Consumption Carbon Footprint: Singapore Case Study

SGFIN Whitepaper Series #7

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Abstract

Our study introduces an analysis of the consumption carbon footprint of households and individuals in Singapore. The methodology integrates GHG emissions associated with various household consumption categories, such as food, transportation, recreation, and utilities. We apply the country-agnostic algorithm described in the SGFIN Whitepaper "*Consumption Carbon Footprint: Country Level Data Framework*" to the Singapore context, based on Singapore-specific features such as consumption preferences, import patterns, international shipping routes, estimated retail prices, inflation rates, currency exchange rates, waste management practices and more. Our study delves into the carbon footprint variations between income levels and consumption categories, exploring potential reductions in individual carbon footprints via the adoption of sustainable consumption practices. Finally, we outline the importance of carbon labelling for products and services and the decarbonization of value chains.

Keywords: *GHG emissions estimation, Environmental impact, Household carbon footprint, Individual carbon footprint, Carbon intensity, Physical emission factors, Monetary emission factors, Sustainable consumption.*

JEL Classification: G39, L52, M14, Q51, Q54

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Foreword

As our global society is increasingly focused on transitioning towards a more sustainable future, the role of individual consumers is emerging as more important than ever. Governments, financial institutions, companies, and communities worldwide are implementing policies and strategies aimed at reducing greenhouse gas emissions in financed portfolios and the real economy.

For these macro-level efforts to accelerate at the pace required to achieve our global climate targets, individual consumers must play an equally ambitious role in consciously addressing their own carbon footprints. Ultimately, all anthropogenic emissions occur in the creation of goods and services consumed by individuals and households.

This paper contributes to this crucial effort by translating household consumption patterns into their environmental impact, and exploring how sustainable lifestyle choices could enable potential emissions reductions. The study applies our country-agnostic carbon footprinting algorithm to the Singapore context, quantifying carbon emissions associated with the consumption of typical goods and services by Singaporean households. By analyzing key consumption categories such as food, transportation, housing, and recreation, this study sheds light on the major drivers of emissions associated with household consumption in Singapore.

The drive behind this project is the need to empower individual consumers with easy to digest information about the environmental impact of their consumption. As we are all increasingly faced with the wicked problem of climate change, we hope this paper can contribute to providing consumers with accurate and relevant carbon consumption information and empowering them to be part of the solution to our global climate challenge.

Prof. Sumit Agarwal
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Professor of Economics and Real Estate
President of Asian Bureau of Finance and Economic Research
February 14th, 2025

Executive Summary

1. **Individual consumers** share the responsibility and opportunities to support climate change mitigation, alongside contributions from regulators, financiers, and companies.

2. To exercise their **agency** more effectively, consumers need to be more **informed** of the carbon impact of the products and services they consume, and in particular of the emission factors that can be associated with their consumption.

3. Environmental impact information regarding products and services is still opaque due to data scarcity, potentially paralyzing actions. We address this need by developing a country-agnostic **algorithm** allowing for mapping, adjustments, conversions and extrapolations of **emission factors** to be associated with products and services enjoyed by individual consumers.

4. Combining this algorithm with **aggregate consumption** data of Singaporean households, we identify the key contributors to the carbon footprint of the average Singaporean households to be **Food** (including Food Serving Services)**, Transport, Recreation and Culture,** and **Housing** (including Utilities).

5. We identify large variations in the carbon intensity of products and services within each consumption category. Focusing on the most carbon intensive products and services in **consumers' lifestyle**, we highlight potentially impactful **sustainability actions**, including switching to a vegan diet, prioritizing food items that are sourced closer to home without the need for air transportation, and opting for mass public transportation.

6. Going forward, we stress the importance of **carbon labelling** for products and services to allow consumers to take more decisive actions, stimulating corporate emissions reporting initiatives and eventually **the decarbonization of global value chains**.

About the Authors

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1. Introduction

1.1 Climate change and climate action

Human activities are an unequivocal cause of **climate change**, through "unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals", leading to "widespread adverse impacts" and "related losses and damages to nature and people" (IPCC, 2023).

Responding to this quintessentially "**wicked problem[1]**" of climate change (Rayner, 2006) – for which one-size-fits-all or compromise-free solutions do not exist and whose uncertain effects have global and inter-generational reach – requires a **concerted transformation** at a scale and speed unseen before in the history of our global society.

With the urgent need for the transformation to be delivered within the timespan of a single generation or even less, a **whole-of-society** approach is essential, requiring action across governments, companies, communities, and individuals. With the "**all hands on deck**" call to action (Hale, 2016), sharing the burden of mitigating climate change has been central to discussions around the role of governments, businesses, and the broader society in the decarbonization of the real economy.

At a global level, key macroeconomic items on the agenda are phasing out fossil fuels, accelerating the energy transition, and realigning financial systems towards prioritizing climate action. Given the urgency and depth of the required shift towards a more sustainable society, there is also ample space and need for **meaningful individual action** (Hampton and Whitmarsh, 2023).

Understanding tangible opportunities and the critical need for individual contribution to the global decarbonization efforts requires a more comprehensive account of consumer emission footprints, which can "provide insights into the social determinants of environmental impacts and can inform household actions directed towards reducing footprints" (Ivanova et al., 2016). Clear and transparent information on their **consumption footprints** can stimulate individual consumers to drive bottom-up societal changes and accelerate systemic transformation.

1.2. How can individual consumers be empowered to act?

Individual action can take a variety of shapes and forms.

Individuals and households adopting more **sustainable lifestyles** can be an effective mechanism to spur corporate sustainability progress. Consumers who are actively

[1] Wicked problems have been defined as complex, multifaceted issues with no definitive formulation (due to their dynamic and interconnected nature), no clear solution (as any possible approach would have its own trade-offs and consequences), not comparable to other problems (which makes the application of previous solutions difficult), systemic and with broad effects for multiple stakeholders (Rayner, 2006).

including environmental and sustainability impacts in consumption choices can collectively exert pressure on companies to improve the sustainability of their supply and value chains. A conscious effort to consume less environmentally damaging products and services is essential in avoiding ecological, and ultimately economic collapse (Meadows et al., 1974).

This paradigm shift requires a change of deeply rooted **societal norms**, some of which entailing conspicuous consumption of items associated with wealth and status[2], or cultural traditions that involve carbon intensive consumption preferences[3]. In addition to a sustainable lifestyle anchored in sustainable consumption, a more **responsible investment** philosophy that integrates sustainability considerations may affect corporate decisions, but we still lack robust, systematic, and generalizable evidence on the effectiveness of financial markets in improving corporate sustainability.

Concurrently, fuelled by growing economies across developing regions and a growing middle class within developed ones, the growth in the global economy unavoidably leads to increased consumption, straining natural resources and accelerating climate change and biodiversity loss. Empowering individuals to **consume more selectively** to optimize their carbon footprints would be critical in transforming the social norm from one where (excessive) consumption is indicative of status and success, into one where thoughtful consumption and educated choices are a trademark of personal achievement. **Conspicuous conservation effects** (Sexton et al., 2014) could further accelerate virtuous circles whereby restraint becomes enshrined among valued behaviours.

A crucial challenge in developing a collective conservation mindset is that individual consumers often lack **adequate information** on the extent of their individual contribution to these problems (Enlund et al., 2023), how to improve their own sustainability performance (Ivanova et al., 2016), and how their collective actions can have substantial impacts. Providing information and education on the causes, impacts, and potential solutions – including collective actions – for climate change is therefore crucial to changing their attitudes (Bergquist et al., 2022).

Equipping individual consumers with relevant information on how their **personal carbon footprint** contributes to global warming could stimulate the transformation towards more optimal individual carbon footprints, and collectively a more sustainable global carbon footprint.

[2] Such as ownership of high fuel consumption private cars or opting for business class flight services.
[3] Such as dietary preferences for animal-based products.

2. Measuring individual carbon footprints

2.1 Carbon accounting and estimation methodologies at country level

At a country level, the main types of GHG emissions allocation methodologies are territorial-based accounting, production-based accounting, and consumption-based accounting (Barrett et al., 2013).

Territorial GHG emissions refer to "emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction" (IPCC, 1996, Barrett et al., 2013). This is the format in which The United Nations Framework Convention on Climate Change (UNFCCC) requires countries to submit annually their National Emissions Inventories (Afionis et al., 2017).

Production-based emission accounting, while often equated with territorial-based accounting, differs through its alignment with the economic domiciles of emissions producers, using the same system boundary as the System of National Accounts used for GDP reporting (Grubb et al., 2022). The intended objective of the Production-Based Accounting (PBA) approach is to assign emissions accountability to producers within a country's territory (Munksgaard and Pedersen, 2001), with inherent limitations due to its inability to capture GHG emissions embodied in international trade (Peters and Hertwich, 2008a; Davis and Caldeira, 2010), or emissions related to international air and sea transportation (Franzen and Mader, 2018, Mangır and Şahin, 2022).

Alongside the production-based approach, the **consumption-based** accounting (CBA) approach reflects emissions "at the point of consumption, attributing all the emissions that occurred in the course of production and distribution to the final consumers of goods and services" (Afionis et al., 2017). In this CBA approach, national GHG inventories can be thought of as a focal country's production-based national emissions adjusted by the emissions associated with international trades, i.e., adding emissions from the production of imported goods consumed in the focal country and subtracting emissions of the focal country's production of goods exported to other countries (Barrett et al., 2013). Such environmentally extended input-output (EEIO) models can be used to assess the environmental impact of economic activities within and between countries (Mangır and Şahin, 2022).

Leveraging EEIO models, the CBA approach attributes all upstream emissions generated along global value chains until the point of consumption of products and services – including from production processes of raw materials and intermediate products across all the countries participating in the supply chain – to the country of consumption (Pottier et al., 2020). While CBA approach provides a more complete view of national emissions, it requires complex macroeconomic calculations with inherently **higher uncertainty** in its estimation (Mangır and Şahin, 2022) and more intensive resource requirements than PBA (Liu, 2015).

2.2 Carbon emissions estimation methodologies at individual level

The **top-down** approaches mentioned above can be used to estimate country-level GHG emission total. We can arrive at estimates of **household** or **per capita** GHG emissions, i.e., averages at the household or individual level, by simply dividing these country-level totals by the country's total population. However, since the underlying estimations are performed at a country (or sectoral) level without differentiating between households or individuals based on their specific consumption patterns, they do not provide a granular picture of the variations in carbon footprints across individuals or households, which are crucial inputs for personal decision making and consumption choices.

The thrust of our study is built on an estimation approach that considers households' consumption of goods and services. The main inputs into this **bottom-up** approach are (1) the financial value of the products and services consumed, and (2) the estimated **Emission Factors (EFs)** that convert these consumed amounts into their associated GHG emissions quantity.[4] We can then aggregate these product or service-level GHG emissions into an individual level GHG emissions footprint.

2.3 Methodology framework development for Emission Factors

We propose a methodology framework for sourcing, assessing, mapping, converting, adjusting and extrapolating existing Emission Factors (EF) data. This proposal is relevant in the context of **scarce and heterogenous EF data** across countries around the world, rendering carbon footprinting a costly and resource intensive exercise. The next three sections will describe the framework development in general and apply the framework to estimate carbon emission footprints in the specific context of Singaporean households. The framework follows principles and methodologies outlined in The Greenhouse Gas Protocol standards and guidance applicable to the carbon footprinting of goods and services (WRI and WBCSB, 2011a, 2011b, 2013).

Section 3 describes our proposed **country-agnostic framework[5]** which is centered around building a set of household-focused Monetary Emission Factors (Monetary EFs)

[4] In our study we sourced and combined both Physical and Monetary EFs. We used Physical EFs and Monetary EFs in association with expenditures on goods and services, subject to a variety of assumptions and considerations around reliability, accuracy and uncertainty of the result. How these original Physical and Monetary EFs were derived is worth noting. To estimate Physical EFs, product or service Life Cycle Assessment (LCA) studies are typically used to measure the net GHG emissions associated with a unit of particular goods or services. Physical EFs might be affected by underestimation due to specific system boundaries or omitted supply chain emissions (Ingwersen and Li, 2020). Their usage for broader groups of products can introduce additional uncertainty. On the other hand, the original Monetary EFs we came across are typically produced by Environmentally Extended Input Output (EEIO) models that allocate "national GHG emissions to groups of finished products based on economic flows between industry sectors", to reflect the GHG emissions associated with the monetary value of groups of goods and services, depending on the industry sector or sub-sector they belong to (WRI and WBCSD, 2011b). Monetary EFs are typically affected by high uncertainty as the broad calculations "may not represent nuances of unique processes and products, especially for non-homogenous sectors" (WRI and WBCSD, 2011b).

[5] We discuss this framework at length in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework".

based on consumption spending, i.e., kg CO_2e per unit of spending (e.g., SGD)[6]. We develop a country-agnostic EF framework that can be paired with country-specific insights. In particular, the Monetary EFs can be contextualized for domestic consumption in a specific country, which can subsequently be associated with financial transactions data at different levels of expenditure resolution in that country. We will elaborate on the methodology framework for EFs in the next section.

Section 4 describes our **country-specific application** of this framework to Singapore, resulting in the development of Singapore Monetary EFs and their application to the Singapore structure of household expenditures. This is followed by Section 5 which details how we factor in Singapore-specific insights such as the patterns of imports of goods that are typically consumed by Singaporean households, considering each exporting country's contribution to specific imported products. We factor in energy mix proxies (i.e., carbon intensity of electricity generation) of Singapore's trade partners, along with the distances and assumed freight modalities of countries exporting to Singapore in order to estimate international shipping emissions. We also use country level waste composition statistics and waste management practices. We apply country-specific currency exchange rates, inflation rates, and estimated average product price points in order to adjust, extrapolate, and convert all emission factors into a standard monetary format (kg CO_2e/SGD 2023).

Contextualizing the EF framework for Singapore, we generate a set of **consumption-based emission factor estimates** for key expenditure items consumed in Singapore, which can then be applied to various levels of aggregation of consumed goods and services. Combining these emission factors with the statistics of the typical Singaporean household expenditures, we generate estimates of the GHG emissions associated with the typical consumption baskets of Singaporean households, classified by income level.

[6] The use of a spend-based method to estimate emissions associated with the purchase of goods and services is in alignment with the GHG Protocol Technical Guidance for Calculating Scope 3 Emissions (version 1.0) (WRI, WBCSD, 2013), absent more specific products or services emissions data.

3. EF Model overview

3.1 Developing a country-agnostic calculation framework

To estimate these emission factors, we apply the data framework and algorithm that we describe in detail in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework". Conceptually, our approach is close to the CBA methodology, in the sense that we look to attribute the entirety of products and services lifecycle emissions to end-consumers. However, we take a **bottom-up** approach by (1) identifying the Emission Factor (EF) for available (product x Country-of-Origin) combinations from publicly accessible data sources, (2) extrapolating these EFs to other (product x Country-of-Origin) combinations lacking publicly available data, and (3) contextualizing them for consumption in the focal country by integrating additional relevant data such as import flows, international shipping routes, and waste management practices[7].

Structurally, the EFs from our **proposed approximation** can function as **temporary placeholders** for high-quality EF data generated using more resource-intensive product/service-specific Life Cycle Assessment (LCA) analyses in all relevant Countries-of-Origin. We propose this approach since accurate LCA processes require a widespread adoption of standardized carbon reporting and / or labelling for all products and services by companies of all sizes, which is unlikely to happen anytime soon in the current global context. Indeed, we see an urgent need for "placeholder" EFs, in order to advance the development of holistic calculation models and obtain preliminary meaningful insights until more extensive EF data becomes available.

For any given country-of-import, we have around up to one million combinations of traded product categories[8] and countries of origin[9]. If for each product category, there were 10 variations of brands and Stock Keeping Units (SKUs) (we anticipate there to be much more), then more than **10 million** different high quality EFs would be required to more accurately estimate the GHG emissions associated with any given consumption basket, anywhere in the world. These millions of data points (originated by different entities across various jurisdictions) would require global governance, standardization, reporting, verification and assurance – along with regular updates, aggregation, and publication. Suffice to say, we do not have a global platform in place for this purpose, and nor are we likely to have one in the foreseeable future.

Our proposed approach offers a robust methodology for filling in the gaps at this critical juncture. Our goal is to build an iterative and **scalable data framework**, allowing for ingestion and refinement of more extensive and granular data points from

[7] We apply different methodologies for products and services, as described in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework.

[8] Within this context, we are considering product categories to be the most granular level at which products are tracked in import and export global reports, which according to our research is the commodity level as per the Harmonized System (as defined by World Customs Organization, 2022a).

[9] For example, for Singapore we have ~217 countries and territories trading up to ~5200 commodities as per the Harmonized System classification, resulting in ~up to 1.12 million (commodity x "Country-of-Origin") combinations.

and in future works – in terms of both the granularity of specific consumer goods and services, and their related GHG intensities. This would allow for potential connectivity with financial transactions enabling real-time carbon footprinting of purchases[10]. A guiding principle for our model has been the feasibility to connect this data framework to consumer transaction data with detailed product-level granularity (e.g., price, quantity/volume, and Country-of-Origin).

3.2 Calculation methodology

Figure 1: Calculation methodology

Source: Figure produced by our project team following principles from The Greenhouse Gas Protocol: Technical Guidance for Calculating Scope 3 Emissions (WRI, WBCSD, 2013).

Our calculation methodology revolves around estimating contextualized **Monetary Emission Factors** (Monetary EFs) that can be associated with domestic expenditures on specific products and services, in order to derive the carbon footprint of each purchase (Figure 1). In examining GHG emissions associated with each household's consumption, our EF methodology starts with the estimates of Monetary EFs denominated in **kg CO_2e/currency units**[11], which are then multiplied with the household's expenditure on the corresponding item to generate the household's carbon footprint due to that item. We can then aggregate the footprint across all goods and services consumed by each household. Figure 1 illustrates our overarching model, which is aligned to the spend-based method for assessing emissions associated with purchased goods and services from The Greenhouse Gas Protocol Technical Guidance for Calculating Scope 3 Emissions (version 1.0) (WRI, WBCSD, 2013)

Our methodology framework therefore starts with the questions: what goods and services do households in a focal country typically consume, where are they imported from, how are they shipped, and how can the related emissions be estimated?

We perform the following analysis for each **product** type (expenditure item):

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[10] Consumer financial transactions, such as they are typically recorded on invoices, receipts from retailers or service providers, typically reflect the products or services sold. If a Monetary EF is in place for every such item and embedded in the retailers or service providers inventory data, then the carbon footprint of these items could be offered as an insight to consumers. It could be printed on the invoices and receipts itself, as a carbon label reflecting the carbon "cost" in addition to the financial cost.

[11] CO_2e stands for carbon dioxide (CO_2) equivalent, which is the standard unit used to convert GHGs to CO_2, based on the global warming potential (GWP) of each of the various greenhouse gases (GHGs). All GHGs are converted based on amount of CO_2 that would have the same impact on global warming. This provides a standard unit of emissions measurement for emissions that are composed of various GHGs (WRI and WBCSD, 2011a).

- We map the product to **traded commodities**[12] in the focal country's import data.
- We assume that the entire value chain of the product is located in the **Country-of-Origin**, which we consider to be the same as the country-of-import.[13]
- We map the **shipping routes** and **distances** from the Country-of-Origin, identifying the most likely **shipping mode** for each product to arrive in the focal country among several modes – air, road, sea freight – depending on the item's perishability.
- We infer **price proxies** for some products, which we will later use for Emission Factors conversion from Physical to Monetary[14].

For **services**, we expect mapping the value chains to be significantly more complex, resulting in less readily available macro or micro level aggregated data. For countries lacking publicly available emission factors data for a particular service type, we decide to apply a parsimonious methodology, whereby we identify emission factors we considered representative for each service type from publicly available data in other countries and then contextualized them for the focal country through the methodology we describe in subsequent sections.

We use these datapoints for products and services to properly **adjust, convert, and extrapolate** EFs that we source from various publicly available data sources. After associating each purchase with an estimated EF, we obtain the carbon footprint of the respective expenditure.

We can sum up these expenditure carbon footprints for each household to obtain the household's **aggregate carbon footprint**, which can be benchmarked against domestic averages, global averages, or even the GHG emissions per capita budgets compatible with a 1.5°C or 2°C global warming pathway.

3.3 Emission Factors (EFs)

The next phase consists of **sourcing Emission Factors** that are representative of the granularity of the expenditure items they will be mapped to. Our recommendation is to prioritize government bodies, reputable international agencies or peer reviewed academic studies. As described in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework", we recommend qualifying each EF, capturing if available the key data points for subsequent algorithmic processing:

- **Product/Service representativeness** (the extent to which the EFs represent the expenditure items they assigned for, at the appropriate level of resolution)
- **Temporal representativeness** (the temporal proximity to the publication year of the EF's source)

[12] We use the term traded commodities to refer to exported and imported goods, as defined through the Harmonised System commodity codes nomenclatures (World Customs Organization, 2022a).
[13] We source the countries-of-import from the BACI CEPII dataset (CEPII, 2023). We use the term country-of-import to refer to the countries where goods consumed in Singapore and imported from.
[14] The usage of estimated average prices for the conversion of physical to monetary EFs can introduce significant uncertainty in the end result. For more accurate emissions estimations, we recommend more extensive price studies for specific product categories in future bodies of work.

- **Geographical representativeness** (the similarity of the EF's source country to the Country-of-Origin of the item of interest)
- **Unit of measurement** (which will subsequently be subject to multi-step conversion)
- **System boundaries** (the lifecycle stages covered by the EF's source)

We then define an algorithm to **adjust, convert, extrapolate and aggregate** this data in order to estimate the focal country's contextualized Monetary Emission Factors. This algorithm translates the source EF data into the common unit of kg CO_2e per local currency as of the focal year of the analysis. A comprehensive discussion on this is available in our companion Whitepaper "Consumption Carbon Footprint: Country Level Data Framework", including a discussion on the extensive data challenges we came across (such as data scarcity and heterogeneity), as well as the assumptions and underlying uncertainty of the model.

3.4 Simplified Life Cycle Assessment (LCA) mapping

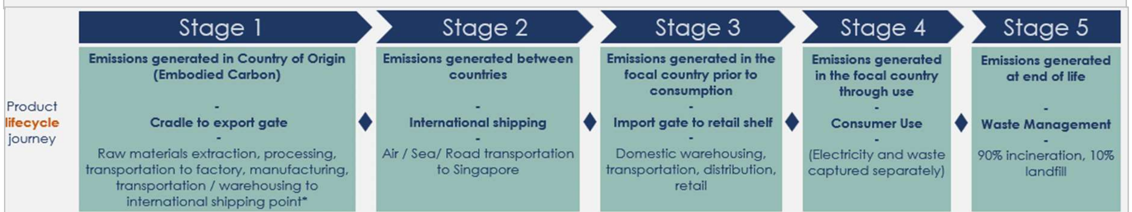
We assign all emissions associated with the **whole lifecycle** of each product and service to the end-consumer, targeting to include raw materials extraction and processing, manufacturing, transportation in the country of origin, export and international shipping, import and domestic warehousing, distribution and retail, use and waste management. This holistic approach is best positioned to drive awareness, responsibility and actions from end-consumers.

For products, we endeavor to take a holistic approach, and attempt to map as many EFs as possible to each stage in the product lifecycle, following a simplified **Life Cycle Assessment (LCA)**[15] approach, by applying a different methodology at each process stage as illustrated in Figure 2, and detailed below:

- **Stage 1**: **Cradle to export gate**, covering the stages of raw materials extraction, processing, manufacturing and transportation in the Country-of-Origin up to the point of export
- **Stage 2**: **International shipping**, covering logistics in international space, be it via air, road or sea freight
- **Stage 3**: **Import gate to retail shelf**, covering local warehousing, distribution and retail operations in the focal country
- **Stage 4: Consumer use**, covering the end user consumption stage
- **Stage 5**: **Waste management**, covering collection and management of waste

[15] Life Cycle Assessments are defined as the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system through its life cycle" (WRI, WBCSD, 2011).

Figure 2: Simplified LCA approach



Source: Figure produced by our project team incorporating guidelines from The Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard (WRI and WBCSD, 2011a).

We develop a set of EFs attributable to each main LCA stage of a given consumption item, which are then subject to contextualization for focal country consumption (such as by considering specific import distances and shipping routes, or national waste management practices), and then sum up to derive the EF covering the cradle-to-grave lifecycle stages for that specific item.[16] The set of derived EFs for any given country is therefore based on contextualized and holistic consumption for that country, which can then be mapped to different levels of resolution of expenditures in that country to take into account the potentially distinct compositions of consumption baskets due to the varying preferences (e.g., import patterns) of different subgroups of the country's population.

[16] For Services we apply a simplified version of this approach, which describes the granular methodology we apply for finished goods.

4. Developing Singapore-specific EFs

The remainder of this study focuses on the case of Singapore and the typical consumption baskets of its households. Despite the lack of domestic LCA for most of the products and services it consumes, Singapore provides a powerful illustration of our proposed bottom-up approach since a large fraction of products consumed by its population is imported.

4.1 Singapore contextualization

In order to contextualize the global, country-agnostic framework that we describe in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework" to the Singapore case study, our model employs several sets of Singapore-specific or Singapore-relevant data sources:

- Singapore **imports data**: We used the data provided by CEPII (Centre d'Études Prospectives et d'Informations Internationales) through the BACI (Base pour l 'Analyse du Commerce International) dataset[17], to obtain the full list of Singapore trading partners, as well as the imported values (in USD) and quantities from each source country, for each traded commodity[18]. For simplicity of calculation, we assume the "country-of-import" to be the "Country-of-Origin". We also assume that the local Singaporean production of the respective commodities to be null, which seems reasonable given the limited space for production in Singapore, which is a small island country.
- **Country-of-Origin EFs**: Country-of-Origin's Emission Factors (subsequently, Country-of-Origin EFs) are sourced looking opportunistically for EFs representative for finished goods, from key Countries-of-Origin covering as much as possible at least one country from the 3 country baskets we have defined[19]. For our study we have chosen highly reliable data sources such as US EPA ORD[20], UK DEFRA[21], UK DESNZ[22], China Institute of Public& Environmental Affairs and China City Greenhouse Gas Working Group [23], Climate Charter,

[17]As retrieved from the BACI dataset, version 202301 (CEPII, 2023).
[18] The BACI dataset offers "yearly data on bilateral trade flows at the product level. Products are identified using the Harmonized System (HS), which is the standard nomenclature for international trade, used by most customs", as retrieved from the CEPII BACI Database description (CEPII, 2023).
[19] In our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework" we describe in detail this concept. Essentially, we define 3 groups of countries that we consider comparable from an energy mix, technological advancement and work practices perspective. We define these groups as "country baskets" and we look to source as much as possible at least one EF for each product, for a Country-of-Origin from each country basket.
[20] As retrieved from the dataset US EPA Supply Chain Greenhouse Gas Emission Factors v1.2 by NAICS-6 (US EPA ORD, 2023).
[21] As retrieved from the dataset UK and England's carbon footprint to 2020. UK full dataset 1990 - 2020, including conversion factors by SIC code. UK Footprint Results (1990 - 2020) (UK DEFRA, 2023).
[22] As retrieved from the dataset UK Government GHG Conversion Factors for Company Reporting (UK DESNZ & UK DEFRA, 2023).
[23] As retrieved from the dataset available in the CPCD, China Products Carbon Footprint Factors Database (China IPE and China City GHG, 2024).

ICRC and IFRC[24], CarbonCloud[25], Ember Climate[26], A*STAR, Deloitte and Temasek (2019)[27] , Mike Berners-Lee (2020)[28], and others[29]. For each product we strive to source Emission Factors that we could associate with specific LCA stages in the product lifecycle journey.

- To extrapolate the EFs we were able to source to missing (product x Country-of-Origin) combinations through energy conversion, **Singapore's trading partners** are divided into 3 country baskets, depending on their technology and energy mix similarities as reflected in GDP per capita and kg CO_2e/kwh indicators, respectively[30].
- To analyze the emissions related to product transportation, we listed Singapore's **shipping routes and distances** from all trading partners, and the most likely shipping mode for each consumption item[31].
- Singapore's **average retail price proxy estimations** for Products and Services. We derive these either from the CEPII BACI inferred Free-On-Board (FOB) exporter prices (CEPII, 2023), or from manual sampling of price points from online platforms. We use these prices for EF conversion from other denominators to SGD (such as from kg CO_2e/kg to kg CO_2e/SGD).
- Singapore's **waste management** practices, including waste composition and recycling statistics[32].
- Singapore's **household consumption data** (particularly the composition of consumption basket of representative households in each income quintile of the population) and expenditure data from the Singapore Department of Statistics Household Expenditure Survey 2017 / 18 (Singapore Department of Statistics, 2019b). We manually map each household consumption item on the survey with the list of imported commodities from the import data above.

4.2 Framework application for Singapore

We process these **Country-of-Origin** EFs through the following adjustment, conversion, and extrapolation algorithm:

- **Stage 1** (**Cradle to export gate):** This is what we consider the **embodied carbon** stage, for which we obtain specific EFs for each product from third party sources.[33]

[24] As retrieved from the Humanitarian Carbon Calculator (Climate Charter, ICRC, IFRC, 2023).
[25] As retrieved from the CarbonCloud website (CarbonCloud website, 2024).
[26] As retrieved from the dataset Yearly Electricity Data (Ember Climate, 2023).
[27] As retrieved from the report Environmental Impact of Key Food Items in Singapore (A*STAR et al.,2019).
[28] As retrieved from the book How Bad Are Bananas? The Carbon Footprint of Everything (Berners-Lee, 2020).
[29] Other sources include: OpenCO2net, 2024, Podong et al., 2019, Poore and Nemecek, 2018, Ukaew and Bunsung, 2018, FoodFootprint, 2024.
[30] We will later use these country baskets to perform the extrapolation of Original EFs from the countries of origin that we found EF data available from third party sources to countries of origin that we did not find any EF data for. We extrapolate the EFs for products and services based on the EFs for electricity in the respective countries of origin.
[31] As retrieved from Sea-distance.org (2024), and Air Miles Calculator (2024).
[32] As retrieved from SG NEA, 2023.
[33] To determine the system boundaries of EFs, we rely when and as available on the insights provided explicitly in (or which we were able to infer from) the specific external dataset we leveraged. In some cases, the EFs we sourced and used for embodied carbon have more extensive system boundaries (broader than the ideal cradle to export gate we were looking for). We accepted this variation primarily due to the scarcity of the EF data itself, and also in an attempt to account for emissions that might not have been accounted for otherwise within typical cradle to factory gate system boundaries, such as emissions from logistics and warehousing operations for goods meant for exports.

- The EFs we were able to source had a high degree of **heterogeneity**, as they were originated from different sources. For Physical EFs (e.g., kg CO_2e/kg of beef), we convert them into Monetary EFs, i.e., the common unit of **kg CO_2e/SGD,** using **price proxies** derived either by leveraging FOB (exporter) [34] values and applying a blanket 141% FOB to retail markup[35], or by sampling current consumer prices from online retailers[36].
- We transform all **Monetary EFs** (e.g. kg CO_2e/USD_2021) into the same unit of **kg CO_2e/SGD_2023** using currency exchange and inflation rates.
- To supplement the gap of EFs for other relevant countries of origin, we used an **extrapolation algorithm** to estimate what could be the potential EFs for products manufactured in other countries. To do so we take into consideration the **electricity carbon intensity differentials**[37] between countries, and the degree of dependency any given product carbon footprint has on the carbon footprint of electricity within the country it is produced in (which we refer to as б). Our key assumptions are that (1) the carbon footprint of a product manufactured in a country depends on the energy mix in that particular country (as reflected in the carbon intensity of electricity), as well as the technological advancement within that particular country (as reflected in the GDP per capita), and (2) the contribution of energy related emissions to the carbon footprint of any given product is the same across countries. We describe this extrapolation methodology, the related formulas and underlying assumptions in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework". While we posit this dependency on б for EFs for the same product from 2 different countries of origin, this **hypothesis** is **not proven**. This is the reason why we consider our extrapolated Emission factors as **placeholders**, until either the б hypothesis is further refined, or until the data ecosystem is enhanced to a point where the need for placeholders is minimized [38].

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[34] Per the BACI dataset documentation (CEPII, 2023), we consider exporter FOB (Free on Board) values are generally reported by exporters. The import data leveraged from BACI CEPII deploys a "fobization technique of CIF import values" which estimates and removes CIF rates for data reconciliation purposes. (Gaulier and Zignago, 2010)

[35] We estimate this average mark-up of 141% by adding the following elements : an estimated ~3% FOB to CIF median ratio (Gaulier et al., 2008), ~8% for Singapore Goods and Services Tax (GST) as of 2022, ~30% estimated average importer mark-up, based on a 20%-40% average range (US ITA, 2024), and a ~100% for retail mark-up as a high level reference point (US ITA, 2024). We acknowledge the actual importer and retailer mark-ups can vary extensively across product categories down to brand level, and we recommend this proxy pricing approach to be refined further in future studies around carbon emissions associated with expenditures.

[36] For products for which we sourced EFs based on units other than kg (and for which FOB value per unit was therefore not available form the BACI CEPII 2023 dataset), we sample a limited set of unit prices from online retail platforms. As for the FOB based price estimation methodology described above, we acknowledge that actual prices can vary extensively from our estimated averages, and we recommend more extensive and in-depth retail price studies for future bodies of work on this topic.

[37] We define the electricity carbon intensity differential as the relative carbon intensity of electricity production between any 2 countries (Electricity EF of Country A/Electricity EF of Country B). We then apply this differential to estimate the EF of a product produced in Country A, based on the EF of the same product produced in Country B. The equation we use for extrapolation is $P_A = (1-\delta)P_B + \delta\left(\frac{E_A}{E_B}\right) \times P_B$, where P_A is the EF of Product P produced in Country A (which we were not able to source), P_B is the EF of Product P produced in Country B (which we were able to source), E_A is the EF for electricity produce din Country A, E_B is the EF for electricity produced in Country B, and б is product P carbon footprint's dependency on electricity. We detail this assumptions-based methodology, as well as the different values we assumed for б, in our companion Whitepaper.

[38] The technique is close to imputation, in the sense that our goal is to fill in missing EF by product by country, as a placeholder until more EF datapoints are in place for more (product x Country-of-Origin) combinations.

- **Stage 2 (International Shipping)**: We estimate EFs for the transportation of each product, depending on its likely transportation modality (Air, Sea or Road), and distances from the countries of origin.
  - We source 3 **Physical EFs,** for international transportation of goods by Air, Sea and Road respectively[39]
  - To determine the distance travelled by each product, we use commodity level decomposition, and related **import patterns[40]**.
  - We assume the most likely **freight mode** by product depending on perishability. For all products imported from Malaysia we assume transport by road, for perishable food items imported from countries other from Malaysia we assume transport by air, and for non-perishable items imported from countries other than Malaysia we assume transport by sea.
  - We map for each Country-of-Origin the key **shipping hubs** for road transportation, air transportation (key airports) and sea transportation (key seaports).
  - We map for each Country-of-Origin shipping hub the **distance to Singapore[41]**.
  - The 3 sourced EFs are expressed as **kg CO_2e/tonne.km**, therefore we use import quantities, import values, and distance from Country-of-Origin, to convert the EFs to Monetary EFs applicable to the value of shipped goods, expressed as **kg CO_2e/SGD[42]**.

- **Stage 3 (Import gate to retail shelf)**
  - We combine 2 EFs sourced from the UK DEFRA 2023 dataset[43] which cover warehousing and retail services. As these are monetary EFs, we use inflation[44] and currency exchange rates[45] to convert them to **kg CO_2e/SGD[46]**.

- **Stage 4: Consumer use**
  - We consider all emissions resulting from actual use of the products to be reflected in other expenditures (such as electricity for domestic appliances, gas for preparation of food items at home, or waste collection and management of residues – all of which are reflected in utility bills or captured in the waste management attributed emissions as described below).

- **Stage 5**: **Waste management**

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[39] The sources we used for international transportation EFs for the shipments of goods are Ritchie, H (2020) and Weber and Matthews (2008a). The international transport of persons overseas for recreation purposes is handled using different methodologies depending on the expenditure categories reflecting this activity, and leveraging EFs applicable for the transport of persons, such as from Myclimate.org, 2024.

[40] Specifically, we look at the commodities as per the Harmonized System nomenclature (World Customs Organization, 2022a) mapped to each product, and the countries of origin they are imported from (CEPII BACI, 2023).

[41] For air transport distances to Changi Airport, we use airmilescalculator.com (Air Miles Calculator, 2024). For sea transport distances to Port of Singapore we use sea-distance.org (Sea Distance, 2024) and Ports.com, 2024.

[42] We describe in detail the formulas and assumptions related to the processing of International Shipping EFs in our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework".

[43] As retrieved from the dataset UK and England's carbon footprint to 2020. UK full dataset 1990-2020, including conversion factors by SIC code, UK Footprint Results (1990-2020) (UK DEFRA, 2023).

[44] We sourced Historical inflation rates from Singapore from Macrotrends, 2023.

[45] We sourced exchange rates from Exchange Rates UK, 2023.

[46] As the original EFs we sourced are representative for UK, we recommend that future research on this topic incorporates a more in-depth analysis of the Singapore specific warehousing and retail emissions structure, for further contextualization beyond unit conversion.

- We use SG domestic waste reports for average quantity and composition insights[47], which we manually map to the product categories in the consumption baskets.
- We use a weighted average of 2 EFs from the UK DEFRA dataset for domestic waste management (90% for incineration and 10% for landfill), aligned with domestic waste management practices[48].
- We derive the average per capita emissions related to waste and assign them to goods in the average consumption basket depending on waste composition statistics in Singapore and associate them with the value spent on the respective goods.
- We apply the derived EFs (measured as **kg CO_2e/SGD**) to further purchases of goods from the respective categories.

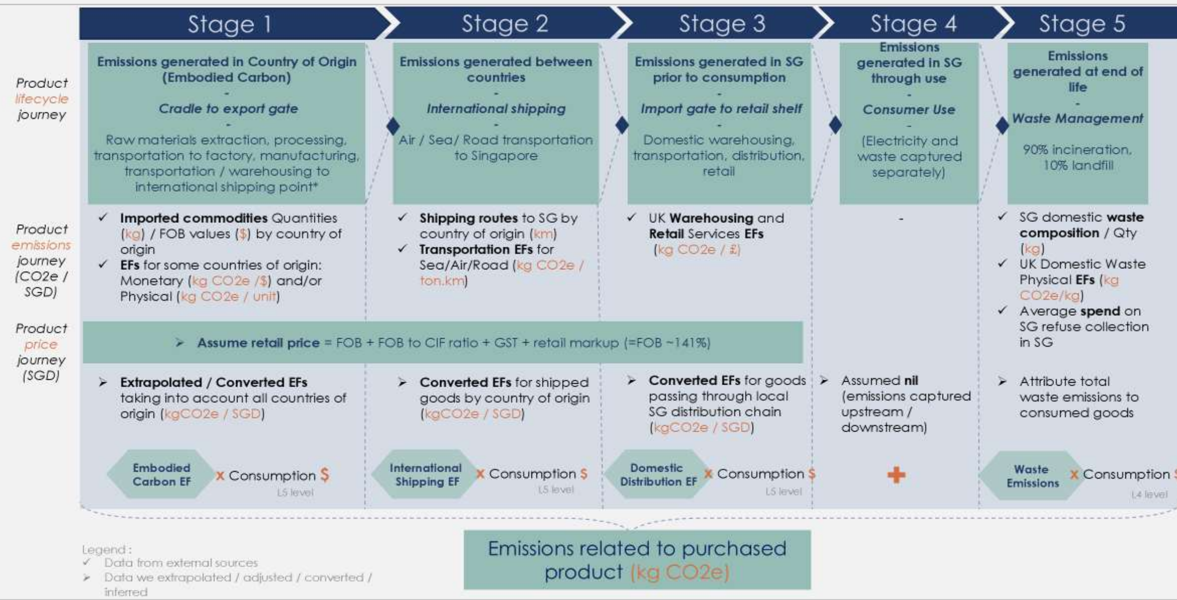
Finally, we sum up the EFs computed above to obtain a holistic EF covering the entire lifecycle of each product, which we later use in relation to expenditures on that specific item.

Figure 3 illustrates an example of how expenditure data, import data (for products only), and EF data is dis-aggregated, mapped, converted, extrapolated, adjusted, rolled up and re-aggregated for each expenditure Item Type. We have marked out differently the data sets that we have leveraged from other sources, versus the data that we have created through extrapolation, adjustments and conversions, and which is subject to a set of assumptions and related uncertainty as discussed at length in the companion Whitepaper "Consumption Carbon Footprint: Country Level Data Framework"**.**

[47] As retrieved from SG NEA, 2023.
[48] We do so under the assumption that the waste composition arriving at landfill and incineration points is similar in UK and Singapore.

***Figure 3**: Emissions allocation logic*

Imported goods



Source: Figure produced by our project team incorporating guidelines from The Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard, and Technical Guidance for Calculating Scope 3 Emissions (version 1.0) (WRI and WBCSD, 2011a, 2013).

5. Singapore consumption analysis: from expenditures to emissions

This section presents an estimation of Singapore households' carbon footprint based on our algorithm[49]. We apply the **estimated emission factors** to the average expenditures reported through the Singapore Household Expenditure Survey (HES) as of 2017 / 18.

These results are to be carefully interpreted in the context of the scope limitations, data challenges, assumptions and layered uncertainty drivers which we have highlighted in the previous sections and which we extensively detail in our companion Whitepaper.

5.1 Singapore household expenditure data

The first step in our model involves leveraging domestic data on **household expenditure composition** at a country level, such as the surveys that are typically the basis for Consumer Price Indexes (CPI) analyses. In this study, we employ the Singapore Household Expenditure Survey (SG DOS HES 2017 / 18[50]) for insights on the consumption mix and associated expenditure for average Singapore households[51]. We used the latest release publicly available at the time we performed the calculation, which is as of 2017 / 18, converted into 2023 SGD through inflation indexing[52]. At the time of research for this study, the SD DOS Household Expenditure Survey 2023 / 24 was not yet published. For future bodies of work building on this model, we recommend running the framework on the 2023 / 24 expenditure data using 2023 as a year of reference, for more reliable results[53].

The expenditures are classified according to the primary function they serve following the **S-COICOP**, the Singapore Standard Classification of Individual Consumption According to Purpose (Singapore Department of Statistics, 2022)**[54],** which is aligned to the UN COICOP.[55] The global nomenclature alignment makes it a useful skeletal framework, with which current and future expenditure and emissions data, domestic or international, could be aligned and integrated in future research.

[49] The application of the model to Singapore is facilitated by the country's high reliance on imports, which informs our assumption of 0 local production that we discuss later on.
[50] The full survey is available on the SG Department of Statistics website (SG Department of Statistics, 2019b).
[51] The survey is run every 5 years in Singapore across a representative sample of Singaporean households and is used as the basis for CPI and inflation index computation, among others.
[52] We applied a ~14.21% compounded inflation rate.
[53] The CPI indexes are averages which we have used are applied homogenously across all expenditures, while there may have been different price dynamics at an expenditure level.
[54] More details on the consumer expenditure classification in the SG DOS HES 2017 / 18 are available in the" Report on the Household Expenditure Survey 2017 / 18" (SG DOS, 2019a) and in the Singapore Standard Classification of Individual Consumption According to Purpose (S-COICOP) (SG DOS, 2022).
[55] More details on the consumer expenditure classification according to UN COICOP are available in the Classification of Individual Consumption According to Purpose (COICOP) (UN DESA, 2018).

5.1.1 Singapore survey consumption categories

The Singapore Household Expenditure Survey 2017 / 18 dataset offers SGD expenditure estimates for a **consumption basket** of goods and services organized in 4 levels of increasing granularity[56]. We are referring to these levels as follows (the listing is in increasing levels of resolution)[57], listed below from the most general (highest hierarchy, lowest level of resolution), to the most specific (lowest hierarchy, highest level of resolution):

- **Level 1: Expenditure Categories (15)**, such as "Food and Non-Alcoholic Beverages".
- **Level 2: Expenditure Sub-Categories (60)**, such as "Food" or "Non-Alcoholic Beverages".
- **Level 3: Expenditure Item Classes (139),** such as "Breads and Cereals", "Meat" or "Fruits".
- **Level 4: Expenditure Item Types (324)**, such as "Fresh tropical fruits" or "Other fresh fruits".

5.1.2 More granular consumption categories

In order to build readiness for this model to potentially integrate real life and potentially more granular consumption data, we built 2 more levels of resolution. They are additional to the previous 4 levels as we do not have actual spend $ data for them from the Singapore Household Expenditure Survey. Level 5 is the level at which we sourced Emission Factors for, and Level 6 is the tradable commodities data from which we extract import patterns.

- **Level 5: Expenditure Items (524)**, such as "Bananas" or "Avocadoes" (both part of "Fresh tropical fruits". This is the level of resolution for which we have Emission Factors available. We see this as a Products and Services Library, which can be enhanced as more expenditure data, or more Emission Factors, become efficiently available. All Items are classified as either "**Product**" or "**Service**".
- **Level 6: Commodities (2101),** such as "80310 – Fruit, edible: plantains, fresh or dried" and "80390 – Fruit, edible: bananas, other than plantains, fresh or dried" (both mapped to "Bananas"). These commodities are defined by codes and nomenclatures in the "Harmonized System" (HS)[58]. This is the level at which we observe import flows by country[59]. We map selected commodities to Level 5 items above[60], and for each item we sum up respective associated commodity quantities, to infer import patterns by **Country-of-Origin**[61]. We use the same data to derive:

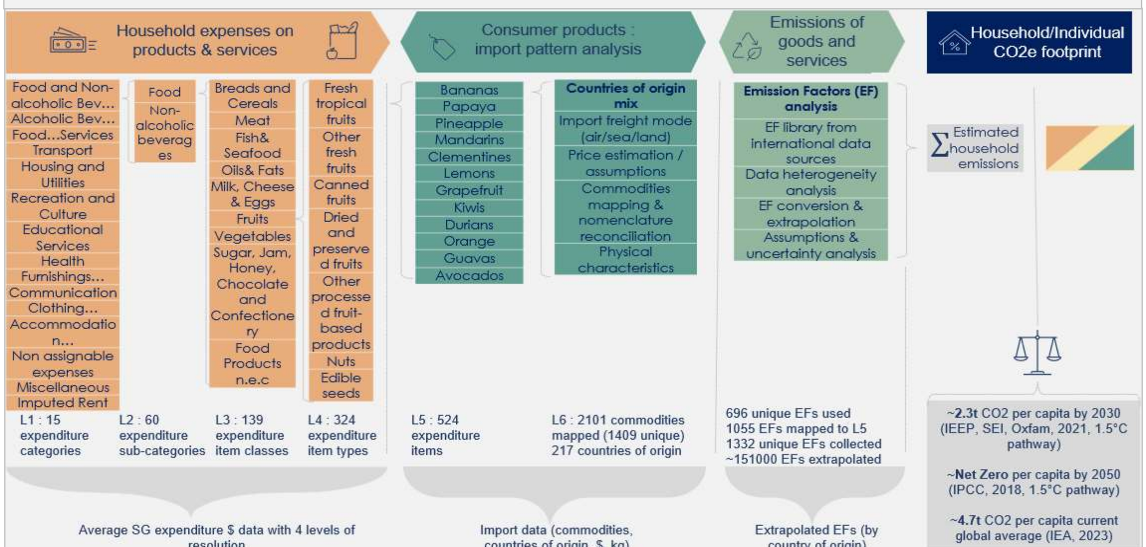
[56] These levels are the maximum resolution available in terms of spend data, that we could use to estimate Singaporean households' emissions based on their spending patterns, which is a theoretical study.
[57] The numbers between brackets represent how many of each.
[58] The Harmonized System is an international trade product nomenclature developed by the World Customs Organization (WCO, 2022a).
[59] Source: CEPII, 2023.
[60] We selected 2101 such commodity codes, which we considered relevant for consumer goods, from which we extracted import data for 217 countries of origin. These commodity codes are mapped to consumer goods on a 1 to 1 or 1 to many bases.
[61] The fundamental assumptions we are working with at this stage is that (a) local production of goods for domestic household consumption is negligible, (b) exports of imported goods are negligeable, (c)import patterns in terms of mix and weight of countries of import are the same for industrial and household consumption.

- import quantities and values by Level 5 Product Items
- price proxies for Level 5 "Expenditure Items"
- the contribution of Level 5 "Expenditure Items" to Level 4 "Expenditure Item Classes", based on Level 5 "Expenditure Items" import values.

In Figure 4, we illustrate the high-level **mapping** of various datasets and key **processing steps**, ranging from the expenditure data (in orange) to commodity import data (in dark green), to Emission Factors data (in light green).

***Figure 4**: Methodology overview*

Household emissions related to consumption



Source: Figure produced by our project team incorporating household expenditure structure from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b), commodities data from CEPII, 2023, EF data from multiple sources, CO2 per capita global average from IEA, 2023, CO_2 per capita target compatible with a 1.5°C global warming pathway from Gore T, IEEP, SEI, Oxfam, 2021, and Net Zero goal from IPCC, 2018.

In Figure 5 we showcase an example focused on the first 2 sections of Figure 4, "Household expenses on products & services" and "Consumer products: import patterns analysis", to illustrate how we perform the mapping of commodities to the expenditure hierarchy.

Figure 5: *Expenditure and commodities data mapping*

Example: Beef & Fruits

SG households' expenditure data Source : SG DOS HES 2017-18										SG imports data by commodity (annual, all import countries) Source: CEPII BACI 2023					
Expenditures resolution				Monthly expenditures by income quintile (SGD)											
Category (L1)	Sub-Category (L2)	Item Class (L3)	Item Type (L4)	Avg	Q 1	Q 2	Q 3	Q4	Q 5	Item (L5)	Harmonized System (HS) Code	HS Code description(1)	Import Value (M USD)	Import Quantity (M t)	Inferred average FOB pric (USD/kg
Food and non-alcoholic beverages	Food	Meat	Chilled Beef	5	3.7	3.5	4.7	4.8	8.5	Chilled Beef	Σ		94.83	6.55	14.48
											20110	Meat: of bovine [...], fresh or chilled	0.55	0.07	7.70
											20120	Meat: of bovine [...] with bone in [...], fresh or chilled	6.75	0.49	13.83
											20130	Meat: of bovine [...], boneless cuts, fresh or chilled	87.52	5.99	14.62
			Frozen Beef	0.9	0.6	0.9	0.7	1.4	0.9	Frozen Beef	Σ		110.46	25.12	4.40
											20210	Meat: of bovine [...], frozen	0.03	0.00	6.38
											20220	Meat: of bovine [...], cuts with bone in[...], frozen	7.50	3.01	2.49
											20230	Meat: of bovine [...], boneless cuts, frozen	102.93	22.10	4.66
Food and non-alcoholic beverages	Food	Fruits	Fresh tropical fruits	18.4	13.2	15.7	19.4	20.8	23.1	Fresh tropical fruits	Σ		174.16	171.50	16.31
										Avocadoes	80440	Fruit [...]: avocados, fresh or dried	17.22	4.86	3.54
										Papaya	80720	Fruit [...]: papaws (papayas), fresh	8.67	19.05	0.46
										Pineapple	80430	Fruit [...]: pineapples, fresh or dried	8.02	21.54	0.37
										Mandarins	80521	Fruit [...]: mandarins [...], fresh or dried	14.42	10.92	1.32
										Clementines	80522	Fruit [...]: clementines, fresh or dried	0.01	0.01	1.76
										Lemons	80550	Fruit [...]: lemons [...], limes [...], fresh or dried	14.60	15.08	0.97
										Grapefruit	80540	Fruit, edible: grapefruit, including pomelos, fresh or dried	5.01	4.94	1.01
										Kiwis	81050	Fruit, edible: kiwifruit, fresh	20.50	5.23	3.92
										Durians	81060	Fruit, edible: durians, fresh	13.68	21.77	0.63
										Orange	80510	Fruit, edible: oranges, fresh or dried	38.27	45.41	0.84
										Guavas	80450	Fruit, edible: guavas, mangoes and mangosteens, fresh or dried	33.76	22.69	1.49
										Bananas	Σ		29.19	56.74	0.51
											80310	Fruit, edible: plantains, fresh or dried	0.24	0.76	0.31
											80390	Fruit, edible: bananas, other than plantains, fresh or dried	28.95	55.98	0.52

Source: Graph produced by authors incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and imported commodities data from the CEPII BACI dataset (CEPII, 2023).

5.2 Singaporean household spending

To investigate the GHG emissions and consumption patterns and structure in relation to household wealth, we map both expenditures and emissions to average household **income quintiles**.

The expenditure-related data is provided at household level. To infer the data points relevant at a per-household member level, we apply the **average household size** per income quintile, extracted from the HES report[62]. This data is used in conjunction with the average expenses as well as average income per household, as summarized in Table 1.

[62] Data extracted from the Singapore Household Expenditure Survey 2017 / 18, Chart 1.7 "Average Household Size by Income Quintile, 2007/08-2017/19" (SG DOS, 2019a).

***Table 1**: Household parameters included in our calculation*

Income Quintiles are organized from lowest income (1) to highest income (5)

Income, expenditure and household size assumptions	Income Quintile 1	Income Quintile 2	Income Quintile 3	Income Quintile 4	Income Quintile 5	Average household
Household **average number of members***	3	3.5	3.5	3.4	2.7	3.00
Household monthly **average expenses** (2017-2018 level, without imputed rent)*	2,569.5	3,752.4	4,811.6	5,825.4	7,572.2	4,906.7
Household monthly **average expenses** (2017-2018 level, with imputed rent)*	3,295.0	4,563.9	5,712.2	6,866.9	9,084.4	5,904.5
Household **monthly average expenses** (2017-2018 level, with imputed rent)– estimated for 2023**	3,763.4	5,212.3	6,524.1	7,842.7	10,375.0	6,744.0
Household monthly **average income** (2017-2018 level)*	2,235	5,981	9,678	14,407	26,587	11,777
Household monthly **average income** (2017-2018 level)– estimated for 2023**	2,552.7	6,831.2	11,053.7	16,454.8	30,366.1	13,451.0

Source data :
*Singapore Department of Statistics (2019). Singapore Household Expenditure Survey 2017/18.
Minor differences may be accounted for by rounding at different computational steps.
**Data estimated by our project team incorporating 2017/18 SG DOS data and adjusting it with inflation to infer potential 2023 expenditure and income levels (compounded inflation rate applied: ~14.21%)

The starting point in our analysis is therefore the data provided by the Singapore Department of Statistics (SG DOS), gathered through the 2017/18 Singapore Household Expenditure Survey[63], which was the most recently available at the time this research was conducted. For future bodies of research focusing on 2023 or subsequent years of study, we recommend using newer reports as and when they become available. This would lead to more accurate results as projections based on inflation indexing for expenditure or income would no longer be required, and assumptions on the average number of household members would be based on more recent survey results.

The key parameters we considered in our calculations are summarized in Figure 6. The data covers **monthly expenses** reported by a statistically relevant sample of Singapore households, grouped in 5 income quintiles[64]. We have processed the data to reflect in Figure 6 the breakdown of expenditures by Expenditure Category, in order to further investigate the correlation with estimated GHG emissions.

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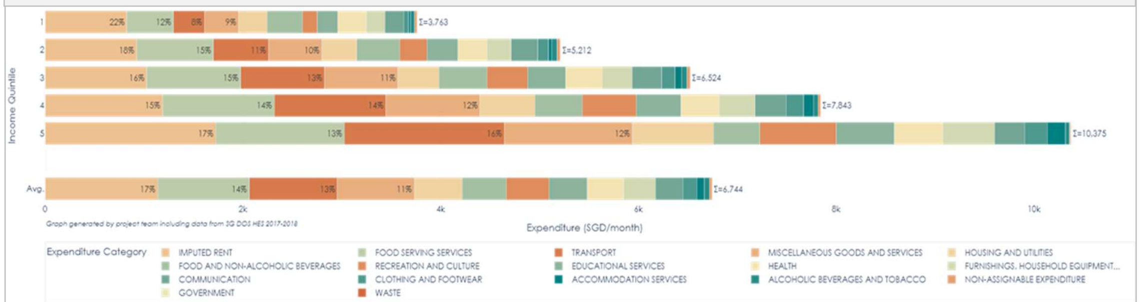
[63] Data retrieved from Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b).
[64] For income quintile 1 (i.e., the lowest income quintile), the average monthly expenditures exceed average monthly income by ~334.5 SGD (excluding imputed rent). In our interpretation, we attribute the difference to the demographic of the lowest 20% income group, a third of which are headed by individuals aged 65 and above. “Households may finance their expenditure through irregular receipts such as proceeds from the sale of properties, lump—sum CPF withdrawals, insurance claims or ad-hoc transfers that are not part of their regular income” (SG DOS, 2019a). Notably as well, we do not include Income Tax expenditures either in the expenditure or in the GHG emissions analysis.

***Figure 6**: Household Expenditures by Expenditure Category*

SGD/month, estimated levels for 2023

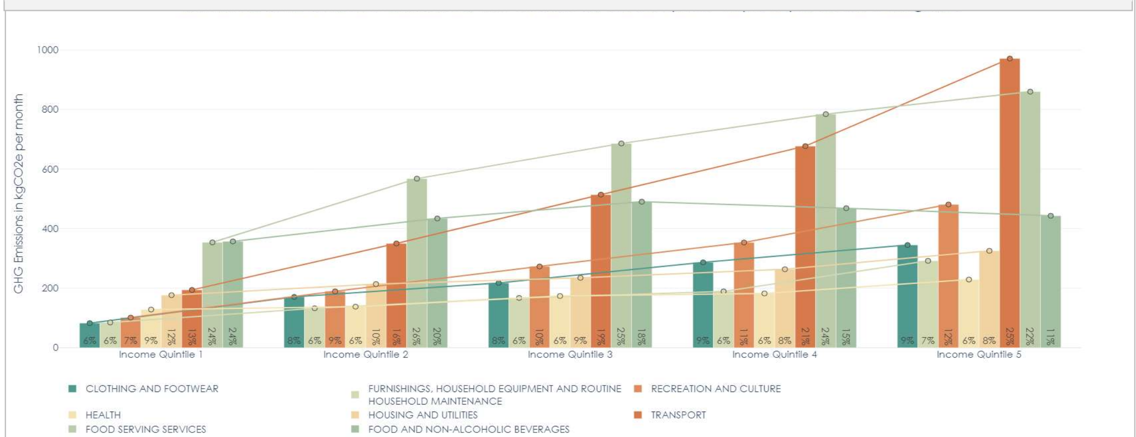


Source: Graph produced by authors incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 expenditure levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

Figure 7 allows for an easier examination of structural changes in the expenditure composition across income quintiles[65]. Based on the average increase of expenses from one income quintile to the next, the fastest growing category is "**Transport**", with an average increase of 51.46%, followed by "**Miscellaneous Goods and Services**" at 39.71%, and "**Educational Services**" at 30.76%. We later on compare this dynamic across Expenditure Categories with the average variations we see in estimated associated emissions.

***Figure 7**: Household top 8 Expenditure Categories*

SGD/month, *estimated levels for 2023*



Source: Graph produced by authors incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 expenditure levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

[65] Source: Singapore Household Expenditure Survey 2017 / 18, Executive Summary (SG DOS, 2019). Datapoints indexed with inflation for updating to 2023.

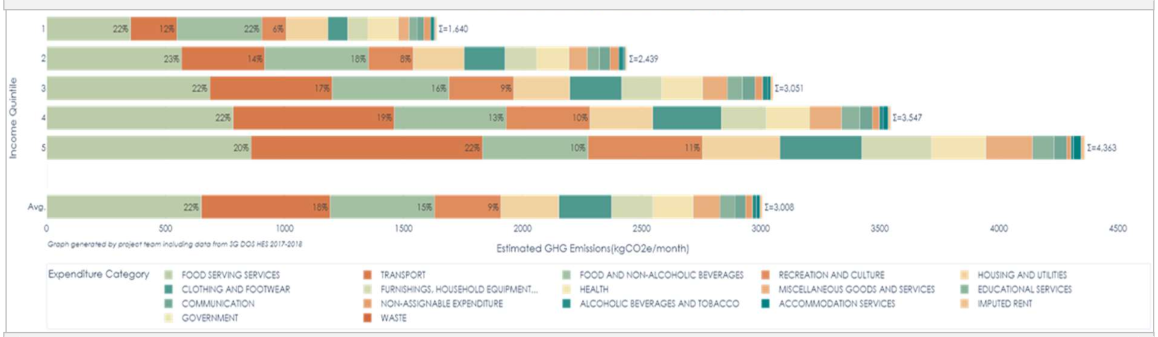
5.3 Singaporean household carbon footprint

When applying the emission factors that we contextualized through the algorithm described in previous sections to projected average household expenditures in 2023, the resulting estimated household carbon footprint is 3.01 t CO_2e/month, equivalent to **36.12 t CO_2e/year**. By income quintile, this carbon footprint ranges from 1.64 t CO_2e/month (19.68 t CO_2e/year) for the lowest income households, to 4.36 t CO_2e/month (52.32 t CO_2e/year) for the highest income ones[66].

For an average household size of 3 members (as described in section 2 Table 1), we estimate the average **Individual Carbon Footprint** to be **12.034 t CO_2e/year**, as displayed in Figure 8. This is significantly above the global average of 4.7 t CO_2 per capita (IEA, 2023), which is equivalent to 6.18 t CO_2e[67]. For individual consumers the annual carbon footprint ranges from **6.56 t CO_2e/year** for **Quintile 1**, to **19.37 t CO_2e/year** for **Quintile 5**.

***Figure 8**: Household GHG Emissions by Expenditure Category*

kg CO_2e/month



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 expenditure and income levels. Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

This carbon footprint **includes** emissions from all goods and services covered by the survey. Emissions related to the international transportation of imported goods are allocated to the respective goods' expenditure categories, based on the methodology described earlier.

There are relevant actual and implicit purchases that are **excluded from calculations**, as the estimation is based on the available expenditure data leveraged from the HES survey. For instance, our calculation does not include real estate purchases or investments, as they are not covered by the underlying HES data. The consumption subsidized by the government is also not included, as the related expenditure is not

[66] The full computational methodology to derive this number is described in our companion whitepaper "Consumption Carbon Footprint: Country Level Data Framework".
[67] To convert CO_2 to CO_2e we have considered a global average contribution of ~76% of CO_2 to GHGs (C2ES, 2023).

directly reported by end consumers. The related emissions can be estimated through different methodologies and can be in scope of future bodies of work.

5.4 Household expenses versus emissions – income comparison

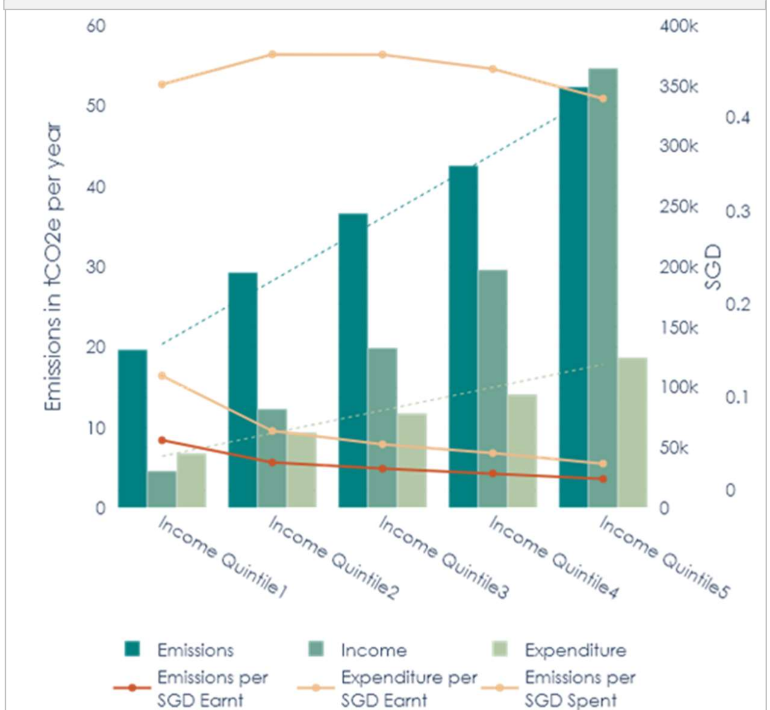
Based on our estimations of average expenditures and income, we see a steep increase in income, at an average of ~**90.7%** increase from one income quintile to the next. Expenditures and emissions grow at a relatively slower pace than income, at **28-29%** average increase across quintiles.

While we have few data points for statistical analysis, the high-level view in Figure 9 offers a few takeaways that can open the door to more granular household consumption studies.

Firstly, the **quantity effect** stands out, as expected: the higher the income, the higher the expenditures and consequently the higher the emissions per household or individual. This result is consistent with findings in Ivanova et al. (2016), whereby **"elasticities** suggest a robust and significant relationship between households' expenditure and their environmental impact"[68].

Subject to the assumptions and the uncertainty drivers detailed in our companion Whitepaper, the disproportionate associated emissions, and consequently negative climate impact, of higher income households is clear.

***Figure 9**: Comparative view of Income, Expenditure and GHG Emissions*



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure and income data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

[68] A similar dynamic of emissions increasing with income across quintiles was also observed by Su et al, 2017, in a structural decomposition analysis of Singapore's carbon emissions with a focus on households.

The average estimated Monetary EF for consumer expenditure does vary by income quintile, due to structural differences in the consumption mix for each group of households:

- **Income quintile 1:** 0.43 kg CO_2e/SGD spent
- **Income quintile 2**: 0.47 kg CO_2e/SGD spent
- **Income quintile 3:** 0.47 kg CO_2e/SGD spent
- **Income quintile 4**: 0.45 kg CO_2e/SGD spent
- **Income quintile 5**: 0.42 kg CO_2e/SGD spent

In the next sections, we are examining the emissions drivers under each category of expenses and also testing a few sustainable consumption scenarios to understand how they would change the households or individual emissions footprint.

On detecting **quality effects** deriving from differences in expenditure composition across income quintiles, one important limitation to re-emphasize is our dependency on publicly available EFs that our project could efficiently retrieve at this stage. As we do not have EFs broadly available for a granularity deeper than product/service level as described in the earlier sections, we cannot go into brand or SKU level granularity, and instead we are constraint to apply the same EFs for all products and services of the same type, consumed by all households.

We note that **brand and SKU level differences** within the same product category can account for very different Monetary EFs (emissions/SGD)[69]. More eco-conscious brands and clean technology in fact can be more expensive. However, at this point, this limitation is systemic and will likely affect similar efforts to develop a household carbon footprinting algorithm[70]. These insights gaps are unavoidable until emissions reporting is adopted and standardized at a greater scale, and manufacturer level/brand level/SKU level carbon labels are in place, allowing them to move away from product average emissions.

***Table 2**: GHG emissions across income quintiles - top 8 Expenditure Categories*

	Monthly Household Estimated Emissions (kg CO2e)						Increase from preceding Quintile(%)					
	Income Quintile 1	Income Quintile 2	Income Quintile 3	Income Quintile 4	Income Quintile 5	Average	Income Quintile 1	Income Quintile 2	Income Quintile 3	Income Quintile 4	Income Quintile 5	Average
FOOD AND NON-ALCOHOLIC BEVERAGES	357	434	490	469	443	439	-	22%	13%	-4%	-5%	6%
FOOD SERVING SERVICES	354	568	686	784	860	650	-	61%	21%	14%	10%	26%
TRANSPORT	**195**	**350**	**514**	**677**	**971**	**541**	**-**	**80%**	**47%**	**32%**	**43%**	**51%**
HOUSING AND UTILITIES	177	214	235	263	325	243	-	21%	10%	12%	23%	17%
HEALTH	128	138	174	182	229	170	-	7%	26%	5%	26%	16%
RECREATION AND CULTURE	**101**	**189**	**273**	**353**	**481**	**280**	**-**	**87%**	**44%**	**30%**	**36%**	**49%**
FURNISHINGS, HOUSEHOLD ..MAINTENANCE	85	133	167	189	292	173	-	56%	26%	13%	54%	37%
CLOTHING AND FOOTWEAR	**83**	**170**	**218**	**287**	**345**	**220**	**-**	**107%**	**28%**	**32%**	**20%**	**47%**

Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

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[69] Spending 400 SGD instead of 200 SGD for a coffee machine does not necessarily mean the emissions related to buying this product are double. It could in fact be the other way around if the more expensive item is so due to eco-friendly considerations (Pottier et al., 2020).

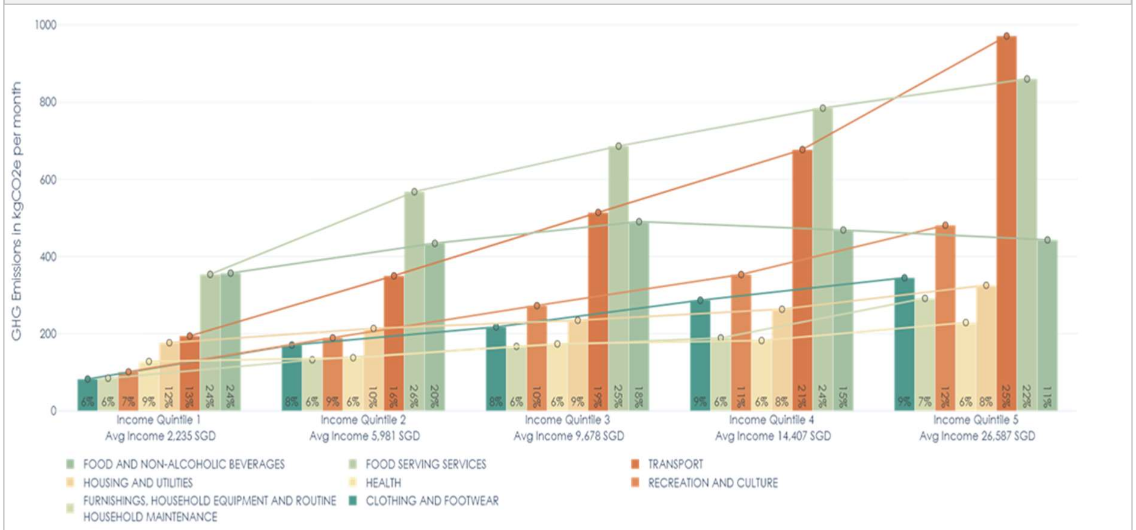
[70] Volume, structural and quality effects are covered extensively by Pottier et al., 2020 in a similar study on France household emissions.

Regarding broader **structural effects**, different emissions categories accelerate at a different pace when moving up on the income ladder.

Table 2 and Figure 10 provide a clear illustration on the increase of discretionary spending across income quintiles, where we see "**Transport**", "**Recreation and Culture**" and "**Clothing and Footwear**" advancing at the fastest pace with higher income, at 50.61%, 49.25% and respectively 46.53% respectively.

Figure 10: *Household GHG Emissions by Expenditure Category*

Top 8 Expenditure Categories, kg CO_2e/month



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

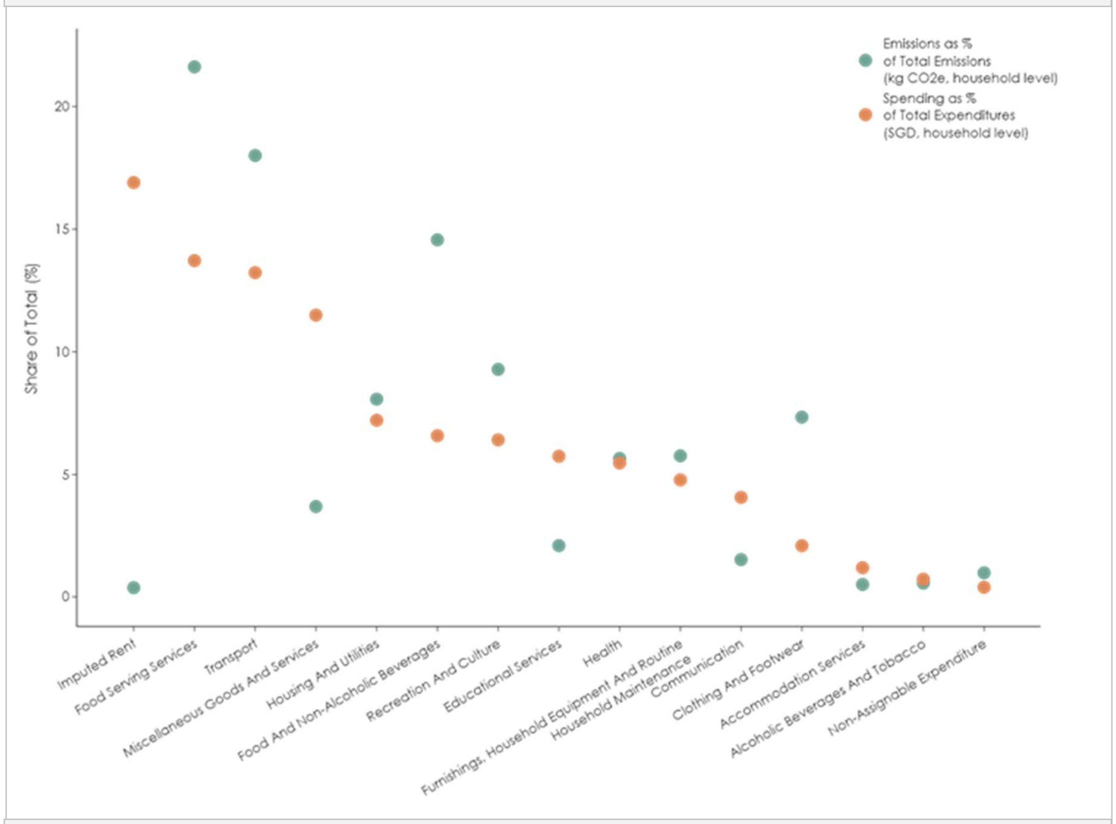
5.5 Emissions drivers

Beyond the relatively straight forward quantity effect, we also observe changes in the weightage of various expenditure categories' contribution in the total expenses and total GHG emissions. This is due to the different **carbon intensities** of products and services that fall within each Expenditure Category (expressed and kg CO_2e/SGD spent), and the different consumption pattern of each income group. Each Expenditure Category is a combination of multiple products and services, for which the individual product's carbon intensity and contribution to the consumption mix can be vastly different by category, as showcased in Figure 11.

Notably "**Imputed Rent**" switches place completely in the hierarchy – it has the highest contribution to household monthly expenses (17%), but it has the lowest contribution to GHG emissions (lowest single digit %). This effect is primarily due to the original EFs attributable to Imputed Rent that we were able to retrieve and process for Singapore contextualization. Given the contribution of residential constructions to global emissions, and the significant share of household expenses allocated to ownership or rental of residential space, we recommend future in-depth research on the attribution of emissions to real estate property owners or renters[71]. Similarly, **Recreation and Culture** and **Transport** are also 2 categories warranting further examination, as both can include air flights (either as standalone expenditures or packaged holidays), which can significantly increase the carbon footprint of individuals and households[72].

Figure 11*: Contribution to total GHG Emissions and Spend*

Expenditure Categories (L1)



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

At the other end of the spectrum is the "**Food Serving Services"** category – while it accounts for **14%** of the estimated average household's expenses, it contributes disproportionately more to its GHG emissions at **22%.** This is explained by the higher

[71] We recommend including important elements such as full embodied carbon of the residential property, its likely useful life, and the share that can be attributed to households depending on the size or number of rooms.
[72] Several factors such as distance, destination, economy or premium classes for the flights and length of stay can influence the accuracy of the end estimation.

carbon intensity of cooked meals (expressed as kg CO_2e/SGD spent), relative to other expenditure categories. For "**Food and Non-Alcoholic Beverages**", the pattern is similar – this category accounts for **6%** of expenditures and **15%** of emissions.

Collectively, food related consumption seems to have high carbon intensity, whether the consumption happens at home or while eating out. However, this observation equally points to a need to further refine and contextualize the emission factors for restaurant foods that we were able to source. On the long tail of the carbon intensity spectrum, we see items such as Imputed Rent, Communication, Education and Accommodation Services.

For example, this dynamic is at play for "**Educational Services**" category (which moves from the 8th top contributor to expenses, to being the 10th top contributor to GHG emissions), and "**Communication**" category (which, however, due to its low % contribution to both Expenditures and GHG Emissions, features less prominently on either ranking).

5.5.1 Carbon intensity of Expenditure Categories

As expected, the carbon intensity of the Expenditure Categories is aligned to the dynamic we saw in Figure 11. Per our estimation, and subject to the assumptions and uncertainty mentioned before, the Expenditure Categories that are most carbon intensive on a per SGD basis[73] are "**Clothing and Footwear**", with an estimated average EF of 1.57 kg CO_2e/SGD, "**Food and Non-Alcoholic Beverages**", with an estimated average EF of 0.98 kg CO_2e/SGD, and "**Food Serving Services**", at 0.7 kg CO_2e/SGD. On the other end of the spectrum, "**Imputed Rent**", "**Miscellaneous Goods and Services**" and "**Educational Services**" feature EFs of 0.01 kg CO_2e/SGD, 0.14 kg CO_2e/SGD, and 0.16 kg CO_2e/SGD, respectively[74].

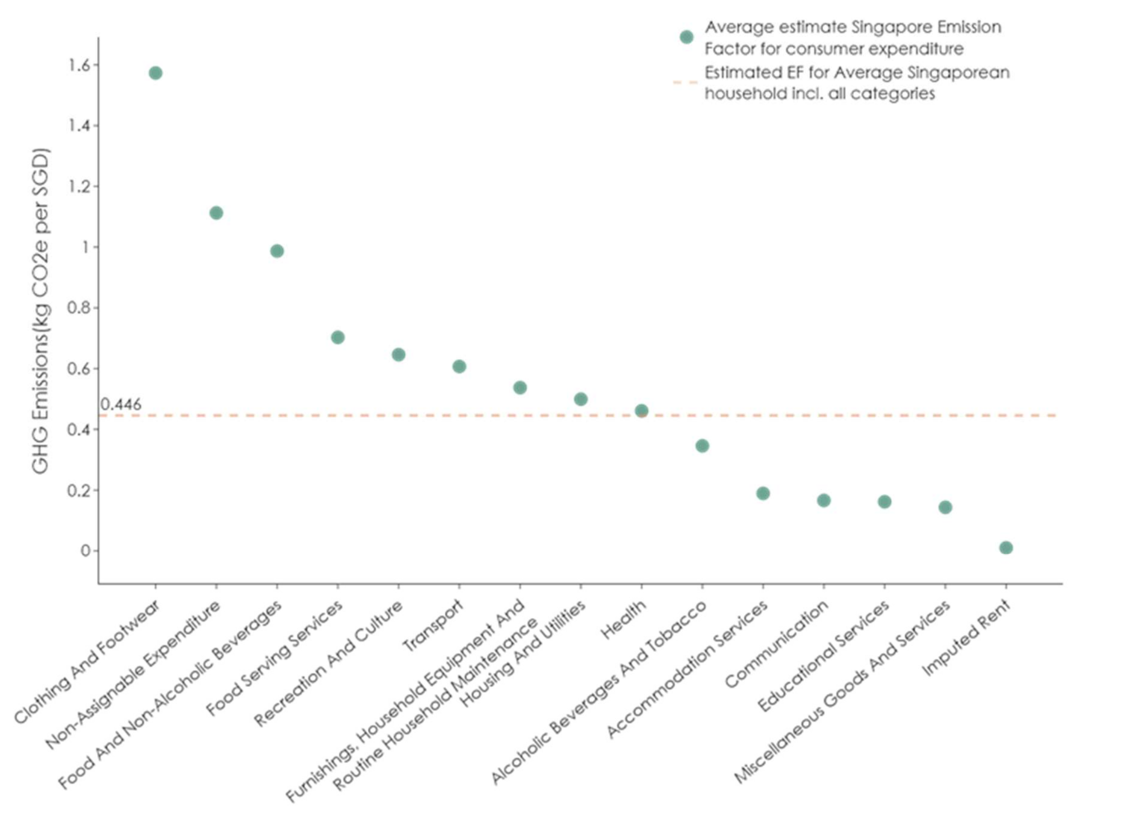
Notably, the average estimated EF for **Singapore residents' consumption**, computed as the average of all GHG emissions estimated for all Expenditure Categories (L1), divided by all expenditures, is at **0.446 kg CO_2e per SGD**.

In Figure 12 we provide a comparison between the **Monetary EF for each Expenditure Category** (L1), relative to the average Monetary EF for overall consumer expenditure in Singapore (which we estimated at 0.446 kg CO_2e/SGD).

[73] An important phenomenon to call out again is that the carbon intensity on a per dollar basis versus on a per unit basis may move in opposite directions. Prices can significantly dilute (if they are high) or elevate (if they are low) the relative carbon intensity of different items.

[74] An additional Expenditure Category included in the survey is "Other Non-Assignable Expenditure", with an estimated Emission Factor of 1.12 kg CO_2e/SGD. The SG DOS HES 2017 / 18 (SG DOS, 2019b) includes only 2 elements for it, across all levels of resolution: "POCKET ALLOWANCES FOR CHILDREN", and "OTHER NON-ASSIGNABLE EXPENDITURE". The biggest contribution in terms of carbon intensity is injected by "POCKET ALLOWANCES FOR CHILDREN", to which we have associated an original Emission Factor from UK DEFRA 2020, relevant for "Canteens", which post currency conversion and inflation adjustment yields 1.14 kg CO_2e/SGD. For future studies and as an opportunity for improvement, we recommend considering alternative estimated EFs instead (such as the EF for "Food Serving Services", which is of 0.7 kg CO_2e/SGD). The contribution of this particular Expenditure Category to the total Household Carbon Footprint is however relatively less impactful than other categories, at ~351.78 kg CO_2e/year/Household.

***Figure 12**: Carbon Intensity by Expenditure Category*



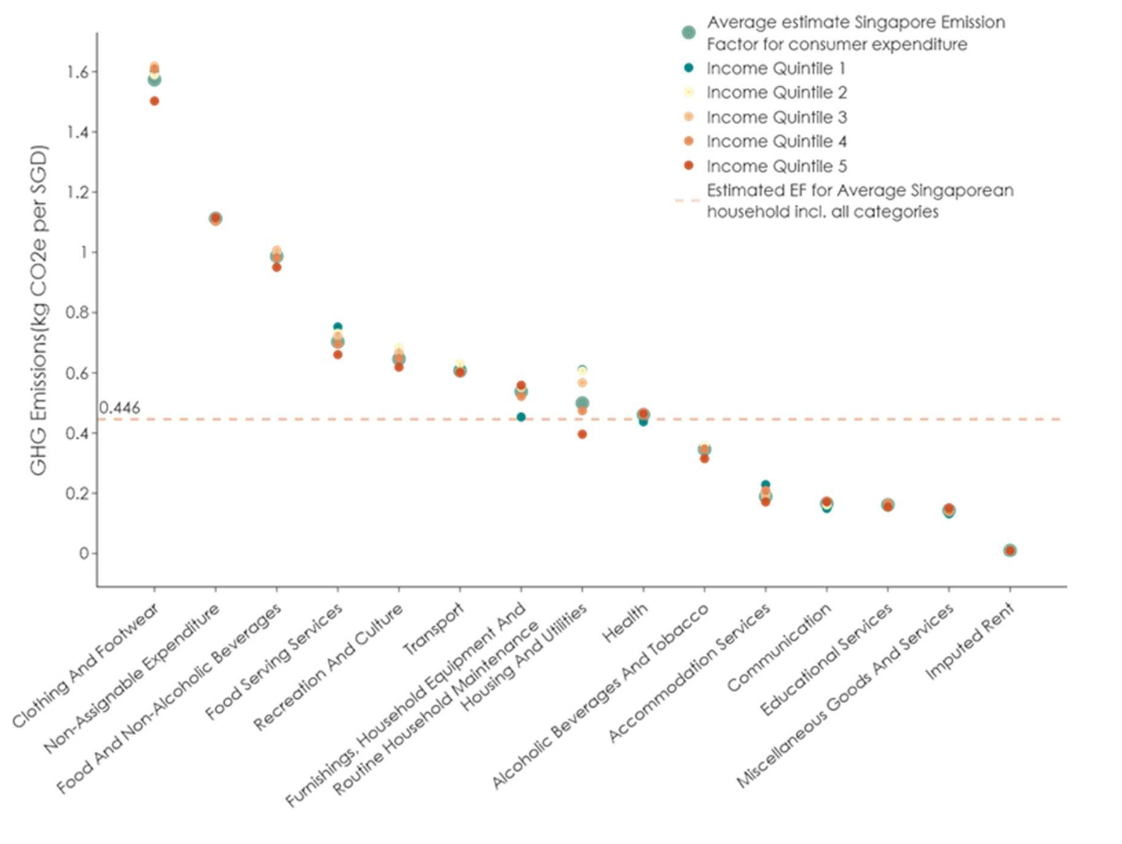
Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

5.5.2 Variation between income quintiles

To examine differences of carbon intensity by Expenditure Category and between income quintiles, we plot the average EF by Expenditure Category in descending order, as showcased in Figure 13. We use standard deviation to measure the distance from the respective Expenditure Category average EF. Across income quintiles, we see variations in the carbon intensity of each Expenditure Category, accounted for by structural effects triggered by differences in **consumption mix** for each Expenditure Category due to increases in income.

***Figure 13**: Variation between income quintiles*

Carbon Intensity of Expenditure Categories



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.
Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

The Expenditure Categories where we see some of the largest variations across income quintiles are "**Clothing and Footwear**" (for which EFs are between 1.5 to 1.6 kg CO_2e/SGD), "**Food Serving Services**" (with EFs between 0.69 to 0.75 kg CO_2e/SGD) "**Furnishings, Household Equipment and Routing Household Maintenance**" (with EFs between 0.45 kg CO_2e/SGD to 0.52 kg CO_2e/SGD) , and "**Housing and Utilities**" (for which EFs range from 0.39 to 0.61 kg CO_2e/SGD)[75]. The drivers of these variations pertain to the differences in the mix of products and services associated with each Expenditure Category across different income quintiles.

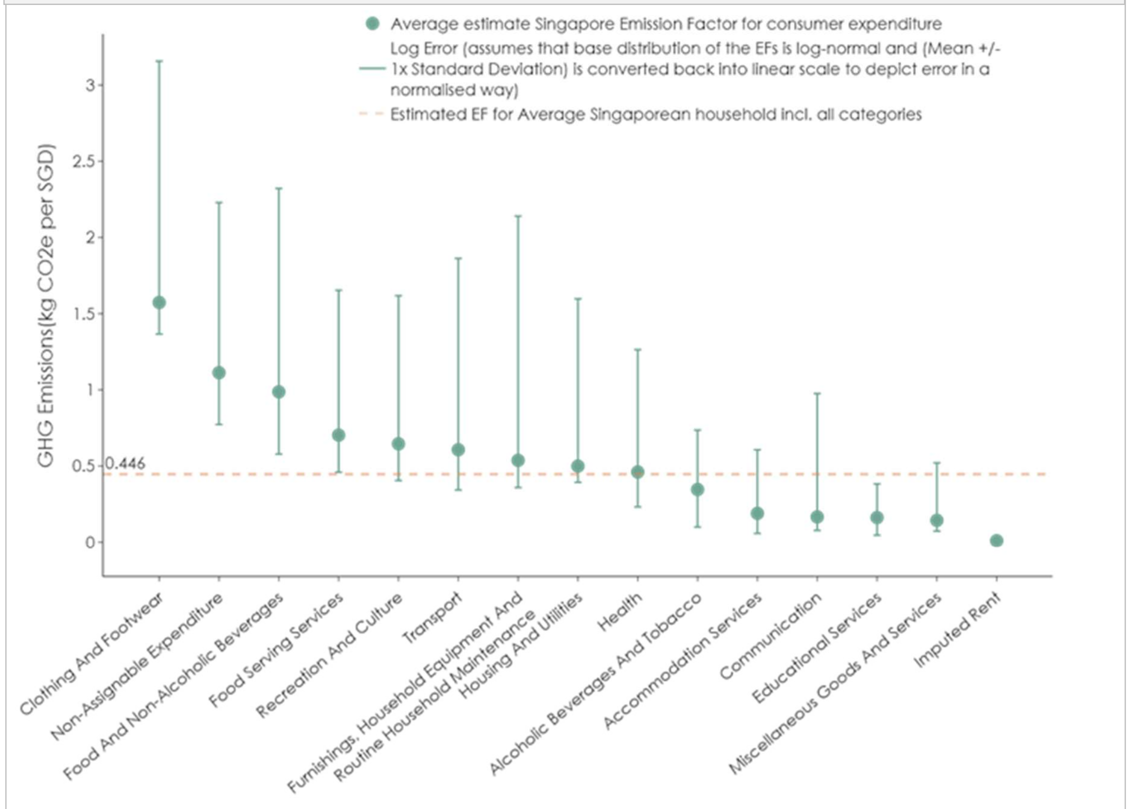
[75] For Housing and Utilities, spend structure varies significantly across Income quintiles especially for "Rentals paid by tenants", which are ~8 times higher in income quintile 5 versus Income Quintile 1. Therefore, the relatively lower Monetary EF of this Expenditure Item lowers the carbon intensity on a per dollar basis for the higher earning households.

5.5.3 Variation within Expenditure Categories

To examine the breadth of variation of EFs within the same Expenditure Categories, we plotted again the individual Emission Factors on a log scale for easier visualization and used log inverse of standard deviation to measure the distance from the Expenditure Categories average of EFs subordinated to each, as illustrated in Figure 14.

***Figure 14**: Variation within Expenditure Categories*

Carbon Intensity of Expenditure Categories (L1)



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded rate) to estimate 2023 levels.

We observe the following variations within each Expenditure Category:

- In "**Clothing and Footwear**" (L1) we have 47 Expenditure Items (L5), with 80 associated EFs ranging from 0.02 kg CO_2e/SGD to 2.48 kg CO_2e/SGD (around an average of 1.57 kg CO_2e/SGD).
- In "**Food and Non-alcoholic Beverages**" we have 142 Expenditure Items (L5), with 397 associated EFs, ranging from 0.21 to 3.34 kg CO_2e/SGD (around an average of 0.98 kg CO_2e/SGD).
- In "**Furnishings, Household Equipment and Routing Household Maintenance**" (L1) we have 63 Expenditure Items (L5), with 139 associated EFs, ranging from 0.04 to 2,92 kg CO_2e/SGD (around an average of 0.53 kg CO_2e/SGD).

- In "**Housing and Utilities**" (L1) we have 12 Expenditure Items (L5), with 15 associated EFs, ranging from 0.07 to 3.53 kg CO_2e/SGD (around an average of 0.49 kg CO_2e/SGD).

The drivers of these variations pertain to the differences in the mix of products and services associated with each Expenditure Category, irrespective of household income quintile, which we will also discuss at length in subsequent section 6. "Emissions analysis for the largest expenditure categories".

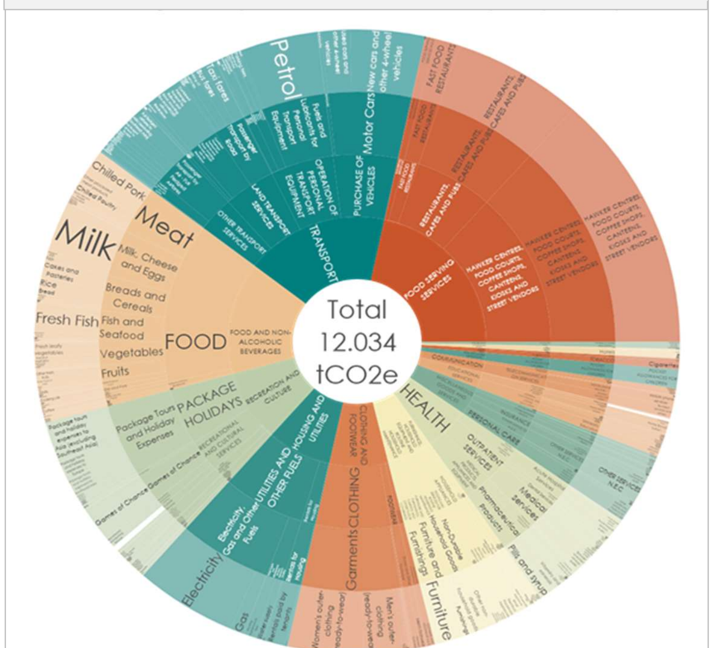
6. Breaking down individual carbon footprints in Singapore

Our study involves different methodologies for estimating GHG emissions related to the delivery of services and respectively the lifecycle of finished goods (for which we cover in a differentiated way production, transportation, warehousing and retail operations, and waste treatment). As detailed in the previous sections, we are attributing all **upstream** emissions (related to sourcing raw materials, manufacturing, international transportation and domestic logistics), as well as **downstream** emissions (related to waste management), to the end consumers[76].

In order to understand the key items driving overall emissions, we **decomposed** all emission categories (corresponding to expenditure categories), down to 4 levels of resolution. We found the following key contributions (Figure 15):

***Figure 15**: Average Yearly Individual Carbon Footprint*

L1 to L4 contributions



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

- **Food Serving Services**, accounting for **22%** of total emissions, driven by emissions associated with restaurants and hawker centers
- **Transport**, accounting for **18%** of total emissions, driven by petrol for personal cars as well as air transport
- **Food and Non-Alcoholic Beverages**, accounting for **15%** of total emissions, driven by animal-based products and air transportation for imported items
- **Recreation and culture**, accounting for **9%** of total emissions, mostly driven by overseas vacations via air transportation
- **Housing and Utilities,** accounting for **8%** of total emissions, mostly driven by electricity

The results are in line with global studies finding that household GHG emissions are mostly contributed by mobility, shelter and food (Ivanova et al., 2016, Hertwich and Peters, 2009).

[76] Emissions mapped strictly to the "Use" phase in a product lifecycle are considered to be null due to the fact that the drivers of those emissions would likely be captured in other consumption expenses – such as electricity for domestic appliances (which is captured and accounted for in the "Housing and Utilities" category), or petrol for vehicles (which is captured in the "Transport" category).

6.1 What can consumers do to reduce their carbon footprints?

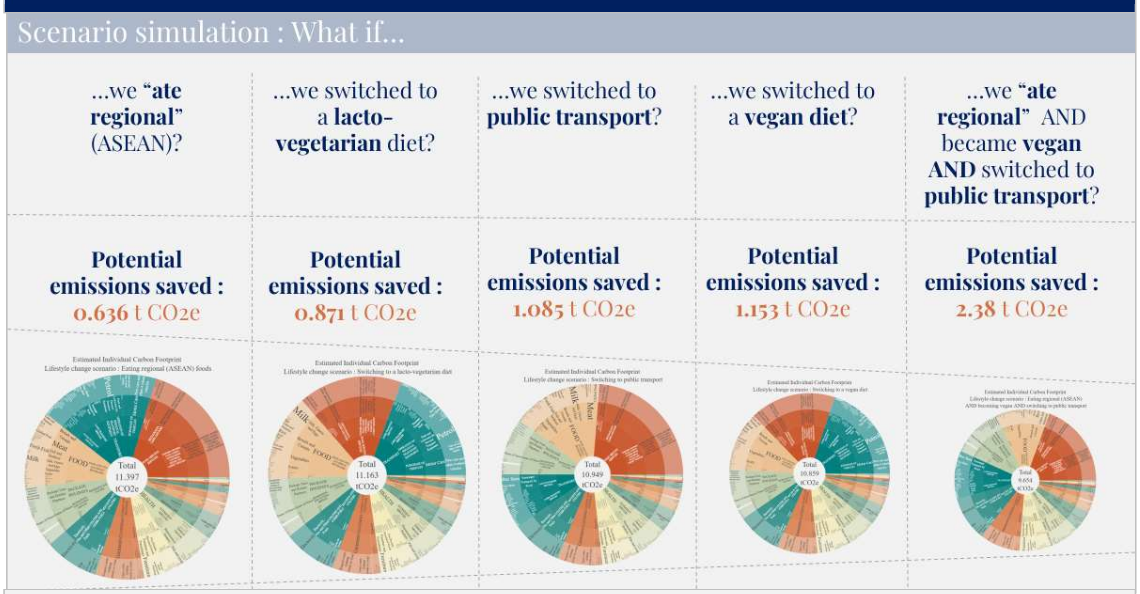
In this section, we investigate how an average individual's carbon footprint could be optimized by making **different consumption and lifestyle choices**. We identified a few such choices that are frequently mentioned as potential ways to reduce carbon footprints, such as prioritizing local food sources, switching to plant-based diets, taking public transportation, or a combination of these lifestyle changes.

We consider the following specific lifestyle choices in the context of Singaporean consumers: (1) prioritizing foods **regionally produced** in ASEAN countries[77], (2) and (3) switching to a **lacto-vegetarian** or a **vegan** diet respectively, (4) opting consistently for mass **public transportation**, and (5) making several impactful changes all at once.

Each of these different choices yields a reduction in carbon footprints. A diet prioritizing regional food sources would reduce the carbon footprint of the average Singaporean resident by an estimated 0.636 t CO_2e/year. Other types of diets would yield an event bigger reduction: a vegan diet would reduce the carbon footprint by an estimated 1.153 t CO_2e/year (9.58% of the average footprint of Singaporean residents), while a lacto-vegetarian diet would yield an estimated reduction of 0.871t CO_2e/year (7.2%). Switching to mass public transportation would reduce carbon

***Figure 16**: Sustainable consumption scenarios*

Potential impact on individual carbon footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

[77] We do recommend for future testing looking into scenarios of locally produced food (within Singapore). Given Singapore's imports dependence, and since one of our assumptions allowing for computational efficiency was to assume 0 local production, we only tested for now the "regional sourcing" scenario.

footprint by an estimated ~1.085 t CO_2e/year (8.9%). Figure 16 provides a graphical summary of these scenarios.

Going all in on multiple environmentally friendly choices such as going for a plant-based diet, consistently taking mass public transport instead of riding or owning a private car, and sourcing foods regionally yields the greatest benefits in terms of emissions saved, of **2.38 t CO_2e/year**, or almost 20% of an average Singaporean resident's carbon footprint. We present a more detailed discussion of each lifestyle change in the following section.

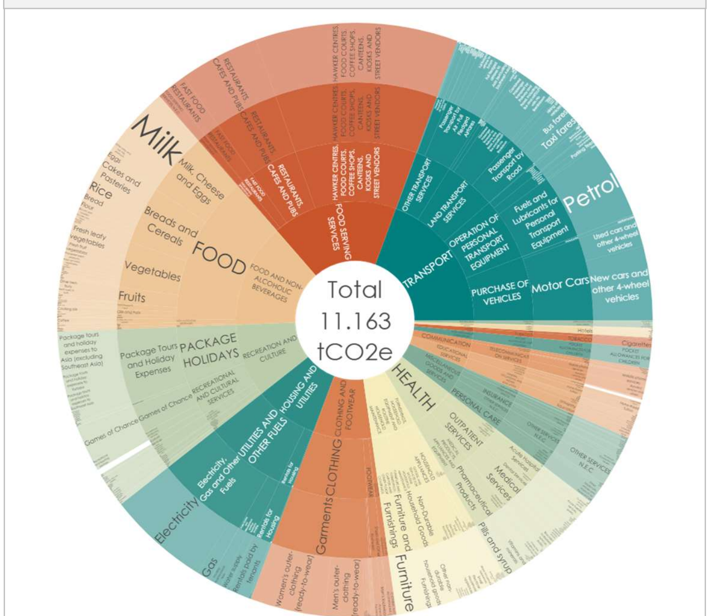
6.2 What if we switched to a lacto-vegetarian diet?

The first scenario we modelled is for an average Singaporean resident, switching to a lacto-vegetarian diet, which excludes any item under the "Meat" or "Fish and Seafood" Expenditure Item Classes (L3), but includes dairy and eggs.

The result at the end of the simulation shows a reduction of **0.871 t CO_2e/year** in GHG emissions (Figure 17).

***Figure 17**: Switching to a lacto-vegetarian diet*

Estimated Individual Carbon Footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

From a methodological perspective, for changes in the "**Food and Non-Alcoholic Beverages**" Expenditure Category (L1), our data modelling approach involved taking out all "**Meat**" and "**Fish and Seafood**" related expenditure SGD amounts, and redistributing them to "**Vegetables**", "**Milk, Cheese and Eggs**" and "**Breads and Cereals**" Expenditure Item Classes (L3)[78].

For "**Food Serving Services**" Expenditure Category (L1), we operated the changes at Expenditure Item (L5) level, as the distinction between vegetarian and non-vegetarian choices is only evident at this level (without associated SGD insights). We removed the non-vegetarian dishes, and kept only the vegetarian ones in the calculation, with increased assumed dish weights in the calculation[79].

[78] The environmental benefits of eliminating Meat and Seafood from households' diets is partially offset by the GHG emissions associated with products like milk and cheese.

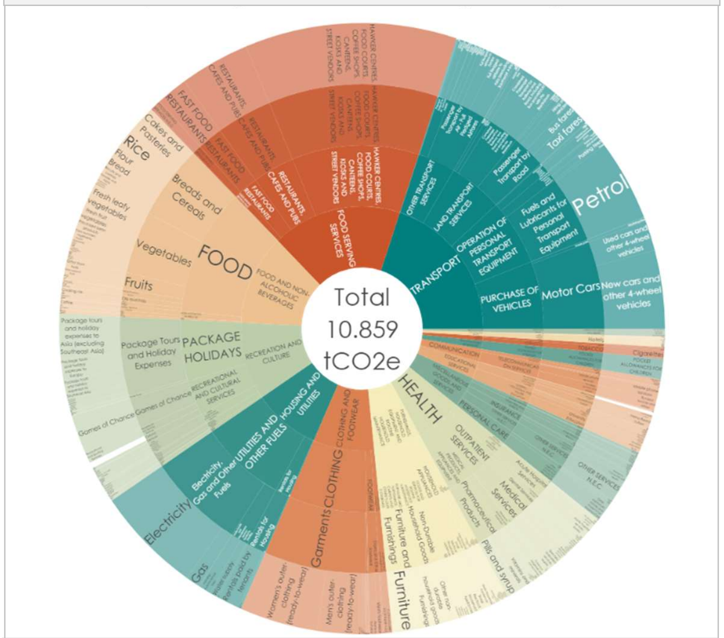
[79] More specifically, we excluded the following dishes: "Restaurant meal containing meat", "Restaurant dish - Portion of Chicken dish", "Restaurant dish - Portion of Lamb dish", "Restaurant dish - Portion of Seafood dish", "Restaurant dish - Portion of Beef dish", "Restaurant dish - Portion of Pork dish", "Restaurant dish - Non Vegetarian pizza", "Fast Food meals - Beef Burger", "Fast food meals - Desserts (Ice-Cream)", "Fast Food meals - Drinks - Non-Alcoholic (Coffee w Milk)", "Fast Food meals - Non-Alcoholic - Soft Drinks", "Hawker Centers - Meal containing meat"
"Hawker Centers - Chicken Rice", "Hawker Center - Chicken Nasi Biryani". We incorporated in our calculation dietary preferences insights from Tan, 2023.

6.3 How about if we went fully vegan?

Prominent academic studies point towards the importance of dietary changes, surfacing evidence that even the lowest impact animal products typically exceed plant-based substitutes in terms of associated emissions, globally (Poore and Nemecek, 2018), as well as specifically for Singapore (Tan et al., 2020). Following these studies, the second scenario we modelled is for an average individual, switching to a strictly plant based (vegan) diet, which excludes animal-based products, and instead is rich in vegetables and cereals.

***Figure 18**: Switching to a vegan diet*

Estimated Individual Carbon Footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

In the data modelling we took a similar approach as in the above exercise, assigning all expenditures associated with "**Meat**", "**Fish and Seafood**", and "**Milk, Cheese and Eggs**" and redistributed them to "**Vegetables**" and "**Breads and Cereals**".

For **Food Servicing Services**, we operated the changes at Expenditure Item (L5) level, since, as in the scenario studied above, the distinction between vegetarian and non-vegetarian choices is only evident at this level (without associated spend information). We removed the non-vegan dishes and kept only the vegan ones in the calculation, with increased assumed dish weights in the calculation[80].

Figure 18 shows a significant GHG emissions reduction of **1.153 t CO_2e/year** associated with this lifestyle change, consistent with prior studies.

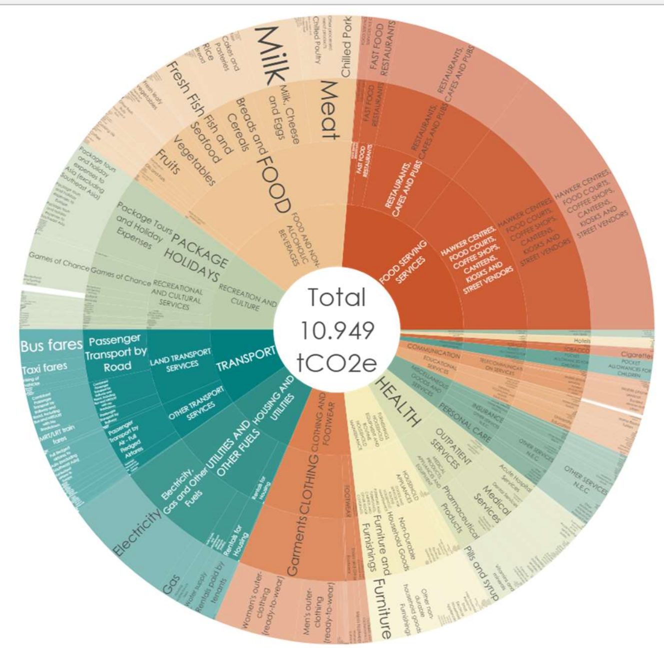
80 More specifically, we excluded the following vegetarian dishes: "Restaurant meal containing meat", "Restaurant dish - Portion of Chicken dish", "Restaurant dish - Portion of Lamb dish", "Restaurant dish - Portion of Seafood dish", "Restaurant dish - Portion of Beef dish", "Restaurant dish - Portion of Pork dish", "Restaurant dish - Non Vegetarian pizza", "Fast Food meals - Beef Burger", "Fast food meals - Desserts (Ice-Cream)", "Fast Food meals - Drinks - Non-Alcoholic (Coffee w Milk)", "Fast Food meals - Non-Alcoholic - Soft Drinks", "Hawker Centers - Meal containing meat", "Hawker Centers - Chicken Rice", "Hawker Center - Chicken Nasi Biryani". In addition to these we excluded non-vegan items: "Restaurant drinks - Non-alcoholic (Coffee w Milk)", "Fast food meals - Desserts (Ice-Cream)", "Hawker centers drinks - Coffee/tea w milk". For pizza we used a vegan pizza instead of the mix used in the mainstream current carbon footprint analysis. We incorporated in our calculation dietary preferences insights from Tan, 2023.

6.4 How about using public transportation instead of driving personal cars?

Another significant source of GHG emissions reduction, well studied in the literature, arises from using mass public transportation as much as possible, instead of using and/or buying private vehicles. In an urban environment with highly efficient, affordable and available mass transport infrastructure like Singapore, this could be a realistic lifestyle change for many residents.

***Figure 19**: Switching to public transportation*

Estimated Individual Carbon Footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

Methodologically, we redistributed all SGD expenses related to Expenditure Item Types (L4) "**Petrol**" and "**Diesel**" evenly to the public transport Expenditure Item Types "**Bus fares**" and "**MRT/LRT train fares**"[81]. We also opted to eliminate completely the monthly expenditures associated with buying vehicles[82], as well as expenditures related to personal vehicles[83]. To keep this lifestyle choice realistic, we opt to keep the expenditures on "**Taxi fares**" and "**Hiring of vehicles**" to account for unforeseen personal transportation requirements.

The estimated carbon footprint reduction associated with this change is **1.085 t CO_2e/year** for the average Singaporean resident (Figure 19).

[81] We used at this stage a 1-1 proportion when attributing expenses from vehicle fuels to public transportation, on grounds that several household members may need to travel and incur separate charges when using the bus or MRT rather than travelling together in the same car. Also depending on key location addresses and bus/MRT connectivity, public transport routes may be longer. We recommend studying these effects along with price/km differences between private and public transportation to determine a more contextualized attribution ratio.

[82] We eliminated from the calculation the SGD amounts associated with Expenditure Item Types "New cars and other 4-wheel vehicles", "Used cars and other 4-wheel vehicles", "Motorcycles".

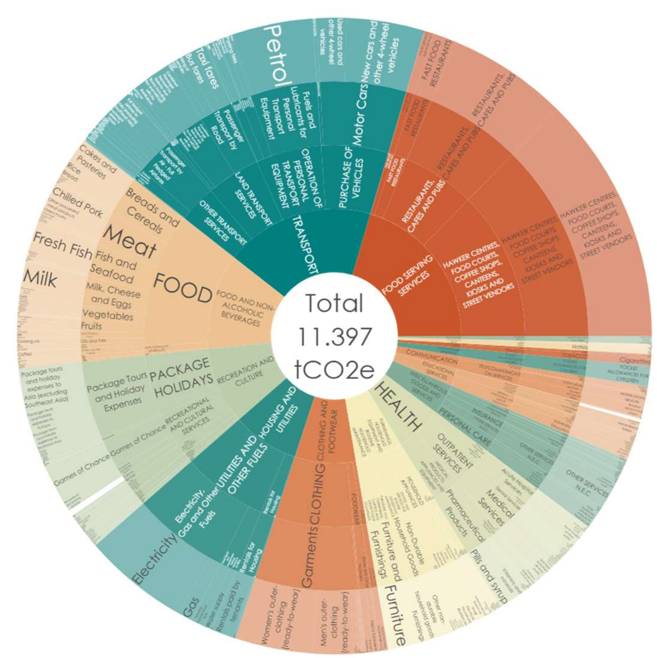
[83] We eliminated from the calculation the SGD amounts associated with Expenditure Item Types "Brake and transmission fluids, coolants", "Other fuels and lubricants for personal transport equipment", "General repairs and maintenance of cars", "Major repairs and maintenance of cars", "Repairs and maintenance of motorcycles and scooters", "Fees for driving lessons/licence", "Car inspection fee", "Parking fees", "Toll charges", "Road tax and other services". Our calculation considers average public trip parameters from Moovit Insights, 2023, as well as pricing data from Singapore SBS Transit Link, 2024a and 2024b.

6.5 How about sourcing foods from closer to home?

For consumers in most countries, switching to a vegetarian or vegan diet could by far outweigh in terms of benefits switching to **locally sourced produce** – whether the meat is produced by the farmer next door or in a facility far away, most carbon embodied in a meal would come from the steak itself (Ritchie, 2020). This is not the case in Singapore with its geographical position as an island nation and its high dependence on imports, including for highly perishable food items (which we assume to be air shipped). Transportation is an important consideration for food products' carbon footprints, as highlighted in other academic studies focused on Singapore (Tan et al., 2020).

***Figure 20**: Switching to eating regionally sourced foods (ASEAN countries)*

Estimated Individual Carbon Footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

We therefore investigate the impact of prioritizing food items originating regionally in **ASEAN countries**[84]. Methodologically, we replace food imports from non-ASEAN countries of origin, with food imports from ASEAN countries (proportionately with their current weights within the total imported quantities for the respective commodities)[85].

It is plausible that imports from ASEAN countries displace relatively less carbon intensive options from other countries of origin[86]. Indeed, looking at the new structure of emissions, Embodied Carbon for Foods (accounting for the lifecycle stages covering raw materials sourcing up until the point of export) shows an increase of 9.24%. Nevertheless, this effect is offset by the reduction in international shipping emissions (arising primarily from air transportation), which are

[84] Defined as Malaysia, Brunei, Indonesia, Philippines, Thailand, Vietnam, Cambodia, Laos, Myanmar.
[85] We consider the Country-of-Origin to be the country-of-import for commodities associated with respective products, as defined through HS Commodity Codes and as captured in the CEPII BACI database (CEPII, 2023).
[86] For the same products and judging by differences in Emission Factors for different countries of origin. Source: A*STAR, Deloitte, Temasek, 2019.

lower by 85.57%, accounting for by the shorter import distances. The GHG emissions for Foods thus decrease by 20.85% (0.365 t CO_2e/year).

We then assume that this reduction would also apply to food services, by applying half of this reduction percentage (i.e. 10.43%) to the carbon footprints of "**Food Serving Services**"[87], which results in a decrease of 0.271 kg CO_2e/year.

In total, this lifestyle change would reduce the typical Singaporean resident's carbon footprint by **0.636 t CO_2e/year** (Figure 20), which illustrates the potential case for "eating regional". The reduction calculation itself offers plenty of opportunities for further refinement, but we find the current result points towards the importance of sourcing food items from nearby countries, or, potentially even better, locally. We infer that "eating local" may yield further incremental emissions savings, and the enhanced food production capabilities would also strengthen domestic food security especially in the face of upcoming climate adaptation imperatives, while supporting the local business community.

[87] We do so to account for the fact that many of the same food ingredients that are bought by households are also procured by restaurants, hawker center and other eateries. A similar import pattern would then apply. For meals eaten in restaurants or cafes, computing the impact of sourcing raw ingredients regionally would require a value chain study which may be restaurant or even meal specific. This exercise is presumably effort and time intensive even for a relatively smaller country like Singapore. We opted instead to partially leverage the reduction in emissions we have seen for food items.

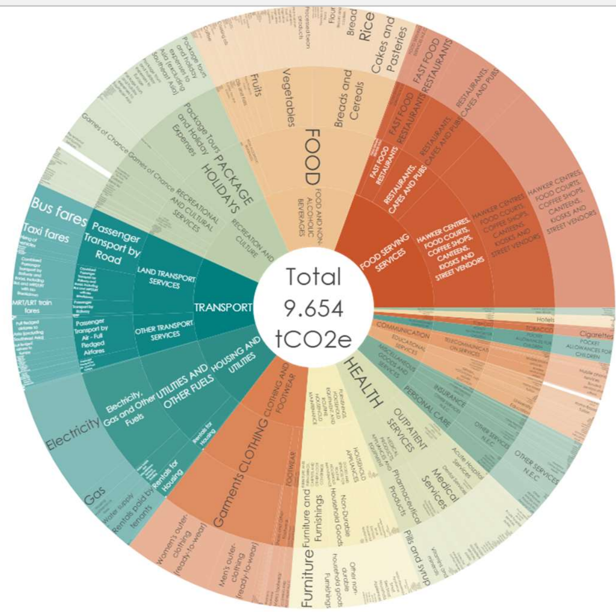
6.6 How about taking a more ambitious approach?

Next, we investigate how individual consumers can make several significant changes towards a more sustainable lifestyle. The combined impact of using public transportation and shared rides, switching to a vegan diet, and prioritizing for consumption regionally sourced foods (from ASEAN countries) is an estimated reduction of **2.38 t CO_2e/year** for the average Singaporean resident (Figure 21).

***Figure 21**: Switching to several changes at once*

"All in" scenario: Vegan diet, with regionally sourced foods (ASEAN countries) and public transportation

Estimated Individual Carbon Footprint



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

We observe a reduction of 28% in emissions associated with "**Food Serving Services**", 50% in "**Transport**", and 35% in "**Food and Non-Alcoholic Beverages**". Notably, we see a reduction of 91% in international shipping emissions (from to 594.49 to 52.43 kg CO_2e/year), accounted for by reducing the export distance for food items.

Each of the lifestyle changes may have underlying offsetting effects, which is why the combined reduction is lower than the sum of the emissions savings across each of these lifestyle changes alone (i.e., 1.09 t CO_2e for switching to a vegan diet, 1.08 t CO_2e for prioritizing public transportation, and 0.64 t CO_2e for sourcing food items regionally).

This scenario is not fully comparable with the others as the total monetary base of monthly expenditures is decreased (e.g., we assume all expenses associated with purchasing vehicles and paying related fees are not spent elsewhere – which is the approach we took when we examine the sustainable transportation options scenario). Nevertheless, the savings in terms of carbon emission (~20% of average emission) is larger than in terms of expenditure (6.65% of average expenditure) for the average Singaporean resident.

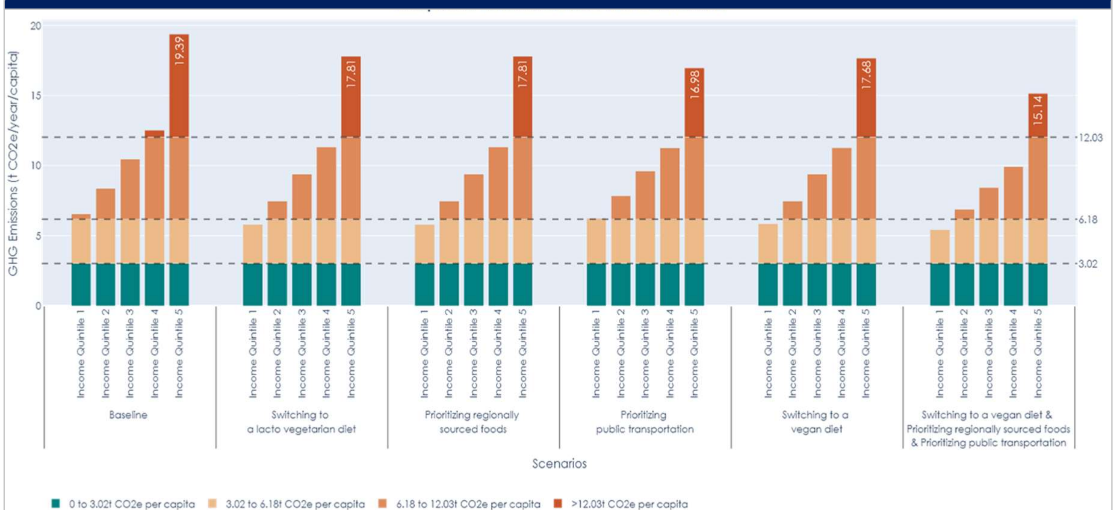
6.7 Lifestyle changes across income quintiles

To examine how the impact of these sustainable lifestyle changes varies across income quintiles, we provide a summarized view in Figure 22.

For comparison purposes, we also bring into the picture three important benchmarks:

- The current **baseline average** of **12.034 t CO_2e** per capita per year (computed by applying the average EFs as estimated through our algorithm, to the average expenditures in Singapore as estimated for 2023 (baseline scenario).
- The **global average** of 4.7 t CO_2 per capita per year in 2021 (IEA, 2023), which for comparability purposes we translate to **6.18 t CO_2e** per capita per year assuming CO_2 contributes 76% to global GHGs (The World Bank, 2023, C2ES, 2024).
- The GHG emissions per capita aligned to a global warming of maximum 1.5°C (**Paris Agreement aligned pathway**) of 2.3 t CO_2 per capita per year by **2030**[88], which for comparability purposes we translate to 3.18 t CO_2e per capita per year under the same assumption that CO_2 contributes 76% to global GHGs.

Figure 22: *Sustainable consumption impact across income quintiles*



Source: Graph produced by authors using the proposed GHG emissions estimation algorithm, incorporating expenditure data from the Singapore Household Expenditure Survey 2017 / 18 (SG DOS, 2019b) and applying inflation indexing (assuming a 14.21% compounded inflation rate) to estimate 2023 levels.

Income ranging from the lowest (Income Quintile 1), to highest (Income Quintile 5).

Thresholds, assuming CO_2 has a contribution of 76% to GHGs globally (C2ES, 2024, The World Bank, 2023):
3.02 t CO_2e ~2.3 t CO_2 per capita by 2030 (Gore T., IEEP, SEI, Oxfam, 2021, 1.5°C global warming pathway)
6.18 t CO_2e ~4.7 t CO_2 per capita current global average (IEA, 2023)

[88] Lower boundary of the global per capita emissions range compatible with a 1.5°C global warming pathway (Gore, T, IEEP, SEI, Oxfam, 2021).

In Figure 22 we can observe both the opportunities and limitations that individual consumers face when trying to take meaningful climate change actions. On the bright side, we clearly see the potential of reducing the carbon footprint related to consumption through lifestyle choices. On the darker side, we can directly see the adverse impact on the environment of any **increase in welfare** as well. In the baseline (current) scenario, average Singaporean residents have associated emissions which are above the global average of 6.18 t CO_2e/capita (IEA, 2023), and twice above an ambitious Paris Agreement compatible target of 3.02 t CO_2e/capita (Gore, T, 2021). Even if significant measures of sustainable lifestyle were adopted by all households (the scenario presented in Figure 22 utmost to the right), higher earning households would still have a more than double carbon footprint than the lowest income ones, which would barely make it below the line of global average carbon footprints.

This leads us to 2 conclusions, both hard to take. First, reducing significantly the carbon footprint for Singaporean residents therefore would not only mean changing what is being consumed, but also how much. Average to high income households would have to **scale back** to the lowest income ones. In a country with the infrastructure and public services that Singapore offers, this would still mean a safe, comfortable and dignified standard of living.

Secondly, changing the structure of, and lowering the level of consumption, even by making relatively radical lifestyle changes, is not enough. Decarbonizing **global value chains** and the real economy re-emerge as indispensable to achieving our climate ambitions. While the impact of individuals in this space may be indirect, it may still be effective, if not crucial, in the long run. Intentionally inquiring about and selecting climate-friendly products and brands would de facto sponsor the more sustainable producers and penalize the less sustainable ones. The demand for emissions disclosure through **carbon labelling**[89] could effectively enhance the supply of sustainability tracking, management and reporting at company level.

Our hope and drive behind this Whitepaper is, therefore, that education and accountability could have ripple effects upwards across value chains, offering a stimulus and the market signal for enhanced investments in cleaner energy, greener technology, and more broadly available data.

[89] A definition of carbon labelling found in the literature covers emissions covering products lifecycle of production to use (Taufique et al., 2022). We would like to encourage carbon labelling that covers at least the production and distribution segments of products lifecycle that may be easier for producers to quantify absent consumption related assumptions.

7. Conclusion

While the science supporting the assertion that global warming is caused by human activities is unequivocal, the actions that each individual and company can and need to take are the subject of **heated debates** – around who needs to act first, how to act in concert, how the necessary data and technology may not yet exist (or be economically viable), and so on.

The bitter reality is that we all need to make a sacrifice today, in order to protect the next generations from the worst effects of irreversible climate change. In front of a looming global catastrophe, the difficulty of advancing a more sustainable lifestyle agenda – e.g., renouncing favorite dishes or owning a car – exemplifies the urgent need for **sustainability education**.

We argue that the cornerstone of such education is **actionable information**. There is increasing evidence that the majority of GHG emissions occur upstream in the supply chain for some categories of consumption (Ingwersen, W. and M. Li, 2020). To reduce such emissions via consumer actions, we need more granular, comparable and easily accessible information on the impact of different consumption choices.

The sustainability data ecosystem, particularly around GHG emissions tracking, reporting and benchmarking, is still plagued by scarcity, heterogeneity, and uncertainty. Nevertheless, we perform an analysis of **consumer carbon footprint** using available data for Singaporean households and find that food, transport, recreation and utilities account for most of their carbon footprints. We also identify various opportunities to reduce individual carbon footprints: prioritizing foods sourced from closer to home (from ASEAN countries), opting for public instead of private transportation, and switching to a plant-based diet.

The **call to action** from this study is broad and deep. At the consumer level, even the lowest emitting households in Singapore – those with the lowest levels of income – would have to reduce their carbon footprint by almost half to have a chance of keeping within a "carbon allowance" aligned to a 1.5 C global warming pathway. Even making several environmentally ambitious changes at once (i.e. a combination of impactful lifestyle changes as we explored above) may not be sufficient to be aligned with the pathway.

For expenditures that are both highly carbon intensive and difficult to avoid within the local context, awareness could drive more extensive usage of **personal carbon offsets**, of which there are increasing number of options offered by products and services providers. It could also facilitate the materialization of personal carbon quotas and the scale-up of personal carbon trading platforms (Wang et al., 2024).

Equally important, **incentives** through price signals, such as a potential carbon tax applied to households, could accelerate behavioural changes. At a national and international level, the calls for policy makers, financial institutions and industry to initiate and support meaningful climate actions emerge as loudly as ever before – without extensive and rapid decarbonization of the real economy, carbon emissions will continue to be embedded in value chains of consumption items.

Going forward, with the sustainability data ecosystem growing at a fast pace, the more stringent climate regulation across jurisdictions, and the increasing body of research offering insights into carbon footprinting methodologies, we hope that extensive recording and reporting across the value chains will enable **carbon labelling** for products. Until then, the proliferation of multi-region environmentally extended input output (**MREE-IO**) models for major exporter countries would offer enhanced data points that can be used in future bodies of work for more accurate estimations of emission factors and product carbon footprints.

Equally, the enhancement of national, contextualized, consumption-based **emission factors** repositories, is a powerful step forward towards enabling company level GHG emissions tracking, management and reporting at greater scale. At the time of publication of this study, we were happy to see the recent development and launch of the Singapore Emissions Factors Registry through the NetZeroHub.SG free digital platform in 2024 (Singapore Business Federation, 2024). As similar initiatives appear and expand their scope fueled by joint efforts from Academia, Government agencies and the private sector, the sustainability data ecosystem can evolve to a point where emissions factors data is more credible, reliable, easily retrievable and efficiently usable by all parties vested in understanding the carbon footprint of what they produce, distribute or consume.

Last but not least, in disseminating this information to individual consumers, there is a crucial role to be played by **financial institutions**. These entities could offer GHG emissions estimates associated with consumers' financial transactions, which would facilitate environmental impact education with added credibility. Some financial institutions (e.g., banks, credit card providers) are offering basic versions of such products, which would benefit from the addition of personalized targets and feedback, peer benchmarking, and carbon offsetting options – or even direct incentives such as preferential financing terms for greener consumers and borrowers.

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Definitions

Assurance	In the context of product lifecycle assessments: "The level of confidence that the inventory and report are complete, accurate, consistent, transparent, relevant, and without material misstatements" (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p. 137).
Biodiversity loss	"Human actions dismantling the Earth's ecosystems, eliminating genes, species and biological traits, thereby altering the functioning of ecosystems and their ability to provide society with the goods and services needed to prosper" (Cardinale et al., 2012, p. 1).
Carbon footprint	"A measure of the total greenhouse gas emissions (expressed in tonnes of carbon dioxide [CO_2] equivalents) that is directly and indirectly caused by a product across its lifecycle from the production of raw materials used in its manufacture to the disposal of the finished product (Wiedmann and Minx, 2008, p 3 & 4).
Carbon intensity	We use this term to refer to the GHG emissions associated with the holistic, cradle-to-grave, lifecycle stages of goods and services, reflected as kg CO_2e /product or service unit, or kg CO_2e/currency unit spent on the respective product or service. We use this term interchangeably with "GHG emissions intensity", "emissions intensity" and "carbon intensity".
Carbon labelling	One definition used in the literature is the following: "Carbon labelling summarizes data on the greenhouse gases (GHGs) emitted from the production, distribution and use ('carbon footprints') of a good or service in a simple indicator presented at the point of purchase" (Taufique et al., 2022, p 1). In this Whitepaper we use the term to refer to the GHG emissions resulting ideally from the entire lifecycle of goods and services (including waste).
Carbon offsets	A reduction in GHG emissions that is used to compensate for emissions that occur elsewhere. Carbon offsets are used to "convey a net climate benefit from one entity to another." (Carbon Offset Guide, 2024)
CIF (Cost, Insurance and Freight)	We use the Cost, Insurance and Freight (CIF) Incoterm to refer to the costs incurred by importers, which we equivalate with importer price. These costs are formed of the cost of goods charged by the exporter (which we equivaled with the FOB price), in addition to the insurance and freight required for goods transportation to the port of import (International Chamber of Commerce, 2020).
CO_2e (CO_2 equivalent)	CO_2e stands for carbon dioxide (CO_2) equivalent, which is the standard unit used to convert greenhouse gases (GHGs) (such as CH4, N2O, etc) to CO_2, based on the global warming potential (GWP) of each of the GHGs. All GHGs are converted based on amount of CO_2 that would have the same impact on global warming.

	CO_2e therefore functions as "the universal unit of measurement to indicate the global warming potential (GWP) of each greenhouse gas, expressed in terms of the GWP of one unit of carbon dioxide. It is used to evaluate releasing (or avoiding releasing) different greenhouse gases against a common basis." (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 136).
(CBA) Consumption-based Accounting	Consumption-based accounting measures the emissions associated with the consumption of goods and services within a country. Unlike traditional production-based inventories, which focus solely on emissions produced within a country's borders, consumption-based accounting recognizes that imports and exports also contribute to a nation's carbon footprint. This approach holds that individuals who benefit from goods and services should bear some responsibility for the associated emissions. It acknowledges that emissions are not only generated within sovereign territories (as captured by production-based methods) but also through international trade (Davis and Caldeira, 2010).
Commodity	In our paper we refer to commodities as defined by the World Customs Organization (WCO) within the Harmonized System (HS), which is used for international trade of physical goods. Commodities are thereby defined as goods or items traded internationally, which are classified and reporting using a standardized nomenclature. This streamlines customs processing, tariffs computation, international trade reporting. The list of commodities as identifies through HS Codes is available on the World Customs Organization website (World Customs Organization, 2022b).
Conspicuous conservation effect	Phenomenon through which "individuals seek status through displays of austerity amid growing concern about environmental protection" (Sexton et al., 2014).
Consumer	We use this term with the same meaning as in the GHG Protocol: An individual who purchases, rents or acts as the end user of a product or service. (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 134). We use this term interchangeably with "user" or "customer",
Consumer carbon footprint	In this Whitepaper we consider the consumer carbon footprint to be formed of all GHG emissions associated with the products and services consumed or used by the respective individual. In this context we use the words consumer and individual interchangeably. This is in line with definitions used in the literature such as "the consumer footprint assesses the potential environmental impacts coming from household consumption through process-based LCA of goods and services purchased and used by a certain entity (Sala and Castellani, 2019, p 2). The household carbon footprint is cumulatively formed of all household members' individual carbon footprints.
Consumption carbon footprint	We use this term to refer to the GHG emissions associated with the entire lifecycle of goods and services, regardless of where these

	emissions occur. It covers both direct and indirect emissions including upstream emissions from supply chains, or downstream emissions caused by the use and disposal of products. The concept is used similarly in the literature (such as in Ozawa-Meida et al., 2013, p 1). We use this term with a similar meaning to “individual carbon footprint” or “household carbon footprint”, depending on context.
Country-of-Origin	The country where most of the value chain of a product is located. In our paper we consider the Country-of-Origin to be the same as the country-of-import as reported in the international trade database we retrieved from CEPII, 2023. We assume the entire value chain of imported products to take place within that country-of-import.
Cradle-to-exporter-gate	All emissions incurred in the lifecycle of a product up until the point of export to Singapore. We consider this lifecycle stage to cover all emissions resulting from the extraction, processing and domestic transportation of raw materials, all manufacturing process, and distribution to the point of international shipping.
Cradle-to-grave	“Removals and emissions of a studied product from material acquisition through to end-of-life” (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 134).
Decarbonization	"Decarbonization is the process of reducing average carbon intensity over time through the continuous replacement of fuels with high carbon content with low carbon alternatives (IPCC, 2007). It involves a shift towards sustainable practices across various sectors such as agriculture, construction, finance, manufacturing and transport (Rockström et al., 2017)”.
Demand Based Emissions	Same as (National) Consumption Based Emissions, we use the term interchangeably and in line with the definition from OECD DSTI, 2016.
Economic domicile	“Legal residence or principal place of business where an entity or individual is considered to reside for tax purposes” (Investopedia, 2024).
EEIO (Environmentally Extended Input-Output) models	“A model that links economic input-output tables with environmental data and can be used for environmental assessment of supply chains of industries or commodities, as performed in life cycle assessments” (Ingwersen and Li, 2020). One of the outputs of these models are Monetary EFs, which are defined as “Emission factors developed through the analysis of economic flows and used to estimate GHG emissions for a given industry or product category” (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 134).
EF Extrapolation	In the context used in our Whitepaper, this is the technique we apply to estimate EF data points beyond the range we were able to collect, based on logical assumptions on products and services GHG emissions dependency on electricity emissions, for any given product in any given country. From a statistical point of view, unlike for more typical extrapolation exercises, we do not use observed patterns in the EF data for extrapolation due to data scarcity. The technique is close to imputation, in the sense that our goal is to fill in missing EF by

	product by country, as a placeholder until a global database is in place. The definition of extrapolated data from GHG Protocol is: "Data from a similar process or activity that is used as a stand-in for the given process or activity and has been customized to be more presentative of the given process or activity" (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 137).
Electricity/Energy mix differential	We define the electricity carbon intensity differential (which we refer to as б) as the relative carbon intensity of electricity production between any 2 countries (б = Electricity EF of Country A/Electricity EF of Country B). This is the coefficient that we use to extrapolate the EF for a product manufactured in Country A to the EF for the same product manufactured in Country B.
Embodied Carbon	In this Whitepaper we use "Embodied Carbon" to refer to GHG emissions associated with the Production stage, covering all the life cycle stages from cradle to export gate (covering raw materials extraction, raw materials processing, manufacturing and assembly, transportation to the point of shipment for export).
Emission Factor	A factor that converts a unit of product into associated GHG emissions, in alignment with the GHG Protocol definition: "A factor that converts activity data into GHG emissions data (e.g., kg CO_2e emitted per liter of fuel consumed…" (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 137). The term often referred to in the industry as "Conversion Factor", such as in the dataset "UK Government GHG Conversion Factors for Company Reporting" (UK DESNZ and UK DEFRA, 2023)
Energy mix	We use this term in alignment with the following definition "The energy mix refers to the diverse range of sources such as coal, oil, gas, nuclear, hydropower, solar, wind, and biofuels. However, it mainly consists of fossil fuels, renewable technologies and nuclear power (Ritchie and Rosado, 2020).
Expenditure Item Category	We use this term to refer to the first level of resolution (L1) we use in this Whitepaper to map goods and services. Aligned to the first level of grouping of expenditures in the SG Department of Statistics Household Expenditure Survey 2017 / 18 (SG DOS, 2019b).
Expenditure Item Sub-Category	We use this term to refer to the second level of resolution (L2) we use in this Whitepaper to map goods and services. Aligned to the second level of grouping of expenditures in the SG Department of Statistics Household Expenditure Survey 2017 / 18 (SG DOS, 2019b).
Expenditure Item Class	We use this term to refer to the third level of resolution (L3) we use in this Whitepaper to map goods and services. Aligned to the third level of grouping of expenditures in the SG Department of Statistics Household Expenditure Survey 2017 / 18 (SG DOS, 2019b).
Expenditure Item Type	We use this term to refer to the fourth level of resolution (L4) we use in this Whitepaper to map goods and services. Aligned to the fourth level of grouping of expenditures in the SG Department of Statistics Household Expenditure Survey 2017 / 18 (SG DOS, 2019b).

Expenditure Item	We use this term to refer to the fifth level of resolution (L5) we use in this Whitepaper to map goods and services. This level of resolution goes beyond the granularity available in the SG DOS HES 2017 / 18 (SG DOS, 2019b). Therefore, this is a level of grouping we do not have spend information for, however we this level it to assign EFs with a higher degree of representativeness. We use this term interchangeably with "Item", "Product" or "Service".
FOB (Free on Board) Prices	We use the Free on Board Incoterm to refer to estimated exporter prices, corresponding to the prices charged for goods at the point of export, as derived from the CEPII BACI dataset (CEPII, 2023), (Gaulier and Zignago, 2010). In our calculations we consider this to be the price paid at the point of import, on top of which several other markups are incurred up until the point of sale: CIF (Cost for Insurance and Freight) rates for international shipping, followed by warehousing, logistics and retail markups for domestic distribution.
Fresh/Chilled/Frozen (Foods)	We consider fresh and chilled foods to be highly perishable and thus require faster transport for international shipments (by road from neighbouring countries and by air from further distanced countries). We consider frozen foods to be less perishable if maintained at controlled temperature, and thus able to withstand longer shipment duration (by road from neighbouring countries, and by sea from further distanced countries).
GHGs (Greenhouse Gases)	For the purposes of this Whitepaper we have endeavoured to source emission factors covering as many as possible of the main GHGs covered by the Kyoto Protocol and recommended by the GHG Protocol (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 138): carbon dioxide (CO_2), methane (CH4); nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). Some of the datasets we sourced include NF3 also[90], which has been recently identified to have a high global warming potential, while other studies may cover only the top 3 (CO_2, CH4 and N2O)[91]. We therefore use GHGs to refer generically to the greenhouse gases as they are captured in the underlying Original EFs sourced and used in the calculations. We use this term interchangeably with "Emissions", "carbon emissions", or "GHG emissions".
GHG Emissions Intensity	We use it this term to refer to the GHG emissions associated with a unit of a product or service (reflected as kg CO_2e/unit of product or service, or kg CO_2e/monetary unit). We use this term interchangeably with "GHG Intensity", "carbon intensity" and "Emission Factors".

[90] Such as the UK Government GHG Conversion Factors for Company Reporting (UK DESNZ and UK DEFRA, 2023), or the US EPA Supply Chain Greenhouse Gas Emission Factors v1.2 (US EPA ORD, 2023).
[91] Such as the EF data from the Environmental Impact of Key Food Items in Singapore (A*STAR et al., 2023).

Green Nudge	An intervention that influences people's behaviour without prohibiting choices or significantly changing incentives (Thaler and Sunstein, 2009), with the intent to reduce a negative environmental externality (Carlsson et al., 2021).
GWP (Global Warming Potential)	GWP stands for Global Warming Potential, which is a multiplier used to convert a specific Greenhouse Gase to CO_2 as a common denominator, for comparability purposes of total emissions associated with goods, services, processes or activities. "GWPs are multipliers applied to greenhouse gases such as methane (CH_4) and Nitrous Oxide (N_2O) to equate the impact they have on the Earth's temperature with that of Carbon Dioxide (CO_2[92]) (ERCE, 2021). Another definition of GWP is "a factor used to calculate the cumulative radiative forcing impact of multiple specific GHGs in a comparable way" (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 135).
HS (Harmonised System)	" The Harmonized Commodity Description and Coding System generally referred to as 'Harmonized System' or simply 'HS' is a multipurpose international product nomenclature developed by the World Customs Organization (WCO). It comprises more than 5,000 commodity groups; each identified by a six-digit code, arranged in a legal and logical structure and is supported by well-defined rules to achieve uniform classification. The system is used by more than 200 countries and economies as a basis for their Customs tariffs and for the collection of international trade statistics. Over 98 % of the merchandise in international trade is classified in terms of the HS." (World Customs Organization, 2024)
HS (Harmonised System) Commodity Codes	This refers to the unique six digits identifier allocated to commodities, for international trade tracking, reporting and customs processing. (World Customs Organization, 2024) We use this term interchangeably with "HS codes", "HS commodity codes" or "commodity codes".
Imputed Rent	We use this term in the context of expenditure for owner-occupied accommodation, as quantified and defined through the SG DOS Household Expenditure Survey 2017 / 18. Thereby the imputed rent is the estimated rent that homeowners would have to pay if they were renting their own homes instead of owning them (SG DOS, 2019a, p. 3).
Incoterm	Short for International Commercial Term, a standardize trade term used in international and national agreements for the sale of products. Published by the International Chamber of Commerce (International Chamber of Commerce, 2020).
Life Cycle	"Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life." (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p. 139)
LCA (Life Cycle Assessment)	"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system through its life cycle"

	(WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p. 135).
Life Cycle Stage	Per the GHG Protocol, "a life cycle stage is one of the interconnected steps in a product's life cycle". (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 11).
Monetary Emission Factor	An Emission Factor measured in kg CO_2e/unit of currency, used to convert a purchase of a specific product or service into the GHG emissions associated with the respective product or service. They are particularly useful in the absence of actual physical data, or when the examination of the environmental impact of consumption is conducted starting from expenditures rather than physical consumption. We use this term interchangeably with "spend-based Emission Factors" and "carbon intensity on a per dollar basis" (kg CO_2e per unit of spending).
MREE IO (Multi Region Environmentally Extended Input Output) model	Analytical models focused on the environmental impacts associated with economic activities within and between countries. These models extend traditional input-output (IO) macroeconomic tables by incorporating environmental data from various national and international sources, thus offering insights on the environmental impact of various economic sectors and countries (Wiedmann, 2009).
(National) Consumption Based Emissions	Consumption-based accounting of GHG emissions allocates emissions to the final consumer of the goods and services, regardless of where the emissions were physically generated, and by whom. It thus places the responsibility of GHG emissions to the final consumers or users of products or services, even if those emissions occur outside their national borders or produced by entities outside of their control (Davis and Caldeira, 2010). Furthermore, "the terms consumption-based emissions and demand-based emissions can be used interchangeably and include emissions embodied in final consumption (households and government) as well as gross fixed capital formation (investment), changes in inventories and direct purchases abroad by residents" (OECD DSTI, 2016).
(National) Territorial Emissions	Territorial emissions capture emissions that occur within a country's borders. They include emissions from activities such as fossil fuel combustion, cement production, and gas flaring. These cover emissions embodied in exports, and include emissions embodied in imports (Knight and Schor, 2014). "The calculation of production-based and territorial emissions differs according to the allocation of non- resident emissions. For example, for territorial emissions, the emissions associated with fuel-purchases by non-residents are allocated to the country where the fuel is purchased, while for production-based emissions the same emissions are allocated to the country of residence of the emitting source" (OECD DSTI, 2016).

(National) Production Based Emissions	"The greenhouse gas emissions from all the oil, coal, and gas consumed in a country by private households, industrial production of goods and services, and electricity production". It does not cover emissions from international transportation as they are outside jurisdictional territories, or emissions embodied in the production of goods in other countries (Franzen and Mader, 2018).
Physical Emission Factor	An Emission Factor measured in kg CO_2e/physical unit, used to convert the unit of a specific product or service into the GHG emissions associated with the lifecycle of the respective product or service. We use the term interchangeably with "carbon intensity on a per unit basis" (kg CO_2e per unit).
Product	Tangible good, in consumer ready finished form, purchasable from retail operators.
Production stage	We use the term in line with the GHG Protocol definition: "A life cycle stage that begins when the product components enter the production site for the studied product and ends when the finished studied product leaves the production gate." (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 136).
Proxy Data	"Data from a similar process or activity that is used as a stand-in for the given process or activity without being customized to be more representative of the given process or activity. "(WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 140).
Service	"An intangible product. "(WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 140).
Stock Keeping Unit (SKU)	"A unique identification number that defines an item at the identifiable inventory level; for example, in retail applications, the SKU may designate style, size and colour" (Gartner, 2024).
Supply Chain	"A network of organizations (e.g., manufacturers, wholesalers, distributors and retailers) involved in the production, delivery, and sale of a product to the consumer." (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 141).
System boundary	We use this term to refer to the scope and stages in a product or service life cycle that EFs are computed for. For example, an EF for a certain product can offer emissions estimation covering the entire cradle-to-grave lifecycle, whereas another EF may cover only the cradle-to-gate lifecycle. The broader definition of the term refers to the set of criteria that identifies which unit processes are included in a product system, thereby determining the limits of the system being analysed (ISO, 2006).
Tonne.km	Tonne-Kilometre. Unit of measurement used in international shipping, representing the transport of one ton of a specific product, over a distance of one kilometre.
Uncertainty	We use the term in various contexts, in alignment with the GHG Protocol:

	"1. Quantitative definition: Measurement that characterizes the dispersion of values that could reasonably be attributed to a parameter. 2. Qualitative definition: A general and imprecise term that refers to the lack of certainty in data and methodology choices, such as the application of non-representative factors or methods, incomplete data on sources and sinks, lack of transparency etc." (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 141). In our Whitepaper "Consumption Carbon Footprint: Country Level Data Framework" we describe in detail our sensitivity analysis approach. In brief, we compute the uncertainty of our Consumer Carbon Footprint estimation - as Simulated Std Deviation over Simulated Mean, for Monte Carlo simulations run against parameters affected by assumptions injected into the model.
Use stage	"A life cycle stage that begins when the consumer takes possession of the product and ends when the used product is discarded for transport to a waste treatment location or recycled into another product's life cycle" (WRI, WBCSD, 2011a – GHG Protocol, Product Life Cycle Accounting and Reporting Standard, p 137).
Value Chain	"All of the upstream and downstream activities associated with the operations of the reporting company, including the use of sold products by consumers and the end-of-life treatment of sold products after consumer use." (WRI and WBCSD, 2011b, GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard, p 141).
Warehousing, Distribution and Retail emissions	All emissions incurred after the point of import, due to storage of the product, domestic logistics, and retail operations.
Waste emissions	All emissions incurred after the end of life of the product, when any related waste associated with the product, or its packaging are discarded for transportation to waste management facilities.

Acronyms

ASEAN	Association of Southeast Asian Nations
BACI (French)	Base pour l 'Analyse du Commerce International
CBA	Consumption-Based Accounting
CEPII (French)	Centre d'Études Prospectives et d'Informations Internationales
CH4	Methane
CIF	Cost, Insurance and Freight
CO	Country-of-Origin
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CPI	Consumer Price Index
EEIO	Environmentally Extended Input-Output
EF	Emission Factor
(US) EPA	(US) Environmental Protection Agency
FOB	Free on Board
GDP	Gross Domestic Product
GHG(s)	Greenhouse Gas(es)
GWP(s)	Global Warming Potential(s)
HES	Household Expenditure Survey
HFCs	Hydrofluorocarbons
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
KG	Kilogram
KM	Kilometre
KWH	Kilowatt-hour
LCA	Life Cycle Assessment
MREE IO	Multi Region Environmentally Extended Input Output
MRIO	Multi Regional Input Output Analysis
NF3	Nitrogen trifluoride
NGO	Non-Governmental Organization
N2O	Nitrous oxide
NM	Nautical Mile
PBA	Production-Based Accounting
PFCs	Perfluorocarbons (used in the context of GHGs examples)
(S) COICOP	Singapore Classification of Individual Consumption According to Purpose
SF6	Sulphur Hexafluoride
SG	Singapore
(SG) DOS	(SG) Department of Statistics
SGD	Singapore Dollar
SKU	Stock Keeping Unit
t	Tonne (Metric Ton)

(UK) DEFRA	(UK) Department of Environment, Food & Rural Affairs (UK Government Ministerial Department)
(UK) DESNZ	(UK) Department for Energy Security and Net Zero
(UN) COICOP	The United Nations Classification of Individual Consumption According to Purpose
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WBCSD	World Business Council for Sustainable Development
WCO	World Customs Organization
WRI	World Resources Institute

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