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Review

How urban societies can adapt to resource shortage and climate change

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With more than half the world's population now living in urban areas and with much of the world still urbanizing, there are concerns that urbanization is a key driver of unsustainable resource demands. Urbanization also appears to contribute to ever-growing levels of greenhouse gas (GHG) emissions. Meanwhile, in much of Africa and Asia and many nations in Latin America and the Caribbean, urbanization has long outstripped local governments' capacities or willingness to act as can be seen in the high proportion of the urban population living in poor quality, overcrowded, illegal housing lacking provision for water, sanitation, drainage, healthcare and schools. But there is good evidence that urban areas can combine high living standards with relatively low GHG emissions and lower resource demands. This paper draws on some examples of this and considers what these imply for urban policies in a resource-constrained world. These suggest that cities can allow high living standards to be combined with levels of GHG emissions that are much lower than those that are common in affluent cities today. This can be achieved not with an over-extended optimism on what new technologies can bring but mostly by a wider application of what already has been shown to work.

Keywords: urbanization; sustainable development; climate change

1. Introduction

Urban centres and urbanization (the increasing proportion of a population living in urban centres) do not enjoy good reputations from an ecological perspective and are often cited as drivers of unsustainable environmental change [1,2]. Certainly, the much increased pressures on the world's natural resources and ecological systems over the last century or so has been accompanied by a very rapid growth in the world's urban population—from 260 million in 1900 [3] to over 3.4 billion today [4]. The world's population has urbanized rapidly, driven mainly in recent decades by the very large expansion in the world's economy and by changes in its structure. Most new investment, economic value and employment

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have been in industry and service enterprises and most such enterprises have chosen to locate in urban areas. This helps in explaining why the ratio of rural : urban dwellers changed from 7 : 1 in 1900 to around 1 : 1 today [5]. The rapid increase in urban population and urban production has been accompanied by an even more rapid increase in the use of fossil fuels (and hence in carbon dioxide emissions) and in most other mineral resources and in freshwater, fish and forestry products. Urbanization is also associated with increasing wealth (at least for a proportion of the growing urban population) and increasing *per capita* consumption levels. In many nations, urbanization has also been influenced by the locations chosen by multi-national corporations for their production and for the centres where they concentrate their management [6]. Thus, urbanization can be seen as one of the key drivers of high levels of resource use and waste generation that have serious ecological consequences locally (within and around urban centres), regionally (where resource and waste flows from urban centres shift to the wider region) and globally (for instance in regard to climate change and in the reduction in the ozone layer).

However, these local, regional and global ecological consequences are not so much driven by urbanization as by the rapid increase in consumption levels and in the number of people with high-consumption lifestyles—and the (increasingly globalized) production systems that serve and support these. A considerable proportion of this consumption is from middle- and upper-income rural inhabitants and when the consumption and waste generation patterns of rural and urban inhabitants with comparable incomes are compared, urban inhabitants generally have lower consumption and less waste generation. The paper also highlights how not all urbanization is associated with large regional and global ecological impacts—and ends with a discussion of how urbanization can help to delink high standards of living from large local, regional and global ecological impacts. Urbanization brings obvious economic advantages for businesses which explain why private investment concentrates in urban areas but it also brings some environmental advantages that are less obvious—for reducing resource use and greenhouse gas (GHG) emissions, for good environmental health and for building resilience to the likely impacts of climate change. But whether these advantages are realized depends on how urban centres are structured and governed, and, for resource use and waste generation, on the choices made by their wealthier inhabitants.

2. Urban characteristics

Urban centres share some characteristics—a concentration of people and enterprises and their buildings and wastes, infrastructure and usually some public institutions (for instance for schools, police force and for some the seat of local government). They also share a reliance on resources from outside their boundaries (food, usually freshwater and fossil fuels and other mineral resources) and often extra-urban sinks for their wastes. And as urban centres expand, so they transform natural landscapes and land use and land cover—for instance creating more stable sites by filling valleys and swamps and reshaping hills and in the process disrupting local ecologies, changing water flows and increasing impermeable areas [7,8]. The creation and expansion of urban centres also draws

in large volumes of materials—for land fill and building materials, food, forestry products and other natural resources and these material flows also change and often transform the areas from which they are drawn. Larger cities often outgrow the capacity of their locality to provide freshwater and many cities have helped decrease such supplies through polluting local sources or mismanaging local aquifers [9].

Urban centres also change the environment of their locality—for instance by reducing rainfall and increasing night-time temperatures [10]. Almost all large urban centres are warmer than their surrounding rural areas, although the size and timing of these differentials are highly variable and influenced by many factors [1]. The urban heat island effect is generally higher in larger urban centres or in particular districts of large urban centres—for instance high-density areas with multi-storey buildings, little open space and little effective natural ventilation. Heat islands have both local and extra-local impacts; locally, they can increase heat stress with particularly serious consequences for vulnerable and working populations [11], pollution (as the higher temperature facilitates more generation of ozone if the precursors are already present) and energy demands for cooling (which when achieved through air conditioning also means more waste heat). Regionally, they usually increase demand for water and globally, they can increase GHG emissions, if a growing use of air conditioning is powered by electricity from thermal power stations.

Thus the energy and material demands of enterprises, residents and institutions in urban areas can alter land use and land cover and freshwater availability locally and often regionally while the disposal of their wastes into water, soils and the atmosphere can impact local to regional and global biogeochemical cycles and climate [12].

The energy and material demands that larger and wealthier urban centres concentrate for natural resources are often increasingly met by imports from beyond their region—including imports from abroad. For instance, around 80 per cent of the food consumed in London is imported from other countries [13]. Many major cities draw on freshwater resources far from their boundaries [14,15]—for instance Mexico City now has to draw some of its water supplies from 150 km away, and pump it up nearly 1000 m [16,17].

But there is such diversity among urban centres in their size, structure, spatial form, economy, wealth, local resource availability and local, regional and global ecological impact that few generalizations are valid. Urban centres vary in size from a few thousand (or in some nations a few hundred) inhabitants to the 21 metropolises that by 2010 had (or were estimated to have) more than 10 million inhabitants [4] and were termed megacities. United Nations (UN) estimates for 2010 suggest that around half the world's urban population lives in urban centres of under 500 000 inhabitants [4] and a considerable proportion of these lives in urban centres with under 20 000 inhabitants (although the proportion living in such urban centres in any nation is much influenced by the criteria used to define an urban centre—for instance if urban centres are all settlements with over 1000 inhabitants or all settlements with over 10 000 inhabitants) [18]. There is no universally accepted definition for an urban centre or for a city or for when an urban centre becomes a city but the term city implies a scale or a political or religious status that would mean that a large section of the world's urban population does not live in cities. Although it is common to see the comment

that more than half the world's population lives in cities, this is not correct; they live in urban centres, a high proportion of which are small market towns or service centres that would not be considered to be cities.

Urban centres have economies that vary from the simple—for instance small market towns, mining centres or tourist resorts—to the complexities of large cities and metropolitan regions whose economic base serves local, regional, national and global markets and who sit within large and complex transport systems where a high proportion of the workforce may live outside the city. The differentials between urban centres for all aspects of material and energy use and waste generation are likely to be very large, although the analyses of material and waste flows undertaken to date have given little attention to urban centres in low-income nations. But most small market towns or service centres in low-income nations are likely to have very low levels of use for non-renewable resources as incomes and consumption levels are low so demand for material-intensive capital goods is also low and there is little or no industry. These urban centres draw most of their material needs (food, other natural resources, water) from close by. A high proportion of the urban population in many low-income nations do not have electricity and use biomass fuels [19]. For instance, among the nations that the UN classifies as the Least Developed Countries, close to half the urban population lack access to electricity and more than three-fifths lack access to modern fuels [19]. This also implies very low levels of GHG emissions per person. A proportion of low-income nations has GHG emissions below 0.1 tonnes of carbon dioxide equivalent (CO_2e) per year [20] and it is likely that a proportion of their small urban centres have comparable levels. From a perspective of ecological sustainability, these small urban centres perform extremely well. Even some larger urban centres in low-income nations have GHG emissions that are around 0.1 tonnes CO_2e per person per year while many cities in (for instance) India and Bangladesh have below 1 tonne [21]. But as discussed below, most of the more ecologically sustainable urban centres have low living standards with much of their population facing large preventable health burdens.

Meanwhile, there are many wealthy cities with GHG emissions that are 10–25 tonnes of CO_2e per person per year and so 100–250 times those with 0.1 tonnes per person per year. Also with levels of resource use for fossil fuels and many minerals that are far higher and likely to be unsustainable if extended to a larger section of the world's urban population.

3. Measuring the environmental performance of urban areas

The original definition of sustainable development was a combination of two goals: meeting the needs of the present without compromising the ability of future generations to meet their needs [22]. For urban centres, this requires that they meet their residents' needs (being healthy, enjoyable, resilient places to live and work for all their inhabitants) while ensuring that the draw of their populations' consumption and enterprises' production on local, regional and global resources and sinks is not disproportionate to their finite capacities. Anthropogenic climate change adds to the urgency of the second goal and requires no disproportionate

contribution to GHG emissions. It also requires urban adaptation to achieve the resilience needed for the new hazards and increased risk levels that climate change will bring.

How the term 'disproportionate' gets interpreted has long been debated, as have the metrics to be used for measuring sustainability [23]. Initially, the concerns for sustainability focused on the depletion of non-renewable resources, especially oil; then there was a realization that key resources such as fertile soils, freshwater, forests and fisheries that are renewable need to be included because their supply is finite—and can be reduced (through deforestation, soil degradation, pollution or over-fishing). To this were added concerns of global systems degraded or disrupted, including the depletion of the stratospheric ozone layer, global warming and the loss of biodiversity. But there are no easy ways to measure whether a city, smaller urban centre or rural area has a 'disproportionate' draw on local, regional and global resources and sinks. In part, this is because much of its draw on resources and sinks may be embedded in the goods that are sold or used there but manufactured elsewhere. For instance, wealthy cities can retain parks, forests and wilderness sites within and around them because most goods used by their citizens that are water-, energy-, pollution-, waste- and land-intensive are drawn from beyond their surrounds—and much of it from abroad [12].

To manage any city's draw on resources and sinks, there need to be measurements that indicate the scale and nature of this draw [24,25], including draws from beyond the city and its surrounds. Various ways have been developed for mapping the energy and material flows into cities and the wastes out of cities [26,27]. There are also a range of ways of measuring some of the ecological impacts of particular goods or services consumed in urban areas that consider these from the point of production (and its material needs) to the point of consumption or disposal—for instance the natural material input into a product in relation to the service it provides [28] or the measuring of 'virtual water' (for instance to consider the water-using implications of goods imported into a city in their original production) or food miles (the distance that food is transported from where it is produced to where it is consumed). There is also a particular interest in the ecological impacts of food systems; these have successfully met rising demands worldwide, including the rapid increase in the proportion of non-agricultural workers to agricultural workers that accompanies urbanization and including diets that are far more meat-intensive. But there are the environmental and ecological consequences of a far more energy-, chemical- and carbon-intensive food production to consider [29].

Perhaps the best-known and most widely used measure for cities and nations is the ecological footprint [30]. This calculates the productive land area that a city or nation draws on continuously to provide the food and resources that its inhabitants, enterprises and institutions use, to process the wastes and to absorb the carbon dioxide produced. From this can be calculated the average ecological footprint of each person within a city or nation in terms of productive land area. This can be compared with the land area estimated to be the global average that is sustainable. Figures for wealthy nations or cities in wealthy nations have been shown to be several times this average. Ecological footprints can also be calculated for individuals or households—for instance to highlight the much larger ecological footprint of wealthy households when compared with low-income households [24].

But getting a precise and complete measure of resource use and waste generation within a city is limited by data availability. In many nations, much of the data needed are not available or only available for nations. There are also the complications as to what to include—for instance for a city, do the material, energy and waste implications of the consumption of tourists and of commuters who work in the city but live outside get included in the figures for the city? Is it possible to take out of the accounting for a city the material, energy and waste generated in the fabrication of goods or services that are sold outside the city? If this is not subtracted, the cities that are centres for the manufacture of key goods for lowering ecological footprints such as photovoltaic cells, windmills or hydrogen buses will appear to be unsustainable. There are also difficulties with avoiding double counting—for instance with energy consumption that may be accounted for within goods (for instance food and water) that then has to be subtracted from energy statistics [13].

There are data showing the much higher levels of resource use per person in high-income nations when compared with low- and middle-income nations and the higher levels of domestic waste [15]. But it is difficult to judge whether a nation's, city's or individual's draw on planetary resources and sinks is 'disproportionate' when there is uncertainty about the size of the resource or the capacity of the sink. For instance, for many resources, the quantity available depends on the price (as prices rise so a greater stock becomes available as higher prices allow the exploitation of lower quality ores or oil-bearing materials). Higher prices encourage more exploration that can lead to finding new sources that expand the global stock.

For global warming, the metrics for measuring the global impacts of nations or sub-sets of nations including cities are more straightforward—and done through GHG emission inventories. For cities, these have been based on the methods and sources used for national GHG emission inventories, and follow guidelines set by the Intergovernmental Panel on Climate Change (IPCC) [31]. City GHG emission inventories have now been done for over a 100 cities [21] and as noted above, these show the enormous range in the scale of average *per capita* emissions of GHGs.

An inventory of emission sources can allocate their emissions between cities, other urban centres and rural areas but this is not a simple exercise. For instance, the places with large coal-fired power stations are very high GHG emitters although most of the electricity they generate may be used elsewhere. This is why GHG emission inventories generally assign cities the emissions generated in providing the electricity consumed within their boundaries, even when the electricity is produced elsewhere. This helps explain why some cities have surprisingly low *per capita* emissions relative to their wealth—for instance cities supplied with electricity from hydropower or nuclear power.

There are other difficulties in assigning GHGs to particular locations. For instance, transport is one of the main sources of GHG emissions in all cities but do the emissions from the fuels used by car-driving or rail or bus using commuters get attributed to the city where they work or the place where they live (which may be a suburb or a rural area outside the city where they work)? Which locations get assigned the carbon emissions from air travel? Total carbon emissions from any city with an international airport are much influenced by whether or not the city is assigned the fuel loaded onto the aircraft. Total carbon emissions for cities such as Sao Paulo, Rio de Janeiro, London or New York are much

influenced by whether or not these cities are assigned the fuel loaded onto aircraft in their airports [32,33]. If aviation was included in New York's GHG emission inventory, it would constitute 14 per cent of total CO_2e emissions [32]. Then there are the complications of city airports that are outside city boundaries—so should London be allocated the carbon emissions from planes fuelled just at Heathrow and City airports (that are within its boundaries) or also Stansted, Gatwick and Luton airports that serve Londoners (even though a proportion of the passengers flying from these airports are in transit and do not come to London or do not live in London)?

But at least for global warming, there is an information base on the GHG emissions taking place within each nation's boundaries and thus a guide to their contribution to the global problem. This can guide action now to reduce GHG emissions globally. But here too, there is debate about how responsibility should be allocated between nations. Should it take account of historic contributions to GHGs in the atmosphere (which would further increase the responsibility of high-income nations)? Should the system that sets limits on emissions be based on where the emissions are produced or the homes of the consumers whose consumption caused the emissions (again the latter greatly increases the responsibilities of high-income nations as emissions within their borders are kept down by importing most goods whose fabrication involved large emissions)? But whichever method is used for assigning responsibilities, how urban centres perform as places to live and as centres of production and consumption has great relevance. So the issue is whether urban centres are or could be centres of 'good' development and environmental management and centres with carbon emissions or ecological footprints that are sustainable. This also means centres of lifestyles that keep average *per capita* GHG emissions below whatever level is calculated as the average level for the world's population that would avoid dangerous climate change—sometimes called the fair share level. These goals have to be considered together. As noted above, most urban centres in low-income nations have very low levels of GHG emissions per person because there is little or no industry and consumption levels are so low (including a high proportion of the population that do not get enough to eat). Many urban centres in high-income nations are among the world's healthiest and safest places but with ecological footprints that are vastly disproportionate, including *per capita* GHG emissions that are 3–15 times the global fair share level. So for low-income nations, the issue is whether urban centres with small ecological footprints can become healthy, safe, desirable places to live and work without vastly increasing this footprint. This would mean going against the general trend in the past which has been for a strong association between better health and larger ecological footprints and carbon emissions [12]. For high-income nations, the issue is whether urban centres can retain or enhance their quality of life and economic base while radically reducing their carbon dioxide emissions or more generally their ecological footprint. The performance of urban centres in both of these has even greater relevance in a world where the proportion of the world's population living in cities and towns is growing and likely to continue growing at least in the next decade or two [4].

For anthropogenic GHG emissions, it is possible to estimate an average figure for each person's emissions (usually expressed in terms of CO_2e) which if achieved globally should avoid dangerous climate change (the 'fair share' figure). This will be substantially below current figures for global emissions (in 2004, this was

around 7.5 tonnes per person [34]), although there are still uncertainties as to the extent to which and the speed with which global emissions must fall. But to bring down global emissions by 2050 sufficiently to avoid dangerous climate change, it needs a global average of around 2 tonnes of CO_2e per person [35]. There are also other issues that need to be resolved in setting this fair share level—for instance in setting it, is consideration given to the maintenance or expansion of carbon sinks (so do people in nations where carbon sinks can be expanded get higher allowances [36])? Also do people who have more carbon-intensive needs—for instance much larger space heating needs during the year—get higher annual allowances [36]?

However, highlighting the fact that it is individuals' consumption patterns and lifestyles that are the real drivers of most GHG emissions means that it is possible to set a fair share level to which those above this level must contract and those below this level are allowed to increase to this level (the concept of contraction and convergence) [37]. This highlights how avoiding dangerous climate change depends on the personal responsibility of consumers. It highlights the large draw of wealthy people's lifestyles on fossil fuel reserves and on the world's forests (as fossil fuel consumption and deforestation are such important contributors to GHG emissions). It also indirectly brings in the use of some mineral resources in that the GHG emission accounts for any individual would include the goods they purchase and thus the fossil fuels used in the mining, refining and use of the resources in manufacturing these goods and transporting, promoting and selling them.

Another reason for focusing on the performance of individuals or households rather than their settlements (cities, small urban centres, rural areas) is the large differentials in GHG emissions per person within such settlements. For instance, the city of Toronto has average *per capita* emissions far above the fair share level—but there are citizens in Toronto and small pockets in Toronto where *per capita* emissions are below the fair share level [21]. A study looking at residential and transport related GHG emissions per person (in CO_2e) in Toronto's 832 census tracts found that the top 10 tracts had average annual emissions of 12.3 tonnes *per capita* compared with 3.6 for the bottom 10 tracts. All the top 10 tracts were outside the central city and private automobile use accounted for 61 per cent of emissions. For the bottom 10 tracts, only 30 per cent of emissions were for private automobile use and all but one of these tracts was in the central city [38].

The differentials are likely to be even larger in cities in many low- and middle-income nations. *Per capita* emissions among low-income groups will often be between 0.1 and 0.5 tonnes of CO_2e [39] while *per capita* emissions in many high-income low-density suburbs may be comparable to those in the high-income nations.

4. Using the opportunities/advantages that urbanization brings for health

Concentrating people, enterprises, motor vehicles and their wastes can make cities very dangerous places—but this same concentration brings many potential advantages for health. That cities have economies of scale, proximity and agglomeration that bring substantial benefits for most businesses is well known; indeed, that is why the world urbanized. But less discussed are the economies

of scale and proximity for public goods and services. High densities and large population concentrations usually lower the costs per household and per enterprise for the provision of infrastructure (all-weather roads and paths, good quality piped water, sewers, drains, electricity) and services (including all forms of schools and healthcare, emergency services and access to the rule of law and to government). The concentration of industries reduces the unit cost of making regular checks on plant and equipment safety, as well as on occupational health and safety, pollution control and the management of hazardous wastes [15]. There are also economies of scale or proximity for reducing risks of disasters, and generally a greater capacity among city dwellers to pay for these, or at least to contribute towards the costs. Disasters are much less frequent in well-governed cities with good quality housing, infrastructure and services and when disasters occur in such cities, fatalities are usually much lower [40]. For instance, fatalities from cyclones are far higher in low- and middle-income nations than in high-income nations, even though high-income nations such as Japan and the USA have high exposure to cyclones [41] and even though there are exceptions such as Hurricane Katrina's devastating impact on New Orleans.

But in the absence of needed infrastructure and services and city governments with the needed competence and accountability, cities become very dangerous places to live and work. There are many cities in Africa with life expectancies that are half what they should be—and as low as those in the industrial cities in Europe 160 years ago before key reforms of local governments and of water, sanitation, healthcare, housing access, minimum wages and occupational health. In cities in low- and middle-income nations, it is common for a third to half the population to live in poor quality, overcrowded housing in informal settlements that lack adequate provision for water, sanitation, healthcare, schools, the rule of law and often even the right to vote (as this requires a legal address that houses in informal settlements lack). In such settlements, it is common for infant and child mortality rates to be 10–20 times what they should be [15].

Urbanization is also associated with a growing health burden from chronic non-communicable diseases for adults, related to changes in diet and less exercise and often from large health impacts from air pollution and traffic accidents [42]. In some nations, cities are also associated with high levels of violence [43]. But these too are issues that can be addressed and have been addressed; a well-governed city should also be a city that addresses these health risks.

5. Resource use and density

Before suburban trains and high levels of private car ownership, cities were dense largely because of the value of close physical proximity for city businesses and institutions. Low-income groups value central locations for the easier and cheaper access it provides to employment opportunities. Close physical proximity is still valued by most businesses and many people, even though improvements in road, rail and air transport in most cities have allowed a larger physical separation between home and work. The shift of residences from the city to the suburbs and beyond that these improvements brought was in part driven by the possibilities for those who moved to get more space and escape urban pollution and congestion.

But the urban sprawl that this often produced brought with it a set of health problems [44] and generally a greater dependence on private automobile use and so higher GHG emissions.

Dense cities have great potential for limiting the use of motor vehicles (and the associated use of fossil fuels, the generation of air pollution and GHGs). This might sound contradictory, as most large cities have problems with congestion and motor-vehicle-generated air pollution but these are problems that can be addressed. As air pollution levels in wealthy cities came down and as commuting times, costs and inconveniences increased for those living in the suburbs or beyond, so the advantages of living in more dense cities became apparent. Dense cities allow many more journeys to be made by walking or bicycling, and they make a greater use of public transport and a high-quality service more feasible. Many prosperous European cities, with among the world's highest quality of life, have one-fifth of the gasoline use per person of the USA's less compact, more car-dependent cities [45]. Most European cities have high-density centres where walking and bicycling are preferred by much of the population, especially where good provision is made for pedestrians and bicyclists (including public transport that can accommodate bicycles). Many European cities also have high-quality public transport that keeps down private automobile ownership and use, and many cities here and in other regions have invested in improving public transport, including greater use of bus-based rapid transit (that is much cheaper and easier to install than light rail or metros). In dense cities where there is good provision for walking, bicycling and public transport, automobile ownership and use can be low, even in prosperous cities and among prosperous households. Singapore has one-fifth of the automobile ownership per person of most cities in other high-income nations, yet also a higher income per person [46]. Among the limited number of cities for which there are data on GHG emissions by sector, the percentage generated by transport varies from 11 to 59 per cent [47]. It is generally the higher density cities that have the lower proportions; the North American cities have among the highest levels of transport energy per person, the highest GHG emissions per person and the lowest densities. However, some of the differences in the contribution of transport may be related to other factors that include the extent to which space heating is needed, the role of industry in the city's economy, the extent to which air conditioning is used and the carbon intensity of electricity production. Some of the differences may also be the result of differences in methods in undertaking emission inventories and their assignment to different sectors.

Meanwhile, in some cities in low- and middle-income nations, the disadvantages of high density have lessened as strategies to improve housing and living conditions in high-density low-quality tenements and informal settlements (often termed 'slum' or 'squatter' upgrading) have transformed the quality of housing and living conditions there, while retaining the advantages of high-density residential areas. For instance, in Thailand, many high-density informal settlements with poor quality housing and a lack of basic infrastructure and services have been transformed without expelling the low-income population and without reducing the density. This has been supported by the central government's Community Organizations Development Institute (CODI) that channels infrastructure subsidies and housing loans direct to savings groups formed by low-income inhabitants in informal settlements. It is these savings

groups who plan and manage the improvements to their housing or develop new housing on the same site. They also negotiate with the landowner to sort out legal tenure and work with local governments or utilities to improve infrastructure and services. From 2003 to early 2008, within the Baan Mankong (secure housing) programme, CODI approved 512 projects in over 200 urban centres covering 53 976 households and it plans a considerable expansion in the programme within the next few years. In terms of density, many of the upgraded settlements had 150–300 units per hectare, achieved with two or three storey terraces [48].

For most cities in low- and middle-income nations, one of the most important issues is retaining the high-density low-income residential areas but improving the quality without expelling the low-income population who need to keep close proximity to livelihoods. Generally, the redevelopment of these areas drives out the original inhabitants. But there are a growing number of examples like those of CODI above that have supported the low-income inhabitants to develop their own upgrading. It is also possible to do this at very high densities—as demonstrated in some high-density central city locations in Karachi [49]. In Mumbai, India, there is the long-running debate about how to redevelop Dharavi, a long-established very dense informal township with around 600 000 residents and a high concentration of jobs squeezed into a 2 km^2 site. From a resource-using perspective, Dharavi is very efficient; most residents have low consumption levels and walk to work and many are engaged in reusing or recycling wastes. GHG emissions per person would also be very low. But from a health perspective, it is mostly poor quality and very overcrowded housing and a lack of infrastructure and services. But even with densities this high, Dharavi can be redeveloped incrementally in ways that accommodate residents and livelihoods and that keep the area's economic dynamism and that greatly improve living conditions—and thus keep the resource-using advantages without the health disadvantages [50,51].

For regions that require space heating for part of the year, high-density residential areas with high-quality housing make possible less energy-intensive homes. Space heating constitutes one of the main energy users in most high-income nations and high-density buildings can have an inherent advantage for lower energy use from less external wall area and less indoor space per person. For instance, three to six storey terraces can combine high densities with very high-quality living environments with much less energy use for space heating than detached housing. High density is often seen as one of the problems in cities—but it depends on how it is accommodated. Some of the world's most expensive and desirable housing is in four to six storey terraces in European cities. These have high densities, often between 150 and 300 units per hectare and thus higher than most informal settlements with one-storey buildings, but the indoor space and often outdoor space per person are much higher. Energy use per dwelling can be much lower than in detached housing in suburban or rural areas. High-quality high-density dwellings can also be within city districts with good provision for open space—from small household gardens and neighbourhood squares and playgrounds to larger parks. There are also examples of new high-density residential developments that cut energy and water use, carbon dioxide emissions and the carbon footprints of materials used for their construction—as in the Beddington Zero Energy Development in South London [52]. High-density residential areas and cities generally have lower rates of private

automobile ownership and use in relation to household income—and provide more possibilities for car clubs through which members have quick and easy access to car use when they want at a far lower cost than car ownership.

6. Cities and resource use

Cities also have many potential advantages for reducing resource use and waste. It is worth recalling the example of Toronto cited earlier showing the tenfold difference in GHG emissions per person between a dense inner city neighbourhood with good access to public transport and a low density suburb distant from shops [21]. Many of the innovations discussed in *Factor Four*, the study of how to double wealth while halving resource use [28] are facilitated by the potential material, transport and water using efficiencies that more dense cities provide.

In cities, the close proximity of so many water consumers gives greater scope for recycling or directly re-using wastewaters. The concentration of consumer and business wastes in cities cheapens the cost of recovering or re-using material from these waste streams—for instance in separate household and business collections for recyclable or compostable wastes. In most cities in low- and middle-income nations, there is a large and diverse 'waste economy' through which materials are recovered from waste streams for recycling or reuse and which greatly reduces the volume of wastes that need to be disposed of [15]. Although there are many practices here that need improvement, especially in reducing the health risks facing those engaged in these informal waste economies, there is also a need to keep their very large environmental and livelihood-related advantages.

Urbanization has been accompanied by changes in diets, including increased meat consumption, more processed food and more expensive and exotic food items that generally imply more carbon-intensive production and transport to markets. But studies in a range of nations have shown that this has been driven by higher incomes, not urbanization, as can be seen by the consumption patterns of more prosperous rural dwellers that are similar to those of more prosperous urban dwellers [53].

7. Cities' physical expansion

Cities are often portrayed as being 'bad' for rural areas but city dwellers' demand for agricultural produce is a large part of the underpinning for farmers' incomes. In addition, most farmers (and their families) depend on markets, goods and services provided by urban enterprises. Most urban centres also concentrate populations in ways that reduce the demand for land relative to population [5]. There is no evidence that agricultural productivity has dropped in nations that are urbanizing and a declining proportion of land used for agriculture around a city may also be accompanied by more intensive production for land that remains in agriculture [54].

Various studies have sought to establish the proportion of land area globally and within each continent or nation that can be considered urban. One recent study suggests that the urban built-up area represents only 0.5 per cent of global land area and it is only in Europe that it exceeds 1 per cent [55]. Other sources using different methodologies suggest higher figures—for instance the Global

Rural–Urban Mapping Project suggested 2.7 per cent of global land area [56] although this is the land areas of urban settlements and so includes open land of various types within urban boundaries. Of course, if most urban expansion has been over high-quality agricultural land and only a small proportion of a nation's land area is high-quality agricultural land, urban areas expanding from (say) one to three per cent of total land area could mean a serious loss of agricultural land. But it is also likely that there is much agricultural production within a proportion of the area defined as urban, particularly under the second study mentioned above. In cities where the role of urban agriculture has been studied, its scale and its contribution to livelihoods and food supply have often been found to be significant [57].

However, many cities in low- and middle-income nations expand without any land-use plan or strategic planning framework to prevent sprawl and unnecessary loss of agricultural land and to protect watersheds and other areas that provide key ecological services. The expansion is determined by where different households, enterprises and public sector activities locate and build, legally or illegally [15]. This also produces a patchwork of high- and low-density land uses that no longer have the advantages noted above for reducing infrastructure costs and resource use.

In most locations, governments could and should restrict the loss of agricultural land to urban expansion. But this can also bring serious social consequences as a government policy that restricts the conversion of land from agricultural to non-agricultural uses around a growing city will push up land and house prices and often reduce still further the proportion of households that can afford a legal housing plot with infrastructure.

8. Using the advantages cities have for reducing greenhouse gas emissions

Many sources claim that cities are responsible for 75–80% of all GHG emissions, although from the production perspective and drawing on IPCC figures [58], the figure is likely to be 40–45% with agriculture, land-use changes and deforestation contributing to 31 per cent and the rest coming from energy supply, industry, transport, buildings and wastes in rural areas and in urban centres that are not cities [59]. But it is not cities (or small urban centres or rural areas) that are responsible for anthropogenic GHG emissions but particular activities by particular people, enterprises and institutions, a proportion of which are in cities. So one fundamental question is whether the GHG emissions used in producing goods or services are allocated to the enterprises that made, transported, promoted and sold the goods and services or the person or household that consumed these. If emissions are assigned to the final consumer, some of the allocation issues discussed earlier become clearer. For instance, GHG emissions from aviation are allocated to the person who flies. So a flight by a Londoner travelling from New York to South America would be allocated to London. Under this consumption-based accounting, emissions from agriculture, deforestation and industry could be assigned to the people who are the consumers of the industrial goods, wood products and food.

The choice of which system to use in setting limits and targets on GHG emissions has great significance for how responsibilities are assigned between and within nations and cities. Dhakal's [60] study of Asian cities showed that Beijing and Shanghai had higher *per capita* GHG emissions than Tokyo, when considering the emissions produced within these cities, but Tokyo had much higher *per capita* emissions if emission inventories for the cities included emissions that went into the goods purchased by city residents. If China's manufacturing cities are assigned all the GHG emissions that were generated producing goods for export and transporting them to their final market, this implies a much larger responsibility for these Chinese cities (and China as a nation) in moderating and eventually reducing such emissions than if these emissions were allocated to the people who consumed these goods (and by implication to the nations or cities where they live) [61]. For London, a shift from production- to consumption-based accounting for GHG emissions increases the average Londoner's responsibility for GHG emissions from 6 to 12 tonnes of CO_2e a year [62].

Both production- and consumption-based accounting are useful. Assigning GHG emissions to the range of enterprises involved in production highlights more resource-intensive centres of goods production while assigning emissions to consumers highlights more affluent places [63]. Under the consumption-based accounting, the contribution of cities to GHG emissions would increase, although it is not cities in general that are the problem but cities (or other settlements) where there are concentrations of high-consumption individuals and households.

If responsibility for GHG emissions is allocated to the consumer, very large differentials become evident. The world's wealthiest high-consumption individuals are likely to be contributing tens of thousands of times more to global warming than many of the poorest individuals (although this is in part because the poorest individual's contribution can be close to zero). For any individual to contribute to global warming, they have to consume goods and services that generate GHG emissions. Perhaps as many as 1.2 billion rural and urban dwellers worldwide have such low consumption levels that they contribute almost nothing to climate change. Their use of fossil fuels is very low (most use wood fuel, charcoal or dung for fuels) and they use no electricity. Most of these 'very low-carbon' people will use transport that produces no carbon dioxide emissions (walking, bicycling) or low emissions (buses, mini-buses and trains, mostly used to more than full capacity [39]).

A recent study examined global carbon dioxide emissions from fossil fuel use based on the individuals whose consumption caused these emissions rather than the nations within whose boundaries the emissions took place [64]. The wealthiest 700 million people's consumption is responsible for around half of all GHG emissions while the poorest 2.4 billion people contribute very little. What the paper emphasizes is the need to focus emission reduction policies on the high emitters (wherever they live). The paper also shows that allowing the growing number of people with very low emissions per person to achieve a good living standard (and its implications for increased emissions) does not add much to needed global emissions reduction targets. It also notes how many of the lowest-cost opportunities for reducing carbon dioxide emissions will be among the many millions who move to cities for the first time and could be housed in well-built energy-efficient accommodation with efficient appliances and well served by public transport.

There is the obvious concern in regard to what urbanization implies for population growth as most of the world's growth in population is taking place in urban centres in low- and middle-income nations and UN projections suggest that this is likely to continue [4]. But the GHG emissions generated by a person added to the world's population varies by a factor of more than 1000 depending on the circumstances into which they are born and their life possibilities and chances. In addition, in low- and middle-income nations, urbanization is associated with falls in population growth rates as fertility rates in urban areas are generally significantly lower than in rural areas [42,65]. In terms of future worries about resource constraints and GHG emissions, it is not the growth in population but the growth in consumption that is the primary concern. Most of the growth in GHG emissions from 1980 to 2005 occurred in nations with low population growth rates [39]. London's current population is smaller than it was in 1941 yet Londoners' total consumption of resources and their implications for GHG emissions are likely to have multiplied many times since then.

9. Urban governance in a resource constrained world

None of the potential advantages that urban centres have for high living standards (and good health) or for keeping down resource use, waste and GHG emissions happen automatically. They depend on governance structures—local governments and their relations with the population and civil society groups within their boundaries—making and implementing appropriate choices. This includes choices serving those with low incomes so they do not suffer profound health disadvantages. For wealthier cities, this includes the interests of people outside their boundaries and future generations [66]. So it depends on an acceptance by citizens and businesses of everyday practices that do not directly serve them (and may limit their consumption choices) to make local and regional resource use and waste disposal and global systems sustainable for future generations. It also depends on modifying so many aspects of local government—for instance the regulations governing land use and buildings and ensuring that all public buildings and government contracts for goods and services address these multiple goals. It also depends on incentives, regulations and standards set at higher levels of government—although it often falls to local government to implement them. It will be particularly difficult for many local governments in wealthy nations or wealthier districts of low- and middle-income nations to address these goals because it is difficult and expensive to modify the buildings, infrastructure and settlement patterns that developed in the era of cheap oil and no concern for GHG emissions. This is especially the case for low-density sprawl.

Table 1 illustrates some of the different implications of a concern for environmental health and a concern for sustainable use of resources and sinks and the potential conflict between many of these is obvious.

There are many examples of innovation and better practice from city governments in low- and middle-income nations where the need for improved governance is most evident. Many come from local initiatives that arise from more competent and democratic urban governments in nations where decentralization programmes have given more power and resources to such governments [68]. Some address regional and global environmental issues as well

Table 1. Comparing a concern for environmental health and for the sustainable use of resources and waste sinks for cities [67].

	environmental health	sustainable use of resources and waste sinks
key impact	human health within the city	ecosystem health, damage to ecosystem services and climate change much of it outside the city
timing of human impact	immediate	delayed; often indirect
scale and spatial focus	local and city wide	the region around the city and global
worst affected	lower income groups	future populations
aspects emphasized in relation to:		
water	need for increased quantities and better quality to address inadequate access facing much of the population	over-use; need to reduce use, protect water resources and implement water demand-management
air	high human exposure to hazardous pollutants at home and work	acid precipitation beyond city boundaries, GHG emissions
solid waste	inadequate provision for collection and removal of household wastes	excessive generation of waste and poorly managed waste disposal
land	inadequate availability inhibiting supplies of housing that low income groups can afford	loss of natural habitats and agricultural land to urban development and expansion
human wastes	inadequate provision for safely removing faecal matter (and waste water) from homes and living environments	loss of nutrients in sewage and damage to water bodies from release of sewage into waterways
typical proponent	urbanist	environmentalist

as local environment and development issues—for instance Manizales in Colombia with its comprehensive monitoring of the city's environmental performance and its much-copied 'environmental traffic lights' for keeping inhabitants informed of this [69]. Many others come from innovative local civil-society groups—usually a combination of grassroots organizations and local non-governmental organizations—and increasingly from partnerships that these groups form with local governments, which in turn contributes to more accountable and democratic local governments.

It is common to see city problems blamed on rapid city growth. But there are cities that have grown rapidly in the last 50 years that have avoided most of the problems noted above. For instance, Porto Alegre in Brazil has grown from under half a million inhabitants in 1950 to around 3.5 million in its metropolitan area today. It has high-quality living environments and innovative environmental policies. Its inhabitants enjoy an average life expectancy and many indicators of environmental quality that are comparable to cities in Western Europe and North America—and also a city government that during the 1990s was well known for its commitment to supporting citizen participation, greater government accountability and good public health and environmental management. Porto

Alegre also integrated a wide-ranging environmental management policy into its participatory budgeting, rooted in a comprehensive regional environmental analysis [70,71].

Urban governance in a resource constrained world also needs programmes to tackle the backlog in infrastructure and services in the poorer and worst-served areas of urban centres and to support ways in which lower income households can get better quality housing. This is also needed to build resilience to climate change. Many of the most serious risks from climate change in cities arise because of poor quality housing built on sites at risk that lack basic protective infrastructure. Many cities in Latin America, Africa and Asia may have low GHG emissions per person but they house hundreds of millions of people who are at risk from the increased frequency and/or intensity of floods, storms and heat waves and water supply constraints that climate change is bringing or likely to bring [72]. It is generally low-income groups that are most at risk as they live on sites at risk of flooding or landslides, lacking the drains and other needed protective infrastructure. The costs of addressing this very large backlog in basic infrastructure and housing which underpins vulnerability to climate change are at present not included in estimates for the costs of climate change adaptation [73]. Perhaps more worryingly, even if the funding was available, for many cities, the capacity and willingness to address the risks, especially those faced by lower income groups, is not there.

However, there are many co-benefits between improving housing and living conditions and building resilience to climate change. Many cities have had major 'upgrading' programmes to improve provision for water, sanitation, drainage and garbage collection in inner-city tenement districts and in squatter settlements. Initially, these were seen as one-off projects in 'targeted' neighbourhoods; now there is a recognition that city and municipal governments need the capacity and competence to support continuous upgrading programmes throughout the city, working in partnership with their inhabitants. The example of CODI given earlier has particular significance in three aspects: the scale; the extent of community involvement; and the extent to which it seeks to institutionalize community-driven solutions within local governments [48]. Although this programme was never intended as a response to climate change, it has reduced risk levels because of better quality housing with needed infrastructure and services.

In many other nations, national organizations or federations of 'slum' dwellers are working with local governments to improve housing conditions and reduce risks from disasters [40,74]. What is unusual about these federations is that they recognized that making demands on governments that those governments cannot fulfil did not serve them. Many had tried the conventional approaches of protest, strikes, barricades and marches. They came to recognize that they had to change their relations with politicians and civil servants, especially to show that 'slum' dwellers and their settlements were not 'the problem' and how, with local government support, they could generate solutions [75]. Federations in many nations have demonstrated to governments their capacity to design and build housing and infrastructure that is cheaper and better quality than if governments get these built by contractors. These federations have also demonstrated a capacity to undertake the enumerations and mapping of informal settlements needed for planning upgrading. With these demonstrations of their competence and capacity, they offer local governments partnerships—and where

local governments work with them, the scale of what can be achieved increases greatly. Partnerships between local governments and these federations can address the critical health issues and contribute to resilience to local climate change impacts. The kind of high-density upgrading or new house development that these federations prioritize are also compatible with high-density and resource use efficiency.

10. Desirable urban centres with low ecological footprints

Cities concentrate so much of what contributes to a very high quality of life that need not imply high material consumption levels (and thus high GHG emissions)—theatre, music, museums, libraries, the visual arts, dance, festivals, the enjoyment of historic buildings and districts, diverse choices for eating, easy access to many other services or simply the enjoyment of being in a diverse and vibrant place. Cities have also long been places of social, economic and political innovation at local and national levels. Indeed, in high-income nations, many city politicians have demonstrated a greater commitment to GHG reduction than national politicians. Achieving the needed reduction in GHG emissions globally and more sustainable patterns of resource use depends on understanding this potential of cities to combine a high quality of life with less material resource use and waste and low GHG emissions. New technologies may help but the scale of the needed reduction in GHGs suggests that, as Rees notes, the wealthy may have to accept lower material standards for enhanced geopolitical and ecological security [76]. It will also need the expertise of ecologists applied to urban systems [2] and urban governments recovering control over land-use changes and integrating ecological concerns and climate resilience into this [77].

This paper has also highlighted how it is not cities or urbanization but high-consumption lifestyles that underpin unsustainable or potentially unsustainable levels of resource use, waste and GHG emissions—whether or not those who have such lifestyles live in cities or other urban centres or rural areas. In high-income nations and in many parts of middle-income nations, most of the rural population no longer work in agriculture, forestry or fishing. They also enjoy levels of infrastructure and service provision that used to be associated with urban areas. A high proportion of those of working age commute to urban centres and also travel there for recreation. Advanced communications systems allow much work to be done from people's homes that need not be in cities. It is the resource use and waste generation implications of income levels and consumption choices that need consideration much more than the proportion of people living in cities.

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References

1 Grimmond, S. 2007 Urbanization and global environmental change: local effects of urban warming. *Geogr. J.* **173**, 83–88. (doi:10.1111/j.1475-4959.2007.232_3.x)

2 Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X. & Briggs, J. M. 2008 Global change and the ecology of cities. *Science* **319**, 756–760. (doi:10.1126/science.1150195)

3 Bairoch, P. 1988 *Cities and economic development: from the dawn of history to the present*. London, UK: Mansell.
4 United Nations, Department of Economic and Social Affairs, Population Division. 2010 *World urbanization prospects: the 2009 revision*. CD-ROM edition, data in digital form POP/DB/WUP/Rev.2009.
5 Satterthwaite, D., McGranahan, G. & Tacoli, C. 2010 Urbanization and its implications for food and farming. *Phil. Trans. R. Soc. B* **365**, 2809–2820. (doi:10.1098/rstb.2010.0136)
6 Sassen, S. 2006 *Cities in a world economy*. Thousand Oaks, CA: Pine Forge Press.
7 Douglas, I. 1983 *The urban environment*. London, UK: Edward Arnold.
8 Douglas, I. 1986 Urban geomorphology. In *A handbook of engineering geomorphology* (eds P. G. Fookes & P. R. Vaughan), pp. 270–283. Glasgow, UK: Surrey University Press (Blackie and Son).
9 UN-Habitat. 2003 *Water and sanitation in the world's cities*: *local action for global goals*. London, UK: Earthscan Publications.
10 Kovats, R. S. & Akhtar, R. 2008 Climate, climate change and human health in Asian cities. *Environ. Urb.* **20**, 165–176. (doi:10.1177/0956247808089154)
11 Kjellstrom, T. & Mercado, S. 2008 Towards action on social determinants for health equity in urban settings. *Environ. Urb.* **20**, 551–574. (doi:10.1177/0956247808096128)
12 McGranahan, G. 2007 Urban transitions and the spatial displacement of environmental burdens. In *Scaling urban environmental challenges: from local to global and back* (eds P. J. Marcotullio & G. McGranahan), pp. 18–44. London, UK: Earthscan Publications.
13 Best Foot Forward Ltd. 2002 *City limits: a resource flow and ecological footprint analysis of Greater London*. London, UK: Chartered Institution of Wastes Management Environmental Body.
14 Anton, D. J. 1993 *Thirsty cities: urban environments and water supply in Latin America*. Ottawa, Canada: IDRC.
15 Hardoy, J. E., Mitlin, D. & Satterthwaite, D. 2001 *Environmental problems in an urbanizing world: finding solutions for cities in Africa, Asia and Latin America*. London, UK: Earthscan Publications.
16 Connolly, P. 1999 Mexico City: our common future? *Environ. Urb.* **11**, 53–78. (doi:10.1177/095624789901100116)
17 Romero Lankao, P. 2010 Water in Mexico City: what will climate change bring to its history of water-related hazards and vulnerabilities? *Environ. Urb.* **22**, 157–178. (doi:10.1177/0956247809362636)
18 Satterthwaite, D. 2010 Urban myths and the mis-use of data that underpin them. In *Urbanization and development: multidisciplinary perspectives* (eds J. Beall, B. Guha-Khasnobis & R. Kanbur), pp. 83–99. Oxford, UK: Oxford University Press.
19 Legros, G., Havet, I., Bruce, N. & Bonjour, S. 2009 *The energy access situation in developing countries: a review focusing on the least developed countries and Sub-Saharan Africa*. New York, NY: World Health Organization and United Nations Development Programme.
20 CAIT. 2010 Climate Analysis Indicators Tool, CAIT version 6.0. Washington, DC: World Resources Institute. See http://cait.wri.org/cait.php.
21 Hoornweg, D., Sugar, L. & Lorena Trejos Gomez, C. In press. Cities and greenhouse gas emissions: challenges and opportunities. *Environ. Urb.* (doi:10.1177/0956247810392270).
22 World Commission on Environment and Development. 1987 *Our common future*. Oxford, UK: Oxford University Press.
23 McManus, P. & Haughton, G. 2006 Planning with ecological footprints: a sympathetic critique of theory and practice. *Environ. Urb.* **18**, 113–128. (doi:10.1177/0956247806063963)
24 Wackernagel, M. & Rees, W. 1995 *Our ecological footprint: reducing human impact on the earth*. Gabriola, Canada: New Society Publishers.
25 Wackernagel, M., Kitzes, J., Moran, D., Goldfinger, S. & Thomas, M. 2006 The ecological footprint of cities and regions: comparing resource availability with resource demand. *Environ. Urb.* **18**, 103–112. (doi:10.1177/0956247806063978)
26 Weisz, H. & Steinberger, J. K. 2010 Reducing energy and materials flows in cities. *Curr. Opin. Environ. Sust.* **2**, 185–192. (doi:10.1016/j.cosust.2010.05.010)

27 Barles, S. 2010 Society, energy and materials: the contribution of urban metabolism studies to sustainable urban development issues. *J. Environ. Plann. Manage.* **53**, 439–455. (doi:10.1080/09640561003703772)
28 Von Weizsäcker, E., Lovins, A. B. & Hunter Lovins, L. 1997 *Factor four: doubling wealth, halving resource use*. London, UK: Earthscan Publications.
29 Kennedy, G., Nantel, G. & Shetty, P. 2004 Globalization of food systems in developing countries: a synthesis of country case studies. In *Globalization of food systems in developing countries: impact on food security and nutrition*, pp. 1–25. FAO Food and Nutrition Paper 83. Rome, Italy: FAO.
30 Rees, W. E. 1992 Ecological footprints and appropriated carrying capacity. *Environ. Urb.* **4**, 121–130. (doi:10.1177/095624789200400212)
31 IPCC. 2006 *Guidelines for national greenhouse gas inventories*. Cambridge, UK: Cambridge University Press.
32 Bloomberg, M. R. 2007 *Inventory of New York greenhouse gas emissions*. New York, NY: Mayor's Office of Operations, Office of Long-Term Planning and Sustainability.
33 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.
34 IPCC. 2007 *Climate change 2007: synthesis report*. Geneva Switzerland: Intergovernmental Panel on Climate Change.
35 Stern, N. 2009 *A blueprint for a safer planet*. London, UK: The Bodley Head.
36 Caney, S. 2009 Justice and the distribution of greenhouse gas emissions. *Glob. Ethics* **5**, 125–146. (doi:10.1080/17449620903110300)
37 Meyer, A. 2007 The case for contraction and convergence. In *Surviving climate change: the struggle to avert global catastrophe* (eds D. Cromwell & M. Levene), pp. 29–56. London, UK: Pluto Press.
38 VandeWeghe, J. R. & Kennedy, C. 2007 A spatial analysis of residential greenhouse gas emissions in the Toronto census metropolitan area. *J. Ind. Ecol.* **11**, 133–144. (doi:10.1162/jie.2007.1220)
39 Satterthwaite, D. 2009 The implications of population growth and urbanization for climate change. *Environ. Urb.* **21**, 545–567. (doi:10.1177/0956247809344361)
40 IFRC. 2010 *World disasters report 2010: focus on urban areas*. Geneva, Switzerland: International Federation of Red Cross and Red Crescent Societies.
41 United Nations. 2009 *Global assessment report on disaster risk reduction: risk and poverty in a changing climate*. Geneva, Switzerland: United Nations.
42 Dye, C. 2008 Health and urban living. *Science* **319**, 766–769. (doi:10.1126/science.1150198)
43 Moser, C. O. N. 2004 Editorial. Urban violence and insecurity: an introductory roadmap. *Environ. Urb.* **16**, 3–15. (doi:10.1177/095624780401600220)
44 Frumkin, H., Frank, L. & Jackson, R. 2004 *Urban sprawl and public health: design, planning and building for health communities*. Washington, DC: Island Press.
45 Newman, P. 2006 The environmental impact of cities. *Environ. Urb.* **18**, 275–295. (doi:10.1177/0956247806069599)
46 Newman, P. 1996 Reducing automobile dependence. *Environ. Urb.* **8**, 67–92. (doi:10.1177/095624789600800112)
47 Dodman, D. 2009 Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *Environ. Urb.* **21**, 185–201. (doi:10.1177/0956247809103016)
48 Boonyabancha, S. 2005 Baan Mankong: going to scale with 'slum' and squatter upgrading in Thailand. *Environ. Urb.* **17**, 21–46. (doi:10.1177/095624780501700104)
49 Hasan, A., Sadiq, A. & Ahmed, S. 2010 *Planning for high density in low-income settlements: four case studies from Karachi*. Human Settlements Working paper. London, UK: IIED.
50 Patel, S. & Arputham, J. 2008 Plans for Dharavi: negotiating a reconciliation between a state-driven market redevelopment and residents' aspirations. *Environ. Urb.* **20**, 243–254. (doi:10.1177/0956247808089161)

51 Patel, S. & Arputham, J. 2007 An offer of partnership or a promise of conflict in Dharavi, Mumbai? *Environ. Urb.* **19**, 501–508. (doi:10.1177/0956247807082832)
52 Chance, T. 2009 Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond. *Environ. Urb.* **21**, 527–544. (doi:10.1177/0956247809339007)
53 Stage, J., Stage, J. & McGranahan, G. 2010 Is urbanization contributing to higher food prices? *Environ. Urb.* **22**, 199–215. (doi:10.1177/0956247809359644)
54 Bentinck, J. 2000 *Unruly urbanization on Delhi's fringe: changing patterns of land use and livelihood*. Netherlands Geographical Studies 270. Utrecht, The Netherland: KNAG.
55 Schneider, A., Friedl, M. A. & Potere, D. 2009 A new map of global urban extent from MODIS satellite data. *Environ. Res. Lett.* **4**, 044003. (doi:10.1088/1748-9326/4/4/044003)
56 Balk, D., Pozzi, F., Yetman, G., Deichmann, U. & Nelson, A. 2004 The distribution of people and the dimension of place: methodologies to improve the global estimation of urban extents. GRUMP, New York, NY: CIESIN. See http://sedac.ciesin.columbia.edu/gpw/documentation.jsp.
57 Redwood, M. (ed.) 2009 *Agriculture in urban planning: generating livelihoods and food security*. London, UK: Earthscan Publications.
58 IPCC. 2007 Technical summary. In *Climate change 2007: mitigation* (eds B. Metz, O. R. Davidson, P. R. Bosch, R. Dave & L. A. Meyer). Cambridge, UK: Cambridge University Press.
59 Satterthwaite, D. 2008 Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. *Environ. Urb.* **20**, 539–550. (doi:10.1177/0956247808096127)
60 Dhakal, S. 2004 *Urban energy use and greenhouse gas emissions in Asian cities: policies for a sustainable future*. Kitakyushu, Japan: Institute for Global Environmental Strategies.
61 Walker, G. & King, D. 2008 *The hot topic: how to tackle global warming and still keep the lights on*. London, UK: Bloomsbury Publishers.
62 Bioregional and London Sustainable Development Commission. 2010 *Capital consumption: the transition to sustainable consumption and production in London*. London, UK: Greater London Authority. See www.londonsdc.org.uk and www.bioregional.com.
63 McGranahan, G. 2005 An overview of urban environmental burdens at three scales: intra-urban, urban-regional and global. *Int. Rev. Environ. Strat.* **5**, 335–336.
64 Chakravarty, S., Chikkatur, A., de Coninck, H., Pacala, S., Socolow, R. & Tavonia, M. 2009 Sharing global CO_2 emission reductions among one billion high emitters. *Proc. Natl Acad. Sci. USA* **106**, 11 884–11 888. (doi:10.1073/pnas.0905232106)
65 Montgomery, M. R., Stren, S., Cohen, B. & Reed, H. E. (eds) 2003 *Cities transformed: demographic change and its implications in the developing world*. Washington, DC: The National Academy Press.
66 Haughton, G. 1999 Environmental justice and the sustainable city. *J. Plan. Educ. Res.* **18**, 233–243. (doi:10.1177/0739456X9901800305)
67 McGranahan, G. & Satterthwaite, D. 2000 Environmental health or ecological sustainability? Reconciling the brown and green agendas in urban development. In *Sustainable cities in developing countries* (ed. C. Pugh). London, UK: Earthscan Publications.
68 Campbell, T. 2003 *The quiet revolution: decentralization and the rise of political participation in Latin American cities*. Pittsburgh, PA: University of Pittsburgh Press.
69 Velasquez, L. S. 1998 Agenda 21; a form of joint environmental management in Manizales, Colombia. *Environ. Urb.* **10**, 9–36. (doi:10.1177/095624789801000218)
70 Menegat, R. 2002 Participatory democracy and sustainable development: integrated urban environmental management in Porto Alegre, Brazil. *Environ. Urb.* **14**, 181–206. (doi:10.1177/095624780201400215)
71 Menegat, R. (main coordinator) 1998 *Atlas Ambiental de Porto Alegre*. Porto Alegre, Brazil: Universidade Federal do Rio Grande do Sul, Prefeitura Municipal de Porto Alegre and Instituto Nacional de Pesquisas Espaciais.
72 Satterthwaite, D., Huq, S., Reid, H., Pelling, M. & Romero Lankao, P. 2009 Adapting to climate change in urban areas; the possibilities and constraints in low- and middle-income nations. In *Adapting cities to climate change* (eds J. Bicknell, D. Dodman & D. Satterthwaite), pp. 3–47. London, UK: Earthscan Publications.

73 Parry, M. *et al.* 2009 *Assessing the costs of adaptation to climate change: a review of the UNFCC and other recent estimates*. London, UK: IIED and Grantham Institute.
74 Rayos Co, J. C. 2009 *Community-driven disaster intervention: the experience of the Homeless People's Federation Philippines*. Human Settlements Working Paper, no. 25. London, UK: HED.
75 Arputham, J. 2008 Developing new approaches for people-centred development. *Environ. Urb.* **20**, 319–337. (doi:10.1177/0956247808096115)
76 Rees, W. E. 1995 Achieving sustainability: reform or transformation? *J. Plann. Lit.* **9**, 343–361. (doi:10.1177/088541229500900402)
77 Roberts, D. 2008 Thinking globally, acting locally—institutionalizing climate change at the local government level in Durban, South Africa. *Environ. Urb.* **20**, 521–538. (doi:10.1177/0956247808096126)