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The Relative Carbon Footprint of Cities

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Abstract:

The contribution of cities to climate change is significant, but cities are not all the same. City rankings and comparisons should take into account that differences in the Carbon Footprint of cities can be related to different stages of economic development, geographical conditions, social or political factors, or specific public policies – that all shape and are shaped by national contexts. The Relative Carbon Footprint is a measure that takes these factors into account and can be a useful a tool for both national and local urban policy makers for the identification of strategic emissions sectors. For policy makers at the national level, the Relative Carbon Footprint offers concrete insights on the conditions under which particular cities are a driver of national GHG emissions or are a solution for reducing them, by highlighting the particularities of a specific urban system vis-à-vis its national counterpart. At the city level, the RCF enables vertically integrated policy making for a city by considering it within its national context, and provides indications on how to draw environmental priorities based on feasibility and expected returns. In particular, the findings of our research focused on São Paulo and Cape Town draw attention to three dimensions of influence on the Relative Carbon Footprint: the ways that energy is produced and supplied at the city and country level (the *energy matrix*), the average levels of income, and the structure of the economy of the city and the country.

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1. Introduction[1]

There are wide debates about whether cities are a form of human settlement that amplify or reduce the anthropogenic impact on the environment, and whether they are to blame for climate change or not. Some cities may be, while others not – and understanding this distinction is of key strategic importance for transformation towards sustainable and low carbon futures. To distinguish between cities that are drivers of climate change in their countries and other cities who help reduce their country’s per capita emissions, we must relate the measures of a city’s environmental impact to the corresponding averages of the country in which it is located. With this goal in mind, the present study introduces a new measure to be of use for urban climate policy making: the Relative Carbon Footprint (RCF), given by the ratio of a city’s carbon footprint over its country’s national average.

Comparing cities worldwide based on their absolute carbon footprint does not take into account the geographical context, the stage of economic development, the political context and other preconditions that are shaped by a city’s national as well as local context. Regardless of its absolute level of carbon emissions, however, a low Relative Carbon Footprint tells us that a city deserves attention from scholars and urban stakeholders as it represents a virtuous model of a city with low carbon emissions when the national average is higher. Further, in order to make policy relevant observations, we need exact tools for measuring the environmental impact and carbon footprint from specific sectors, such as transportation or residential heating. We give examples here of the potential of analysing the RCFs for specific sectors, given the limited data currently available to us, and encourage the continued development of detailed GHG inventories. At the country level, such a tool helps drafting policy recommendations by addressing the specificity of a city's contribution to carbon emissions given its position within the national context.

Exploring the RCF further helps us to identify which economic, social or physical dimensions of the city to look at in order to understand why a city performs better or worse than the country it is located in. To develop our argument and test the potential of the RCF for pointing out areas that present certain obstacles or potentials for climate change reduction, we will make use of two explorative and contrasted case studies: São Paulo, Brazil, and Cape Town, South Africa. This will allow us to identify and discuss the importance of specific policies, national contexts and relevant governance dynamics that play a role in determining the relative performance of cities, to raise questions and suggest hypotheses to be explored further in future studies.

[1] This is a further developed version of a paper presented by Nicola da Schio in Rio de Janeiro on the occasion of the 2012 UN Conference on Sustainable Development, at the side event organized by the International Society for Ecological Economics: *“ISEE 2012 - Ecological Economics and Rio+20: Challenges and Contributions for a Green Economy”*.

2. Material and methods

2.1. The carbon footprint: existing knowledge and debates

Cities are complex social and ecological systems that interact with the rest of the world. Cities are nodes where flows of people, energy, goods, as well as immaterial flows of ideas, money and modes of life converge. All these activities have direct and indirect impacts on the environment, including in and outflows of solid, liquid and gaseous matters. Different measures have been created to account for these flows[2]. One of them is the *carbon footprint*, which measures the quantity of greenhouse gases (GHG) emitted into the atmosphere[3]. The carbon footprint is surely neither the only nor the single most important dimension of a city's impact on the environment. However, we have adopted it as the unit of analysis for this study, as it represents one of the most significant "out-flows" from a city with worldwide consequences. Furthermore, the level of GHG emissions, for which data are increasingly available for cities as well as countries, can be taken as a "common currency" to which most anthropogenic contributions to climate change are converted, allowing for quantitative analysis and correlation to other variables.

One way of presenting a city's carbon footprint is the compilation of GHG inventories. Hoornweg et al.[4] have recently put together what is today one of the broadest lists of comparable GHG inventories of the world's cities, and their respective countries. This list represents the starting point of the present research. To this date, no consensus has been reached on any one method for allocating GHG emissions to cities, due mainly to the issue of determining of the boundaries of analysis, as GHG emissions can either be attributed to the spatial location of the actual release (production-based GHG inventories), or to the location of the activity that led to the GHG release (consumption-based GHG inventories)[5]. An alternative methodology, albeit not very common, is to base the attribution of the emissions on the place of residence of the individuals responsible for them[6]. The present study is limited by a "production perspective"[7] being based on GHG inventories that include the emissions taking place within the city boundary and those deriving from the production of waste and of energy consumed within the city, even if they are released elsewhere, as per ICLEI's International Local Government GHG Emissions Analysis Protocol[8].

[2] See for instance Decker et al., 2000; and Wackernagel et al., 2006:104.

[3] According to the survey of the literature developed by Wiedmann and Minx on the different uses of the expression it is broadly accepted that "carbon footprint stands for a certain amount of gaseous emissions that are relevant to climate change and associated with human production or consumption activities" (Wiedmann, and Minx, 2008:2).

[4] Hoornweg et al., 2011.

[5] Vandeweghe and Kennedy, 2007.

[6] See for instance Brown et al., 2008.

[7] While it includes the emissions deriving from the production of goods and services that take place in a city (the only exception being energy and waste), it does not take into account the emissions from goods and services which are consumed inside the city but come from outside (from a "distant elsewhere" according to Rees words, 1992:121). The use of the production perspective in this study is entirely due to data availability, and a comparison between the different approaches goes beyond the purposes of this study. For an overview on the debate see, among others, Dodman, 2009a; Kates et al., 1998; Ramaswami et al., 2008; Satterthwaite, 2008a.

[8] See Kennedy et al., 2010.

Looking over the literature on this theme, one of the main debates is about whether urban areas generate higher or lower per capita emissions than suburban or rural areas. Cities are often blamed for being major contributors to global warming through the high level of GHG emissions for which they are responsible[9]. The higher level of income and the concentration of economic and social activities that characterises cities lead directly to higher levels of energy consumption and waste generation[10]. However, there are also questions of population density to take into account, and in other circumstances cities are considered to be the solution for reducing the anthropogenic impact on the environment, as “incubators of green innovation”[11], or the “greatest invention to make us greener”[12].

A different debate concerns the comparison between cities. The fact that one city has lower or higher GHG emissions than others, mostly depends on the amount of energy consumed by the local urban activities, including the energy used to produce electricity and the energy that is directly employed to power machines and cars, and to heat buildings. The literature tends to explain the different performances by looking at the physical characteristics of the city (e.g. density, building design, average temperature), or by looking at to their socio-economic profile (e.g. income level, cultural dimension, public policy and legislation)[13].

2.2. The “Relative Carbon Footprint”

As mentioned above, previous research has illustrated the peculiarity of the urban form and its potential of magnifying or reducing the human impact on the environment. Other research has explored the variety existing among different cities and their carbon footprint. The present study suggests a different entry point, which goes further and combines these two perspectives. Starting from the urban GHG inventories, the unit of analysis is a city’s *Relative Carbon Footprint* (RCF) defined as the ratio between a city’s level of GHG emissions per capita and the respective national average of its host country:

Relative Carbon Footprint (RCF) =
City per capita GHG emissions (tCO2e[14]) / Country per capita GHG emissions (tCO2e)

Studying the RCF implies a preliminary analysis of a city’s of GHG emissions vis-à-vis the national average, and then a comparison between cities in these terms. This perspective allows ranking different cities of the world, while taking into consideration their national context and the potential of their specific urban profile. This goes beyond the mere analysis of the peculiarities of the urban reality, and “localises” the analysis on specific cases. On the other hand, it also allows measuring the potential of transforming one specific urban reality, given its economic and geographical preconditions and the national political context in which it is embedded.

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[9] Clinton Climate Initiative, n.d.

[10] On this topic see, among others, Dodman, 2009b:6; Glaeser, 2011; Mehaffy, 2012; UNEP, 2011; Kamal-Chaoui and Robert, 2009; and Bai, 2002.

[11] UNEP, 2011a: 464.

[12] Glaeser, 2011.

[13] Newman and Kenworthy 1989; Dodman, 2009b; Rickwood et al., 2008; Glaeser and Kahn, 2010; UN-Habitat, 2011; OECD, 2010; Satterthwaite, 2008a; Walker, 2007; Glaeser and Kahn, 2008.

[14] “concentration of CO2 that would cause the same amount of radiative forcing as a given mixture of CO2 and other GHG” – IPCC, 2001.

The RCF is a particularly relevant tool in a historical moment that sees the share of the global urban population rapidly increasing, together with an expanding level of consumption. Understanding the conditions to lowering or augmenting the national average becomes crucial in order to shape how these future cities will be. The study of cities' RCF, and the comparison between cities according to this value, can be useful to enable vertically integrated policy making for a city's environmental issues, which is considered in its local and national dimension. At the national level, the RCF offers concrete insights on the conditions under which particular cities are a driver of the national GHG emissions or are a solution for reducing them. At the local level, the RCF provides indications towards the issues that need to be prioritised for achieving environmental goals, based on the feasibility of certain policies and the expected returns given the national context. Local stakeholders, in fact, will find it useful to learn from other cities and from their achievements vis-à-vis their national context, regardless of their absolute carbon footprint, which might depend on the stage of economic development or the geographic location.

2.3. An overview of cities' RCF worldwide

To give an overview of the RCF worldwide, the graph below (Figure 1) is an elaboration of the data from Hoornweg et al. (2011:5-6)[15]. The horizontal axis reports the level of GHG emissions measured at the city level, and the vertical axis reports the level of GHG emissions for the country in which the city is located. The graph thus gives an immediate picture of the cities' carbon footprints in relation to the national one, as cities to the left of the bisector (red line) have a smaller carbon footprint than their countries, and vice-versa. We will be analysing São Paulo and Cape Town precisely to understand why the two are located on one and the other side of the bisector.

2.4. Methodology

To begin answering the question of why certain cities let out *higher* levels of GHG emissions than the national average in their country (i.e. RCF>1), while in others emission-levels are *lower* (i.e. RCF<1), we will use two in-depth case studies, of the municipalities of São Paulo and Cape Town, to identify certain determinants and explanations of their RCFs. Now, in order to learn policy-relevant lessons from the RCF, one must be able to disaggregate it and look at the RFC of individual sectors for policy action. These sectors are partly determined by which data is provided in the GHG inventories that are available at present[16]. Further, for these individual categories in the GHG inventories to be comparable between the national and the city-level in our study, the data from the GHG inventories of the two cities and the two countries were disaggregated and in some cases recombined[17]. Then, the Relative Carbon Footprint of each sector was calculated by taking the ratio of the city's GHG emission value to the national value. The resulting tables (in Appendices A and B) clearly identify the sectorial inventory categories that showed significant differences between the national and local carbon footprint, and provides a preliminary vision that indicates the importance of each category to the total RCF of each city.

[15] Hoornweg et al. (2011:5-6), data for São Paulo and Cape Town have been reviewed after analysing their respective inventory. Cape Town: Kennedy et al. (2009a; 2009b; 2010) ; São Paulo: SVMA, 2005

[16] The data for calculating the RCFs were taken from Hoornweg et al. (2011:5-6), a study that presents the emissions level of a number of cities and countries for which data is available and comparable.

[17] The fact that the various inventories are not directly comparable highlights the need for developing common standard measurements of climate change/environmental indicators. With the continued development of better data, GHG inventories that are detailed and *comparable*, the RCF can help identify important variables that explain the environmental impact of a city as well as what variables are more important in determining the RCF of cities. This might prove useful for quantitative analyses and comparisons of cities on a larger scale.

Qualifying these indications – in order to later explain them – required a first analysis of the physical and socio-economic profile of the cities as opposed to the average of their host countries. To be clear, *we are not comparing cities and countries*, rather examining the local per capita CF to explain why it is different from the national, making use of our two case studies. This is not a comparative study between São Paulo and Cape Town. The approach, rather, has been to use the two explorative case studies as a means to present the potential of the RCF in pointing out areas that present certain obstacles or potentials for climate change reduction, to raise questions and suggest hypotheses to be explored further in future studies.

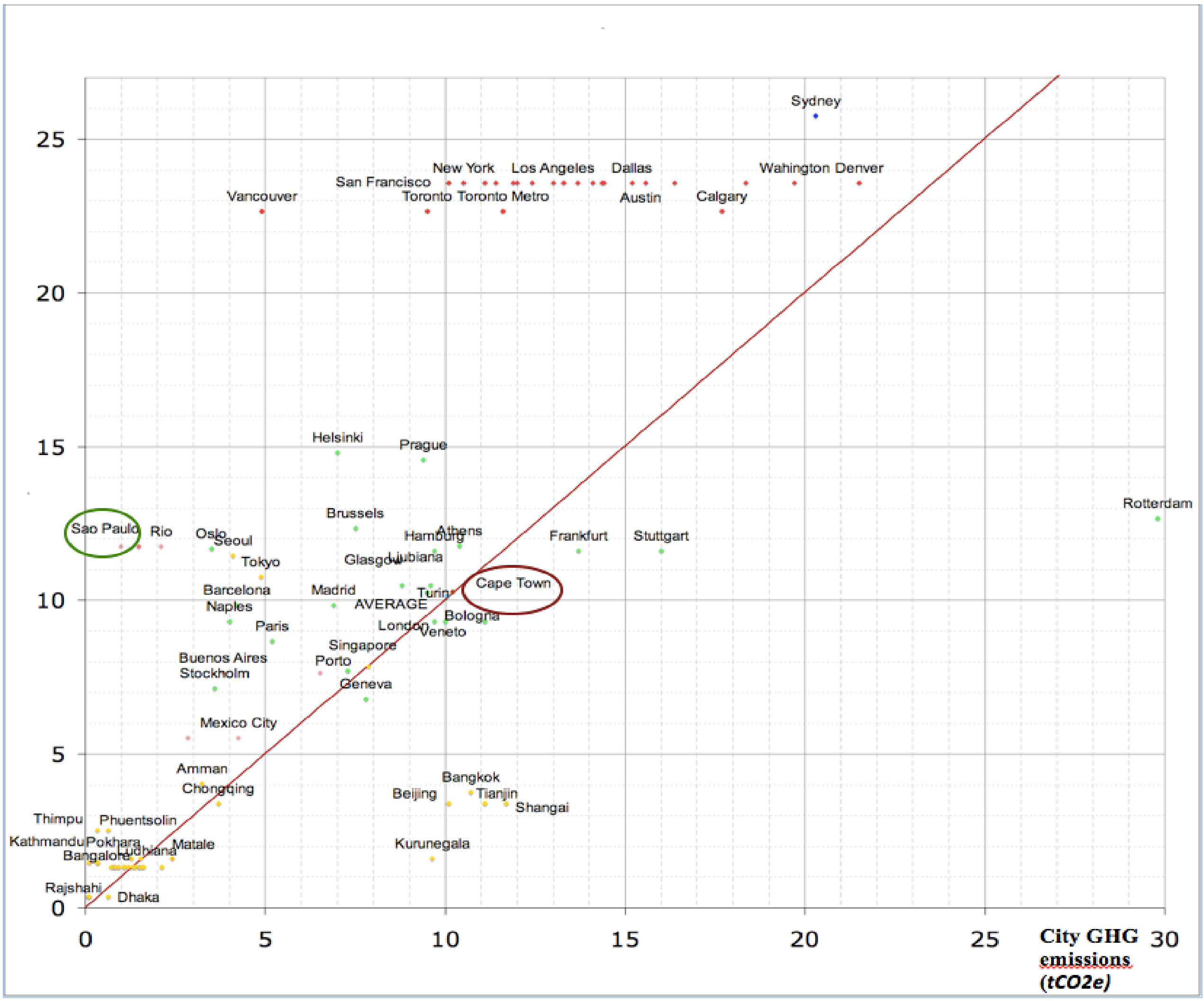

Figure 1 - Overview of Cities’ and Countries’ Carbon Footprint. Created by authors, using data from Hoornweg et al., 2011.

The analysis of country and city profiles also serves as a preliminary step to look more closely at the cities in these relative terms. When looking at the inventories of São Paulo and Cape Town, we sought to identify a pattern for where the RCFs of the two cities differ or show similarities, and found that the discrepancies and commonalities in their sectorial RCFs could be grouped in three dimensions, which will be presented below. In order explain the different values of the two cities’ RCFs, a deeper analysis of these dimensions was undertaken looking into the direct or indirect mechanisms by which they affect the RCF. A subsequent analysis of national and city-level policies related to each dimension, and the main actors and governance dynamics involved, was used in order to explain the current state of the sectorial RCFs and why São Paulo’s CF is below the Brazilian average, and Cape Town’s above the South African. This also allows the identification of dormant potentials or obstacles for policy-makers to improve the RCF of São Paulo and Cape Town respectively.

3. Applying the RCF to two cities

In order to get closer to the drivers of the RCFs we will now look more closely at the RCF of São Paulo whose per capita GHG emissions are lower than the national level (RCF=0.125), and of Cape Town, whose per capita emissions are higher than the national level (RCF = 1.030). The motivations of the choice of these two cities are diverse and concern the availability and the comparability of data on GHG emissions at the national and city level, as well as the decision to look at two cities that hold similar demographic and economic positions in their countries (at least in comparison to the other cities of the list), while they present different RCFs[18].

3.1. São Paulo’s Relative Carbon Footprint

The per capita level of emissions of São Paulo equals 1.47 tons of CO2e per year, as opposed to the national level of Brazil, which is 11.76 tCO2e/pc, for a RCF value of 0.125. Breaking down the overall GHG inventory (Appendix A), the difference between the city and country per capita GHG emissions is largely explained by looking at the value of emissions deriving from agriculture, forestry and land use. GHG emissions from these categories account for almost 80% of the Brazilian total GHG emissions, while they are negligible in São Paulo. The reason is to be found in the profile and range of economic activities of the city and of the country: forest activities and agriculture (including livestock) are important components of the national geography and economy, but they are almost absent in the city of São Paulo, as in many other urban municipalities. These two categories represent an important but not sufficient explanation of why São Paulo has a per capita level of GHG emissions that is lower than Brazil. Even if these two categories were not included, the per capita carbon footprint of São Paulo would still be smaller than the Brazilian (i.e. RCF<1).

Now, analysing the ‘energy’ category (tCO2e/capita 1.14 for São Paulo vs. 1.92 for Brazil) we see that there are areas in which São Paulo’s footprint is smaller, and others where it is bigger than Brazil’s. The generation of electricity, for instance, is a sector for which São Paulo’s per capita footprint is half as large as the Brazilian one (0.13 tCO2e vs. 0.27 tCO2e). This happens despite the higher electricity consumption at the city level, due to the lower carbon intensity of the electricity production matrix of the São Paulo region (33.46 tCO2e/GWH against the 74.73 tCO2e/GWH for Brazil)[19]. Similarly, in the production of energy for the industrial sector, the city’s emissions are lower than the country’s (0.07 vs. 0.63 tCO2e). While in economic terms the relative importance of the industrial sector is similar, this difference is due to the fact that industries in the city are less energy intensive than

[18] Criteria include: national HD (UNDP, 2011), share of national population resident in the city, share of national income produced in the city, city per capita income, national per capita income (data at the city level are from citymayor.com; data at the national level are from htttp://www.databank.worldbank.org)

[19] SVMA, 2005, for São Paulo; and MME, 2003, for Brazil.

at the national level[20]. Finally the energy for agricultural activities accounts for 0.0003 tC02e in São Paulo vs. 0.08 tCO2e at the national level, once again, due to the fact that in São Paulo the agricultural sector is almost absent[21].

There are, however, also sectors that produce a higher per capita carbon footprint in São Paolo relative to the national average, although they are not significant enough to outweigh the elements explained above. The building sector, for instance, accounts for 0.12 tCO2e/capita in São Paulo and for 0.10 in Brazil. In this case, the difference might be attributed to different income levels (higher in São Paulo) leading to higher energy consumption, or to a different average number of dwellers per residential unit (3.43 person/unit in São Paulo vs. 3.75 in Brazil in 2000)[22]. Also, the per capita emissions deriving from the transport-related energy consumption are higher in the city than in the country (0.79 and 0.73 tC02e respectively). This is probably due to the much higher rate of car ownership in the city (520 per 1000 inhabitants) than in the country (131 per 1000 inhabitants)[23]. Finally, emissions related to the waste disposal sector are 1.4 times higher in São Paulo than the national value (0.35 vs. 0.25 tCO2e/capita), probably because of the larger generation of waste (1.4 vs. 0.9 kg per day/capita)[24]. At the country level, moreover, it is estimated that 32.83% of the waste was recovered in 2000, as opposed to the city, where virtually all waste was sent to landfills[25].

The graph below (Figure 2) shows the composition of São Paulo’s RCF, marked by the green line. The grey area represents the values RCF<=1, which means that for emissions sectors where the green line is within this area the city’s carbon footprint equals or is lower than the national. The sectors where the line surpasses the grey area are those where São Paulo’s per capita carbon footprint is greater than Brazil’s average (the RCF>1). This, we may note, is only the case in a few sectors.

[20] SVMA, 2005, for São Paulo; and MME, 2003, for Brazil.

[21] As the ‘fugitive emissions’ were not calculated at the city level, an estimation has been made based on the national value. For this reason, the total value result to be different than the city GHG inventory. In this section, the comparison is carried on only for what concerns the ‘fuel combustion’ sub-category.

[22] IBGE, 2010.

[23] SVMA, 2005, for São Paulo; and databank.worldbank.org, 2012, for Brazil.

[24] UNEP and PMSP 2004, for São Paulo; and stats.oecd.org, 2012, for Brazil.

[25] Data from UNEP 2003, for São Paulo; and stats.oecd.org, 2012, for Brazil.

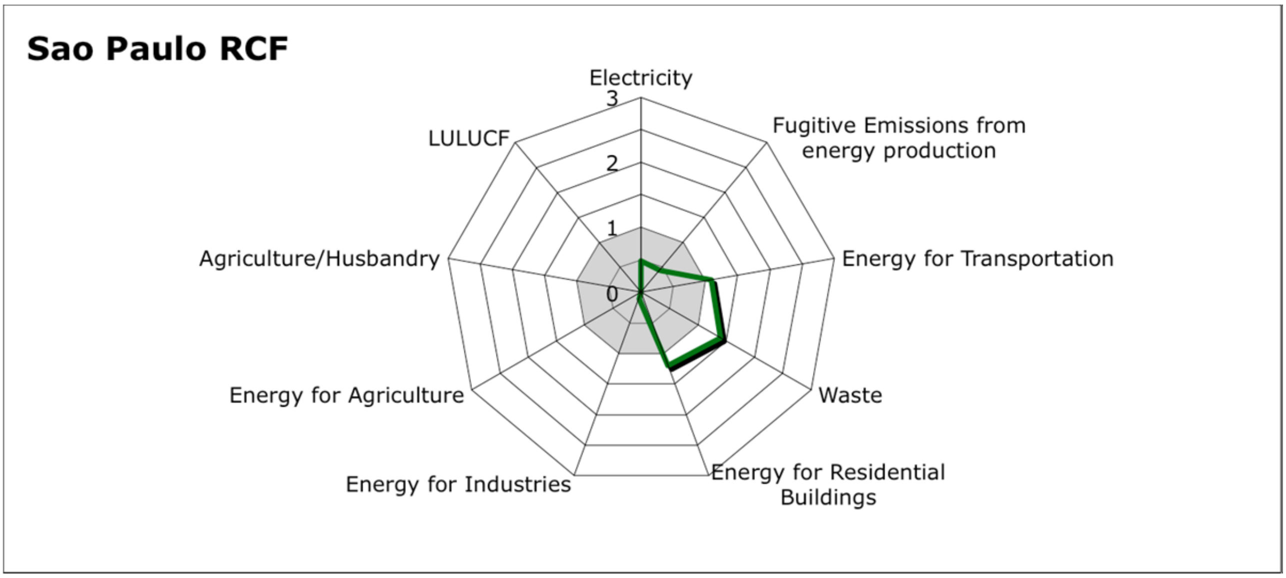

Figure 2: São Paulo Relative Carbon Footprint

3.2. Cape Town’s Relative Carbon Footprint[26]

Cape Town’s GHG emissions amount to 10.21 tons of CO2e per capita, which is equal to 103% of the national level (9.91 tCO2e/capita)[27]. A careful analysis of the data, however, reveals that the two inventories include slightly different categories, and interpreting this mismatch in different ways might lead to different results. For this reason it is necessary to distinguish which sectors are directly comparable, and which are not. For instance, certain sectors were not included in the inventory of Cape Town[28]. This does not change the overall result (RFC>1), since, if these values were accounted for in the city’s inventory, the difference between the total city and country level emissions would have been even greater. At the same time, the ‘marine and aviation’ category was calculated with different methodologies for the city’s and the country’s inventories[29]. Considering the role of the city as a national and international transportation hub, moreover, it is likely that the per capita level of GHG emissions related to this sector would in any case be higher than the national level. It has to be noted, that even if none of the non-comparable sectors were included in either one of the inventories, the per capita footprint of Cape Town would still be higher than the national one, i.e. 6.4 and 6.02 tCO2e/capita respectively[30].

[26] The details of Cape Town and South Africa’s GHG emissions are in Appendix B. Except when specified otherwise, the data on South Africa come from the national GHG inventory, DEAT, 2009. Data on Cape Town the city’s GHG inventory presented in three papers by Kennedy et al. (2009a; 2009b; 2010).

[27] Comparing Cape Town’s to South Africa’s carbon footprint is a difficult task, as the GHG inventories report slightly different variables. It has been therefore necessary to calculate again the respective values and draw a new set of variables, by aggregating or disaggregating the data available.

[28] These include: industrial processes and product use, agriculture, forestry and land use, petroleum extraction, wastewater handling, fugitive emissions from fuels.

[29] The IPCC 2006 guidelines, applied to compile the South African national inventory, recommend including, as a memo, item GHG emissions from international aviation, including take-offs and landing and international water-borne navigation. At the same time, the Cape Town inventory has been calculated on the basis of the total fuel loaded locally into planes and ships “in order to include impacts from the movement of people and goods to and from the ten cities” (Kennedy et al. 2010:4833).

[30] Nonetheless, Cape Town is an environmental reference for South African cities having adopted the first local climate action plan of the country. See, amongst others, Cartwright et al. (2012).

As it is the case for São Paulo, carefully analysing the sectorial RCFs can help identify why Cape Town’s per capita emissions are higher than South Africa’s. The category including buildings heating and energy for industries, for instance, accounts for 1.15 tCO2e/capita in Cape Town and 1.07 in the whole South Africa. This is due to a 1.7 times higher level of energy consumption in Cape Town than in South Africa, possibly due to a difference in average incomes. The higher income of Cape Town lifts up the GHG emissions in the transportation sector too, as it is related to a higher car ownership rate, twice as high as the national rate[31], and corresponding gasoline consumption 1.8 times as high[32]. This difference is likely to also reflect the fact that Cape Town suffers from a very low degree of connectivity, making private cars by large the preferred means of transportation[33]. Finally, it is difficult to compare the waste-related GHG emissions, as the two inventories have used different methodologies[34]. However, it is likely that the footprint is indeed significantly higher in Cape Town, provided that the city generates more than twice as much waste per capita than the average South African[35].

The production and consumption of electricity represents the only sector where the city’s footprint is lower than the national one (3.38 tC02e/per capita for Cape Town and 3.88 tC02e for South Africa). The difference – Cape Town’s levels only corresponding to 87% of the South African level – is due to lower levels of energy consumption in Cape Town. This might appear surprising, when considering that average incomes are higher in Cape Town than nationally. Nevertheless it may be explained by the fact that countrywide, 60% of the national electricity supply is consumed by the industrial sector[36], which in Cape Town is relatively small (17% of the GDP according to the OECD 2008), as opposed to the national level where the sector accounts for 30% of the GDP. Another possible factor of the low per capita consumption might be the underinvestment in the electricity supply, which has not kept the pace with demand, leading to occasional supply shortages[37].

As for São Paulo, the graph below (Figure 3) shows the composition of Cape Town’s RCF, marked by the red line. Again, the RCF surpasses 1 in the waste and transportation sectors, but we also clearly see the importance of the “marine and aviation” sector, as described above.

[31] City of Cape Town 2009, for Cape Town; and databank.worldbank.org 2012, for South Africa.

[32] Kennedy et al. 2009a, for Cape Town; and databank.worldbank.org, for South Africa.

[33] OECD, 2008.

[34] The national inventory has been calculated using a First Order Decay (FOD) model, as described by the IPCC 2006 guidelines. Conversely, Kennedy et al. used the Total Yield Gas approach (IPCC, 1996).

[35] Kennedy et al., 2010.

[36] ABB Group, 2011.

[37] OECD, 2008.

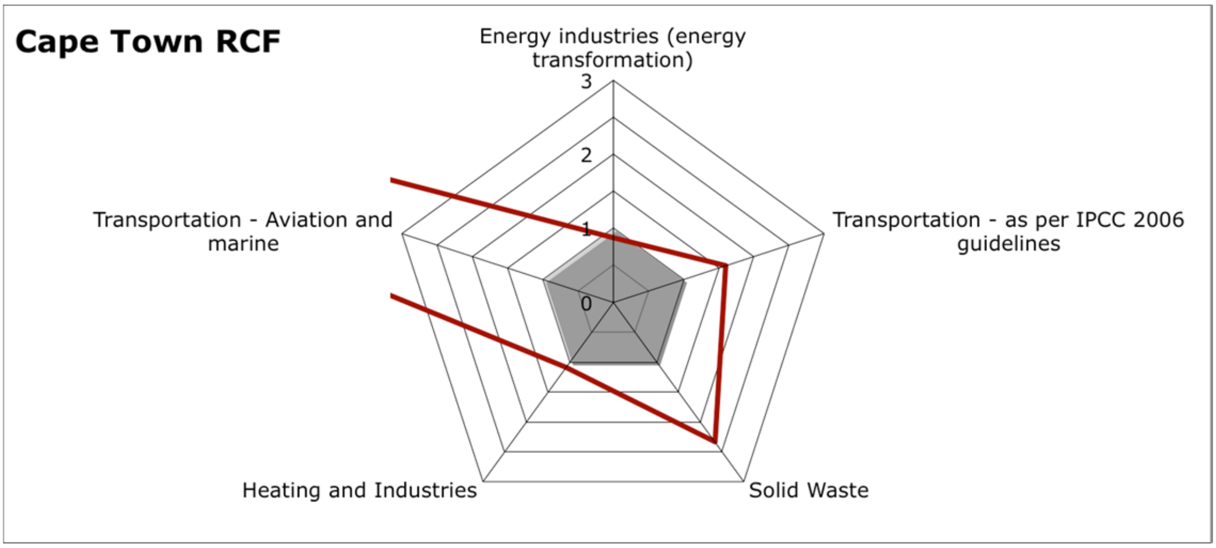

Figure 3: Cape Town Relative Carbon Footprint

3.3. The RCF in three critical dimensions

The first analysis conducted above of the GHG inventory of a city and of the country in which it is located, represents the preliminary step to understanding its RCF. The result of this analysis, in fact, allows the comparison of a city and its RCF to other cities. The table below (Table 1) presents the RCFs of São Paulo and Cape Town broken down by emissions sectors.

The most interesting result of the study of São Paulo and Cape Town's RCFs is the identification of the dimensions of a city that are necessary to explore in order to understand a city's RCF. In both cases, in fact, all differences between city and country can be regrouped into three macro dimensions: the energy matrix, the income level, and the range of economic activities. The analysis of these three dimensions, e.g. the related policies, stakeholders, and governance dynamics, will help understanding why São Paulo and Cape Town have different RCFs.

First, we find that the sectors for which both cities are seen in Table 1 to have a low RCF (<1), are found to be related to energy sources. The RCF is directly influenced by the different ways that energy is produced and supplied at the city and at the country level, i.e. the *energy matrix*. This might include the generation of electricity, but also the production of energy for heating or for powering industrial engines. For instance, in the region of São Paulo, the electricity generation is less carbon intensive than the national average. In Cape Town the situation is different, as the city sources its energy from the national grid. Yet, the carbon-intensity of the energy mix for the 'heating and industry' sector is different at the city and at the country level and contributes to partially lower the city's RCF from this sector.

Secondly, we find that the sectors for which both cities' RCFs are high (>1) can be related to income-levels and consumption patterns; i.e. certain similarities between São Paulo and Cape Town RCF are found in the transportation sector, waste, and sub-sectors of energy (e.g. residential buildings, space heating). Higher emissions from these sectors seem to be related to the level of per capita income, which in both cities is higher than the national average. Although these factors alone do not explain the difference in the RCF between the two cities, it is nonetheless interesting to examine more closely whether their policy and governance structures create different challenges for lowering income-related RCFs.

Table 1: Proposed clustering of the sectorial RCFs of São Paulo and Cape Town

Dimension	São Paulo’s RFC by sector		Cape Town’s RCF by sector*	
Energy Matrix	Electricity	0.481	Electricity	0.871
	Fugitive Emissions	0.444	Heating and industries	1.085
	Energy for Industries	0.111		
Income Level	Transportation	1.082	Transportation (excl. aviation..)	1.6
	Waste	1.4	Solid Waste	2.333
	Residential buildings	1.2	Heating and Industries	1.085
Economic Activities	Energy for Industries	0.111	Transport Aviation & Marine	14.111
			Heating and industries	1.085
	Agriculture /husbandry	0.002		
	Energy use in agriculture	0.004		
	LULUCF	0.001		

**Certain sectors are repeated, as they might relate to several different dimensions, e.g. Cape Town’s Heating and Industries sector. Source: elaborated by authors.*

All other differences in GHG inventories relate to differences in economic activities at the city and at the country level, i.e. the *structure of the local economies* vis-à-vis their national counterparts. For the case of São Paulo, this is evident when looking at sectors such as “agriculture/husbandry” or LULUCF, which largely explain the gap between the local and national carbon footprint. The different emissions from the ‘marine and aviation’ sector produce an opposite result in Cape Town. The range of economic activities, yet, also explains other smaller differences, such as those found in the industrial profile of both cities and countries.

The most interesting result of the study of São Paulo and Cape Town’s RCFs is the identification of the dimensions of a city that are necessary to explore in order to understand a city’s RCF. In both cases, in fact, all differences between city and country can be regrouped into three macro dimensions: the energy matrix, the income level, and the range of economic activities. The analysis of these three dimensions, e.g. the related policies, stakeholders, and governance dynamics, will help understanding why São Paulo and Cape Town have different RCFs.

First, we find that the sectors for which both cities are seen in Table 1 to have a low RCF (<1), are found to be related to energy sources. The RCF is directly influenced by the different ways that energy is produced and supplied at the city and at the country level, i.e. the *energy matrix*. This might include the generation of electricity, but also the production of energy for heating or for powering industrial engines. For instance, in the region of São Paulo, the electricity generation is less carbon intensive than the national average. In Cape Town the situation is different, as the city sources its energy from the national grid. Yet, the carbon-intensity of the energy mix for the ‘heating and industry’ sector is different at the city and at the country level and contributes to partially lower the city’s RCF from this sector.

Secondly, we find that the sectors for which both cities’ RCFs are high (>1) can be related to income-levels and consumption patterns; i.e. certain similarities between São Paulo and Cape Town RCF are found in the transportation sector, waste, and sub-sectors of energy (e.g. residential buildings, space heating). Higher emissions from these sectors seem to be related to the level of per capita income, which in both cities is higher than the national average. Although these factors alone do not explain the difference in the RCF between the two cities, it is nonetheless interesting to examine more closely whether their policy and governance structures create different challenges for lowering income-related RCFs.

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4. Policies and governance in São Paulo and Cape Town

There is not a single answer explaining the different RCF values in the two cities, and the analysis of the difference between each of the components of the national and the local inventories sheds light on where to look in order to understand why this happens. As mentioned above, the most critical dimensions to examine are the carbon intensity of the energy matrix; the level of per capita income and what is directly influenced by it; and the structure of the economy. Comparable indicators and detailed data on these sectors become crucial to explain cities’ Relative Carbon Footprint with precision and to identify virtuous city models. Understanding the policy dynamics underlying these dimensions in a given city allows us to highlight the conditions and the possibilities for shaping a city’s RCF. The following sections present the analysis of the policy and governance dynamics that might contribute in shaping the characteristics of the two cities, for what concerns these three dimensions.

4.1. Energy Matrix

We have explained above how the carbon intensity of a city’s and a country’s energy matrix contributes to determine the RCF of the two cities: in the case of São Paulo, the electricity consumed in the region presents an emission factor that is lower than the national average. Cape Town, on the other hand, sources its electricity from South Africa’s national grid, meaning that its electricity matrix has the same carbon intensity as the national average. Yet, it is still relevant to look at Cape Town’s energy matrix where it differs between the city and the country, i.e. in industrial production and for space heating purposes.

São Paulo’s performance is due to the system through which electricity is produced, transmitted and distributed nationwide – the national grid *Sistema Interligado Nacional* (SIN), which covers almost the totality of the country, and is composed of four regional subsystems that are interconnected in order to allow the exchange of energy between regions and balance temporary abundances or scarcities of energy[38]. The energy matrix of São Paulo's subsystem (South-east/Centre-east), is much cleaner than the Brazilian average (emitting 33.46 tCO2e/GWH against the 74.73 tCO2e/GWH for Brazil[39]), directly affecting the value of São Paulo's RCF. The national government plays the central role in the management of electricity and constitutionally has exclusive competence over sources, generation, transmission, distribution and pricing of energy[40]. In particular, policies are elaborated and overseen by the Ministry of Mines and Energy, supported by the National Council for Energy Policy, while all the regulation and monitoring of the national grid falls is carried out by the National Electricity Agency (ANEEL)[41]. The extensive production of hydroelectricity in the region in and around São Paulo, has its origin in authorizations given by the national government at the end of the 19th century to the Canadian company São Paulo Tramway, Light and Power Company (*Light São Paulo*), which responsible for immense works along the River Tietê – although it may have been encouraged or shaped by the São Paulo State government and other local stakeholders. Sub-national governments have very limited possibilities to shape the city's energy matrix and can only influence the production and the consumption of energy through indirect solutions. The municipality of São Paulo, for instance, implemented a law in 2007 to promote the use of solar water heating in the city[42]. Such installations do not *produce* energy, but simply *use* solar energy to heat water, and thus are not subjected to national legislation and supervision[43].

In Cape Town, and in South Africa as a whole, the production of electricity, heat and energy for industries is highly GHG intensive, due to the large use of coal, highly available and relatively cheap[44]. The city – as mentioned above – sources its electricity from the national grid meaning its energy matrix is approximately identical to South Africa's. The country has one dominant energy provider, Eskom, a state owned entity responsible for supplying 95% of the electricity in the country. While Eskom does not have exclusive generation rights, it “has a practical monopoly on bulk electricity” in the whole country[45], the remainder coming from small inputs from local authorities. In Cape Town, however, the share of electricity produced (or procured) by the local government is likely to increase, with a direct impact on the carbon intensity of the electricity matrix. In fact, the need of making the city more energy independent while lowering its level of GHG emissions has pushed the municipality to promote locally produced renewable energy. To do so, the city has adopted the first local climate action plan of the country (targets include 10% Renewable and Cleaner Energy Supply by 2020, and all growth in electricity demand to be

[38] ANEEL 2009:30.

[39] SVMA, 2005, for São Paulo; and MME, 2003, for Brazil.

[40] Setzer, 2009.

[41] ANEEL, 2009:34.

[42] *Lei nº 14.459*, municipal legislation passed in June 2007 by which all new buildings in the municipality must have solar energy installations for water heating.

[43] ICLEI and IRENA, 2013.

[44] Ward and Walsh 2010:3.

[45] GCIS, 2008:391-392.

met by cleaner/renewable sources) and facilitates the procurement of renewable energy (e.g. see Darling Wind Farm Initiative)[46].

4.2. Income per capita

One of the most evident dimensions driving the GHG emissions of a city or a country is economic growth and the average income-level of its population via the consumption patterns and resource demands enabled by higher incomes. The high RCFs of São Paulo and Cape Town in income-level related sectors such as waste, transportation and residential energy use are not surprising then, since both cities have average incomes more than 3.5 times higher than their respective national averages. However, the GHG effects of higher income-levels in urban areas can be magnified or neutralised by the way cities are designed, planned and governed[47], thus “decoupling” increased incomes and living standards from increased GHG emissions.

The link between income-levels and GHG emissions is clearly seen in the generation and treatment of waste, a sector that in São Paulo accounted for 23.7% of the total carbon footprint of the city[48]. The City of São Paulo, however, took action to reduce the pollutants in the waste treatment stage: the *Bandeirantes* Landfill Gas to Energy Project, started operating in 2004 to collect landfill gas in order to destroy volatile organic compounds and use the methane collected as a clean energy source[49]. According to the projections made at the activation of the project, per capita emissions from the waste sector in São Paulo should today be below the national level (98.6% by 2009)[50], implying a current RCF<1 despite the city’s higher per capita waste generation. In Cape Town, per capita waste generation[51] is more than twice as high as the national rate causing per capita emissions approximately 2.3 times higher than the national average. The absence thus far of methane capture during treatment in Cape Town’s landfills has likely increased the level of GHG emissions[52], leading the City to take action to reduce its CF in this sector with the recent project submission for landfill gas collection at two sites[53]. Further studies are required to examine how other public policies might lead to a fall of the RCF, e.g. changing citizens’ consumption behaviour, or promoting recycling[54].

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[46] ICLEI and IRENA, 2013.

[47] Satterthwaite, 2008b; ibid, 2011.

[48] SVMA, 2005.

[49] The project is was developed as a Clean Development Mechanism (CDM), also so that “the income derived from the […] CDM credits provides the city with needed funds that are aimed at further sustainable development projects.” (ICLEI, 2009a: 1)

[50] ICLEI, 2009a.

[51] Estimated according to the quantity of waste sent to landfills.

[52] Kennedy et al., 2009b.

[53] Like São Paulo’s, it is financed through a Clean Development Mechanism (CDM) enabled by the United Nations Framework Convention on Climate Change (UNFCCC), thus minimizing the financial risk for the local government (Energy Department, 2012).

[54] cf. studies by Langenhoven and Dyssel, 2007; and Miraftab, 2004.

São Paulo’s RCF from the transportation sector is barely above 1, at 1.082, whereas Cape Town’s per capita transportation emissions are 160% that of South Africa’s (RCF 1.6)[55]. In both cities, this is mostly due to road transportation and the predominance of journeys in private automobiles rather than public transportation[56]. In both countries local governments are in charge of transportation policies. Therefore, a lessening of the local CF (and of the RCF) from transportation only seems likely if local policy-makers took strong positions and actions. For instance, in its *Comprehensive Integrated Transport Plan: 2013-2018* the City of Cape Town has set the objective of having “50% of homes within 5 min of quality public transport by 2018”[57]. In São Paulo, conversely, planned metro extensions are highly unambitious and hugely delayed. In a policy environment where an automobile culture and elite attitudes are ever dominant, transformation may require federal government incentives that, for example, “stipulate public transportation density in the directive plans of urban development”[58]. In both cities, changing attitudes can also use the potential contribution by the private sector[59], e.g. encouraging diesel-run or electric engines in Cape Town’s wide spread private collective minibus taxis.

The RCFs of our two cities are well above 1 in the emission categories “energy consumption in residential buildings” in São Paulo (1.200), and “heating” in Cape Town (1.085)[60]. Through wide policy action both cities could utilize their economies of scale and become even more energy efficient, which would reduce their RCF. Examples include scaling up projects like São Paulo’s policy for solar water heaters[61], energy efficient lighting in public spaces and buildings, and finally if local governments use their legislative capacity in matters of land use and real estate development as a means to shape the characteristics of the built environment and the consequent energy consumption emissions are likely to fall[62].

4.3. Structure of the economy

The analysis of São Paulo and of Cape Town shows that an important reason why they have different RCFs is to be found in the structure of their economy, i.e. on whether the activities characterising the local economy are more or less GHG intensive than the national average. Such a statement, yet, carries a certain degree of ambiguity. A low RCF might be due to the development of local economic activities, which are genuinely climate

[55] In 2005, as per IPCC 2006 guidelines, excluding marine and aviation.

[56] The difference between the two cities’ transport related RFCs is probably connected to São Paulo having a very high population density (7,216/km^2), and Cape Town a much lower density (1,700/km^2) as well as a more fragmented urban form.

[57] City of Cape Town, 2012: 9.

[58] Gambogi Boson, 2011:134.

[59] Gambogi Boson, 2011:134; and Winkler et al., 2006.

[60] The category used for comparing Cape Town and South Africa in the GHG emission inventories, “heating and industries”, comprises primarily emissions from the combustion of fossil fuels for heating purposes in buildings (e.g., space heating, water heating and cooking) in residential, including commercial and industrial buildings since Cape Towns inventory only presents the sum of these as a whole.

[61] ICLEI & IRENA, 2013; Winkler et al., 2006.

[62] Glaeser and Kahn, 2008.

friendly, or simply due to the fact that carbon intensive activities are located outside of the city all the while providing it with a constant flow of vital products and materials (e.g. meat or wood). Conversely, a high RCF could be due to a local economy characterised by large production of carbon intensive goods and services for local use, or to the fulfilment of functions serving the whole national economy (e.g. logistic services). The GHG inventories available for São Paulo and for Cape Town do not allow us to provide a clear answer, since they are ‘production-based’ inventories and only capture a fraction of the economic process[63]. Such inventories only focus on the production of goods and services and partially on their disposal, neglecting other stages including consumption and extraction of resources. This necessitates a careful analysis of both local economies as opposed to the average of their respective countries.

The range of economic activities currently carried out in São Paulo presents very different characteristics than the national average. The city’s low carbon footprint is due to the fact that the service sector is highly predominant, contributing to 75,4% of the city’s total value added (VA). This is followed by the industrial sector (24.6% of total VA), and an almost entirely absent primary sector[64]. In Brazil, conversely, the high-emitting industrial and primary sectors present a higher weight in the economy (27.8% and 7.4% of total VA respectively)[65]. The primary sector, in particular, presents tremendously high GHG emissions, due to the continuous clearance of large portions of forested land to provide space for soy, coffee and sugar cane farms, and one of the largest livestock herds of the world[66]. A look at São Paulo’s history shows how the city has got rid of the carbon intensive sectors that characterise the national economy. São Paulo first grew around a prosperous agricultural sector, producing large quantities of coffee for exportation. The international crisis of the 1930s made the exports fall and the city transformed its economy in a massive process of industrialisation to supply both internal and regional markets[67]. In the past three decades the city’s economy has developed even further by moving industrial production outside the municipal boundaries, shifting the central urban economy towards the service sector and making it one of the most important financial centres of Latin America.

In the case of Cape Town the implications of the different economic activities for the RCF are less evident than in São Paulo. The city’s logistics cluster, for instance, is particularly prosperous (in 2006 approximately 23.3% of South Africa’s total cargo has gone through Cape Towns ports and airports). Thanks to its geographical position and history, Cape Town is a major node for the national and international transportation of agricultural food products, refined oil and steel. The large use of fossil fuel in this sector contributes to increase the city’s emissions from transport as opposed to the national one, and therefore to increase Cape Town’s RCF. Conversely, this element is partially outweighed by other carbon intensive sectors being underrepresented in the city’s economic structure when compared to the national average (e.g. mining and industrial sector)[68].

[63] For discussion on these themes see, among others, DODMAN, 2009a and KATES et al., 1998.

[64] Municipality of São Paulo website, 2012.

[65] World Bank Databank, 2012.

[66] globserver.com, 2012; De Faccio Carvalho, 2006.

[67] Deák, 2001.

[68] for Cape Town: Western Cape Government, 2006:8; for South Africa: World Bank Databank, 2012, data for 2004.

Both São Paulo and Cape Town, while having a vibrant local economy, are deeply embedded in the national and global economies. Both cities constantly extract resources from the whole country and beyond, and benefit from activities that take place (and release GHG) outside the city boundaries. At the same time, they supply goods and services consumed by the local residents as well as the outside world. While these circumstances make it impossible to unambiguously allocate São Paulo’s and Cape Town’s emissions, the study of the RCF provides a useful tool. The study of RCFs does not aim to place the responsibility for climate change onto a city or a country. Rather, it helps identifying priorities for integrated policy making. By suggesting that the carbon intensive activities are located outside the city, a RCF<1 value indicates that a change of the city’s carbon emissions depends upon the behaviour of the local *consumers*[69]. Conversely, a RCF>1 value indicates that it is a behavioural change of local *producers* that might have important implications for the carbon emissions of the city and that of its whole region of economic interaction.

5. Conclusion

Cities are increasingly where demographic, social, economic, cultural, and public policy trends are determined. As for their role in climate change, this study has contributed towards identifying the conditions under which cities may provide solutions for reducing their country’s total GHG emissions. We have introduced the Relative Carbon Footprint (RCF) as a new way of ranking and comparing cities that takes into account their preconditions for decreasing their carbon footprint, i.e. the economic, social, geographic, and political factors that are shared and shaped by a city’s national context. Having calculated the RCFs of all cities with currently available and comparable GHG inventories, we chose the municipalities of São Paulo and Cape Town as our explorative case studies. Comparing the sectorial contributions to the RCF of São Paulo and to the RCF of Cape Town brought us to our analysis of the policy conditions in three dimensions found to influence the cities’ GHG emissions: the sources, or “matrix”, of the city’s energy supply; the level of income per capita and related consumption behaviours; and the structure of the local economy vis-à-vis the national economy.

First, we saw that the carbon-intensity of the energy matrix will be determined by the systems through which energy is produced, transmitted and distributed nationwide. Even in the cases when the issue lies outside the immediate sphere of urban policy making, however, it remains an important indicator to consider. If the energy matrix already presents a low carbon-intensity, investments and policies targeting energy efficiency are unlikely to have high returns in terms of GHG reduction and could probably be more beneficial if targeted elsewhere. Further, the presence of powerful private companies and lobbies is among the factors that shape the capability and will of policy-makers to encourage low-carbon solutions for their city’s energy supply (through regulations, taxes, subsidies, state owned enterprises etc.).

Secondly, both cities have higher than national average incomes, as well as higher GHG emissions from the sectors directly related to income, i.e. waste, transportation, and buildings’ heating. This highlights how the identification of a strategy for decoupling economic growth and people’s well-being from resource depletion and

[69] In this sense, an interesting example is São Paulo’s “*Programa Madeira é Legal”* (Legal Wood Program), which promotes the use of certified wood in the city (ICLEI, 2009b).

environmental degradation (in this case through GHG emissions) has not yet fully occurred and needs to be of paramount political priority. We see in both São Paulo and Cape Town that local governments have significantly decreased waste related emissions in the treatment stage. But since there now exist numerous technological solutions for limiting emissions already from the stage of waste *generation*, it becomes a political issue whether policymakers take up the battle to change citizens’ behaviours. Similarly, the RCF confirms findings that road transportation is one area where cities can improve their record vis-à-vis their national averages, and where there is the population density to support widespread collective public transportation, and the economies of scale to introduce new technologies. Further studies might find similarities between the two cities and countries, in terms of resistance to such progressive transportation policy, that are in part explained by elitist political cultures, including clientelism and class or race politics. Finally, for transformation in the residential energy and heating sector, there is a lack of a certain *consciousness* in different governmental departments regarding the potential of ‘green growth’ policies and the encouragement of energy-efficient construction and private retrofitting, and the cities do not yet have significant business coalitions of green industries to pressure for support from policy-makers.

Thirdly, an important difference between São Paulo and Cape Town was found by looking at the carbon footprints of their economies: while both cities are economically successful vis-à-vis their respective country averages, São Paulo also seems to be a virtuous case of environmental performance. However, both cities constantly extract resources from the whole country and beyond and benefit from activities that take place (and release GHGs) outside their city boundaries. At the same time, they supply goods and services consumed by the local residents as well as the outside world. It so happens that São Paulo has expelled its high-carbon economic activities and carries out low-carbon functions for the city and the country, while in Cape Town the case is rather the opposite. Thus, by looking at specific sectors and dynamics such as the stage of economic development in comparative terms (i.e. *relative* to a country average), the RCF sheds light on the actual potentials of a specific urban reality.

The analysis of these three dimensions shows the importance of both local and national contexts and institutions for policy responses. When it comes to determining how greater importance might be given to the urgency of transforming cities with low carbon solutions, political cultures matter. Explaining and identifying virtuous examples of climate action and transformation of cities will therefore require further studies focussed on the rationality of stakeholders, entering into their political calculus and understanding local and national urban regimes and coalitions. Finally, the approach that has been used here, i.e. analysing the indicator of one determinant of a city’s carbon footprint *as opposed* to the average in the country the city is located in, can be developed with regard to other indicators of environmental status. The analysis of more indicators at the city level relative to the national level helps assess the potential of one specific urban form and organisation over others, while also allowing a new ranking of cities countrywide and worldwide.

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Appendix A

Brazil and São Paulo GHG inventories (in tCO2e)					
2003	Br Total	Br/capita	SP total	SP/capita	SP / Br
Energy	348,454,800	1.92	11,896,000[70]	1.12	**0.583**
Electricity	48,934,200	0.27	1,334,478	0.1300	0.481
Industries	113,799,800	0.63	769,070	0.0700	0.111
Transportation	132,642,600	0.73	8,422,810	0.7900	1.082
Residential Buildings	17,957,600	0.10	1,316,223	0.1200	1.200
Agriculture	14,900,400	0.08	2,779	0.0003	0.004
Other sector	3,934,800	0.02	213,739	0.0200	1.000
Fugitive Emissions	16,285,200	0.09	476,347	0.0400	0.444
Industrial Processes	36,121,000	0.20	-	-	**-**
Agriculture/Husbandry	447035400	2.46	780	0.0050	**0.002**
LULUCF	1259520600	6.93	52,000	0.005	**0.001**
Waste	45655000	0.25	3,703,000	0.35	**1.400**
Total	2,136,786,800	11.76	15,651,780	1.47	**0.125**

Data on Brazil are from the national GHG inventory 2009, Brazilian Ministry of Science and Technology (MCT 2009); Data for the year 2003 are estimated using the historical data for 1990, 1994, 2000 and 2005; Data on São Paulo are from the city's GHG inventory Secretaria Municipal do Verde e do Meio Ambiente SVMA, 2005.

[70] This is less than the total of the Energy sub-sectors to avoid double counting of emissions from electricity production.

Appendix B

South Africa and Cape Town GHG inventories (in tCO2e)					
Sector	SA total (2000)	SA per capita	CT total (2005)	CT per capita	CT/SA
Energy	268,452,528	6.10	34,207,938	9.78	**1.603**
Energy industries	170,716,300	3.88	11,826,518	3.38	0.871
Heating and Industries[71]	46,532,424	1.06	4,021,662	1.15	1.085
Transportation - as per IPCC 2006 guidelines	39,445,315	0.90	5,035,820	1.44	1.600
Transportation - Aviation and marine	11,758,490	0.27	13,323,940	3.81	14.111
Solid Waste	8,085,000	0.18	1,484,881	0.42	**2.333**
Other Sectors	166,339,550	3.62	-	-	**-**
Industrial processes and product use	61,469,090	1.40	-	-	-
Agriculture, forestry and land use	20,493,510	0.43	-	-	-
Energy Industry - Petroleum extraction	42,658,510	0.90	-	-	-
Waste water handling	1,307,800	0.03	-	-	-
Fugitive emissions from fuels	40,410,640	0.86	-	-	-
Grand Total	442,877,078	9.91	35,692,819	10.21	**1.030**
Total of the comparable information (with aviation and Marine)	276,537,528	6.28	35,692,819	10.21	**1.626**
Total of the comparable information (without aviation and Marine)	264,779,038	6.02	22,368,880	6.40	**1.063**

Data on South Africa come from the national GHG inventory (DEAT, 2009); Data on the city of Cape Town's GHG inventory presented by Kennedy et al. (2009a; 2009b; 2010.

[71] Emissions in this category are primarily due to fossil fuels used for heating in buildings, e.g., space heating, water heating and cooking. Also included are fossil fuels used by combined heat and power facilities within cities (mainly natural gas and oil) and fossil fuels combusted by industry.