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COMPARING MADRID AND SALVADOR GHG EMISSION INVENTORIES: IMPLICATIONS FOR FUTURE RESEARCHES

ABSTRACT

This paper compares the Greenhouse Gas (GHG) emission inventories of Madrid and Salvador and discusses some implications for future researches, focusing on city-level carbon accounting (CLCA) of emissions from urban supply chains (USC) and final consumers. To carry out this study, secondary data were collected from official documents of municipal governments of these two cities. According to the results, there are differences in stationary energy GHG emissions due to the big distinction concerning electricity emission factors used by each city. Air transportation GHG emissions are also very different. These two cities share some common figures regarding road transportation and per capita waste sector GHG emissions. In the conclusion section, we discuss opportunities for improvement of the cities' GHG emission inventories as well as some implications for policy-making and future researches on carbon accounting, with focus on an integrated production-consumption system.

KEYWORDS | Greenhouse Gas emissions, urban supply-chain, city-level carbon accounting, Salvador, Madrid.

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INTRODUCTION

Estimates show that the Greenhouse Gas (GHG) emissions caused by three European consumption areas (food, mobility and housing) showed no significant reductions between 2000 and 2007. However, when looking from a production perspective, in many economic sectors, there has been reduction in GHG emissions, or a decoupling between growth and emissions. The GHG emissions of goods consumption in the European Union (EU) are higher than the production emissions of the goods produced there, with the largest difference occurring in 2008 when consumption emissions were about a third higher than production emissions. Between 1995–2010, the EU production emissions decreased, whereas consumption emissions were slightly higher in 2010 than in 1995 (Gandy, Wiebe, Warmington, & Watson, 2014). In 2009, the GHG emissions associated with EU consumption equaled 4,407 million tonnes, which was 2% higher than in 1995. In comparison, the United Nations Framework Convention on Climate Change (UNFCCC) production-based (PB) estimate of 4,139 million tonnes in 2009 was 9% lower than in 1995. These data indicate that, in order to meet its 2050 objectives and contribute fully to meeting the global 2°C target, the EU will need to accelerate its implementation of new policies, while restructuring the ways that Europe meets its demand for energy, food, transport and housing (EEA, 2015).

Thus, making cities more sustainable is one of the most vital challenges of the 21st century, especially because cities exert a significant impact on the environmental status quo. When it comes to tackling climate change cities play a key role. The ability of city policy-makers and other stakeholders to take effective action depends on access to good quality data on GHG emissions. Therefore, a greater emphasis placed on the measurement of emissions and transparent data on GHG emissions is crucial. City-level carbon accounting (CLCA) standards are fundamental to enable city decision-makers to identify emission sources and their drivers, to reduce the carbon dependence of their economy and to stimulate opportunities for more efficient urban supply chains (USC).

Cities need to establish mitigation objectives and develop environmental policies in order to hold back the consequences of climate change. The most frequently used analytic tool is the GHG emission inventory, which estimates the emissions associated with the activities of the city or country studied. The devel-

opment of these inventories is the first step towards achieving the different goals set up by the regulatory organism and they are particularly helpful in tracking the progress over time.

In order to compare inventories and facilitate the integration of inventories from different cities, standardised methodologies for developing and reporting GHG emissions have been developed. Considering this, the Compact of Mayors, supported by 457 cities, published the Global Protocol for Community-Scale GHG Emission Inventories (GPC) in 2014. This internationally accepted methodology helps cities develop their GHG inventories in a consistent and widely recognised way.

Therefore, most of the city-level GHG inventories using the GPC methodology are carried out focusing on a production approach and they do not account for all the emissions embedded in products and services consumed in a city. The large and increasing share of GHG emissions 'hidden' in imported goods underlines the importance of calculating the carbon emissions and impacts of USC and final consumers (Schaltegger & Csutora, 2012).

This paper compares the GHG emission inventories of Madrid and Salvador, which reported in 2015 their 2013 emissions to GPC, and it discusses some implications for future researches focusing on CLCA of GHG emissions from USC and final consumers.

These two cities were chosen for some reasons. Firstly, Madrid has a long trajectory in doing the integration of the air pollutant and the GHG emission inventories. In fact, since 1999, the city has been producing its two inventories following the Core Inventory of Air Emissions (CORINAIR) methodology, which is coordinated by the European Environment Agency (EEA), and meets the requirements established by the Intergovernmental Panel on Climate Change (IPCC) and the Task Force on Emission Inventories and Projections of the United Nations Economic Commission for Europe (TFEIP - UNECE).

Although Madrid has been producing GHG emission inventories for more than 10 years, only in 2015 the GPC methodology was implemented in order to report the 2013 Madrid's GHG emission inventories (Madrid, 2015a). Even if Madrid's experience regarding the use of the GPC standards is not very long, it does have a long experience in gathering data and calculating emissions using international principles. Therefore, the recent adoption of the GPC methodol-

ogy has not implied a significant change for the city's usual inventory development. In fact, the distinction mainly resides in a different activity classification, which led to a reorganization of the results and the calculation of some indirect emissions that were not considered before.

On the other hand, Salvador's first attempt to develop a GHG emission inventory was in 2015, with 2013 emission data. This has been the only inventory produced so far by this Brazilian city and it was developed using the GPC methodology. Then, Salvador is at an initial stage of the development of GHG emission inventories under the GPC framework. Thus, this comparison between GHG emission inventories from two cities with different trajectories regarding their experiences in producing air pollutant emission inventories could provide useful contributions to scholars and practitioners improving the quality of CLCA methods.

Secondly, this comparison acts as an evaluation method for the GHG emission inventories of Salvador and Madrid. Comparing results from Madrid, to the first-stage results from Salvador could contribute to these Brazilian city decision-makers improving the quality of the future inventories.

Additionally, the availability of the GHG emission inventory data for these two cities and the existence of an academic research collaboration between the Technical University of Madrid in Spain and Federal University of Bahia in Brazil about urban carbon accounting methods. It is important to point out that most of GHG emission inventories of cities around the world are not of open public access to academic researchers.

Finally, large cities like Madrid and Salvador are considered more consumers of goods and services than producers. Then, this paper contributes to put into discussion some challenges regarding the necessity of a future urban carbon accounting academic research agenda to switch the focus from current GHG inventories to an integrated production-consumption carbon accounting system.

LITERATURE REVIEW

A number of international initiatives have been developed over the past decade to standardize the methodology for conducting a city GHG inventory. The most widely referenced programs include: the International Local Government GHG Emissions Analysis Protocol (IEAP), developed by the Local Governments for Sustainability (ICLEI) in 2009; the International Standard

for Determining GHG Emissions for Cities (ISDGC), jointly developed by the World Bank, the United Nations Environmental Programme (UNEP) and the United Nations Human Settlements Programme (UN-HABITAT) in 2010; the Baseline Emission Inventory/Monitoring Emission Inventory Methodology (BEI/MEI), developed by the Covenant of Mayors Initiative in 2010; the U.S. Community Protocol for Accounting and Reporting of GHG Emissions, developed by the ICLEI USA in 2012; the Publicly Available Specification (PAS) 2070:2014 for measurement of GHG emissions of a city, developed by the British Standards Institution (BSI) in 2013; and, finally, the GPC, jointly developed by the World Resources Institute (WRI), ICLEI and the Cities Climate Leadership Group (C40) in 2014. These methodologies present differences that range from the use of different emissions categories to the consideration of different GHG emission boundaries (WRI, 2014).

Normally, the existing methodologies have two distinct focuses: PB inventories and consumption-based (CB) inventories. Conceptually, CB inventories can be thought of as: consumption equals PB emissions minus the emissions from the production of exports plus the emissions from the production of imports. While PB inventories allocate GHG emissions to the producer, CB inventories allocate emissions to the final consumer.

CB methodologies typically account for a larger number of emissions as most goods and services consumed in cities are not usually produced locally. Cities import most of their goods and services from other regions. The methods used following the principles of consumption are very different from the ones used in the more traditional approach of PB inventories. The idea of allocating emissions to the final consumer is not recent, but, given its complexity, there has not been a global consensus on what type of methodology to apply yet: Life-Cycle-Analysis (LCA) inventories, Environmentally-Extended-Input-Output (EEIO) matrixes, Compound Method based on Financial Accounts (MC3) etc. (Peters, 2008; Cagiao, Gomez, Domenech, Mainar, & Lanza, 2011; Larsen, Pettersen, Solli, & Hertwich, 2013).

Some of the CLCA standard that adopted the CB methodologies, like the PAS 2070 standard, recognize cities as both consumers and producers of goods and services. The PAS 2070 sets out requirements for the assessment of GHG emissions of a city or urban area by using two methodologies: Direct plus Supply Chain

(DPSC) and CB.

The DPSC methodology captures territorial GHG emissions and those associated with the largest supply chain serving cities. It is consistent with the GPC. Thus, the DPSC accounts for GHG emissions from six source categories: stationary energy sources (energy use in residential buildings and commercial, industrial and government buildings and facilities), in boundary and transboundary transportation, Industrial Processes and Product Use (IPPU), Agriculture, Forestry, Other Land Use (AFOLU), waste and wastewater treatment and some goods and services (water provision, food and drink and construction materials). The CB methodology uses input-output modeling to estimate direct and life cycle GHG emissions for all goods and services consumed by residents of a city. So, the PAS 2070 captures both direct GHG emissions (from sources with the city boundary) as well as indirect GHG emissions (from goods and services that are produced outside the city boundary for consumption and/or use within the city boundary).

Used to assess 2010 GHG emissions of London, the PAS 2070 has estimated the total GHG emissions using the DPSC and CB methodologies and has compared them to previous results calculated using the London Energy and Greenhouse Gas Inventory (LEGGI). The LEGGI covered GHG emissions only from the combustion of energy used within the city boundary (for transport and to power and heat homes/workplaces). According to the assessment results, the total 2010 GHG emissions of London calculated using the CB methodology are 40% higher than those calculated using the DPSC methodology and 156% higher than those calculated using the LEGGI methodology (Minx et al., 2013; BSI, 2014).

The London case study shows the difference between PB and CB methodologies. Cities like London – and any other large cities, which are considered more “consumers of goods and services” than “producers” – inevitably give rise to the production of GHG emissions beyond their boundaries and highlight the need to include a wider range of emission sources in their GHG inventory.

In some countries like China, cities have higher *per capita* GHG emissions than the national average because they concentrate industrial activities. Weber, Peters, Guan, and Hubacek (2008) documented that, in 2005, approximately 30% of Chinese emissions were related to the production of exports and that this share increased rapidly in the early 2000's. On

the other hand, most Organisation for Economic Co-operation and Development (OECD) countries show the opposite trend (Hoornweg, Sugar, & Gomez, 2011) because the influence of the consumption of imported goods and service on the cities' GHG inventories is higher than the national-scale ones. Weber and Matthews (2007) created a multi-country input-output model to estimate embodied carbon emissions and forecasted that, if this trend continues, emissions embodied in United States (US) imports will exceed emissions of domestic production within 20 years. Thus, a large and increasing share of European and US GHG emissions are embedded in imported goods as a ‘carbon rucksack’ (Schaltegger & Csutora, 2012).

Such divergence between production and consumption perspective trends is common (Hoff, Nykvist & Carson, 2014; Tukker et al., 2014). However, it should be borne in mind that CB methodologies are subject to greater data uncertainty and shorter time series, as well as difficulties in defining system boundaries. EEIO matrixes are still barely developed at city scale and growing complexity of city's supply chains poses substantial challenges to this kind of carbon accounting and makes it more difficult to use CB methodologies in policy-making (Wiedmann et al., 2013).

Therefore, hybrid carbon accounting, which combines economic approaches of input-output analysis with physical approaches, should be used as an approach for urban supply chain and final consumers accounting when physical material flows cannot be measured or only at exorbitantly high costs (Settanni, Tassielli, & Notarnicola, 2011). Physical material flows are approximated based on financial information and are assumed proportional to monetary flows. Such applications, however, should be treated with caution, as the accuracy of hybrid accounting information is far lower than when using physical primary data. The application of hybrid carbon accounting may be justified by high data collection costs or unavailability of data due to confidentiality problems, but this should not be an excuse when primary physical carbon data can be collected with reasonable effort (Schaltegger & Csutora, 2012). Tsai et al. (2012) provided a practical example on how input-output analysis can be combined with activity-based costing to more effectively link physical material flows and economic flows of costs.

Thus, PB methodologies have been further developed and they have a more solid background as compared to CB and hybrid methods. The methodologies used for GHG emission calculation are more standardized

and they allow easier comparison among cities. It is inside this framework that the GPC methodology is presented.

GPC is built upon the worldwide used IPPC Guidelines, which provide detailed guidance on data collection and calculation of GHG emissions. The GPC methodology provides a robust framework for generating GHG emission inventories, divides emission sources into sectors that have been globally adopted, and proposes two different approaches for reporting the results: scope and city-induced frameworks.

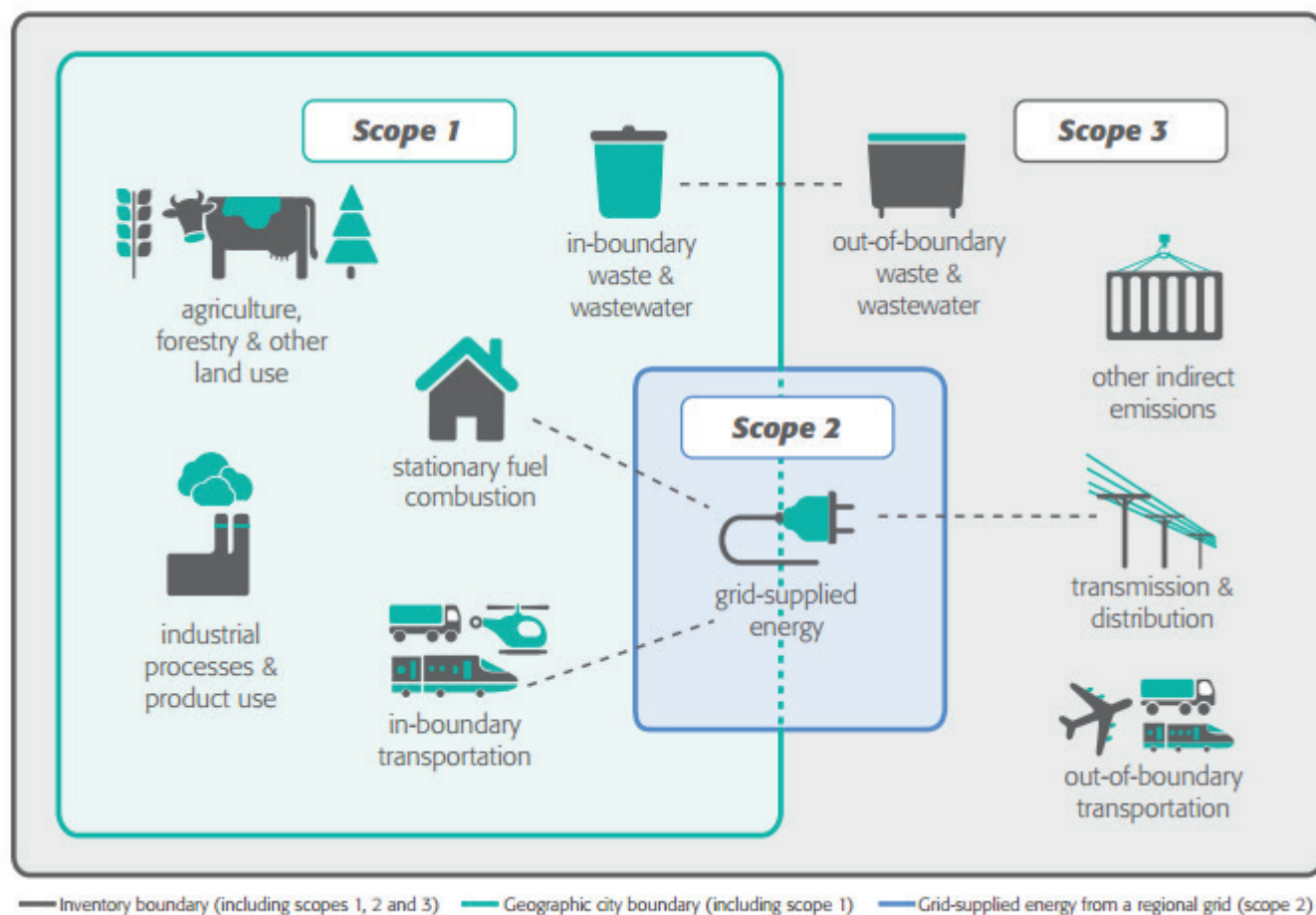
It has been adopted by more programs and initiatives including the Compact of Mayors, the Carbon Disclosure Project (CDP) reporting platform, the PAS2070 and International Organization for Standardization

(ISO) 37120:2014 (Sustainable Development of Communities). Up to date, more than 100 cities have used GPC to measure GHG emissions (WRI, 2014).

Scope framework

This approach adds up emissions by scope. GHG emissions can occur inside and outside the city boundary. Three scopes are objectively defined in order to cover all relevant GHG emissions and avoiding double counting. This is shown in Figure 1:

Figure 1. **GPC Scope Framework: sources and boundaries of city GHG emissions**



Source: WRI (2014)

Scope 1 accounts the GHG emissions from stationary energy, transportation, waste, IPPU and AFOLU sources

located physically within the city boundary. This scope (called territorial emissions) allows for the separate accounting of all GHG emissions produced within the geographic boundary of the city, consistent with national-level GHG reporting.

The scope 2 considers the GHG emissions that occur due to the consumption of grid-supplied electricity, heat, steam and/or cooling within the city boundary. GHG emissions associated with electricity are one of the biggest areas of variability among cities and can be essential in order to mitigate emissions.

Finally, the scope 3 accounts the GHG emissions that occur outside the city boundary because of activities that take place within the city boundary. The GPC includes scope 3 accounting for a limited number of emission sources, including transmission and distribution losses associated with grid-supplied energy, and waste generated in the city but disposed or treated outside the city boundary and out-of-boundary transportation. Cities may optionally report other Scope 3 sources associated with activity in a city—such as GHG emissions embodied in fuels, water, food&drink and construction materials.

CB methodologies are an alternative to the sector-based approach to measure city emissions adopted by the GPC. It focuses on the consumption of all goods and services by residents of a city, and GHG emissions are reported by consumption category rather than the emission source categories set out in the GPC. The CB methodologies allocate GHG emissions to the final consumers of goods and services rather than to the original producers of those GHG emissions. As such, GHG emissions from visitors' activities and the production of goods and services within the city boundary that are exported for consumption outside the city boundary are excluded.

CB inventories typically use an input-output model, which links household consumption patterns and trade flows to energy use and GHG emissions, and their categories cut across those set out in the GPC. So, CB approach is complementary to the GPC and it provides a different insight into a city's GHG emission profile.

For example, King County in the U.S. state of Washington carried out a study published in 2010 using 2008 data to estimate the emissions associated with all goods and services consumed by the region's two million residents, regardless of where the emissions were produced. Total emissions were estimated at 55

million MtCO₂e, of which over a quarter was released outside the US. Overall, emissions associated with local consumption by residents, governments and businesses, including the production of goods, food and services from outside the County, were more than twice as high as emissions that occurred inside the County's borders. King County's "geographic-plus" based inventory separately estimated regional emissions at 23 million MtCO₂e, using a methodology similar to the GPC. The difference in emissions reflects the different sources covered by the two methodologies. Some sources are included in both inventories and, therefore, the results should not be added together in order to evict double-accounting (WRI, 2014).

City-induced framework

This approach gives cities the option of selecting between two reporting levels: BASIC or BASIC+. These levels cover specific scopes in different categories of activities, being the BASIC+ level the one that provides further analysis. The BASIC+ reporting level includes the three BASIC categories (stationary energy, transportation and waste) and aggregates IPPU, AFOLU and any other emissions occurring outside the geographic boundary due to city activities (WRI, 2014).

Stationary energy, the first BASIC reporting level category, includes scope 1 and 2 GHG emissions. A major part of the emissions associated with stationary energy is produced due to residential, commercial and institutional buildings and facilities heating systems; energy industries; and manufacturing industries and construction. Looking at these emissions, the types of fuels employed to produce energy, the levels of energy efficiency of constructions and the climate are the main determinant for stationary energy GHG emissions. Therefore, cities with a higher heating or cooling need and a higher level of fossil fuel energy consumption will normally have higher GHG emission rates related to stationary energy. So, the thermal and electrical energies play an important role in this GHG emission category, and it presents a strict relationship between the level of economic welfare and the quantities of energy consumed (Crocì, Melandri, & Molteni, 2011).

The second one, the transportation category, also covers the scopes 1 and 2 GHG emissions. In scope 1 it covers the fugitive emissions from transportation of primary fossil fuels and in scope 2 it covers all jour-

neys by road, rail, water and air, including inter-city and international travel. GHG emissions are produced directly by the combustion of fuel or indirectly by the use of grid-supplied electricity. Empirical relationships have been established between transportation energy use and population density, with an inverse interaction (Kennedy et al., 2009). Cities that are spread out result in heavy reliance on fossil fuel-powered automobiles and, therefore, account for higher transportation-related GHG emissions. On the other hand, cities with higher population density and with an extensive public transportation network that enables them to satisfy a bigger quota of passengers, normally present significantly lower emissions associated with transportation (Sugar, 2010). The form of a city, the features of the vehicle stock, the type and the prices of fuels utilized are determinants of GHG transportation emissions (Crocì et al, 2011).

Finally, the third one covers the GHG emissions associated with waste category and it includes scopes 1, 2 and 3. The GHG emissions computed within this category are produced due to the inside and outside of city boundary waste and wastewater generation, treatment and disposal.

Management of urban solid waste systems has been implemented in most developed countries, not only with the purpose of optimization of resources, but also with the purpose of reducing GHG emissions. Urban solid waste volume increases with economic and demographic growth and some studies indicate that treatment and disposal of it is third one of the major contributors to GHG emissions after residential, commercial and institutional buildings and facilities; and transportation (Lu, Sun, Ren, & He, 2015). Thus, the *per capita* GHG emissions and urban solid waste

generation are closely correlated to city wealth (Hoorneweg et al., 2011). It is a fact that the cities in the world's poorest regions with lowest *per capita* GHG emissions have lower waste generation rates.

Waste treatment strategies are especially important in order to tackle GHG emissions, as cities grow and consume more resources, there is a clear relationship between emissions and waste. Chinese cities and other cities in developing countries that experiment an incredibly rapid pace of growth have correctly identified this relationship and several thorough studies have been carried out in order to apply the best policies concerning solid waste treatment (Yang et al., 2011; Lin & Huang, 2009; Guerrero, Mass, & Hoggland, 2013).

METHODOLOGY

As previously explained, the GPC standards have been chosen in order to compare the GHG emissions from Madrid to Salvador. In order to carry out this study, no primary data were collected and only public secondary data sources were used. For Madrid as well as for Salvador, public secondary data were collected from official and institutional documents of municipal and national governments (GPC reports, energy balance, urban waste management reports, airport traffic reports etc.).

Table 1 provides Madrid and Salvador's information. They were used as references to estimate the GHG emission inventory boundaries in GPC reports of these cities.

Table 1. Madrid and Salvador's information from GPC reports

City	Madrid	Salvador
Year	2013	2013
Description	Capital of Spain; the third largest city in the EU	Capital of the state of Bahia; the third largest city in Brazil
Area (km ²)	606	693
Average temperature (°C)	15	25.3
Population (million)	3.2	2.9
Density (inhab./km ²)	5,292	4,190
GDP (million US\$)	103,261	18,521

Source: Madrid (2015a, 2015b, 2014a) and Salvador (2015)

Tables 2 and 3 present the data about the GHG emissions of Madrid and Salvador from GPC reports:

Table 2. **GHG emissions of Madrid in 2013 from GPC report**

Madrid	GHG Emissions Source (By Sector)		Total GHGs (tonnes CO ₂ e)				
			Scope 1	Scope 2	Scope 3	BASIC	BASIC+
	Stationary energy	Energy use	2,860	2,985	374.042	5,845	6,219
		Energy generation supplied to the grid	190.900	-	-	-	-
	Transportation	All emissions	2,660	265.751	33.300	2,926	2,959
	Waste	Waste generated in the city	431.481	-	-	431.481	431.481
		Waste generated outside city	5.776	-	-	-	-
	IPPU	All emissions	679.742	-	-	-	679.742
	AFOLU	All emissions	-32.432	-	-	-	-32.432
	Other scope 3	All emissions	-	-	-	-	-
	Total		6,796	3,251	407.342	9,202	10,257

Source: Madrid (2015a, 2015b)

Table 3. **GHG emissions of Salvador in 2013 from GPC report**

Salvador	GHG Emissions Source (By Sector)		Total GHGs (tonnes CO ₂ e)			
			Scope 1	Scope 2	Scope 3	BASIC
	Stationary energy	Energy use	303.734	366.395	-	670.129
		Energy generation supplied to the grid	-	-	-	-
	Transportation	All emissions	2,151	-	-	2,151
	Waste	Waste generated in the city	205.218	-	90.402	295.621
		Waste generated outside city	3.515	-	-	-
	IPPU	All emissions	-	-	-	-
	AFOLU	All emissions	-	-	-	-
	Other scope 3	All emissions	-	-	-	-
	Total		2,663	366.395	90.402	3,117

Source: Salvador (2015)

In 2015 Madrid decided to adopt the GPC methodology to report its 2013 GHG emissions at BASIC and BASIC+ levels (see Table 2). On the other hand, Salvador only covers the BASIC reporting level of the GPC (see Table 3) as this was the first attempt to develop a GHG emission inventory. Therefore, it is only possible to com-

pare Salvador and Madrid at a BASIC reporting level.

So, in order to compare and discuss the results of Madrid and Salvador, the following GHG emission indicators and relations were used:

- *Per capita* urban and national emissions;
- *Per capita* emission by scope and sector;
- *Per capita* emissions associated with transportation;
- Relation between the *per capita* scope 2 emissions and *per capita* electricity consumption from stationary sources;

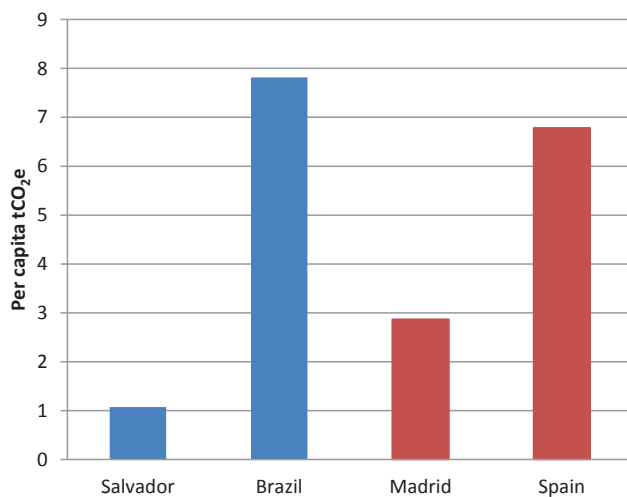
- Relation between population density and *per capita* emissions from road transportation;

- Relation between waste generation rate, *per capita* total emissions and GDP;

RESULTS AND DISCUSSIONS

Figure 2 shows the differences between *per capita* urban and national GHG emissions from Salvador versus Brazil, and from Madrid versus Spain.

Figure 2. ***Per capita* urban and national GHG emissions from Salvador/Brazil and Madrid/Spain**



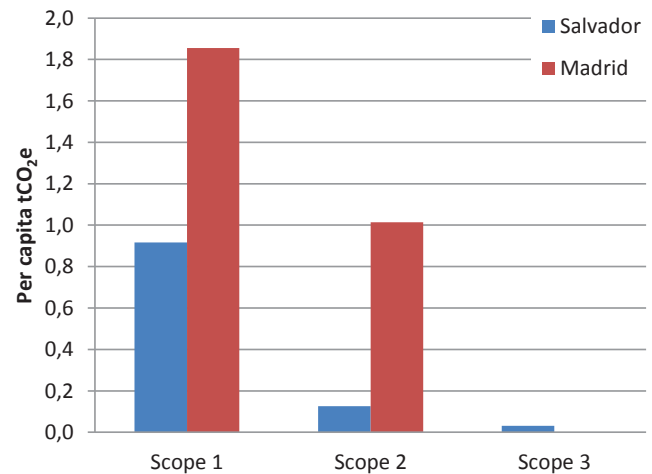
The *per capita* emissions do not only depend on the individual's way of living, but also on the economic structure of the cities. That is clearly shown in Figure 2: Salvador's estimate of 1.07 tCO₂e *per capita* differs largely from the 2.87 tCO₂e *per capita* that correspond to Madrid. This difference can be explained by reasons that rely on the structural, economic, social, environmental and cultural disparities between the two cities.

Both cities have lower *per capita* emissions as compared to the national average. This relationship is explained by the fact that these cities are characterized by a general lack of heavy industry and they act more as "consumers" than "producers". The results would have been different if the GPC methodology did cover emissions associated with consumption of main goods and services, like PAS 2070's DPSC and CB methodologies and EEIO matrixes.

In addition to the distinct way of living between Madrid and Salvador, it can also be noted that the difference of the ratio of Emissions in Salvador/Brazil of 0.14 and in Madrid/Spain of 0.42 reflects the nature of Salvador's higher reliance on hydro-electricity as well as the fact that being Madrid the capital of Spain, it concentrates a lot of government facilities and company headquarters.

An overall glance of the situation of both cities is presented in Figure 3.

Figure 3. **Per capita GHG emissions by scope**



As Figure 3 shows, the largest difference is found in emissions associated with scope 2. Scope 2 emissions occur because of using only the grid-supplied electricity since none of the two cities possesses heat, steam and/or cooling grids. While scope 2 *per capita* emissions for Madrid are 1.01 tCO₂e, Salvador only emits 0.13 tCO₂e. Scope 1 emissions also differ largely since Madrid doubles the 0.92 tCO₂e allocated to Salvador.

Madrid's BASIC reporting level does not take into account any scope 3 emissions. Madrid's GPC report 2013 only has included in scope 3 the emissions from the transmission and distribution losses associated with grid-supplied energy and out-of-boundary transportation (see Table 2). Madrid does not treat waste outside the inventory boundary; whereas 30% of Salvador's waste emissions are classified as scope 3 (see Table 3). The difference concerning the waste sector emission between Salvador and Madrid is shown in Figure 4.

Figure 4. **Per capita GHG emissions by sector**

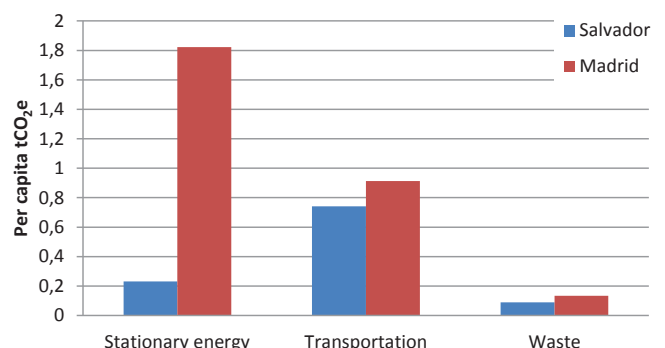


Figure 4 represents total *per capita* emissions for each city categorized by sector. It is remarkable the difference observed in the stationary energy sector: Salvador's *per capita* tCO₂e is 0.23, whereas Madrid's is 1.82. While scope 1 stationary energy of Madrid

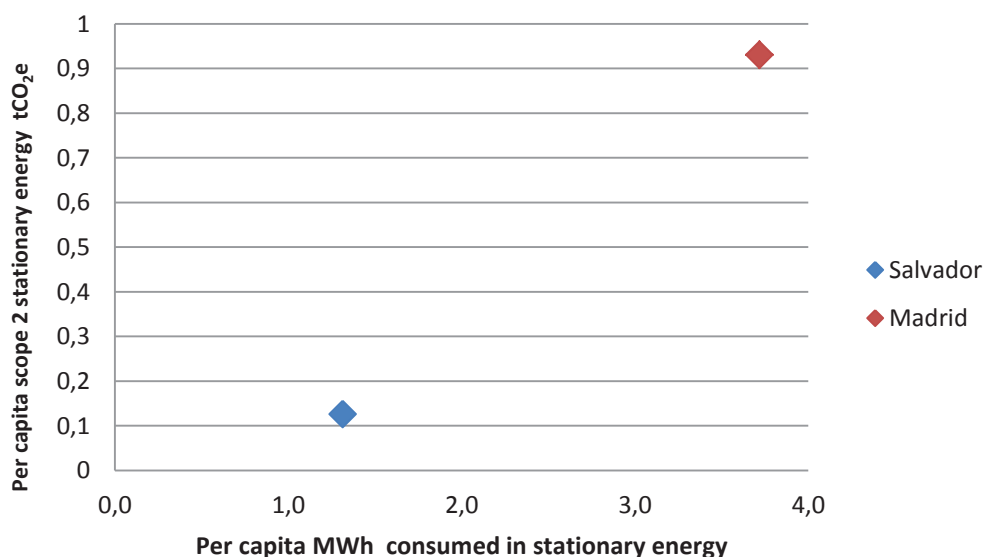
contributes with 45% of the total scope 1, at Salvador the direct emissions from this sector contributes only with 11.4% of total scope 1. Another suitable explanation for this gap is the huge difference between the emission factors of Brazil and Spain. In Salvador, 54% of stationary energy emissions come from electricity consumption, with a national emission factor of only 0.096 tCO₂e/MWh, whereas, in Spain, the electricity

emission factor is 0.25 tCO₂e/MWh (Madrid, 2015c; Salvador, 2015).

Figure 5 shows the differences encountered between scope 2 *per capita* stationary energy GHG emissions and *per capita* energy consumption:

Figure 5. **Per capita scope 2 stationary energy GHG**

emissions and *per capita* energy consumption



It is clearly observed that the relationship is not linear as the ratio of electricity consumption is $\frac{\text{per capita MWh Madrid}}{\text{per capita MWh Salvador}} = \frac{3.7}{1.3} = 2.85$ and the ratio of associated Emissions is

$$\frac{\text{Madrid's per capita t CO}_2 \text{ eq scope 2 stationary energy}}{\text{Salvador's per capita t CO}_2 \text{ eq scope 2 stationary energy}} = \frac{0.925}{0.125} = 7.4.$$

Therefore, one of the main determinants of this gap in scope 2 stationary energy emissions is the difference between the electricity emission factors of Brazil and Spain.

One of the reasons for the big difference in the national electricity emission factor used by both cities is based on the weight that renewable energy has in the electricity matrix of Brazil as compared to Spain. In 2013, almost 75% of Brazilian electricity production was from renewable sources, in particular hydropower with 65% (EPE, 2015). However, in Spain, renewable energies accounted for 42.4% of the national demand coverage (REE, 2014).

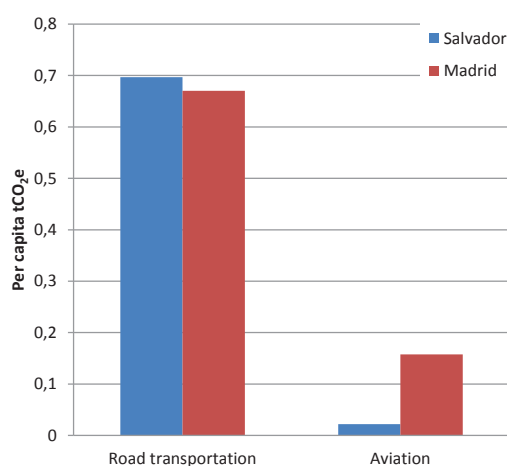
Scope 1 emissions from stationary energy sources are more difficult to compare as these emissions de-

pend on several variables. A large part of stationary energy emissions result from the activity of heating and cooling systems in factories, industries and, most importantly, in residential, commercial and institutional buildings and facilities. The overall results show that Madrid pollutes nine times more in terms of *per capita* scope 1 stationary emissions. Probably, this difference could be associated with the distinct *per capita* demand for heating and cooling systems and distinct types of fuels utilized in Madrid compared to Salvador. In addition to that, part of this gap could be explained by the differences in average temperatures of both cities: Madrid (15 °C) and Salvador (25.3 °C).

Looking again at Figure 4, in terms of transportation, Madrid also possesses the highest rate of Emissions. This difference is due mainly to the structural and transportation system differences between the cities. Figure 6 shows the *per capita* GHG emissions associated with transportation and it helps to point out that one of the main reasons for Madrid's larger transportation emissions is the traffic in its airports:

Figure 6. **Per capita GHG emissions associated with**

transportation



Madrid has one of the biggest airports in Europe and the traffic of national and international flights is incomparable to Salvador's low rate of flight activity. In 2013, the number of passengers at the biggest airport in Madrid was 39.7 million, whereas, Salvador's main airport transported only 8.6 million passengers in the same period (INFRAERO, 2015; AENA 2015).

The differences between *per capita* emissions in road transportation could be associated with several factors: the type and the prices of fuel used; the type, size and capacity of the engines; the vehicle ownership rate, the average age of the vehicles, the population density of the cities, etc. Figure 7 shows the relation between *per capita* road transportation GHG emissions and population density of Madrid and Salvador. The inverse empirical relationship established by Kennedy et al. (2009) between *per capita* road transportation GHG emissions and population density could be observed in Figure 7:

Figure 7. *Per capita* road transportation GHG emissions and population density

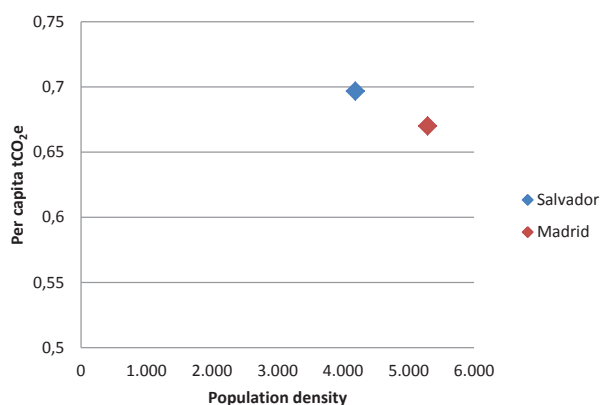


Figure 7 supports the hypothesis of the dependence

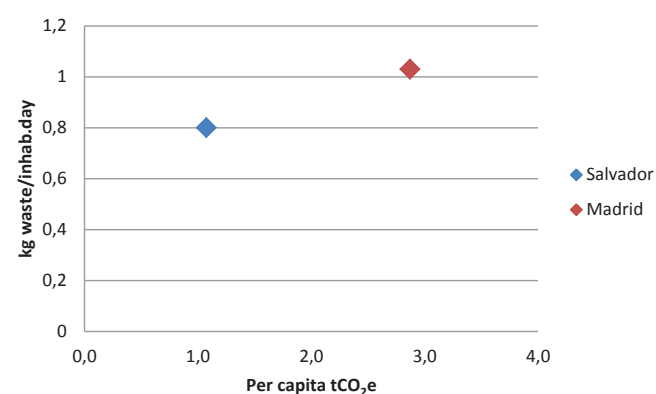
between road transportation emissions and population density as it shows that Madrid, with higher population density, has slightly lower *per capita* emissions than Salvador does in road transportation.

As a typical European city, Madrid has an extensive public transportation system, which encourages less use of private transportation. Besides, Madrid has a more compact city layout as compared to Salvador. Madrid's emissions associated with railways and subway networks represent 0.084 tCO₂e *per capita*.

The *per capita* road motor vehicle ownership rate and the average age of the vehicles could be also determinants of transportation emissions. In 2013, Salvador, with 4.69 inhabitants/automobiles, and Brazil, with 3.87, had lower *per capita* road motor vehicle ownership rates as compared to Madrid (2.19 inhabitants/automobiles) and Spain (1.88) (DENATRAN, 2015; INE, 2014). In addition, the average age of the vehicles in Spain in 2013 was high (9.3 years) compared to Brazil's 8.5 years (Madrid, 2014b; SINDPECAS, 2014). Based on these figures, it should be expected that Madrid present higher road transportation emission rates. Nevertheless, instead of the impact of the European Commission (EC) air quality standards are considered bigger to the air pollutant emissions, these EC standards associated with the higher population density could be the main determinants for Madrid's low road transportation emissions as compared to Salvador.

Regarding the waste sector, in Figure 4, we observed that there was not a significant difference regarding *per capita* waste Emissions, 0.10 tCO₂e in Salvador and 0.13 in Madrid. Figure 8 represents waste generation in relation to total GHG emissions.

Figure 8. *Per capita* total GHG emissions and waste generation rate

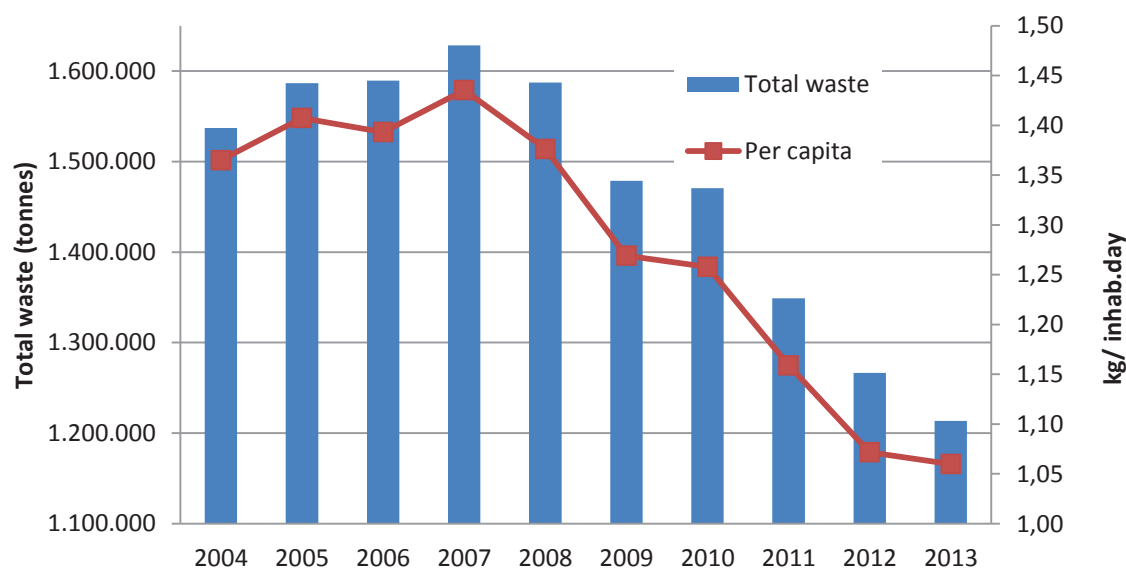


There is a strong correlation between high rates of

emissions and waste generation. Specifically concerning Salvador and Madrid, the relationship between waste and *per capita* emissions is shown in Figure 8. The difference between the waste generation rates is not so high - Madrid (1.03 Kg waste/inhab.day) versus Salvador (0.79 Kg waste/inhab.day) – as compared to the differences between *per capita* emissions. The *per capita* waste sector GHG emission ratio between Madrid and Salvador is similar to the ratio associated with the *per capita* waste generation rates (1.30).

Figure 9 shows the decrease in waste generation rates in Madrid between 2004 and 2013. The daily *per capita* waste generation of Madrid in 2007 was 27% higher than the numbers in 2013. This decline could be due to the impact of the EC Waste Framework Directive 2008 associated with the big economic crisis that hit Spain during this period.

Figure 9. **Evolution of total waste generation and waste generation rates in Madrid (2004-2013)**



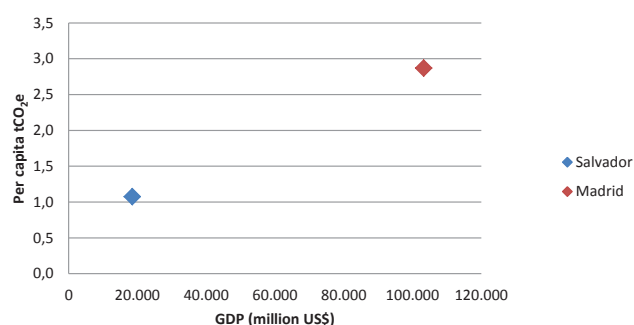
Source: Madrid (2014c)

Madrid suffered the consequences of the Spanish crisis (-1.7% GDP in 2013 at a national level). Whereas, Sal-

vador experimented one year of economic growth in Brazil (+2.5% GDP in 2013) (INE, 2014; IBGE, 2014). Therefore, the not-so-big differences between the waste generation rates of these two cities could be one of the effects of the economic crisis in Spain.

Figure 10 shows a relationship between GDP and *per capita* total GHG emissions for both cities.

Figure 10. ***Per capita* total GHG emissions and GDP**



The relationship between GDP and *per capita* total

emissions in this study ends up being almost linear, as Figure 10 shows. It highlights that it is not only the weight that industrial activity has in a city (both Madrid and Salvador are not considered industrial cities), but the level of citizens revenues and the overall economic transactions in service sectors that result in higher levels of emissions.

CONCLUSIONS

This article has compared GHG emissions from Madrid and Salvador in 2013, using the BASIC reporting level of the GPC. The manuscript is intended to identify some limitations regarding the GHG emission inventories of both cities, especially the one by Salvador, with minor experience as compared to Madrid. The comparison of several GHG emission inventory factors between these two cities has shown that the results are consistent with the outcomes presented by other studies.

Comparing Madrid's and Salvador's inventories, some differences and similarities have been encountered. Regarding the contrasts, there is a big difference in stationary energy GHG emissions. The main determinants that could contribute to explain the GHG emission difference in this sector are: i) the big difference in electricity emission factors; ii) the distinct *per capita* demand for heating and cooling systems and distinct types of fuels utilized. Another big difference concerns aviation emissions: Madrid's busier airport adds up a significant amount of emissions to this city as compared to Salvador.

Despite some differences among the *per capita* road motor vehicle ownership rates, the average ages of the vehicles, and the population density of the cities, Madrid and Salvador share some common figures regarding *per capita* road transportation emission rates: 0.7 tCO₂e for Madrid and 0.67 for Salvador. Further analysis is recommended in order to discuss the influences of the types and prices of fuel used; and the types, sizes and capacities of the engines on the transportation emission rates of these cities.

Even though existing differences among solid waste disposal, incineration, biological treatment and wastewater treatment GHG emissions figures of Madrid and Salvador, the *per capita* waste sector GHG emissions are quite similar for both cities (0.10 tCO₂e *per capita* for Salvador and 0.13 for Madrid). The *per capita* waste sector GHG emission ratio between Madrid and Salvador and the ratio associated with the *per capita* waste generation rates are similar (1.30). Thus, further analysis is recommended in order to discuss and compare the roles that the different waste treatment systems utilized by both cities play in the total of waste sector GHG emissions.

Some limitations have been found during this study. First, the absence of Madrid's scope 3 GHG emissions at a BASIC reporting level of the GPC due to the fact that the city does not treat waste outside the inventory boundary. As Madrid does not account for scope 3 GHG emissions in the waste sector (the only required scope 3 emissions at the BASIC reporting level of the GPC), it was not possible to compare with Salvador's results. At a BASIC+ reporting level, Madrid's GPC report 2013 has only included scope 3 GHG emissions from the transmission and distribution losses associated with grid-supplied energy. Thus, it is necessary to improve the quality of Madrid's inventory in order to it accounts for some oth-

er indirect emissions like ones associated with fuel transportation operations.

The second and biggest limitation of this study is the fact that the results of Salvador come from a first attempt to develop a GHG emission inventory. These results cannot be compared to previous years and, even though basic relationships comparing the two cities have been met, it is not possible to defend the accuracy of the results.

It is important to point out that the GPC framework provides a base for the calculation of GHG emissions, but it is up to the designated organism to choose any calculation method that best fits the information data available and the desired results. It is one of the main limitations for comparing the results of GHG emissions from Madrid and Salvador. In order to do that, this paper has only utilized secondary data and it has not discussed the differences between the calculus methodologies and the quality of the information data.

In order to increase the quality of Salvador's GHG emission inventory, we recommend some improvements on the following points: first, regarding air transportation emissions. The GPC's BASIC reporting level only accounts for scope 1, emissions from kerosene consumed in Land and Take off (LTO), and scope 2 GHG emissions regarding air transportation. The original GPC report provided by Salvador has included all emissions associated with kerosene consumption at the airport, not only GHG emissions derived from LTO cycles. Normally, according to PAS 2070, only approximately 10% of total air transportation emissions could be associated with LTO operations (scope 1).

Secondly, further collection of data regarding waste incineration is recommended. Waste incineration in Salvador is done by several private companies and the data used for the GPC reporting GHG inventory comes from only one of the companies. It is expected that the emissions associated with waste incineration in Salvador is high as compared to the figures of GPC reporting.

Another aspect to be improved in Salvador's GHG emission inventory regards the biological treatment of waste: there was no available data. Despite the fact that the total amount of Madrid's and Salvador's emissions in this category is not significant, it deserves further analysis from Salvador.

Lastly, the results presented by GPC report of Sal-

vador GHG emissions require better identification of data sources and emission factors used, as well as description of the methodology used in calculations and rating the level of data quality. On this issue, the quality of Madrid's GPC report is high when compared to Salvador.

Regarding future projects, this study can be further improved by comparing the two cities at a BASIC+ reporting level, which would give a deeper insight on the substantial differences and similarities between the cities. For this comparison, Salvador would need to develop a new reporting level GHG emissions inventory.

Additionally, a more ambitious study would be to compare inventories that include PAS 2070's CB and DPSC methodologies. Using this kind of approach, all cradle-to-gate life-cycle GHG emissions from goods and services that are produced outside the cities' boundaries for consumption and/or use within the cities' boundaries would be accounted for and reported in their inventories.

5.1 Implications for policy-making and future research: the necessity of an integrated perspective on production-consumption systems

As we have seen, there is some evidence that although Madrid and Salvador have made considerable progress on accounting their GHG emissions from a production perspective, the trend seems to be less positive from a consumption perspective. This suggests that there is a need to look beyond an isolated perspective (production or consumption) and address, in an integrated way, the production-consumption systems to improve their GHG inventories instead.

Such an integrated perspective implies focusing not just on accounting carbon emissions from a territorial approach, but also on accounting emissions from all goods and service consumption in the city (both those produced in a city and the imported ones). Viewing consumption and production as aspects of complex systems exposes some of the challenges in shifting to low-carbon cities. An integrated production-consumption system poses major challenges for city-level policy-making, as well as opportunities to improve the methods for accounting carbon emissions from urban supply chain and final consumers.

The final consumers and regulators alike have little information about carbon emissions associated with highly complex and diverse USC, and they have limited ability to influence them using traditional, city-

bound policy instruments. This reality points to the need for new governance approaches that transcend city boundaries and minimize the difficulty that city-level policy-makers face in dealing with trade-offs and in accounting and monitoring carbon emissions associated with highly sophisticated supply chains and their relatively little scope to influence these impacts in other world regions (EEA, 2015).

In addition, there is insufficient development of urban supply chain carbon accounting methods. They are still at an early stage of development, and this fact underscores the urgent need for interdisciplinary collaboration among scholars and practitioners to develop CLCA methods, which contribute to: i) integrate the production and consumption perspectives in a sustainable production-consumption system for more carbon neutral or low-carbon cities; ii) propose tools (methods), so that city decision-makers will be able to build up carbon-zero city policies.

The production carbon accounting approach is developing quite well, but the consumption aspects of carbon accounting are still barely developed. The GPC and the PAS 2070 standards provide numerous useful guidelines to account the emissions from urban supply chain and final consumers, but they must be further developed to be more helpful to policy-makers' practice.

Firstly, from the perspective of information availability, reliability and methodology, the main challenge lies in CB methodologies for city-level GHG emissions. The recognition of the increasing importance of indirect climate impacts through USC, goods and services use by final consumers is leading researcher to develop new tools to capture the total carbon emissions at a cityscale. Particularly for input-output analysis, new CLCA methods are needed, because, in practical terms, current national-scale input-output models are developing quite well, but little is known about city-level input-output models.

Secondly, conceptually, an integrated production-consumption carbon accounting method should have the ambitious goal of linking producers and consumers within one framework. It captures emissions from both production and consumption activities taking place within the city boundary, but including all emissions released outside the city boundary. It attempts to consider all direct and indirect carbon emissions of the city as well as its suppliers downstream and the chain upstream. It should be designed to measure carbon emissions for the urban supply

chains by quantifying the impacts of all the suppliers. For the vast majority of goods and services, however, the collection of primary data over the whole supply chain has not been done at city level. Some goods and services consumed in cities often have very complex networks of large numbers of suppliers, which makes data collection difficult to manage and expensive to accomplish.

Additionally, significant amounts of data need to be collected to conduct a city-level GHG inventory. This data will vary in quality, format and completeness and, normally, they will need to be adjusted. Particular challenges are associated with the attribution of transboundary emissions and reducing the spatial area of analysis to the city where national or regional data are used. Normally, some of the data that are necessary to account urban carbon emissions are not available at city level, only at national level.

Finally, for that reason, it is crucial to stimulate the development of hybrid carbon accounting, and that CLCA researchers increase their efforts to surmount these challenges in order to contribute for further institutionalization and dissemination of an integrated perspective on production-consumption systems.

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