries captured by our estimated footprint in Section 3. Conversely, other industries like ‘Electricity & gas’, ‘Public administration & defence’, ‘Transportation & storage’, ‘Wholesale & retail’, ‘Administrative & support services’ are responsible of the national CO₂ footprint to a much greater extent because they reveal the pattern of domestic consumption.

Conclusion: towards a CO₂ abatement policy

On the basis of this first CO₂ footprint assessment, the government can take actions to reduce its footprint, mostly by substituting the fossil fuel origin of power used by the citizens and the local industries. It has started to do so, although at a slow pace, with an investment in renewable energy over the past decade. A 6 MW wind farm along with a 5.8 MW grid-tied roof top photovoltaic system supplied nearly 6% of total electricity produced in 2020, the rest being provided by fossil fuels, mostly heavy fuel oil (PUC 2021). The use of electric cars would

be of little effect on direct household emissions as long as the electricity is carbon-based. A significant proportion of emissions related to the domestic supply also comes from imports, through the transportation of commodities (e.g. food and beverage products) and the emissions embodied in foreign production. One type of abatement would stimulate the primary sectors of agriculture and fisheries, or promote other domestic sources of supply such as aquaculture to cover the local food demand of the population. Once again, the government has launched several actions to promote the blue economy, developing coastal fisheries and aquaculture, or investing in blue bonds and marine renewable energy (Rep. of Seychelles 2018).

Another issue to deal with concerns the important content of emissions related to exports, whether they concern the tourism or the fish processing industries. We have shown that the national inventory (i.e. domestic emissions including the demand for exports) is greater than the national footprint. This is the case of many open economies like SIDS attempting to catch foreign exchange revenues, thus creating a livelihood for the population. The Republic of Seychelles has been quite successful over the past decades to create an endogenous development of its economy through tourism (accommodation and food services, air traffic, support services such as tour operators, banking, arts and entertainment activities, etc.). However, the environmental cost could be important for Seychelles because this high-standard activity relies to a great extent on imports and foreign investment, and the 2020 pandemic crisis has also demonstrated the vulnerability of islanders with the steady decline (-70% in 2020 / 2019) in the number of visitors (Rassool et al. 2020). In this research, we have attempted to estimate the post-Covid impact on CO₂ emissions through a simulation of a 58% decrease of expenditure from tourism that has been observed by the Central Bank of Seychelles in 2020. This would be equivalent to a 24% reduction of total exports of goods and services for the country, resulting in a 16% reduction of CO₂ emissions (Fig. 7c). Two thirds of this reduction of emissions would be obtained by the shrinking use of transportation services, and one third by the decreasing foreign demand for accommodation and food services.

This first attempt to estimate the carbon footprint of Seychelles by using a standard EE-IO approach has also several limitations, such as the lack of air emission data monitored by the country, or the incomplete input-output table with regard to the distinction between domestic and imported intermediate consumptions. Many efforts are under way to improve the data collection scheme, and a first Supply and Use Table is now available and can be used to develop IO-based modelling and planning models (NBS 2021). Further endeavour still needs to be made prior to achieve a bigger MRIO framework, a social accounting matrix, a material flow analysis or a computable general equilibrium model, in order to trace more accurately the sinks and sources of carbon emissions, to assess other types of ecological footprints (e.g. plastics) and find effective pathways of reducing outflows. At least this first estimation will serve as a transparent and replicable basis to follow the evolution of the carbon footprint and develop some mitigating projects for the country in a near future.

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References

AfDB (2021), African Economic Outlook 2021, from debt resolution to growth: the road ahead for Africa, African Development Bank Group, www.afdb.org, Abidjan, 180 pp.

Ahmad, N., Wyckoff, A., (2003). Carbon Dioxide Emissions Embodied in International Trade of Goods, STI Working paper 2003-15, OECD, Paris, 65 pp.

Aichele, A., Felbermayr, G., (2012). Kyoto and the carbon footprint of nations, *Journal of Environmental Economics and Management* 63(3): 336-354.

Archer, B., Fletcher, J. (1996), The economic impact of tourism in the Seychelles, *Annals of tourism research* 23(1): 32-47.

Boden, T.A., Marland, G., Andres, R.J. (2017). Global, Regional, and National Fossil-Fuel CO₂ Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2017.

Boutaud, A., Gondran, N. (2018), *L'empreinte écologique*, Ed. La Découverte, 2nd ed., 126 pp.

Brown N. (Ed), Berglund M., Bivered M., Gray M., Nakamura S. (2021). Producing environmental accounts with environmentally extended input output analysis, Eurostat Statistical Working Paper, 2021 edition, 47 pp.

Burns, P. M., Vishan, I. (2010), The changing landscape of climate change: NAMAs, SIDS and tourism. *Tourism and Hospitality Planning & Development*, 7(3), 317-328.

Chassot, E., Antoine, S., Guillotreau, P., Lucas, J., Assan, C., Marguerite, M., Bodin, N. (2021), Fuel consumption and air emissions in one of the world's largest commercial fisheries, *Environmental Pollution* 273: art. 116454.

Crippa, M., Guizzardi, D., Schaaf, E., Solazzo, E., Muntean, M., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E. (2021). Fossil CO₂ and GHG emissions of all world countries - 2021 Report.

Gajos E. and K. Prandecki (2016), National Accounting Matrix with Environmentally Extended IO analysis, *Oeconomia* 15(4): 65-74.

Guillotreau, P., Campling, L., Robinson, J. (2012). Vulnerability of small island fishery economies to climate and institutional changes. *Current Opinion in Environmental Sustainability*, 4(3), 287-291.

Hallegatte, S. (2009), Strategies to adapt to an uncertain climate change. *Global environmental change* 19(2): 240-247.

Hertwich, E.G., Peters, G.P. (2009). Carbon footprint of nations: A global, trade-linked analysis. *Environmental science & technology* 43(16): 6414-6420.

Hertwich, E.G., and Peters, G.P. (2010), Multiregional Input-Output Database, One Planet Economy Network (OPEN) EU Technical Document, Trondheim, 25 pp.

IMF (2021), World Economic Outlook, Update January 2021, www.imf.org.

Kelman, I. (2018). Islandness within climate change narratives of small island developing states (SIDS). *Island Studies Journal*, 13(1), 149-166.

Kim, N. (2020), How long will it take for LDCs and SIDS to recover from the impacts of COVID-19? United Nations, Department of Economic and Social Affairs, <https://euagenda.eu>, 13 p.

Kontovas, C. A., & Sooprayen, K. (2020). Maritime Cargo Prioritisation during a Prolonged Pandemic Lockdown Using an Integrated TOPSIS-Knapsack Technique: A Case Study on Small Island Developing States—The Rodrigues Island. *Sustainability*, 12(19), 7992

Leontief, W. (1970). Environmental repercussions and the economic structure: an input-output approach. *The review of economics and statistics*: 262-271.

Miller, R.E., Blair, P.D. (2009), Input-Output Analysis, Foundations and extensions, Cambridge University Press, 2nd ed., Cambridge, 750 p.

Moran, D., Wood, R. (2014). Convergence between the Eora, WIOD, EXIOBASE, and Open EU's consumption-based carbon accounts. *Economic Systems Research* 26(3): 245-261.

Nath, S., & Madhoo, Y. N. (2021), Climate Change, Sea Level Dynamics, and Mitigation. In *Shaping the Future of Small Islands*. Palgrave Macmillan, Singapore, pp. 185-203.

NBS (2021), Supply and Use Table 2014, Annual National Accounts, Employment & Earnings, www.nbs.gov.sc.

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, 25 pp.

Pratt, S. (2015), The economic impact of tourism in SIDS, *Annals of tourism research* 52: 148-160.

PUC (2021). Public Utilities Corporation annual report, www.puc.sc, the Rep. of Seychelles, Pers. Com. Laurent Sam.

Rassool B., Vel B., Twimukye E., Navarro L., Muhumuza T., Alcindor R. (2020), An assessment of the socio-economic impact of Covid-19 in Seychelles, UNDP Seychelles and Government of Seychelles report, December 2020, 62 pp.

Republic of Seychelles (2018), Seychelles Blue Economy: Strategic Policy Framework and Roadmap: Charting the future (2018-2030), <http://www.seychellesconsulate.org.hk>, 96 p.

Robinson, J., Guillotreau, P., Jiménez-Toribio, R., Lantz, F., Nadzon, L., Dorizo, J., Gerry, C., Marsac, F. (2010), Impacts of climate variability on the tuna economy of Seychelles. *Climate Research*: 43(3): 149-162.

Robinson, S. A. (2020). Climate change adaptation in SIDS: A systematic review of the literature pre and post the IPCC Fifth Assessment Report. *Wiley Interdisciplinary Reviews: Climate Change*, 11(4), e653.

Roth N., Thiele T., von Unger M. (2018), *Blue Bonds: financing resilience of coastal ecosystems*, Report prepared for IUCN and the Swedish Government by 4Climate, Global Ocean Trust and Silvestrum, www.bluenaturalcapital.org, 70 p.

Sannasse, R. V., Seetanah, B. (2016), Trade openness and CO2 emission: evidence from a SIDS. In *Handbook of environmental and sustainable finance*, Academic Press, Chapter 9: 165-177.

Suh, S. [ed.], (2009). *Handbook of Input-Output Economics in Industrial Ecology*. Springer, 882 pp.

Valenghi, J.-P. (2004), *Sustainable Development in the Seychelles: Economic effects of possible tourism development scenarios for the Seychelles*. University of Zurich, Zurich, Switzerland, 76 pp. <https://ethz.ch>

Wiebe, K., Yamano, N. (2016). Estimating CO2 Emissions Embodied in Final Demand and Trade Using the OECD ICIO 2015: Methodology and Results. OECD Science, Technology and Industry WP 2016/05, OECD, Paris.

Wiedmann, T., Wilting, H. C., Lenzen, M., Lutter, S., Palm, V. (2011). Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis. *Ecological Economics* 70(11): 1937-1945.

WTO (2020), *Trade Statistics and Outlook, Trade set to plunge as COVID-19 pandemic upends global Economy*, 8 April 2020, www.wto.org.

Wu, X.D., Guo, J.L., Li, C., Chen, G.Q., Ji, X. (2020). Carbon emissions embodied in the global supply chain: Intermediate and final trade imbalances. *Science of The Total Environment* 707, 134670.

Zheng, D., Shi, M. (2017). Multiple environmental policies and pollution haven hypothesis: evidence from China's polluting industries. *Journal of Cleaner Production* 141 : 295-304.

APPENDICES

Table A1. The 23-industry Seychelles domestic Input-Output Table (IOT) in 2014

| DOMESTIC IOT Million SCR | | INTERMEDIATE USES | | | | | | | | | | | | | | | | | | | | FINAL USES | | | | | | | | | | | | | | |
|--|----|-------------------|-----|------|-----|------|------|------|-----|------|------|------|------|------|------|------|------|-----|------|------|-----|------------|-----|-----|-------|-----------|------------|------------|---------|-------|------|------|------|------|------|-----|
| | | SPC | AA | AB | CA | CB | CC | CD | D_ | E_ | F_ | G_ | H_ | L_ | J_ | K_ | LA | LB | M_ | N_ | O_ | P_ | Q_ | R_ | S_ | Household | Government | Investment | Exports | TOTAL | | | | | | |
| Agriculture | AA | 16 | 0 | 2 | 23 | 6 | 0 | 0 | 0 | 4 | 5 | 2 | 152 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 116 | 0 | 0 | 30 | 356 |
| Fishing | AB | 0 | 0 | 180 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 143 | 0 | 0 | 0 | 349 |
| Manufacture of fishery products | CA | 0 | 0 | 1513 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 77 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 3072 | 4673 | |
| Manufacture of other food | CB | 1 | 0 | 27 | 14 | 3 | 0 | 0 | 0 | 2 | 8 | 2 | 114 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 127 | 0 | 0 | 44 | 344 | |
| Manuf. of beverage & tobacco | CC | 0 | 0 | 0 | 1 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 1 | 121 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 827 | 0 | 0 | 230 | 1220 | |
| Manufacturing, other | CD | 3 | 14 | 98 | 3 | 25 | 48 | 121 | 11 | 212 | 39 | 153 | 51 | 36 | 8 | 22 | 0 | 3 | 15 | 35 | 4 | 25 | 18 | 10 | 205 | 0 | 338 | 275 | 1772 | 205 | 0 | 338 | 275 | 1772 | | |
| Electricity, gas, steam | D_ | 3 | 4 | 24 | 8 | 24 | 6 | 3 | 65 | 25 | 95 | 51 | 300 | 37 | 7 | 86 | 0 | 3 | 10 | 91 | 25 | 14 | 18 | 7 | 382 | 0 | 0 | 0 | 0 | 382 | 0 | 0 | 0 | 1289 | | |
| Water supply; sewerage, waste | E_ | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 1 | 17 | 4 | 12 | 1 | 0 | 3 | 0 | 0 | 0 | 78 | 4 | 2 | 4 | 0 | 154 | 0 | 0 | 0 | 0 | 154 | 0 | 0 | 0 | 286 | | |
| Construction | F_ | 1 | 1 | 25 | 1 | 5 | 7 | 4 | 4 | 81 | 26 | 39 | 47 | 22 | 28 | 17 | 0 | 9 | 10 | 109 | 18 | 1 | 17 | 5 | 89 | 0 | 2444 | 48 | 3058 | 89 | 0 | 2444 | 48 | 3058 | | |
| Wholesale and retail trade; repair | G_ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1300 | 0 | 0 | 0 | 1123 | 2422 | 1300 | 0 | 1123 | 2422 | | |
| Transportation and storage | H_ | 2 | 3 | 241 | 4 | 16 | 12 | 0 | 8 | 49 | 170 | 571 | 78 | 10 | 5 | 26 | 0 | 9 | 456 | 45 | 3 | 5 | 14 | 4 | 342 | 0 | 0 | 0 | 1964 | 4035 | 342 | 0 | 1964 | 4035 | | |
| Accommodation and food service | L_ | 1 | 1 | 7 | 0 | 7 | 2 | 0 | 4 | 2 | 17 | 124 | 53 | 23 | 4 | 3 | 0 | 3 | 2 | 57 | 18 | 31 | 4 | 0 | 551 | 0 | 0 | 0 | 4690 | 5605 | 551 | 0 | 4690 | 5605 | | |
| Information and communication | J_ | 1 | 1 | 18 | 1 | 5 | 6 | 0 | 3 | 12 | 36 | 50 | 60 | 7 | 23 | 26 | 0 | 6 | 17 | 49 | 11 | 6 | 8 | 6 | 602 | 44 | 0 | 0 | 453 | 1452 | 602 | 44 | 0 | 453 | 1452 | |
| Financial and insurance activities | K_ | 19 | 4 | 20 | 1 | 3 | 5 | 0 | 4 | 42 | 68 | 53 | 115 | 13 | 136 | 142 | 0 | 5 | 30 | 30 | 5 | 19 | 18 | 4 | 157 | 83 | 0 | 0 | 459 | 1436 | 157 | 83 | 0 | 459 | 1436 | |
| Real estate activities | LA | 5 | 9 | 6 | 6 | 5 | 15 | 1 | 2 | 32 | 259 | 112 | 114 | 67 | 64 | 33 | 0 | 25 | 31 | 86 | 1 | 45 | 21 | 22 | 143 | 0 | 0 | 0 | 167 | 1271 | 143 | 0 | 167 | 1271 | | |
| Owner occupied dwellings | LB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1562 | 0 | 0 | 0 | 0 | 1562 | 0 | 0 | 0 | 1562 | | |
| Professional, scientific and technical | M_ | 0 | 0 | 41 | 1 | 5 | 2 | 0 | 1 | 7 | 19 | 12 | 74 | 42 | 59 | 12 | 0 | 26 | 9 | 39 | 4 | 2 | 3 | 1 | 0 | 0 | 0 | 0 | 180 | 540 | 0 | 0 | 180 | 540 | | |
| Administrative and support service | N_ | 2 | 3 | 23 | 1 | 1 | 2 | 3 | 8 | 5 | 40 | 221 | 38 | 7 | 32 | 32 | 0 | 3 | 4 | 169 | 19 | 2 | 8 | 1 | 735 | 0 | 0 | 0 | 1361 | 735 | 0 | 0 | 1361 | 735 | | |
| Public administration and defence | O_ | 2 | 4 | 33 | 1 | 2 | 3 | 0 | 2 | 7 | 15 | 13 | 54 | 9 | 17 | 10 | 0 | 5 | 6 | 5 | 3 | 2 | 5 | 2 | 18 | 2743 | 0 | 0 | 0 | 2961 | 18 | 2743 | 0 | 0 | 2961 | |
| Education | P_ | 1 | 2 | 15 | 0 | 1 | 1 | 0 | 1 | 3 | 9 | 6 | 25 | 5 | 8 | 5 | 0 | 2 | 3 | 12 | 5 | 1 | 3 | 1 | 186 | 430 | 0 | 0 | 0 | 726 | 186 | 430 | 0 | 0 | 726 | |
| Human health and social work | Q_ | 0 | 1 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 10 | 2 | 3 | 2 | 0 | 1 | 1 | 1 | 1 | 1 | 21 | 1 | 194 | 477 | 0 | 0 | 0 | 728 | 194 | 477 | 0 | 0 | 728 | |
| Arts, entertainment and recreation | R_ | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 18 | 1 | 2 | 1 | 0 | 0 | 1 | 8 | 0 | 0 | 1 | 0 | 430 | 71 | 0 | 0 | 0 | 542 | 430 | 71 | 0 | 0 | 542 | |
| Other service activities | S_ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 273 | 0 | 0 | 0 | 0 | 273 | 0 | 0 | 0 | 273 | | |
| TOTAL domestic IC | | 59 | 47 | 2286 | 66 | 137 | 110 | 135 | 117 | 486 | 838 | 1417 | 1538 | 280 | 396 | 423 | 0 | 100 | 594 | 816 | 121 | 178 | 143 | 64 | | | | | | | | | | | | |
| Imports | | 44 | 98 | 1570 | 100 | 215 | 336 | 811 | 86 | 1476 | 465 | 1402 | 1312 | 401 | 301 | 236 | 0 | 123 | 310 | 489 | 53 | 179 | 144 | 74 | 2844 | 21 | 2343 | 4766 | | | | | | | | |
| Taxes on products | | 33 | 11 | 6 | 148 | 598 | 1152 | 0 | 0 | 20 | 0 | 17 | 718 | 175 | 6 | 30 | 0 | 0 | 36 | 0 | 0 | 2 | 55 | 10 | | | | | | | | | | | | |
| GVA | | 220 | 192 | 811 | 30 | 270 | 174 | 344 | 84 | 1076 | 1119 | 1200 | 2037 | 596 | 733 | 581 | 1562 | 317 | 421 | 1656 | 552 | 369 | 199 | 125 | | | | | | | | | | | | |
| Output | | 356 | 349 | 4673 | 344 | 1220 | 1772 | 1289 | 286 | 3058 | 2422 | 4035 | 5605 | 1452 | 1436 | 1271 | 1562 | 540 | 1361 | 2961 | 726 | 728 | 542 | 273 | 11389 | 3869 | 5125 | 17504 | | | | | | | | |

Table A2. The Seychelles CO₂ emission coefficients for the 23 industries in 2014 (in ktCO₂ per million SCR of output)

| | e_j^c EU-27 | e_j^d Seychelles |
|---|---------------|--------------------|
| Agriculture | 0,0135 | 0,0335 |
| Fishing | 0,0323 | 0,0798 |
| Manufacture of fishery products | 0,0031 | 0,0075 |
| Manufacture of other food | 0,0031 | 0,0075 |
| Manufacture of beverage and tobacco | 0,0031 | 0,0075 |
| Manufacturing, other | 0,0110 | 0,0272 |
| Electricity, gas, steam and air conditioning supply | 0,0936 | 0,1870 |
| Water supply; sewerage, waste management | 0,0067 | 0,0164 |
| Construction | 0,0018 | 0,0045 |
| Wholesale & retail trade; repair of motor vehicles | 0,0016 | 0,0040 |
| Transportation and storage | 0,0325 | 0,0803 |
| Accommodation and food service activities | 0,0014 | 0,0035 |
| Information and communication | 0,0005 | 0,0013 |
| Financial and insurance activities | 0,0003 | 0,0007 |
| Real estate activities | 0,0002 | 0,0004 |
| Owner occupied dwellings | 0,0000 | 0,0000 |
| Professional, scientific and technical activities | 0,0006 | 0,0015 |
| Administrative and support service activities | 0,0009 | 0,0022 |
| Public administration and defence | 0,0014 | 0,0035 |
| Education | 0,0013 | 0,0031 |
| Human health and social work activities | 0,0011 | 0,0028 |
| Arts, entertainment and recreation | 0,0013 | 0,0033 |
| Other service activities | 0,0012 | 0,0029 |

Note: The EU-27 are the intensity coefficients of CO₂ emissions per unit of output value, expressed in ktCO₂ per million Euro (from Eurostat NAMEA data, <https://ec.europa.eu/eurostat/>) and converted in ktCO₂ per million of Seychelles rupee with an exchange rate of 16.96 (CBS rate in 2014). The Seychelles emission rate is the EU-27 coefficient adjusted for Africa with regard to the IEA deviation coefficients of 2.47 for non-electrical industries and 2.00 for the electricity sector.