Consumption-based GHG emissions of C40 cities

March 2018

This report presents the methodology and results of a study investigating the consumption-based greenhouse gas emissions (GHG) from 79 cities, carried out by the C40 Cities Climate Leadership Group (C40) in partnership with the University of Leeds (United Kingdom), the University of New South Wales (Australia), and Arup.

1. Introduction: What are consumption-based GHG emissions?

To support evidence-based climate action planning, many cities have developed sector-based GHG inventories using standards such as the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC)[1]. These focus primarily on GHG emissions from energy use within the city boundary, through direct combustion (scope 1) or the consumption of grid-supplied electricity, heating and/or cooling (scope 2), as well as GHG emissions from the treatment of waste. The vitality of cities, however, also gives rise to the production of significant quantities of GHG emissions outside their boundaries (scope 3). To estimate this impact, C40 conducted an assessment of the consumption-based GHG emissions for 79 of its member cities.

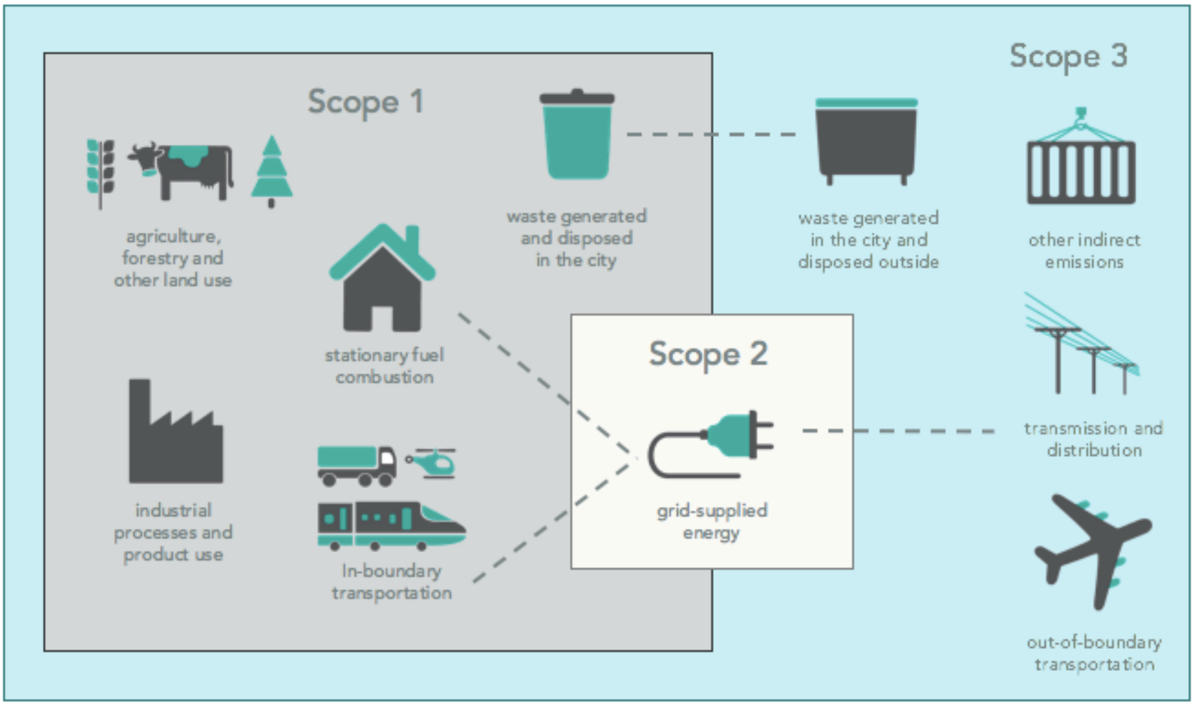

Figure 1: Sources and boundaries of city GHG emissions

[1] In 2014, WRI, ICLEI C40 launched the Global Protocol for Community-Scale GHG Emission Inventories (GPC) to help cities measure and report city-wide GHG emissions in a more robust and consistent way. The GPC provides clear requirements and detailed guidance to estimate GHG emissions for the following sectors: stationary energy (buildings), transportation, waste, industrial processes and product use (IPPU), and agriculture, forestry and other land use (AFOLU). The GPC sets out two reporting levels: BASIC and BASIC+, representing different levels of completeness. The BASIC level covers emission sources that occur in almost all cities (stationary energy, in-boundary transportation, and in-boundary generated waste). The BASIC+ level has a more comprehensive coverage of emissions sources and also includes IPPU, AFOLU and transboundary transportation. All numbers related to GPC emissions in this report refer to those covered by the BASIC reporting level. See http://www.c40.org/gpc for more information.

Consumption-based GHG accounting is an alternative to the sector-based approach to measuring city GHG emissions. This focuses on the consumption of goods and services (such as food, clothing, electronic equipment, etc.) by *residents* of a city, and GHG emissions are reported by consumption category rather than GHG emission source category.

The consumption-based approach captures direct and lifecycle GHG emissions of goods and services (including those from raw materials, manufacture, distribution, retail and disposal) and allocates GHG emissions to the final consumers of those goods and services, rather than to the original producers of those GHG emissions. GHG emissions from visitor activities and the production of goods and services within the city boundary that are exported for consumption outside the city boundary are excluded.

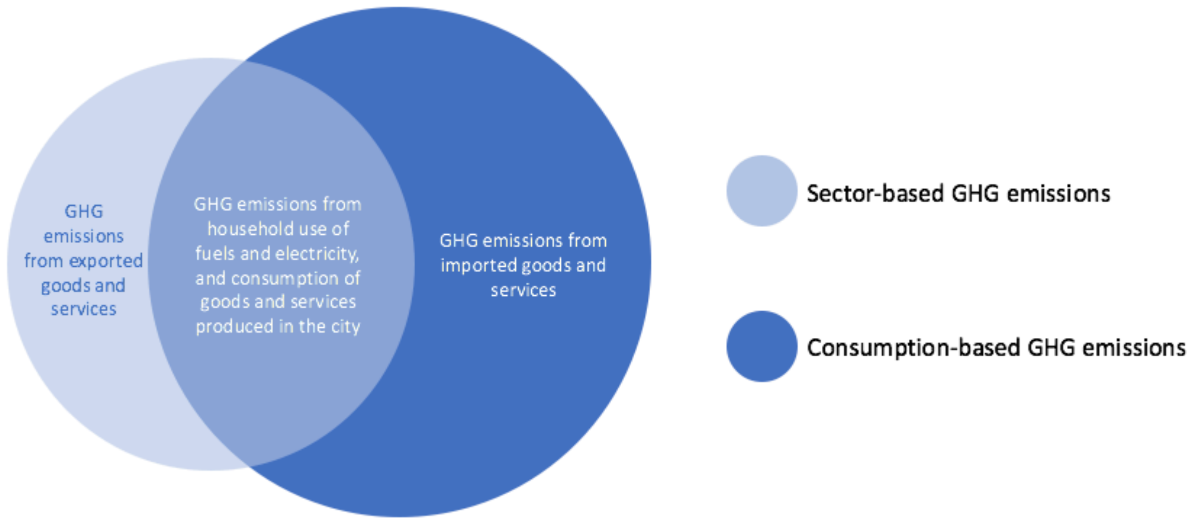

Figure 2: Venn diagram showing the relationship between sector-based and consumption-based GHG emission inventories

As shown in Figure 2, both consumption-based GHG inventories and sector-based GHG inventories include GHG emissions that result from household use of fuels and electricity, as well as goods and services produced and consumed in a city. The sector-based GHG inventory also includes GHG emissions resulting from goods and services produced in the city but consumed elsewhere or by those who aren't residents. The consumption-based GHG inventory is the inverse. It excludes GHG emissions from the goods and services that are exported from the city, or consumed by those who aren't residents. However, the consumption-based inventory adds GHG emissions from goods and services produced elsewhere but consumed by city residents.

In simple terms, therefore, a city consumption-based GHG inventory can be defined as the emissions arising within a city's boundaries, (-) minus those emissions associated with the production of goods and services exported to meet demand outside the city, (+) plus emissions arising in supply chains for goods and services produced outside the city but imported for consumption by its residents:

$$\text{Consumption} = \text{Production} - \text{Exports} + \text{Imports}$$

The purpose of this study is to establish consumption-based GHG inventories to enable C40 to better understand the ability of cities to contribute to GHG emissions reduction activities beyond their city boundaries. The results show how consumption-based GHG inventories compare to sector-based GHG inventories, and which consumption sectors these GHG emissions are attributable to (e.g. construction, food and drink, etc.).

2. Methodology

2.1 Overview

This section provides an overview of the technical approach taken to assess city consumption-based GHG emissions[2]. Calculating the GHG emissions of a system as complex and large as a city is a significant undertaking, particularly if a full supply chain evaluation is required. A bottom-up approach to calculation is not practical given the broad scope of consumption that takes place in a city. The only practical way of undertaking such a calculation is to apply a top-down methodology.

This study focuses on the assessment of consumption-based GHG emissions consistent with the consumption-based methodology described in *PAS 2070: Specification for the assessment of greenhouse gas emissions of a city*[3,4]. As stated above, this covers GHG emissions from the use of energy in homes and vehicles by residents, and GHG emissions associated with the consumption of goods and services by the residents of a city, but excludes GHG emissions from visitor activities and those embodied in exports from the city.

The city boundary definition applied in the study is the jurisdictional boundary of the participating city authority[5]. Total CO_2 equivalent emissions (CO_2e) reported include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). This coverage is consistent with six of the seven main GHG included in the United Nations Framework Convention on Climate Change (UNFCCC) Kyoto Protocol – nitrogen trifluoride (NF_3) is not included in this study.

2.2 Approach

PAS 2070 defines consumption as expenditure on goods and services, and estimates GHG emissions based on economic final expenditure by households, and national, regional and/or local government providing services to those households, and business capital investment.

The assessment of consumption-based GHG emissions requires the combination of different types of data from many sources. To estimate GHG emissions from household energy use in

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[2] A more detailed description of the methodology, and additional guidance on applying the requirements of PAS 2070, will be provided in an accompanying technical report [due for release by June 2018)

[3] https://shop.bsigroup.com/Browse-By-Subject/Environmental-Management-and-Sustainability/PAS-2070-2013/

[4] This includes all scope 3 categories as defined by the Greenhouse Gas Protocol corporate value chain scope 3 reporting standard, where these are associated with goods and services purchased or used by city residents, including: capital goods, fuel- and energy-related activities (not included in scope 1 or scope 2), upstream transportation and distribution, waste generated in operations, business travel, and end-of-life treatment of sold products. See www.ghgprotocol.org/standards/scope-3-standard for more information.

[5] The boundaries used to calculate consumption-based GHG emissions are an important consideration as the boundary definition used in all data sources has to be consistent for a given city for the calculations to be valid. It is important to note that jurisdiction boundaries are not the same across all C40 cities, and will differ in size and morphology. For example, the jurisdiction for Melbourne covers the City of Melbourne Central Business District which has an area of 6.2 km², while the jurisdiction for London refers to the Greater London Authority which includes the 32 London boroughs and the City of London Corporation and covers an area of 1,579 km².

buildings and private vehicles, sector-based GHG inventories are used supplemented with data to provide the required level of disaggregation. For the calculation of supply chain GHG emissions, PAS 2070 recommends using an environmentally extended input-output (EEIO) model. An EEIO model analyses spending from households and government, and business capital expenditure, based on financial flow data from national and regional economic accounts, and estimates GHG emissions using average GHG emission factors for each consumption category depending on where the goods and services consumed in the city are produced (i.e. in the city, rest of the country, or rest of the world)[6]. The Global Trade Analysis Project (GTAP) global multi-region input-output (GMRIO) database was used for this study. A schematic overview of the data requirements and links between data sources and outputs is provided in Appendix A.

[6] Business capital expenditure is allocated based on city resident population

3. Results

The results of the study are presented at global and regional level to illustrate how consumption-based GHG emissions compare to sector-based GHG inventories, and which sectors most consumption-based GHG emissions are attributable to. Data is not provided at a city-level as the purpose here is not to focus on individual city emission profiles. Due to the many assumptions made in the methodology, the results are only able to provide an indicative approximation of the GHG emissions associated with C40 cities' consumption activities. Further analysis is needed for more accurate assessments.

3.1 Comparison of consumption-based GHG emissions with sector-based GHG emissions

Total consumption-based emissions of the 79 C40 cities included in this study are 3.5 $GtCO_2e$ (for the reference year 2011). This represents a 60% increase on the 2.2 $GtCO_2e$ emissions estimated for the same cities using the GPC, and reflects the difference in GHG emissions embodied in imported and exported goods and services. It should be noted that different reference years are used in this work (2011), and the GPC inventories (various between 2011 and 2015). Hence, the comparison of the GHG emissions reported should be considered as an indicative of the difference in emissions, rather than as an exact number.

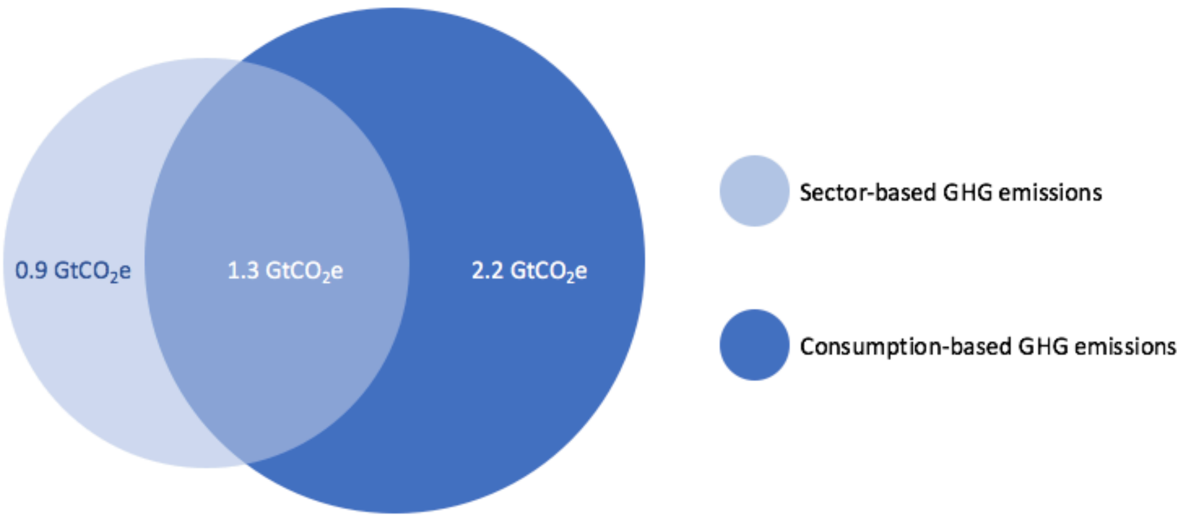

Figure 3: Venn diagram showing the relationship between sector-based and consumption-based GHG emission inventories for 79 C40 cities

Most of the consumption-based GHG emissions of the 79 C40 cities are traded: almost two-thirds of consumption-based GHG emissions (2.2 of 3.5 Gt CO_2e) are imported from regions outside the cities. This shows that consumption activities by residents of C40 cities has a significant impact on the generation of GHG emissions beyond their boundaries.

For an individual city, the sum of the three segments in Figure 3 would represent the combined GHG emissions from both a production and consumption perspective. This would include GHG emissions from household use of fuels and electricity, goods and services produced and consumed in a city, goods and services produced in the city but consumed elsewhere (or by those who aren't resident) (i.e. exports), and goods and services produced elsewhere but consumed by city residents (i.e. imports). Such a calculation is not possible for the combined dataset because any trade between cities would result in double counting.

80% of the cities (63 out of 79) have larger consumption-based GHG emissions than sector-based GHG emissions. For 16 cites – mostly in South and West Asia, Southeast Asia and Africa – the reverse is true, with sector-based GHG emissions larger than consumption-based GHG emissions. These two groups are often referred to as "consumer" cities and "producer" cities respectively. Figure 4 shows that for the majority of cities, the difference between the two approaches is up to 200%. However, for some cities the difference is much greater. 15 cities, mostly in Europe and North America, have consumption-based GHG emissions at least three times the size of their sector-based GHG emissions.

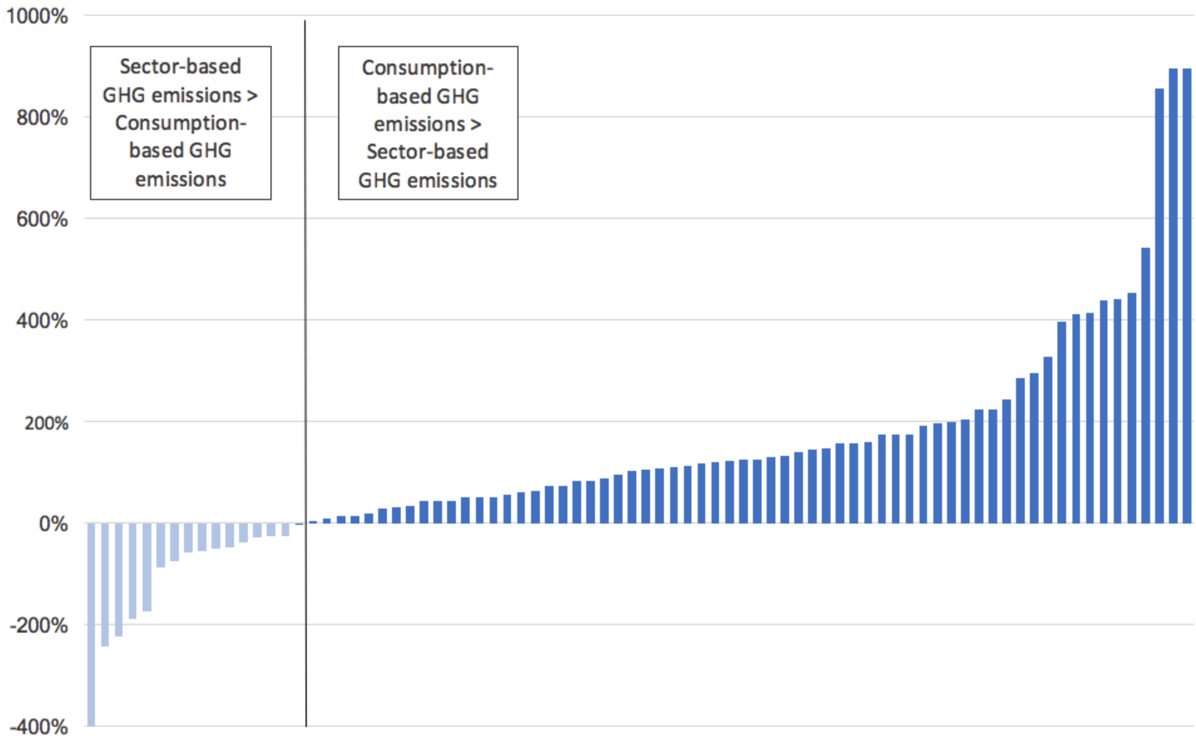

Figure 4: Relative differences between consumption-based GHG inventories and sector-based GHG inventories for 79 C40 cities. A positive difference indicates higher consumption-based GHG emissions than sector-based GHG emissions. A negative difference indicates higher sector-based GHG emissions than consumption-based GHG emissions.

3.2 Consumption-based emissions per capita

Individual consumption-based GHG emissions per city vary widely from 1.8 to 25.9 tCO_2e/capita, with a median and average value of 8.7 tCO_2e/capita and 10.7 tCO2e/capita for C40 cities respectively. There is significant regional variation as shown in Figure 5. Most C40 cities in South and West Asia, Africa and Southeast Asia have individual GHG emissions below 5 tCO_2e/capita. The median for C40 cities in Latin America, and East Asia lies between 5 and 10 tCO_2e/capita, whilst C40 cities in Europe, North America and Oceania have the highest per capita emissions, between 10 and 25 tCO_2e/capita.

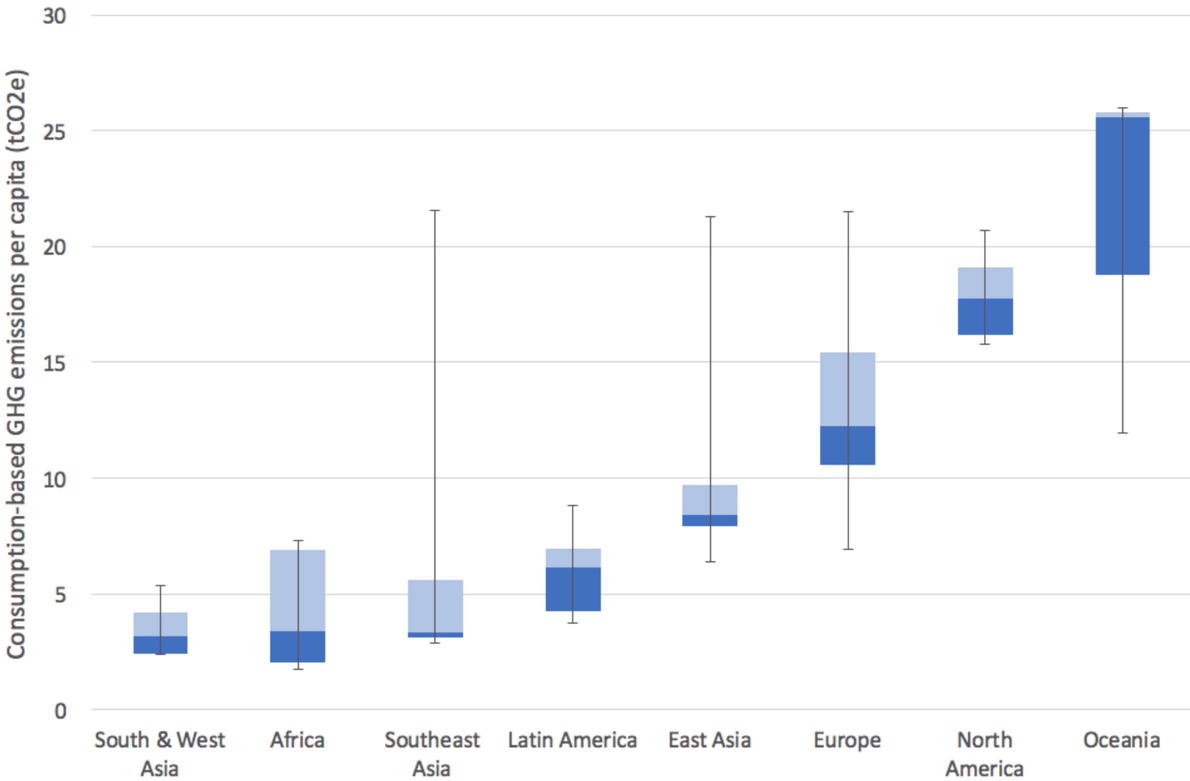

Figure 5: Variation of per-capita consumption-based GHG emissions grouped by world region. The shaded areas show the range from 25th to 75th percentile with the median indicated by a change in shading. The box plot whiskers show the minimum and maximum values.

3.3 Consumption-based emissions by sector

Two reporting frameworks have been used to categorise the consumption of different types of goods and services. The first is the Classification of Individual Consumption According to Purpose (COICOP) structure[7], and the second is the Global Trade Analysis Project (GTAP) structure[8]. COICOP allows for the breakdown of results into 12 household consumption categories, and GTAP disaggregates the results into 57 sector categories. Concordance matrices were used to map COICOP categories to GTAP categories.

3.3.1 Classification of Individual Consumption According to Purpose (COICOP)

Figures 6 uses the COICOP classification to show the percentage split of GHG emission by category per region. The categories identify the function or purpose of a transaction.

[7] https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=5
[8] www.gtap.agecon.purdue.edu

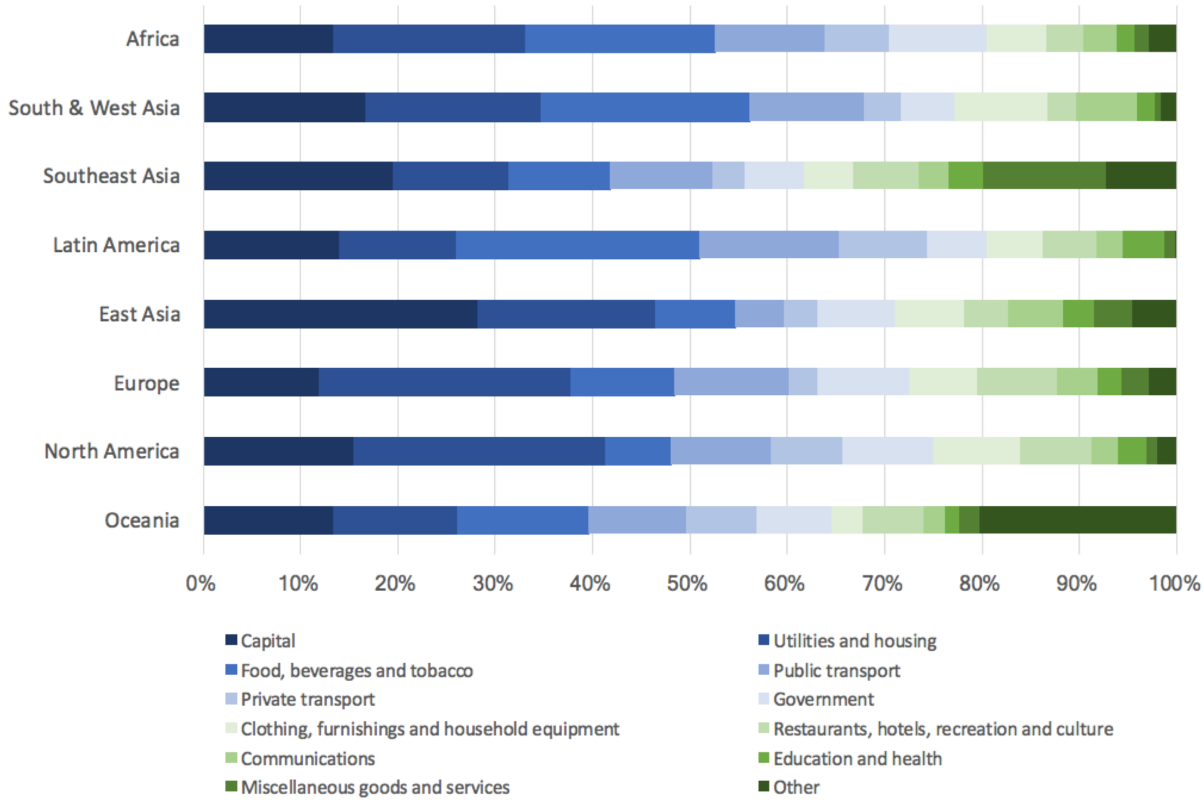

Figure 6: Relative breakdown of consumption-based GHG emissions by Level 1 COICOP category and region (some Level 1 COICOP categories have been aggregated)

Utilities and housing[9], capital[10], transportation (public and private)[11], food supply[12], and government services generally contribute most to consumption-based GHG emissions, although with significant regional variation. For example, on a relative basis, transportation (private and public) emissions are highest for cities in Latin America, capital is most significant for cities in East and Southeast Asia, whilst emissions from food are largest for cities in South and West Asia. The above five categories make up over 70% of total consumption-based GHG emissions. Clothing (including footwear), furnishings and household equipment, and restaurants, hotels, recreation and culture make up a further 7% and 6% of consumption-based GHG emissions respectively.

Figure 7 illustrates the variation in consumption-based GHG emissions by COICOP category on a per capita basis. For example, capital GHG emissions cover a range from 0.07 to 5.7 tCO_2e/capita, with a median value of 1.75 tCO_2e/capita.

[9] Housing (rent, maintenance and repair), water, electricity, gas and other fuels

[10] Business investment in physical assets such as infrastructure, construction and machinery

[11] Purchase of vehicles, operation of personal vehicles and use of transport services. Private transport is responsible for 5% of overall consumption-based GHG emissions, and public transport (which includes rail, shipping and aviation) contributes on average 10% to consumption-based GHG emissions.

[12] This consists of the categories Food and non-alcoholic beverages (93%), and Alcoholic beverages and tobacco (7%)

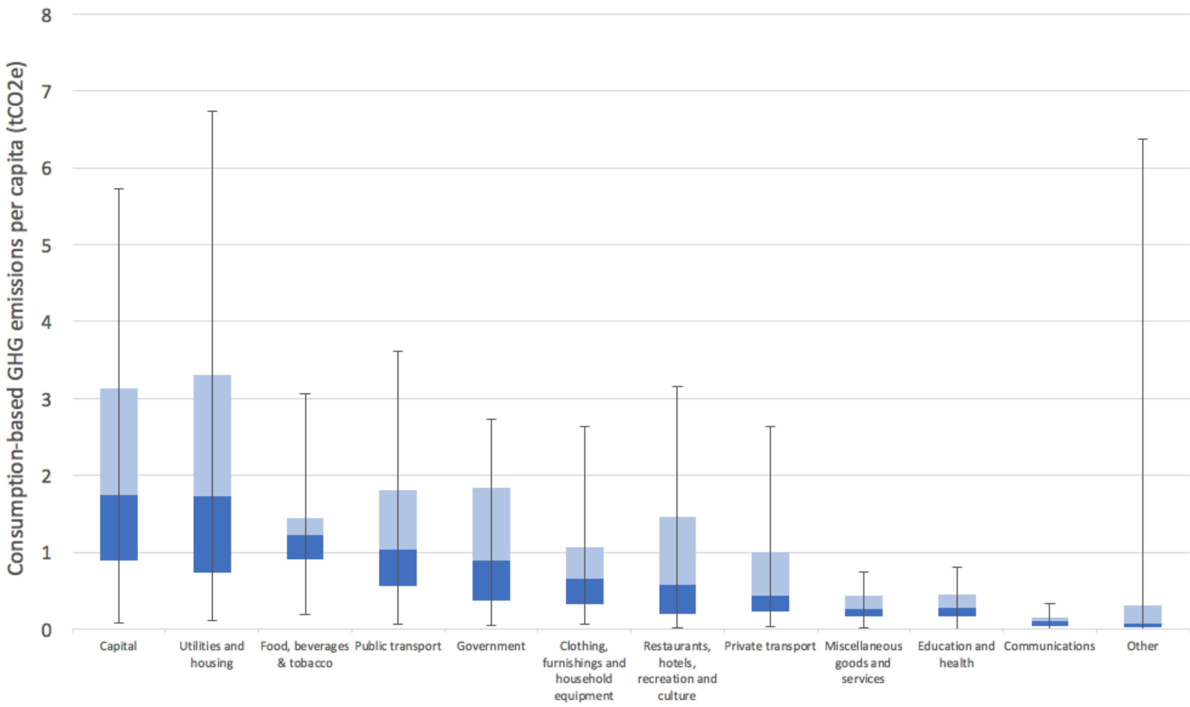

Figure 7: Variation of per-capita GHG emissions per product category. The shaded areas show the range from 25th to 75th percentile with the median indicated by a change in shading. The box plot whiskers show the minimum and maximum values.

3.3.2 Global Trade Analysis Project (GTAP)

GTAP presents a different range of consumption categories and allows for a greater level of disaggregation: 57 consumption categories are provided, including many different manufacturing and consumer products. This can be used to better understand what is driving consumption-based GHG emissions, and the differences between regions (and cities).

Figure 8 illustrates how per capita GHG emissions for a selected range of food-related GTAP categories vary across C40 cities in different regions. For example, meat-based GHG emissions are largest in Latin America whilst GHG emissions related to rice consumption are highest in South and West Asia (both compared to other regions, and amongst the food categories within their region), potentially explaining why food-based emissions make up such a large share of overall consumption-based GHG emissions in these regions. Combined, the categories shown in Figure 8 contribute 9% to total consumption-based GHG emissions. Please note this is not a complete list as not all food categories are shown: GTAP has 14 sectors covering 'agriculture and fishing'. Another illustration is provided in Figure 9 which shows per capita GHG emissions embodied in electronic equipment, with residents of C40 cities in North America record the highest GHG emissions. Electronic equipment makes up an estimated 3% of total consumption-based GHG emissions.

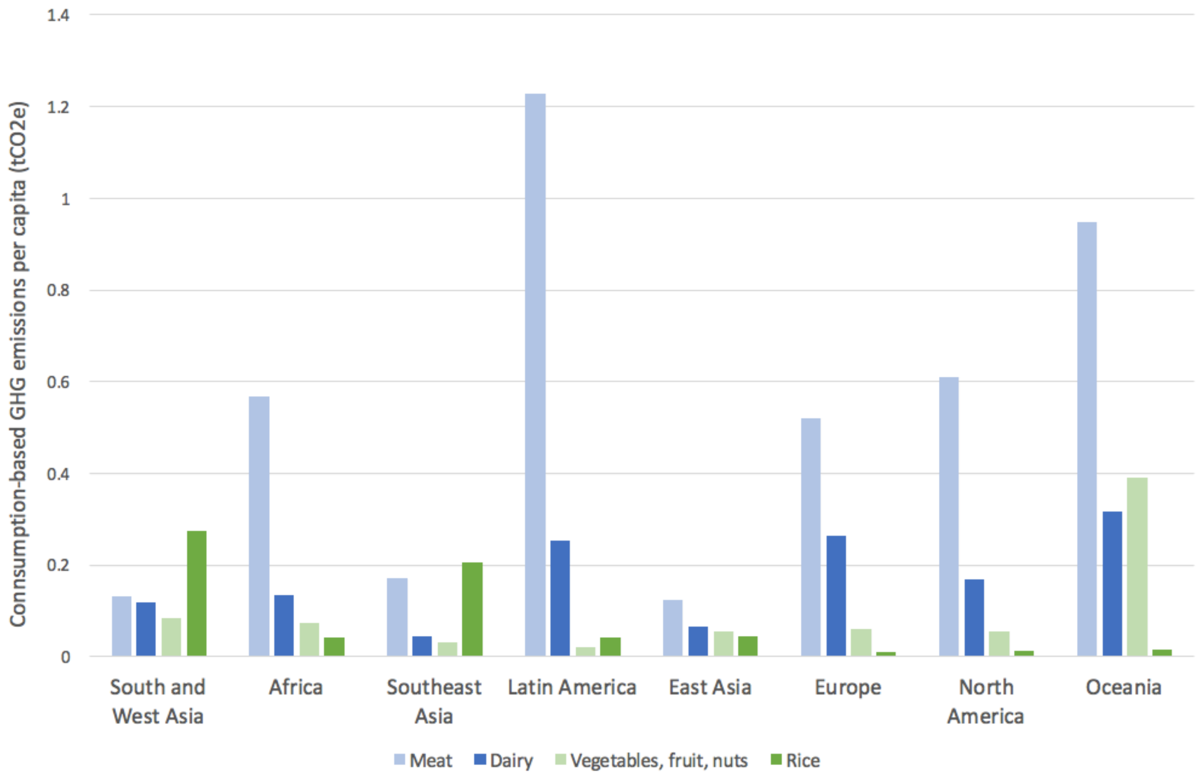

Figure 8: Variation of per-capita GHG emissions by region for a selection of food-related GTAP categories: Meat (includes bovine, bovine meat and other meat); Dairy (includes raw milk); Vegetable, fruit, nuts; and Rice (includes paddy rice and processed rice)

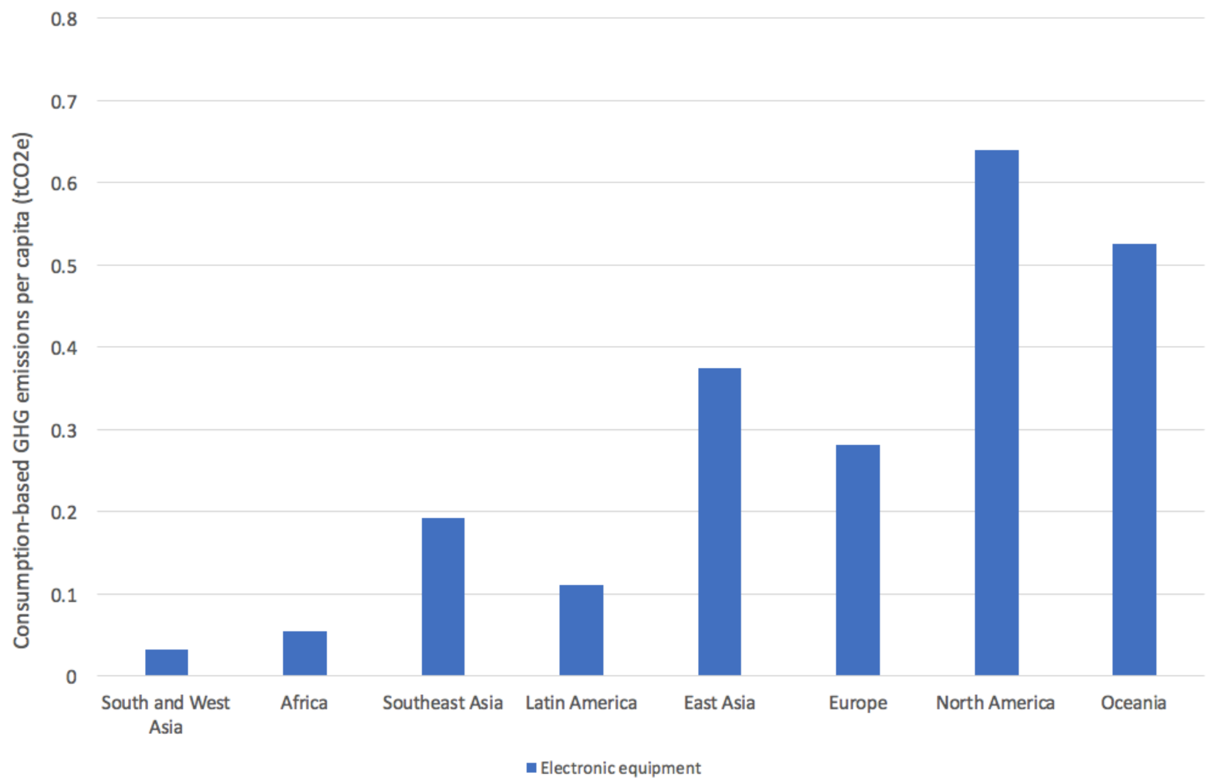

Figure 9: Variation of per-capita GHG emissions by region for electronic equipment (office, accounting and computing machinery, radio, television and communication equipment and apparatus)

4. Taking action on consumption-based GHG emissions

The results of this study show that consumption-based GHG emissions of C40 cities are significant, and significantly larger than sector-based GHG emissions established using the GPC. This is particularly the case for C40 cities in Europe, North America and Oceania. This reflects both the level of consumption in cities, and the global nature of supply chains of the goods and services used by residents of a city. GHG emissions from utilities, capital, transportation, food and government services are found to be most significant.

The large volumes of traded emissions show that C40 cities have an impact on global GHG emissions that stretches far beyond their physical boundaries. By addressing these, in addition to actions targeting sector-based GHG emissions, C40 cities could potentially have a much greater impact in reducing global GHG emissions.

Taken together, consumption-based GHG inventories and sector-based GHG inventories offer complementary insights into the drivers of GHG emissions – recognizing cities as both consumers and producers of goods and services – and can help cities identify a broader range of opportunities to contribute to reducing global GHG emissions.

4.1 Power to act

There are good reasons why most cities focus on sector-based GHG emissions. They occur from sources over which cities often have more direct infuence; are easier and more reliable to estimate and monitor; and align closely with the United Nations Framework Convention on Climate Change and guidelines from the Intergovernmental Panel on Climate Change.

While cities may not have much direct influence over the carbon intensity of power used in the manufacturing process of an imported product, or whether that product is transported by train or truck, as end users and centres of innovation and change, they do offer many opportunities to transform urban lifestyles into more sustainable ones to help reduce consumption-based GHG emissions. This can be achieved through a combination of resource productivity strategies and consumer policies, targeting carbon intensive consumption categories and lifecycle phases with the highest emissions, and supporting shifts in consumption to goods and services with lower emissions, including through public procurement.

Many C40 cities are already taking actions that reduce supply chain GHG emissions. To accelerate and scale such efforts, however, greater understanding is needed on how cities can most effectively target transboundary GHG emissions. This will vary between cities, based on, amongst others, their consumption-based GHG emissions profile, governance structure and ability to act.

4.2 Working together

The many supply chains that connect cities mean that GHG emissions reductions in other parts of the country and around the world will reduce the GHG emissions of cities and vice versa. It is, therefore, recommended that particular focus is placed on collaboration, knowledge sharing and learning between cities, and between cities and their regional and national governments. Networks, like C40, can help to facilitate these outcomes. To make the most of C40's network, a further level of analysis should be undertaken to identify city-to-city linkages in terms of the supply and consumption of goods and services. With this knowledge, C40 cities, and their stakeholders, could work together to better focus efforts (e.g. further research, better policies, joined up action for greater impact).

4.3 Improving the evidence base

The results of this study, and supporting calculations, represent a wealth of data that is available for further analysis and interpretation to help better understand the drivers of consumption-based GHG emissions. However, there is also a need to further improve, and complement, the results of this study.

4.3.1 Life cycle analysis

EEIO modelling does not provide cities with a great level of granularity, or information on where in the supply chain GHG emissions arise. More granular data would enable more detailed consideration of individual consumption categories. This could be achieved by complementing this study with more bottom-up assessments of individual consumption categories. In addition, life cycle analysis (LCA) of the primary sources of consumption-based GHG emissions could be used to disaggregate COICOP and GTAP category-data by life cycle phase - such as mining, construction, operation, and waste management. This will help target mitigation efforts to ensure the greatest opportunity for impact. One proposal is to incorporate an LCA focus on consumption sectors with the largest GHG emissions in an expanded version of the GPC. This would capture sector-based GHG emissions and those associated with the largest supply chains serving cities.

4.3.2 Further data gathering

Further data gathering is recommended to provide a better basis for the regular assessment of such consumption-based GHG inventories. This includes the completion of GPC inventories for all cities with the required level of data disaggregation to avoid the use of proxies to fill gaps and scale data for estimating emissions from energy use, as well as improving city level expenditure data to better estimate supply chain emissions. One of the main uncertainties, which can have a large influence on the results, is the economic final expenditure on goods and services in cities and how this compares to national consumption patterns[13]. The aim should be to obtain complete and consistent energy use and final demand data for all cities without the use of proxy data.

4.3.3 Forecasting emissions

This study is limited to analysis of the year 2011 (primarily due to the composition of the GTAP database used). Conducting a similar assessment for years prior to and after 2011

[13] Wiedmann T, Lenzen M, Owen A, Chen G, Többen J, Wang Y, Faturay F and Wilting H. (2017) Expanding a global MRIO for city footprint analysis. Published at the 25th International Input-Output Conference Atlantic City, New Jersey, USA, 20-23 June 2017

would allow for the creation of a time series and a better understanding of what is driving changes in emissions over time. It is also important to look ahead to better understand how consumption-based GHG emissions are likely to change in the future.

Deadline 2020 (C40 and Arup)[14] and *Focused Acceleration* (C40 and the McKinsey Center for Business and Environment)[15] respectively define a fair share carbon budget and emissions pathway for cities based on a 1.5°C trajectory, and identify the opportunities that have the greatest potential to contribute to this goal based on a sector-based approach to measuring GHG emissions. A similar exercise is needed to establish forecasts and reduction pathways for consumption-based GHG emissions to provide a better understanding of the scope and scale of GHG emissions reductions that are necessary and develop strategies for dealing with supply chain GHG emissions in support of the goals of the Paris Agreement.

4.4 Explore additional uses of a GMRIO model

The calculation of consumption-based GHG emissions was made possible by applying a GHG emissions extension to the GMRIO model used. It is possible to apply other extensions to the model thereby creating broader information on other consumption-lead environmental issues. For example, a water demand extension could be used to estimate a city's consumption-based water footprint. Similarly, an employment extension could help determine the number and location of employees involved in city supply chains[16].

A GMRIO model can also be used to estimate the impact (e.g. economic cost) of a range of disruptive events around the world (e.g. storm, flood, snowfall, drought) on the supply chains of a city. Such studies, for example, could help cities better understand the direct and indirect impact of climate change, helping to strengthen the case for mitigating and adaptation activities.

[14] www.c40.org/other/deadline_2020

[15] www.c40.org/researches/mckinsey-center-for-business-and-environment

[16] It is worth noting that different GMRIO databases include different extensions. For example, EXIOBASE (www.exiobase.eu) is the database that includes the largest number of extensions. It includes over 100 extensions including energy, emissions, water and land footprints, and employment.

5. Conclusions

Cities rely heavily on the supply of goods and services from outside their physical boundaries. The results of this study show that the GHG emissions associated with these supply chains are significant, particularly for C40 cities in Europe, North America and Oceania. Over 70% of consumption-based GHG emissions come from utilities and housing, capital, transportation, food supply and government services.

Cities in these regions, and other cities that have high consumption-based GHG emissions, are recommended to use consumption-based GHG inventories alongside their sector-based GHG inventories, or incorporate key supply chains into the latter. This would encourage more holistic GHG emissions assessments; enable decision-makers to consider a wider range of opportunities to reduce global GHG emissions; and provide an additional perspective with which to engage other stakeholders in climate action.

To support cities take on this challenge, further research is needed to improve the evidence base, and better understand the mechanisms by which cities can influence transboundary supply chains GHG emissions, in addition to those occurring locally.

Acknowledgments

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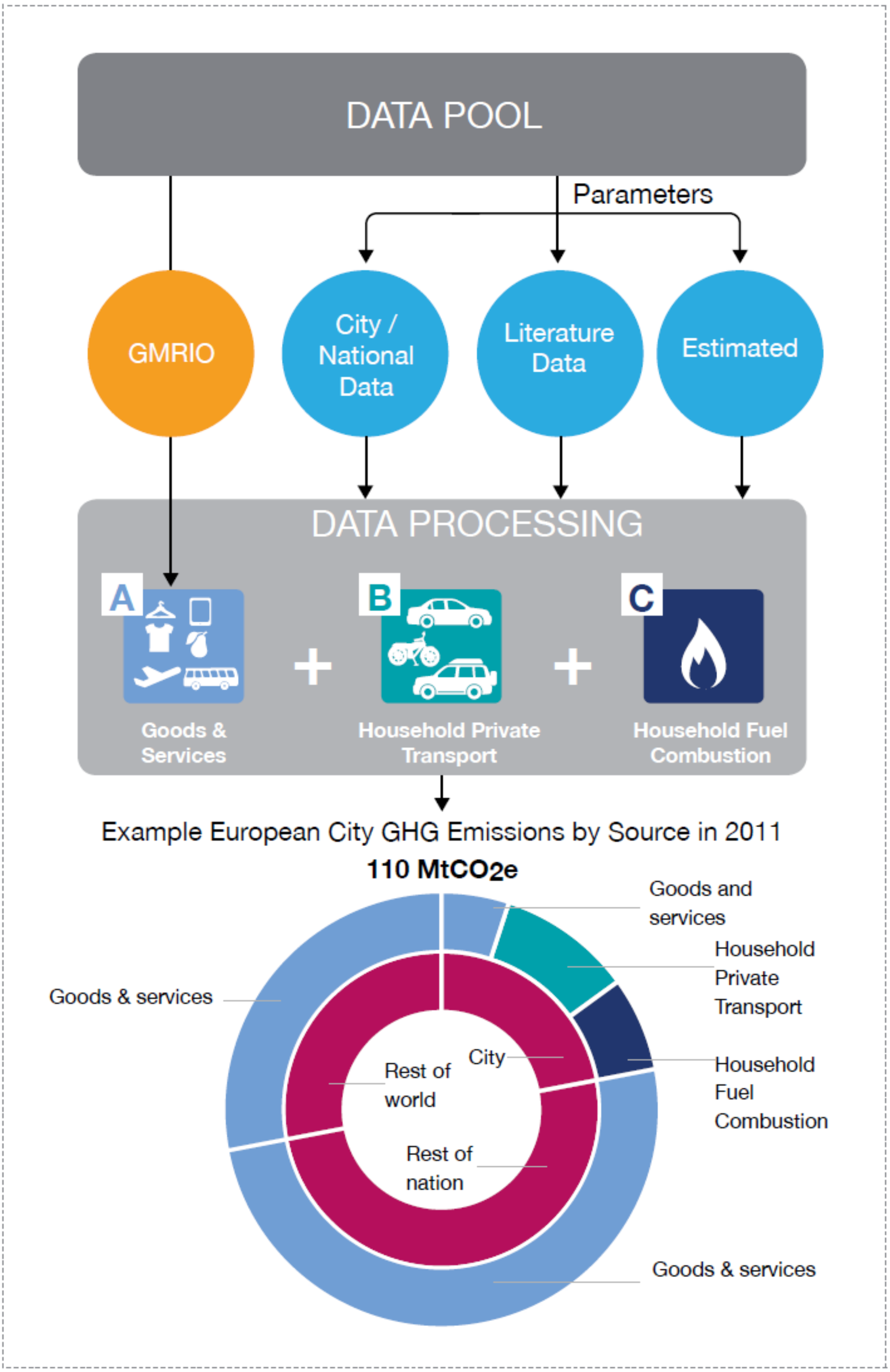
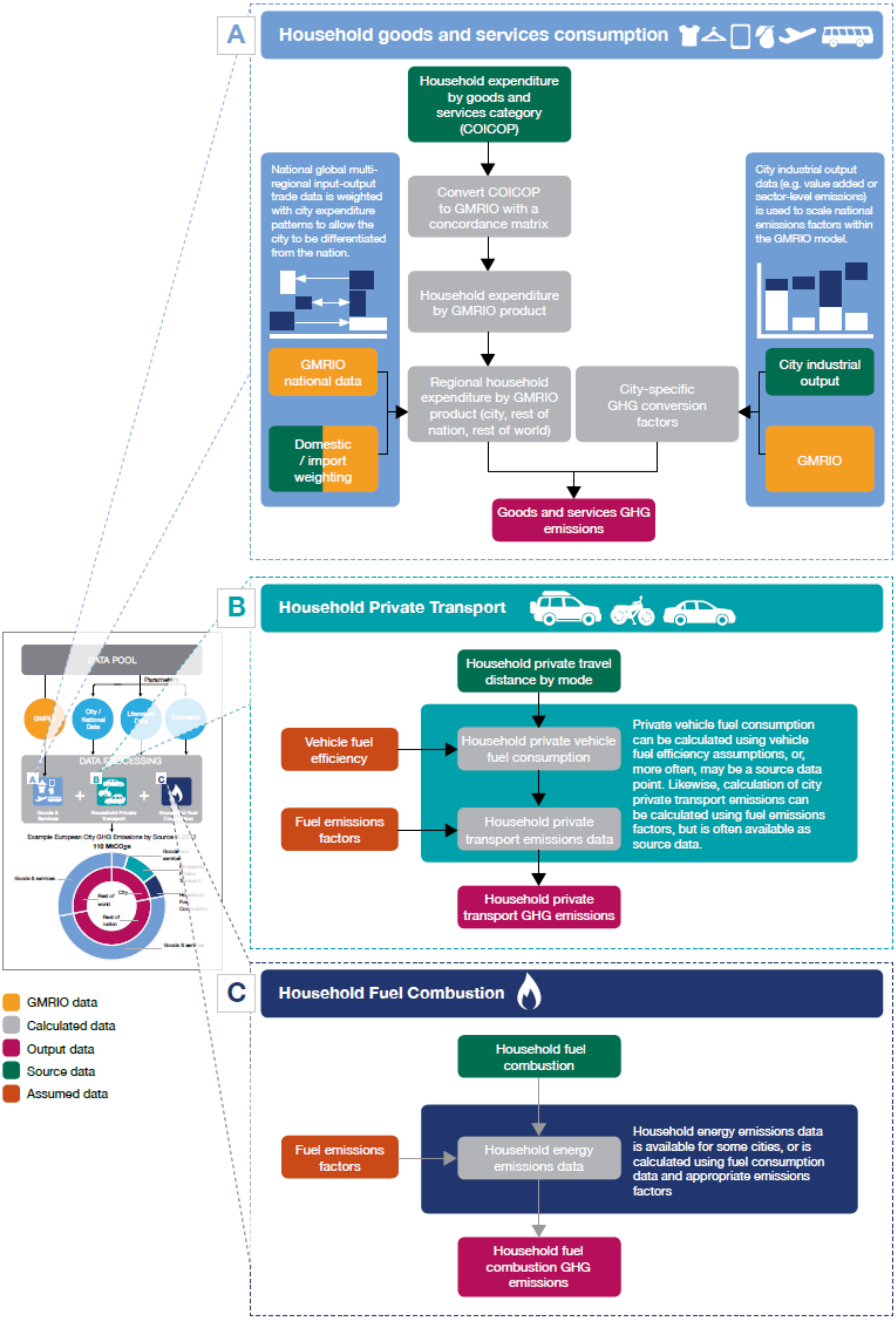
APPENDIX A: Data requirements and links between data sources and outputs





A
Household goods and services consumption
Household expenditure by goods and services category (COICOP)
National global multi-regional input-output trade data is weighted with city expenditure patterns to allow the city to be differentiated from the nation.
Convert COICOP to GMRIO with a concordance matrix
Household expenditure by GMRIO product
GMRIO national data
Domestic / import weighting
Regional household expenditure by GMRIO product (city, rest of nation, rest of world)
City-specific GHG conversion factors
City industrial output data (e.g. value added or sector-level emissions) is used to scale national emissions factors within the GMRIO model.
City industrial output
GMRIO
Goods and services GHG emissions
B
Household Private Transport
Household private travel distance by mode
Vehicle fuel efficiency
Household private vehicle fuel consumption
Fuel emissions factors
Household private transport emissions data
Private vehicle fuel consumption can be calculated using vehicle fuel efficiency assumptions, or, more often, may be a source data point. Likewise, calculation of city private transport emissions can be calculated using fuel emissions factors, but is often available as source data.
Household private transport GHG emissions
C
Household Fuel Combustion
Household fuel combustion
Fuel emissions factors
Household energy emissions data
Household energy emissions data is available for some cities, or is calculated using fuel consumption data and appropriate emissions factors
Household fuel combustion GHG emissions
DATA POOL
DATA PROCESSING
GMRIO data
Calculated data
Output data
Source data
Assumed data