Environment and Urbanization

http://eau.sagepub.com

Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories

David Dodman

Environment and Urbanization 2009; 21; 185
DOI: 10.1177/0956247809103016

Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories

DAVID DODMAN

David Dodman is a Researcher in the Human Settlements and Climate Change groups at the International Institute for Environment and Development. He holds a D.Phil in Geography from the University of Oxford and was previously a Lecturer in Geography at the University of the West Indies (UWI), Mona, Jamaica. He is co-editor (with Duncan McGregor and David Barker) of *Global Change and Caribbean Vulnerability: Environment, Economy and Society at Risk* (UWI Press, forthcoming) and (with Jane Bicknell and David Satterthwaite) of *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges* (Earthscan, forthcoming).

Address: IIED, 3 Endsleigh Street, London WC1H 0DD; tel: +44 207 388 2117; e-mail: david.dodman@iied.org

ABSTRACT Cities are often blamed for high levels of greenhouse gas emissions. However, an analysis of emissions inventories shows that – in most cases – per capita emissions from cities are lower than the average for the countries in which they are located. The paper assesses these patterns of emissions by city and by sector, discusses the implications of different methodological approaches to producing inventories, identifies the main drivers for high levels of greenhouse gas production, and examines the role and potential for cities to reduce global greenhouse gas emissions.

KEYWORDS climate change / ecological footprints / emissions / methodology / mitigation / sustainability

I. INTRODUCTION: BLAMING CITIES FOR ENVIRONMENTAL PROBLEMS

Since the time of the Industrial Revolution, cities have often been blamed for causing environmental problems. Yet although the concentration of people, enterprises, motor vehicles and waste in cities is often seen as a "problem", high densities and large population concentrations can also bring a variety of advantages for meeting human needs and for environmental management. "Economies" of scale, proximity and agglomeration mean that it is cheaper to provide the infrastructure and services needed to minimize environmental hazards; the concentration of enterprises means that it is less costly to enforce environmental legislation; and the relative proximity of homes and businesses can encourage walking, cycling and the use of mass transport in place of private motor vehicles.(1)

Calculations of the ecological footprints of cities have tended to stress the area of land a city requires to supply its needs. For example, Girardet(2) calculated that London's ecological footprint "*...extends to around 125 times its surface area of 159,000 hectares, or nearly 20 million hectares*", equivalent to a figure of 2.8 hectares per person. Although this figure is indeed alarming, it should be noted that as the average ecological footprint of Europeans is three hectares per person, and that of North Americans is 4–5 hectares per person, the average Londoner has a smaller ecological footprint than the average European or North American.

More recently, cities have been blamed for generating most of the world's greenhouse gas emissions and contributing disproportionately to

1. Satterthwaite, D (1999), "The key issues and the works included", in D Satterthwaite (editor), *The Earthscan Reader in Sustainable Cities*, Earthscan, London, pages 3–21.

2. Girardet, H (1998), "Sustainable cities: a contradiction in terms?", in E Fernandes (editor), *Environmental Strategies for Sustainable Development in Urban Areas: Lessons from Africa and Latin America*, Ashgate, Aldershot, page 196.

Environment & Urbanization Copyright © 2009 International Institute for Environment and Development (IIED).
Vol 21(1): 185–201. DOI: 10.1177/0956247809103016 www.sagepublications.com

global climate change. Sánchez-Rodríguez et al.[3] argue that interactions between urban areas and global environmental change create "*…a diversity of impacts that can be grouped in two broad categories: those originating in urban areas that have a* ***negative*** *effect on global environmental change, and global environmental changes that have negative effects on urban areas*." This perspective ignores the fact that many of the processes implicit in urbanization can actually have a positive overall effect on global environmental change, and fails to recognize that the spatially varied consequences of global environmental change are likely to affect different urban areas in a variety of different ways. Referring specifically to climate change, the Executive Director of the United Nations Centre for Human Settlements (UN–HABITAT) has stated that cities are "*…responsible for 75 per cent of global energy consumption and 80 per cent of greenhouse gas emissions*";[4] while the Clinton Foundation suggests that cities contribute "*…approximately 75 per cent of all heat-trapping greenhouse gas emissions to our atmosphere, while only comprising 2 per cent of land mass.*"[5] Yet at the same time, detailed analyses of urban greenhouse gas emissions for individual cities suggest that – per capita – urban residents tend to generate a substantially smaller volume of greenhouse gas emissions than residents elsewhere in the same country.

Few comparative studies have been performed that attempt to draw more precise conclusions about the role played by cities in contributing to global greenhouse gas emissions. This paper brings together the results from several published studies and commissioned reports to assess whether cities do indeed have a disproportionately negative effect on global climate change. This is not an exhaustive listing but, rather, reflects a sample of large cities in Asia, Europe, North America and Latin America for which reasonably comprehensive and up to date data are readily available. The paper then identifies the relative contribution of different economic sectors in these cities and discusses the significance of these figures. This is followed by an assessment and critique of the methodologies used to account for greenhouse gas emissions at the urban and at the national level, particularly in relation to the debate between allocating emissions to producers or consumers. Drawing on the three previous sections, the paper then argues that attempts to blame cities for climate change serve only to divert attention from the main drivers of greenhouse gas emissions – namely unsustainable consumption, especially in the world's more affluent countries. Finally, the paper identifies the potential for cities to function as solutions, rather than problems, in responding to the challenge of climate change.

II. ASSESSING URBAN GREENHOUSE GAS EMISSIONS

As part of a global effort to identify greenhouse gas emissions and to set targets for emissions reductions, the United Nations Framework Convention on Climate Change (UNFCCC) requires all member states to prepare regular reports on inventories of anthropogenic emissions of these gases. The Intergovernmental Panel on Climate Change (IPCC) provides a detailed methodological framework to accomplish this, which assesses all the greenhouse gases emitted from four main sectors: energy; industrial processes and product use; agriculture, forestry and other land use; and waste.[6] These emissions inventories provide a general picture of global

3. Sánchez-Rodríguez, R, K Seto, D Simon, W Solecki, F Kraas and G Laumann (2005), "Science plan: urbanization and global environmental change", International Human Dimensions Programme on Global Environmental Change, Report No 15, Bonn, page 8, emphasis added.

4. United Nations (2007), "City planning will determine pace of global warming", accessed 2 December 2008 at http://www.un.org/News/Press/docs/2007/gaef3190.doc.htm.

5. Clinton Foundation (n.d.) "Clinton climate initiative", accessed 2 December 2008 at http://www.clintonfoundation.org/cf-pgm-cci-home.htm. For a critique of these figures, see Satterthwaite, D (2008), "Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions", *Environment and Urbanization* Vol 20, No 2, October, pages 539–549.

6. Intergovernmental Panel on Climate Change (IPCC) (2006), *Guidelines for National Greenhouse Gas Inventories*, Cambridge University Press, Cambridge.

patterns of greenhouse gas emissions and are used as the benchmark by which countries target their emissions reductions according to international treaties, and measure their success in achieving these. The strengths and weaknesses of this framework are discussed later in the paper, but it remains the most commonly used methodology to construct emissions inventories and forms the basis for most of the city inventories discussed here. The IPCC methodology aims to produce "…*national inventories of anthropogenic greenhouse gas emissions and removals… which contain neither over- nor underestimates so far as can be judged, and in which uncertainties are reduced as far as practicable*",[7] and covers an exhaustive list of sectors and greenhouse gases (Table 1).

7. See reference 6, page 8.

No such international framework exists requiring measurements of city emissions or providing detailed methodological guidance for conducting an urban emissions inventory. However, in recent years urban authorities around the world have begun to commission inventories of this type as a means of measuring the overall carbon footprint of city

TABLE 1
Sectors and gases assessed for national greenhouse gas inventories

Sector	Sub-sectors	Greenhouse gases assessed
Energy	• Stationary combustion • Mobile combustion • Fugitive emissions • CO_2 transport, injection and geological storage	• Carbon dioxide • Methane • Nitrous oxide • Hydrofluorocarbons • Perfluorocarbons • Sulphur hexafluoride • Nitrogen trifluoride • Trifluoromethyl sulphur pentafluoride • Halogenated ethers • Other halocarbons
Industrial processes and product use	• Mineral industry emissions • Chemical industry emissions • Metal industry emissions • Non-energy products from fuels and solvent use • Electronics industry emissions • Emissions of fluorinated substitutes for ozone-depleting substances • Other product manufacture and use	
Agriculture, forestry and other land use	• Forest land • Cropland • Grassland • Wetlands • Settlements • Other land • Emissions from livestock and manure management • N_2O emissions from managed soils, and CO_2 emissions from lime and urea applications • Harvested wood products	
Waste	• Solid waste disposal • Biological treatment of solid waste • Incineration and open burning of waste • Wastewater treatment and discharge	

SOURCE: Intergovernmental Panel on Climate Change (2006), *Guidelines for National Greenhouse Gas Inventories*, Cambridge University Press, Cambridge.

activities, promoting awareness of the need for climate change mitigation, and providing a benchmark against which reductions in emissions can be measured. Many of these use the UNFCCC methodology as the base for measuring emissions, although the problems associated with identifying the spatial area and activities that ought to be included are particularly intense for urban areas. The Cities for Climate Protection campaign, coordinated by Local Governments for Sustainability (ICLEI), identifies conducting a baseline emissions inventory and forecast as the first milestone for reducing greenhouse gas emissions, and this has doubtlessly encouraged some local authorities to make this step. In September 2008, ICLEI released a "local government operations protocol for the quantification and reporting of greenhouse gas inventories", the first part of a two-step process to write the official protocol for greenhouse gas inventories for all US local government authorities.[8]

Although many smaller cities (especially in the United States) have also conducted greenhouse gas inventories,[9] this paper focuses on larger cities, particularly ones of international significance. Table 2 summarizes the findings of 11 city inventories from Europe, North America, South America and Asia conducted since 1996. Because of the lack of a standardized methodology, and because the inventories were conducted in different years, making direct and precise comparisons is difficult. As can be seen in Table 1, with the notable exceptions of Beijing and Shanghai, all the cities surveyed generate a substantially smaller volume of carbon dioxide equivalent (CO_2eq) emissions per capita than the countries in which they are found.[10] Very few detailed inventories have been produced by cities in low-income countries, and it is possible that residents of these urban areas generate a higher level of greenhouse gas emissions than the national average, in large part due to the concentration of wealth in large cities.

a. European cities

Barcelona is the second largest city in Spain, with a population of 1.5 million in 1996. Over the period 1987 to 1996, the total emissions for the city grew from 4.4 million tonnes to 5.1 million tonnes, although over the period 1992 to 1995 there was a decline from 5.3 million tonnes to 4.9 million tonnes. At least part of this decline can be attributed to a decline in population – indeed, over the entire 10-year period, the population of the city shrank from 1.7 million to 1.5 million. Baldasano et al.[11] attribute Barcelona's relatively low level of per capita emissions to several major factors: the city's economy is primarily service based rather than manufacturing based; 90 per cent of the city's electricity is generated by nuclear and hydro energy; the city's mild climate and the rarity of household air-conditioning systems; and the compact urban structure, where many residents live in apartments rather than individual houses.

London is the capital and largest city in the United Kingdom, with a population of just over 7 million. In 2006, London's overall carbon dioxide emissions were 44.3 million tonnes, 8 per cent of the United Kingdom's total emissions; this was a slight decline from the 45.1 million tonnes produced in 1990, despite a rise in population of 0.7 million people during the same period.[12] This decline can be attributed to the halving of industrial emissions, as industrial activity has relocated to other parts

8. ICLEI (2008), "Local government operations protocol for the quantification and reporting of greenhouse gas emissions inventories", accessed 2 December 2008 at http://www.icleiusa.org/action-center/tools/lgo-protocol-1.

9. Many of these reports are available for public consultation on the Internet. Examples include Aspen (Colorado) with a population of approximately 17,000 (http://aspenglobalwarming.com); Menlo Park (California) with a population of approximately 30,000 (http://service.govdelivery.com/docs/camenlo/camenlo_101/camenlo_101_20071117_en.pdf); Bellingham (Washington) with a population of approximately 67,000 (http://www.cob.org/documents/pw/environment/2007–04–12-Greenhouse-gas-inv-rpt-and-action-plan.pdf); and Chula Vista (California) with a population of approximately 227,000 (http://www.cacities.org/resource_files/26338.chula%20vistaGHG_InventoryReport_Final.pdf).

10. Carbon dioxide equivalent (CO_2eq) refers to the combined effect of all greenhouse gases, standardized according to the warming potential of a given quantity of carbon dioxide.

11. Baldasano, J, C Soriano and L Boada (1999), "Emission inventory for greenhouse gases in the city of Barcelona, 1987–1996", *Atmospheric Environment* No 3, pages 3765–3775.

12. Mayor of London (2007), *Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan*, Greater London Authority.

TABLE 2
Selected urban greenhouse gas emissions

City (date of study)	Total GHG emissions (million tonnes CO_2 equivalent)*	GHG emissions per capita (tonnes of CO_2 equivalent)	National GHG emissions per capita (tonnes of CO_2 equivalent)[11]	City emissions as percentage of national emissions (per capita)
European cities				
Barcelona (1996)[1]	5.1	3.4	10.03 (2004)	33.9%
Glasgow (2004)[2]	12.5	8.4	11.19 (2004)	75.1%
London (2006)[3]	44.3	6.2	11.19 (2004)	55.2%
North American cities				
District of Columbia (2005)[4]	11.3	19.7	23.92 (2004)	82.4%
New York City (2005)[5]	58.3	7.1	23.92 (2004)	29.7%
Toronto (2001)[6]	37.1	8.2	23.72 (2004)	34.4%
South American cities				
Rio de Janeiro (1998)[7]	12.8	2.3	8.2 (1994)	28.0%
São Paulo (2003)[8]	15.7	1.5	8.2 (1994)	18.3%
Asian cities				
Beijing (1998)[9]	n/a	6.9	3.36 (1994)	205.4%
Seoul (1998)[9]	n/a	3.8	6.75 (1990)	56.3%
Shanghai (1998)[9]	n/a	8.1	3.36 (1994)	241.1%
Tokyo (1998)[9]	n/a	4.8	10.59 (2004)	45.3%
Older case studies (all figures for 1988)[10]				
Ankara	–	3.6	–	–
Bologna	–	5.7	–	–
Copenhagen	–	7.5	–	–
Dade County (Miami)	–	11.6	–	–
Denver	–	22.3	–	–
Hanover	–	10.6	–	–
Heidelberg	–	7.9	–	–
Helsinki	–	8.3	–	–
Minneapolis	–	17.5	–	–
Portland	–	10.1	–	–
Saarbrucken	–	10.4	–	–
San Jose	–	8.8	–	–
Toronto City	–	15.0	–	–
Toronto Metro	–	13.5	–	–

*Throughout this paper, the term "tonne" is used to refer to a metric tonne (metric ton in the USA) or 1,000 kilogrammes.

SOURCES: [1]Baldasano, J, C Soriano and L Boada (1999), "Emission inventory for greenhouse gases in the city of Barcelona, 1987–1996", *Atmospheric Environment* No 3, pages 3765–3775; [2]Glasgow and the Clyde Valley Structure Plan Joint Committee (n.d.), "Glasgow and the Clyde Valley greenhouse gas inventory: a summary guide", accessed 2 December 2008 at http://www.gcvcore.gov.uk/downloads/GCVGreenhouseGasInventory.pdf; [3]Mayor of London (2007), *Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan*, Greater London Authority; [4]Air Quality Division (2005), *District of Columbia Greenhouse Gas Emissions Inventories and Preliminary Projections*, District of Columbia Department of Health, Air Quality Division; [5]PlaNYC (2007), "Inventory of New York City greenhouse gas emissions", Mayor's Office of Operations, New York City; [6]VandeWeghe, J and C Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144; [7]Dubeux, C and E La Rovere (2007), "Local perspectives in the control of greenhouse gas emissions – the case of Rio de Janeiro", *Cities* Vol 24, No 5, pages 353–364; [8]Secretaria Municipal do Verde e do Meio Ambiente de São Paulo (SVMA) (2005), *Inventário de Emissões de Efeito Estufa do Município de São Paulo*, Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas (Centro Clima) da Coordenação dos Programas de Pós-graduação de Engenharia (COPPE) da Universidade Federal do Rio de Janeiro (UFRJ); [9]Dhakal, S (2004), *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-cities*, Institute for Global Environmental Strategies, Kitakyushu, Japan; [10]Harvey, L (1993), "Tackling urban CO_2 emissions in Toronto", *Environment* Vol 35, No 7, pages 16–44; [11]United Nations Statistics Division – Environmental Indicators (n.d.), accessed 2 December 2008 at http://unstats.un.org/unsd/environment/air_greenhouse_emissions.htm.

of the UK or overseas or has closed down. However, by 2025, a business-as-usual approach would lead to a 15 per cent increase in emissions as a result of expected economic and population growth. The per capita emissions from London are the lowest of any region in the UK, and at 6.18 tonnes per capita in 2006 were just over half the national average of 11.19 tonnes per capita (2004). Per capita emissions from Glasgow – at 8.4 tonnes per capita in 2004 – are higher than those for London, but this may also reflect the fact that the analysis covered the entire area of Glasgow and the Clyde Valley, an area comprising eight local authorities and covering 3,405 square kilometres. This area also emits a higher than average quantity of agricultural emissions due to a proportionately larger dairy farming sector in the area.[13]

b. North American cities

Toronto was one of the earliest cities to recognize the need to reduce carbon dioxide emissions: in January 1990, the city council declared an official target of reducing the city's carbon dioxide emissions to 20 per cent below the 1988 level by 2005.[14] A more recent survey[15] depicts both the overall patterns of greenhouse gas emissions for Toronto and also examines how these vary spatially throughout the Toronto Census Metropolitan Area (CMA): as the distance from the central core increases, automobile emissions begin to dominate the total emissions.

The overall per capita greenhouse gas emissions for the District of Columbia (the central area of Washington DC) are relatively high compared with the other North American cities analyzed. Although the District of Columbia is a densely populated urban centre, with very little in the way of industrial activities, it also has a relatively small population (572,059 in 2000) in relation to the large number of offices for government and related functions, and large sections are very wealthy. In this regard, it may be more appropriate, for comparative purposes, to use the emissions from the entire Washington, DC metropolitan area. In New York, despite the high concentration of wealth, there are several factors that help to keep the city's emissions relatively low. First is the density of the city's buildings and the smaller than average dwelling unit size, which means less energy is needed to heat, light, cool and power these buildings. Second, the extensive public transport system means that car ownership levels in the city are much lower than those nationally.[16]

c. Latin American cities

Detailed assessments of greenhouse gas emissions have been undertaken in Rio de Janeiro and São Paulo in Brazil.[17] These studies utilize the IPCC framework for the creation of national inventories, and as such are more detailed than many of the other studies discussed in this paper. The pattern of greenhouse gas emissions from these two cities are obviously strongly affected by the level of economic development of Brazil as a country. In this regard, emissions from solid waste are much higher than in many other cities, while emissions from the transportation sector (both individual and mass transit) are much lower. However, in the case of Brazil as a whole, the main sources of emissions at the national level are related primarily to rural activities such as deforestation and cattle raising.[18]

13. Glasgow and the Clyde Valley Structure Plan Joint Committee (n.d.), "Glasgow and the Clyde Valley greenhouse gas inventory: a summary guide", accessed 2 December 2008 at http://www.gcvcore.gov.uk/downloads/GCVGreenhouseGasInventory.pdf.

14. Harvey, L (1993), "Tackling urban CO_2 emissions in Toronto", *Environment* Vol 35, No 7, pages 16–44.

15. VandeWeghe, J and C Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronoto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144.

16. PlaNYC (2007), "Inventory of New York city greenhouse gas emissions", Mayor's Office of Operations, New York City.

17. Rio Prefeitura Meio Ambiente (2003), *Inventário de Emissões de Gases do Efeito Estufa da Cidade do Rio de Janeiro*, Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas, Rio de Janeiro; also Secretaria Municipal do Verde e do Meio Ambiente de São Paulo (SVMA) (2005), *Inventário de Emissões de Efeito Estufa do Município de São Paulo*, Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas (Centro Clima) da Coordenação dos Programas de Pós-graduação de Engenharia (COPPE) da Universidade Federal do Rio de Janeiro (UFRJ).

18. Carolina Dubeux, personal communication.

Greenhouse gas emissions have also been calculated for Mexico City, although the figures generated by different studies vary widely: from a total of 34.9 million tonnes CO_2eq in 1996 to 60 million tonnes in 2000 and 62.6 million tonnes in 2004. This variation is a result of the scarcity and inconsistency of official inventories, and methodological issues related to the inclusion and exclusion of emissions from solid waste and aviation. However, even at the higher level this equates to per capita emissions of 3.6 tonnes per year, lower than the national figure of 4.6 tonnes.[19]

19. Gobierno del Distrito Federal (2004), *Local Climate Action Strategy of Mexico City*, Secretaría de Medio Ambiente, Gobierno del Distrito Federal, México; also Patricia Romero Lankao, personal communication.

d. Asian cities

A variety of factors have been identified as affecting the greenhouse gas emissions of cities in Asia. Lebel et al.[20] examine the ways in which patterns of mobility, the design and distribution of houses, the organization of food and water systems, and individual lifestyle choices affect emissions in Manila, Jakarta, Ho Chi Minh City, New Delhi and Chiang Mai (although they do not provide overall figures for these cities). Similarly, Dhakal[21] examines energy use and carbon dioxide emissions in four Asian cities – Beijing, Seoul, Shanghai and Tokyo – but provides only per capita, and not total, emissions figures for these cities. What is particularly notable in comparing these cities is that the wealthiest – Tokyo – has considerably lower emissions than the two Chinese cities in the table, clearly indicating that there is not an inevitable relationship between increasing prosperity and increasing emissions.

20. Lebel L, P Garden, M Banaticla, R Lasco, A Contreras, A Mitra, C Sharma, H Nguyen, G Ooi and A Sari (2007), "Integrating carbon management into the development strategies of urbanizing regions in Asia: implications of urban function, form and role", *Journal of Industrial Ecology* Vol 11, No 2, pages 61–81.

21. Dhakal, S (2004), *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-cities*, Institute for Global Environmental Strategies, Kitakyushu, Japan.

III. ATTRIBUTING GREENHOUSE GAS EMISSIONS BY SECTOR

In order to assess – and thereby reduce – the overall greenhouse gas emissions from these cities, it is necessary to identify the main sources of these emissions. At a global level, greenhouse gas emissions by sector have been calculated by the IPCC, and just over one-quarter can be attributed to energy supply. Transport, agriculture, forestry and industry all contribute between 10 and 20 per cent, while waste and wastewater, and residential and commercial buildings contribute less than 10 per cent each (Figure 1).[22]

22. Intergovernmental Panel on Climate Change (IPCC) (2007), "Summary for policymakers", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 851 pages.

Variations in the proportion of greenhouse gas emissions that can be attributed to different sectors reflect the economic base of different cities (whether this is primarily industrial or service oriented), the urban morphology (the density and distribution of settlement) and the level of wealth (with, for example, its influence on private car ownership rates). However, it must also be remembered that the figures discussed below are proportions, reflecting only the relative contributions of these sectors in the particular cities, and cannot be used to assess whether these levels of emissions are sustainable or not.

a. Industrial activity

Although most cities in North America and Europe were formed and grew as a result of industrial activities, and still require industries to provide jobs and revenue, these same activities generate unwanted pollution. However, in recent decades the global pattern of industrial activities has

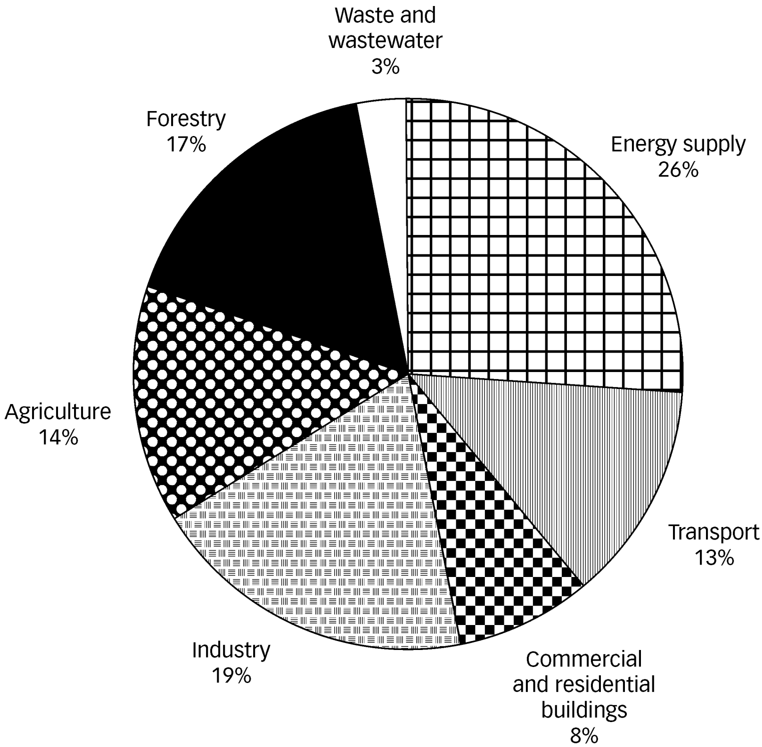

FIGURE 1
Anthropogenic greenhouse gas emissions by sector (2004)

SOURCE: Intergovernmental Panel on Climate Change (IPCC) (2007), "Summary for policymakers", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 851 pages.

shifted, in part due to transnational corporations seeking lower wages and higher profitability, and in part due to the increasing success of companies and corporations from China, India, Brazil and elsewhere in competing on the world market. Differences in environmental legislation (although this has rarely explicitly taken greenhouse gas emissions into account) have also transformed the geography of industrial location. Bai argues that "*…when [cities] are able, they will get rid of polluting industries, pushing them away from city centres to suburbs or to other cities.*"[(23)]

These patterns can be seen in the large variations in the proportion of a city's greenhouse gas emissions that can be attributed to the industrial sector, particularly between China and the rest of the world. In 1999, industrial activities were responsible for 80 per cent of Shanghai's emissions and 65 per cent of Beijing's. Weber et al.[(24)] identified that, in 1987, 12 per cent of Chinese emissions were due to the production of exports, a figure that rose to 21 per cent in 2002 and 33 per cent (equivalent to 6 per cent of total global CO_2 emissions) in 2005. As Walker and King[(25)] describe the situation:

23. Bai, X (2007), "Industrial ecology and the global impacts of cities", *Journal of Industrial Ecology* Vol 11, No 2, page 2.

24. Weber, C, G Peters, D Guan and K Hubacek (2008), "The contribution of Chinese exports to climate change", *Energy Policy* Vol 36, pages 3572–3577.

25. Walker, G and D King (2008), *The Hot Topic: How to Tackle Global Warming and Still Keep the Lights On*, Bloomsbury Publishers, London, pages 199–200.

> "Many of the countries in the western world have dodged their own carbon dioxide emissions by exporting their manufacturing to... China. Next time you buy something with 'Made in China' stamped on it, ask yourself who was responsible for the emissions that created it."

In contrast, greenhouse gas emissions from the industrial sector in cities elsewhere are much lower, generally reflecting a transition to service-based urban economies: just 0.04 per cent in Washington DC (largely because of the narrow spatial definition of the District of Columbia); 6.2 per cent in Rio de Janeiro; 7 per cent in London; 9.7 per cent in São Paulo; and 10 per cent in Tokyo and New York (compared to 29 per cent for the United States as a whole). The declining importance of industry in causing emissions is evident in several cities: in Rio de Janeiro, the industrial sector's proportion of emissions declined from 12 per cent in 1990 to 6.2 per cent in 1998; and in Tokyo the contribution of this sector has declined steadily from 30 per cent to 10 per cent over the last three decades.

b. Transportation

Urban density is one of the most important factors influencing the amount of energy used in private passenger transport, and therefore also has a significant effect on greenhouse gas emissions. With the exceptions of the Chinese cities included in these rankings (with high levels of manufacturing emissions), the most densely populated cities utilize less energy for private passenger transport and generally have lower greenhouse gas emissions per capita (Table 3).

These variations can also be seen in the proportion of a city's greenhouse gas emissions that can be attributed to the transportation sector. Shanghai and Beijing generate approximately 11 per cent of their emissions from the transportation sector, a figure dwarfed by their emissions from manufacturing. In London, New York and Washington DC, transportation represents a significant contribution to the city's emissions (22 per cent, 23 per cent and 18 per cent, respectively), whereas in Barcelona (35 per cent), Toronto (36 per cent), Rio de Janeiro (29.7 per cent) and São Paulo

TABLE 3
Private passenger energy use, urban density and GHG emissions

Private passenger transport energy per person (lowest to highest)	Urban density (highest to lowest)	GHG emissions per capita (lowest to highest)
Shanghai	Seoul	São Paulo
Beijing	Barcelona	Barcelona
Barcelona	Shanghai	Seoul
Seoul	Beijing	Tokyo
São Paulo	Tokyo	London
Tokyo	São Paulo	Beijing
London	London	New York City
Toronto	Toronto	Shanghai
New York City	New York City	Toronto
Washington DC	Washington DC	Washington DC

SOURCE: Compiled from Newman, P (2006), "The environmental impact of cities", *Environment and Urbanization* Vol 18, No 2, October, pages 275–295; and other sources as identified in Table 1.

(59.7 per cent), these figures are much higher – and are growing in relative importance in the Brazilian cities. At the same time, it should be noted that London's transportation emissions are lower than those for most major world cities, as a result of high levels of public transport usage, strong investment in infrastructure and policies to promote alternatives to private motor vehicle use; whereas the extensive public transport system in New York means that car ownership and usage levels are much lower than those in the United States as a whole.

Perhaps the most notable omission from this list is emissions from the aviation industry. These are not included within a country's national greenhouse gas inventory as a result of the lack of consensus as to where exactly these should be allocated: to the country from which the aircraft takes off; the country in which the aircraft lands; the country in which the aircraft is registered; or the country of origin of the passengers? These issues are even more complex in the case of city emissions, as many of the passengers using major international airports situated in or close to major cities may be from elsewhere in the country, or may only be using these airports for transit purposes. The IPCC has estimated that aviation is responsible for around 3.5 per cent of human-induced climate change[(26)] and that this is growing by approximately 2.1 per cent per year.[(27)]

The greenhouse gas inventories produced by London and New York offer an alternative set of figures that do take emissions from aviation into account. As a major UK and international air travel hub, London's airports handle 30 per cent of the passengers entering or departing the country.[(28)] If incorporated into the city's emissions inventory, aviation would be responsible for 34 per cent of London's emissions, and would raise total emissions from 44.3 million tonnes to 67 million tonnes for 2006. In the case of New York, aviation would add 10.4 million tonnes per year to the city's emissions. However, as is the case with industrial emissions, allocating responsibility for all aviation-based emissions to a city's inventory is misleading – large city airports provide a service not only to individuals from elsewhere in the same country but also from abroad.

c. Waste generation

At a global level, the IPCC records waste and wastewater as being responsible for 3 per cent of greenhouse gas emissions. However, this figure varies widely between cities: from New York (with negative net emissions as a result of the capture of methane from managed landfills), to São Paulo (23.6 per cent of total emissions), Barcelona (24 per cent) and Rio de Janeiro (36.5 per cent). These variations are likely to be due not only to different patterns of consumption and waste generation but also to differences in the management of waste and differences in accounting mechanisms – variations that are almost impossible to assess in the absence of a standardized urban framework for conducting emissions inventories.

IV. ASSESSING EMISSIONS INVENTORIES: METHODOLOGICAL ISSUES

Measuring greenhouse gas emissions at the urban or local scale is fraught with difficulties. In particular, the smaller the scale, the greater the challenges posed by "boundary problems", whereby it is increasingly difficult

26. Intergovernmental Panel on Climate Change (IPCC) (1999), *Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

27. Kahn Ribeiro, S, S Kobayashi, M Beuthe, J Gasca, D Greene, D Lee, Y Muromachi, P Newton, S Plotkin, D Sperling, D Wit and P Zhou (2007), "Transport and its infrastructure", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pages 323–386.

28. In this context, "London's airports" refers to London Heathrow and London City airports. Gatwick, Stansted and Luton are not included as they are located outside the boundaries of the Greater London Authority.

to identify which emissions ought or ought not to be allocated to a particular place[29] – an issue that is equally relevant when applying ecological footprint analyses.[30] The city greenhouse gas emissions inventories discussed in this paper all use a traditional production-based approach to allocating emissions, meaning that they take into account the carbon dioxide and other greenhouse gases produced within the area under consideration (with the exception of Dhakal,[31] who produces an alternative set of figures for Shanghai, Beijing and Tokyo using a consumption-based approach). However, it does not take into account the location in which items are consumed. Many polluting and carbon-intensive manufacturing processes are no longer located in Europe or North America, but have been sited elsewhere in the world to take advantage of lower labour costs and less rigorous environmental enforcement. In other words, "*…emissions can be attributed either to the spatial location of actual release or to the spatial location that generated activity that led to the actual release*."[32] Because of this, it should also be noted that the measure of "greenhouse gas emissions per capita" used above, is different from the measure of an individual's "carbon footprint" – as the carbon footprint takes into account the overall implications of an individual's activities, including the purchasing of manufactured goods.

The type of methodology used to account for greenhouse gas emissions has both moral and practical implications. Morally, a production-based system diverts attention and blame from the high consumption lifestyles that drive unsustainable levels of greenhouse gas emissions. Practically, this system fails to identify the areas in which interventions are required to reduce emissions, by focusing attention on only one part of multiple complex commodity chains. In addition, analyzing emissions at a city scale generates a variety of logistical problems: there are large information gaps (particularly in low- and middle-income countries); different information is available at different scales; and political boundaries of cities may change over time and often include both rural and urban populations (as is the case for Beijing and Shanghai).[33]

The use of production-based emissions methodologies distorts the responsibility of different cities for generating greenhouse gases. Different types of cities will be affected in different ways by this approach, because "*…in service-oriented cities, consumption-related emissions are more important than those produced by production*."[34] Because of this, the responsibility of successful production-oriented centres (such as Beijing and Shanghai) is exaggerated, while that of wealthy service-oriented cities (including many cities in North America and Europe) is underemphasized. The fact that Beijing and Shanghai have per capita emissions of more than twice the Chinese average therefore reflects not only the relative affluence of these cities (and the spatially uneven incorporation of different parts of China into global economic networks) but also the role they play in manufacturing consumer products that are used elsewhere in China and throughout the world.

Alternative systems of compiling emissions inventories can be based on assessing consumption patterns. An entirely consumer-focused approach is based on ecological footprint methodology, in which the ecological impacts of a particular economic process are allocated to the consumer.[35] This type of accounting system would result in a lower level of greenhouse gas emissions to low- and middle-income countries (with a likely substantial reduction in the greenhouse gas emissions allocated to

29. Kates, R, M Mayfield, R Torrie and B Witcher (1998), "Methods for estimating greenhouse gases from local places", *Local Environment* Vol 3, No 3, pages 279–298.

30. McManus, P and G Haughton (2006), "Planning with ecological footprints: a sympathetic critique of theory and practice", *Environment and Urbanization* Vol 18, No 1, April, pages 113–127.

31. See reference 21.

32. See reference 15, pages 136–137.

33. See reference 21.

34. See reference 23, page 2.

35. Wackernagel, M and W Rees (1995), *Our Ecological Footprint*, New Society Publishers, Gabriola; also Wackernagel, M, J Kitzes, D Moran, S Goldfinger and M Thomas (2006), "The ecological footprint of cities and regions: comparing resource availability with resource demand", *Environment and Urbanization* Vol 18, No 1, April, pages 103–112.

China and Chinese cities) and should – in theory – influence consumers in high-income countries to assume responsibility for choosing the best strategies and policies to reduce emissions.[36] Consumption-based mechanisms inherently have greater degrees of uncertainty (as there are many more systems to be incorporated in the final calculation), but they do provide considerable insight into climate policy and mitigation and should probably be used at least as a complementary indicator to help analyze and inform climate policy.[37]

The national and urban inventories discussed above reflect a focus on measuring the entire emissions for the country or city and then dividing this by the relevant population size. An alternative mechanism involves measuring the emissions that can be directly attributed to individuals. Brown et al.[38] provide an assessment of the carbon footprint of urban residents in the United States that takes into account highway transportation and energy consumption in residential buildings, but not emissions from commercial buildings, industry or non-highway transportation. Their findings state that the average resident of metropolitan areas in the United States has a smaller carbon footprint (2.24 tonnes) than the average US citizen (2.6 tonnes), and that despite housing two-thirds of the US population and three-quarters of its economic activity, the 100 largest metropolitan areas in the US emitted just 56 per cent of the country's carbon emissions from highway transportation and residential buildings in 2005. However, there is substantial variation between these metropolitan centres, with residents of Lexington, Kentucky (the highest emitting metropolitan area) emitting 2.5 times more carbon than residents of Honolulu, Hawaii – with development patterns, the fuels used to generate electricity, weather and the availability of rail transit having an important effect on these variations. The authors conclude "…*large metropolitan areas offer greater energy and carbon efficiency than non-metropolitan areas*."[39] There are also issues associated with the scale at which emissions inventories are compiled. Although policy debates over emissions inventories and reductions are generally conducted within global and national arenas, action to reduce emissions usually requires actions by local institutions and communities.[40]

V. IDENTIFYING THE CULPRITS: THE REAL CAUSES OF HIGH GREENHOUSE GAS EMISSIONS

The analyses presented in this paper clearly show that it is not cities that are to blame for high levels of greenhouse gas emissions. Indeed, in almost all the cases presented, urban per capita emissions are substantially lower than the average per capita emissions for the countries in which they are located. For example, a regional analysis of UK greenhouse gas emissions shows that the regions with the highest per capita greenhouse gas emissions are the relatively rural northeast, and Yorkshire and the Humber, whereas London has the lowest figure, followed by the highly urbanized West Midlands.[41]

However, there are even more striking differences between greenhouse gas emissions in different world regions. The 20 per cent of the world's population living in high-income countries account for 46.4 per cent of global greenhouse gas emissions, while the 80 per cent of the world's population living in low- and middle-income countries account for the

36. Bastianoni, S, F Pulselli and E Tiezzi (2004), "The problem of assigning responsibility for greenhouse gas emissions", *Ecological Economics* Vol 49, pages 253–257.

37. Peters, G (2008), "From production-based to consumption-based national emission inventories", *Ecological Economics* Vol 65, pages 13–23.

38. Brown, M, F Southworth and A Sarzynski (2008), "Shrinking the carbon footprint of metropolitan America", Brookings Institution, Washington DC, accessed 2 December 2008 at http://www.brookings.edu/papers/2008/05_carbon_footprint_sarzynski.aspx.

39. See reference 38, page 7.

40. Kates, R and R Torrie (1998), "Global change in local places", *Environment* Vol 40, No 2, pages 5 and 39–41; also Angel, D, S Attoh, D Kromm, J DeHart, R Slocum and S White (1998), "The drivers of greenhouse gas emissions: what do we learn from local case studies?", *Local Environment* Vol 3, No 3, pages 263–278.

41. United Kingdom Government (n.d.), "Greenhouse gas emissions – summary", accessed 5 June 2008 at http://www.sustainable-development.gov.uk/regional/summaries/01.htm.

remaining 53.6 per cent. The United States and Canada alone account for 19.4 per cent of global greenhouse gas emissions, while all of South Asia accounts for 13.1 per cent and all of Africa just 7.8 per cent.[42] Even greater differences can be seen if individual countries are compared: per capita CO_2eq emissions vary from less than one tonne (e.g. Bangladesh 0.38; Burkina Faso 0.6) to more than 20 tonnes per year (e.g. Canada 23.72; the USA 23.92; Australia 26.54).[43]

These figures clearly illustrate that it is the high consumption lifestyles of the world's wealthiest countries that result in unsustainable and harmful levels of greenhouse gas emissions. Yet, neither is it appropriate to apportion blame entirely at the national level when there are high-consuming elites within almost all of the world's nations. For example, a recent study in India showed that the average greenhouse gas emissions of an Indian earning more than Rs. 30,000 (approximately US$ 700) per month are 4.52 tonnes CO_2eq per annum – more than four times as much as the 1.11 tonnes CO_2eq per annum generated by an Indian earning less than Rs. 3,000 (approximately US$ 23) per month.[44] Although few studies of this type have been conducted, this particular example illustrates the importance of wealth and its associated patterns of consumption in generating greenhouse gas emissions.

42. Rogner, H, D Zhou, R Bradley, O Crabbé, O Edenhofer, B Hare, L Kuijpers and M Yamaguchi (2007), "Introduction", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate*, Cambridge University Press, Cambridge, 851 pages.

43. United Nations Statistics Division – Environmental Indicators (n.d.), accessed 2 December 2008 at http://unstats.un.org/unsd/environment/air_greenhouse_emissions.htm. Data for Bangladesh and Burkina Faso are from 1994; data for Canada, the USA and Australia are from 2004.

44. Ananthapadmanabhan, G, K Srinivas and V Gopal (2007), "Hiding behind the poor: a report by Greenpeace on climate injustice", Greenpeace India.

VI. CONCLUSION: CITIES AS SOLUTIONS TO GREENHOUSE GAS EMISSIONS

This analysis, however, is not intended to mask the scale of the problem or to disguise the need for substantial action at the city level to address greenhouse gas emissions. Although there have been substantial debates about the overall level of atmospheric carbon dioxide that will result in "acceptable" levels of global climate change, some agreement has been reached over a figure of 450 parts per million, resulting in a temperature rise of approximately 2.5°C.[45] However, because of population growth and other uncertainties, there is even greater doubt over how this equates to individual emissions, although Time for Change[46] has proposed a sustainable annual average figure of 2.5 tonnes CO_2eq per person by 2013. With the exceptions of São Paulo and Rio de Janeiro, all of the cities surveyed above already exceed this per capita figure, in some cases by a very large margin. It must be stressed, therefore, that measuring greenhouse gas emissions is only a preliminary step in addressing climate change rather than an end in itself. Once the level of emissions has been identified, this needs to be used as a base for adopting emissions reduction targets, preparing action plans, implementing policies and measures, and monitoring and verifying results – and many of the city greenhouse gas emissions inventories described above have been prepared specifically with this in mind.

There is also the need to develop comprehensive adaptation strategies for urban areas, particularly in low- and middle-income countries. Hundreds of millions of urban dwellers in these countries are at risk from the direct and indirect impacts of climate change. These include: sea-level rise; an increase in the frequency of heat waves, storms and floods; and more gradual changes that increase risks or exacerbate resource constraints.[47] There is a growing body of evidence demonstrating the dimensions of vulnerability in these settlements, yet there has been insufficient focus on appropriate methods and mechanisms for adaptation.

45. See reference 25.

46. Time for Change (n.d.), "CO_2: the major cause of global warming", accessed 2 December 2008 at http://timeforchange.org/co2-cause-of-global-warming.

47. Bicknell, J, D Dodman and D Satterthwaite (editors) (2009 forthcoming), *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*, London, Earthscan.

It is particularly appropriate to address climate change mitigation at the urban scale for several reasons. First, urban authorities and local governments have the potential to implement mitigation programmes effectively, because of the type of responsibilities they hold in relation to land use planning, local public transportation and the enforcement of industrial regulations. Urban authorities can also set ambitious targets for emissions reductions: the Mayor of London has set a target of stabilizing carbon dioxide emissions in 2025 at 60 per cent below 1990 levels, considerably more ambitious than the UK government's target of a 60 per cent reduction from 2000 levels by 2050;[48] and Canadian cities have continued a programme of home energy rating systems despite the fact that funding for this has been cancelled at the national level.[49] This can be the case even where curbing greenhouse gas emissions is not seen as being the most important urban environmental priority, as cities "*…can use climate change as a reason to promote sustainable patterns of urbanization, which include energy-efficient production utilities*."[50]

Second, the concentration of people and industries in large cities provides the opportunity for technological innovations, such as combined heat and power and waste-to-energy generation plants that can generate electricity more efficiently; and it also makes mass transit systems cost and time effective. Efforts of this type can increasingly be seen, even in cities in low- and middle-income countries: for example, the replacement of the city administration's cooling system in Cebu City, Philippines, with a more energy and carbon effective mechanism;[51] or the development of electricity generation from landfill gas recovery in Dar es Salaam, Tanzania.[52]

Third, this concentration also provides the opportunity for the rapid spread and adoption of new ideas and innovations, both in technical and behavioural solutions. For example, Ken Livingstone, the former Mayor of London, has stated that addressing climate change requires determination on the part of the city authorities, sophisticated financial institutions to respond to carbon trading and investment technologies, and state of the art scientific and technical research facilities to develop the technologies of the future[53] – a combination of features that can only be found in major metropolitan centres.

Finally, reducing greenhouse gas emissions can also lead to various other urban benefits. In Vienna, increasing the efficiency of power generation and encouraging more effective thermal insulation in homes and offices is expected to reduce fuel costs alongside greenhouse gas emissions, and it is anticipated that reducing emissions from traffic and transport will simultaneously increase pedestrian safety.[54] More generally, curbing greenhouse gas emissions may also improve local public health through reduced air pollution and increased physical activity.[55]

As shown in this paper, there is no fundamental link between urbanization and high levels of greenhouse gas emissions – rather, it appears that well-planned, well-managed cities can play a central role in helping to mitigate against climate change.[56] This does not necessarily entail increasing densities (particularly in low- and middle-income countries) but, rather, an awareness of broader issues of the urban form and urban structure.[57] In addition, there still need to be major reductions in emissions – particularly from the cities of Europe and North America – if climate change targets are to be met. Local emissions inventories are key, as these provide the basis from which local mitigation plans can be formulated. This requires commitment on the part of international organizations to

48. See reference 12.

49. Parker, P and I Rowlands (2007), "City partners maintain climate change action despite national cuts: residential energy efficiency programme valued at local level", *Local Environment* Vol 12, No 5, pages 505–518.

50. Romero Lankao, P (2007), "How do local governments in Mexico City manage global warming?", *Local Environment* Vol 12, No 5, page 520.

51. Francisco Fernandez, personal communication.

52. Information on this and other Clean Development Mechanism-financed activities can be found at http://cdm.unfccc.int.

53. See reference 12.

54. Klip Wien (n.d.), "Klimaschuts Programm Wien: planning and design", accessed 2 December 2008 at http://www.energyagency.at/klip/.

55. Bloomberg, M and R Aggarwala (2008), "Think locally, act globally: how curbing global warming emissions can improve local public health", *American Journal of Preventive Medicine* Vol 35, No 5, pages 414–423.

56. Bulkeley, H and M Betsill (2003), *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*, Routledge, Abingdon.

57. Burgess, R (2000), "The compact city debate: a global perspective", in M Jenks and R Burgess (editors), *Compact*

Cities: Sustainable Urban Forms for Developing Countries, Spon Press, London, pages 9–24; also Jenks, M (2000), "The appropriateness of compact city concepts to developing countries", in Jenks and Burgess, see above, pages 343–350.

support and guide these activities, national governments to provide the necessary legislative framework, urban authorities to implement activities, and individual citizens to change their lifestyles in appropriate ways. However, as this paper also shows, this alone is not sufficient. Although well-planned, energy efficient cities with good public transportation systems may appear to be winning the battle to reduce emissions if these are accounted for on a "production" basis, these apparent gains will be undercut unless the consumption patterns of these cities' inhabitants – who purchase imported manufactured goods, consume energy intensive diets and travel extensively around the world – are not changed as well.

REFERENCES

Air Quality Division (2005), *District of Columbia Greenhouse Gas Emissions Inventories and Preliminary Projections*, District of Columbia Department of Health, Air Quality Division.

Ananthapadmanabhan, G, K Srinivas and V Gopal (2007), "Hiding behind the poor: a report by Greenpeace on climate injustice", Greenpeace India.

Bai, X (2007), "Industrial ecology and the global impacts of cities", *Journal of Industrial Ecology* Vol 11, No 2.

Baldasano, J, C Soriano and L Boada (1999), "Emission inventory for greenhouse gases in the city of Barcelona, 1987–1996", *Atmospheric Environment* No 3, pages 3765–3775.

Bastianoni, S, F Pulselli and E Tiezzi (2004), "The problem of assigning responsibility for greenhouse gas emissions", *Ecological Economics* Vol 49, pages 253–257.

Bicknell, J, D Dodman and D Satterthwaite (editors) (2009), *Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges*. London, Earthscan.

Bloomberg, M and R Aggarwala (2008), "Think locally, act globally: how curbing global warming emissions can improve local public health", *American Journal of Preventive Medicine* Vol 35, No 5, pages 414–423.

Brown, M, F Southworth and A Sarzynski (2008), "Shrinking the carbon footprint of metropolitan America", Brookings Institution, Washington DC, http://www.brookings.edu/papers/2008/05_carbon_footprint_sarzynski.aspx.

Bulkeley, H and M Betsill (2003), *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*, Routledge, Abingdon.

Burgess, R (2000), "The compact city debate: a global perspective", in M Jenks and R Burgess (editors), *Compact Cities: Sustainable Urban Forms for Developing Countries*, Spon Press, London, pages 9–24.

Clinton Foundation (n.d.) "Clinton climate initiative", http://www.clintonfoundation.org/cf-pgm-cci-home.htm.

Dhakal, S (2004), *Urban Energy Use and Greenhouse Gas Emissions in Asian Mega-cities*, Institute for Global Environmental Strategies, Kitakyushu, Japan.

Dubeux, C and E La Rovere (2007), "Local perspectives in the control of greenhouse gas emissions – the case of Rio de Janeiro", *Cities* Vol 24, No 5, pages 353–364.

Girardet, H (1998), "Sustainable cities: a contradiction in terms?", in E Fernandes (editor), *Environmental Strategies for Sustainable Development in Urban Areas: Lessons from Africa and Latin America*, Ashgate, Aldershot.

Glasgow and the Clyde Valley Structure Plan Joint Committee (n.d.), "Glasgow and the Clyde Valley greenhouse gas inventory: a summary guide", http://www.gcvcore.gov.uk/downloads/GCVGreenhouseGasInventory.pdf.

Gobierno del Distrito Federal (2004), *Local Climate Action Strategy of Mexico City*, Secretaría de Medio Ambiente, Gobierno del Distrito Federal, México.

Harvey, L (1993), "Tackling urban CO_2 emissions in Toronto", *Environment* Vol 35, No 7, pages 16–44.

http://aspenglobalwarming.com.

http://cdm.unfccc.int.

http://service.govdelivery.com/docs/camenlo/camenlo_101/camenlo_101_20071117_en.pdf.

http://www.cacities.org/resource_files/26338.chula%20vistaGHG_InventoryReport_Final.pdf

http://www.cob.org/documents/pw/environment/2007–04–12-Greenhouse-gas-inv-rpt-and-action-plan.pdf.

ICLEI (2008), "Local government operations protocol for the quantification and reporting of greenhouse gas emissions inventories", http://www.icleiusa.org/action-center/tools/lgo-protocol-1.

Intergovernmental Panel on Climate Change (IPCC) (1999), *Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Intergovernmental Panel on Climate Change (IPCC) (2006), *Guidelines for National Greenhouse Gas Inventories*, Cambridge University Press, Cambridge.

Intergovernmental Panel on Climate Change (IPCC) (2007), "Summary for policymakers", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, 851 pages.

Jenks, M (2000), "The appropriateness of compact city concepts to developing countries", in M Jenks and R Burgess (editors), *Compact Cities: Sustainable Urban Forms for Developing Countries*, Spon Press, London, pages 343–350.

Kahn Ribeiro, S, S Kobayashi, M Beuthe, J Gasca, D Greene, D Lee, Y Muromachi, P Newton, S Plotkin, D Sperling, D Wit and P Zhou (2007), "Transport and its infrastructure", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pages 323–386.

Kates, R, M Mayfield, R Torrie and B Witcher (1998), "Methods for estimating greenhouse gases from local places", *Local Environment* Vol 3, No 3, pages 279–298.

Kates, R and R Torrie (1998), "Global change in local places", *Environment* Vol 40, No 2, pages 5 and 39–41; also Angel, D, S Attoh, D Kromm, J DeHart, R Slocum and S White (1998), "The drivers of greenhouse gas emissions: what do we learn from local case studies?", *Local Environment* Vol 3, No 3, pages 263–278.

Klip Wien (n.d.), "KlimaschutsProgramm Wien: planning and design", http://www.energyagency.at/klip/.

Lebel L, P Garden, M Banaticla, R Lasco, A Contreras, A Mitra, C Sharma, H Nguyen, G Ooi and A Sari (2007), "Integrating carbon management into the development strategies of urbanizing regions in Asia: implications of urban function, form and role", *Journal of Industrial Ecology* Vol 11, No 2, pages 61–81.

Mayor of London (2007), *Action Today to Protect Tomorrow: The Mayor's Climate Change Action Plan*, Greater London Authority.

McManus, P and G Haughton (2006), "Planning with ecological footprints: a sympathetic critique of theory and practice", *Environment and Urbanization* Vol 18, No 1, April, pages 113–127.

Newman, P (2006), "The environmental impact of cities", *Environment and Urbanization* Vol 18, No 2, October, pages 275–295; and other sources as identified in Table 1.

Parker, P and I Rowlands (2007), "City partners maintain climate change action despite national cuts: residential energy efficiency programme valued at local level", *Local Environment* Vol 12, No 5, pages 505–518.

Peters, G (2008), "From production-based to consumption-based national emission inventories", *Ecological Economics* Vol 65, pages 13–23.

PlaNYC (2007), "Inventory of New York city greenhouse gas emissions", Mayor's Office of Operations, New York City.

Rio Prefeitura Meio Ambiente (2003), *Inventário de Emissões de Gases do Efeito Estufa da Cidade do Rio de Janeiro*, Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas, Rio de Janeiro.

Rogner, H, D Zhou, R Bradley, O Crabbé, O Edenhofer, B Hare, L Kuijpers and M Yamaguchi (2007), "Introduction", in B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (editors), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate*, Cambridge University Press, Cambridge.

Romero Lankao, P (2007), "How do local governments in Mexico City manage global warming?", *Local Environment* Vol 12, No 5, page 520.

Sánchez-Rodríguez, R, K Seto, D Simon, W Solecki, F Kraas and G Laumann (2005), "Science plan: urbanization and global environmental change", International Human Dimensions Programme on Global Environmental Change, Report No 15, Bonn.

Satterthwaite, D (1999), "The key issues and the works included", in D Satterthwaite (editor), *The Earthscan Reader in Sustainable Cities*, Earthscan, London, pages 3–21.

Satterthwaite, D (2008), "Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions", *Environment and Urbanization* Vol 20, No 2, October, pages 539–549.

Secretaria Municipal do Verde e do Meio Ambiente de São Paulo (SVMA) (2005), *Inventário de Emissões de Efeito Estufa do Município de São Paulo*, Centro de Estudos Integrados sobre Meio Ambiente e Mudanças Climáticas (Centro Clima) da Coordenação dos Programas de Pós-graduação de Engenharia (COPPE) da Universidade Federal do Rio de Janeiro (UFRJ).

Time for Change (n.d.), "CO_2: the major cause of global warming", http://timeforchange.org/co2-cause-of-global-warming.

United Kingdom Government (n.d.), "Greenhouse gas emissions – summary", http://www.sustainable-development.gov.uk/regional/summaries/01.htm.

United Nations (2007), "City planning will determine pace of global warming", http://www.un.org/News/Press/docs/2007/gaef3190.doc.htm.

United Nations Statistics Division – Environmental Indicators (n.d.), http://unstats.un.org/unsd/environment/air_greenhouse_emissions.htm.

VandeWeghe, J and C Kennedy (2007), "A spatial analysis of residential greenhouse gas emissions in the Toronoto census metropolitan area", *Journal of Industrial Ecology* Vol 11, No 2, pages 133–144.

Wackernagel, M and W Rees (1995), *Our Ecological Footprint*, New Society Publishers, Gabriola.

Wackernagel, M, J Kitzes, D Moran, S Goldfinger and M Thomas (2006), "The ecological footprint of cities and regions: comparing resource availability with resource demand", *Environment and Urbanization* Vol 18, No 1, April, pages 103–112.

Walker, G and D King (2008), *The Hot Topic: How to Tackle Global Warming and Still Keep the Lights On*, Bloomsbury Publishers, London.

Weber, C, G Peters, D Guan and K Hubacek (2008), "The contribution of Chinese exports to climate change", *Energy Policy* Vol 36, pages 3572–3577.