CHAPTER 1

URBANIZATION AND THE CHALLENGE OF CLIMATE CHANGE

As the world enters the second decade in the new millennium, humanity faces a very dangerous threat. Fuelled by two powerful human-induced forces that have been unleashed by development and manipulation of the environment in the industrial age, the effects of urbanization and climate change are converging in dangerous ways which threaten to have unprecedented negative impacts upon quality of life, and economic and social stability.

Alongside the threats posed by the convergence of the effects of urbanization and climate change, however, is an equally compelling set of opportunities. Urban areas, with their high concentration of population, industries and infrastructure, are likely to face the most severe impacts of climate change. The same concentration of people, industrial and cultural activities, however, will make them crucibles of innovation, where strategies can be catalysed to promote reductions in greenhouse gas (GHG) emissions (mitigation) and to improve coping mechanisms, disaster warning systems, and social and economic equity, to reduce vulnerability to climate change impacts (adaptation).

While some cities are shrinking, many urban centres are seeing rapid and largely uncontrolled population growth, creating a pattern of rapid urbanization. Most of this growth is now taking place in developing countries[1] and is concentrated in informal settlements and slum areas. Therefore, the very urban areas that are growing fastest are also those that are least equipped to deal with the threat of climate change, as well as other environmental and socio-economic challenges. These areas often have profound deficits in governance, infrastructure, and economic and social equity.

People arriving in already overstressed urban centres are forced to live in dangerous areas that are unsuitable for real estate or industrial development, many constructing their own homes in informal settlements on floodplains, in swamp areas and on unstable hillsides, often with inadequate or completely lacking infrastructure and basic services to support human life, safety and development. Many of these slum residents are often blamed by their governments for their own poor living conditions. Even without additional weather-related stresses, such as higher-intensity or more frequent storms, these are dangerous living environments.

Climate change, the second major force unleashed by human industrial development, is quickly building momentum. Climate change is increasing the magnitude of many of the threats to urban areas that are already being experienced as a result of rapid urbanization. Yet, climate change can also be a source of opportunities to redirect the patterns of production and consumption of cities and individuals, at the same time enhancing their capacity to cope with hazards.

Climate change is an outcome of human-induced driving forces such as the combustion of fossil fuels and land-use changes, but with wide-ranging consequences for the planet and for human settlements all over the world. The range of effects include a warming of sea water, and its consequent expansion, that has provided some warning signs, including the collapse of the ice shelves such as Larsen A (1995) and Larsen B (2002) in Antarctica. This melting polar ice threatens to add more water to the already expanding warmer seas, accelerating a dangerous sea-level rise that threatens many coastal urban centres. At the same time, the increasingly warm (and acidic[2]) seas threaten, along with pollution and other anthropogenic or human-related drivers, the very existence of coral reef ecosystems around the world, giving rise to new risks in urban coastal areas that gain protection from the ecosystem services of coral reefs and other aquatic ecosystems. These changes to the natural world gravely threaten the health and quality of life of many urban dwellers.

The effects of urbanization and climate change … threaten to have unprecedented negative impacts upon quality of life, and economic and social stability

With sea-level rise, urban areas along the coasts, particularly those in low-elevation coastal zones,[3] will be threatened with inundation and flooding, saltwater intrusion affecting drinking water supplies, increased coastal erosion and reductions in liveable land space. All of these effects, however, will be compounded by other climate impacts, including increase in the duration and intensity of storms such as hurricanes and cyclones, creating extreme hazards for both rich and poor populations occupying low-elevation coastal zones.

Climate change can also be a source of opportunities to redirect the patterns of production and consumption of cities and individuals

Even in non-coastal areas, the convergence of rapid urbanization with climate change can be very dangerous. Poor people living on unstable hillsides could face continuous threats of being swept away or buried by rain-induced mud- and rock-slides. Uncontrolled growth of urban centres into natural forest or brush areas that will dry out with increases in temperatures and in the intensity and duration of droughts will see increases in the frequency of life- and property-threatening wildfires. Droughts in both coastal and non-coastal cities could disrupt urban water supplies and supplies of forest and agricultural products. These impacts will fall disproportionately upon the urban poor in developing as well as developed countries.

In developed countries, an uneven distribution of political and economic power is the reason why the poor, ethnic and other minorities, and women will bear the brunt of climate change. This uneven distribution of vulnerability can have a destabilizing effect within these countries. This can be seen, for instance, in the racial and social tension that came to the fore in the US when it became evident that African-Americans, the poor and the elderly were disproportionately affected by Hurricane Katrina in 2005.

An uneven distribution of political and economic power is the reason why the poor, ethnic and other minorities, and women will bear the brunt of climate change

It is true that destruction of property and loss of life in the coastal areas and elsewhere will certainly not be limited to the poor; but it is also true that affluent segments of the population will be much better protected by insurance, political and economic advantages. It is, however, highly probable that the need for responses to an increased frequency of disasters will stress national economies even in developed countries, also creating much higher stress on the global economy.

The challenges associated with the rapid pace of urbanization will complicate responses to climate change. The other side of the coin, however, is that urbanization will also offer many opportunities to develop cohesive responses in both mitigation and adaptation strategies to deal with climate change. The populations, enterprises and authorities of urban centres will be fundamental players in developing these strategies. In this way, climate change itself will offer opportunities, or it will force cities and humanity, in general, to improve global, national and urban governance to foster the realization of human dignity, economic and social justice, as well as sustainable development.

Urbanization will also offer many opportunities to develop cohesive responses in both mitigation and adaptation strategies to deal with climate change

The purpose of this chapter is to identify the main issues of concern as they relate to urban areas and climate change. It describes, in the section below, key urbanization trends as they relate to climate change, and presents the reasons why it is important to explore the factors shaping urban development and changes in the Earth's climate system. The section after that presents, in summary form, the most important and recent evidence of the causes of climate change, and briefly looks at climate change implications for urban centres. This is followed by a presentation of the framework for exploring linkages between urban areas and climate change used in this Global Report, covering two main issues: drivers of urban contributions to climate change; and urban vulnerability and resilience. The final section contains some concluding remarks and a short description of the main contents of the rest of the report.

Urbanization and climate change are co-evolving in such a way that populations, often in densely packed urban areas, will be placed at much higher risk from climate change

URBANIZATION AND CLIMATE CHANGE

Development and its many environmental impacts are inextricably bound. As such, urbanization and climate change are co-evolving in such a way that populations, often in densely packed urban areas, will be placed at much higher risk from climate change as well as from other profound societal and environmental changes. The pace of these changes is rapid, and for this reason, many aspects of urban change during recent decades are of importance for this Global Report. There are six primary reasons why it is important to understand the forces shaping the world's growing urban areas in order to be able to mitigate climate change and to cope with its inevitable consequences. *First* among these is the rapid pace of urban population growth. By the end of the last decade the world reached a milestone when, for the first time in human history, half of the world's population lived in urban areas. The pace of urbanization in the world today is unprecedented, with a near quintupling of the urban population between 1950 and 2011.[4]

The *second* important issue bearing on urbanization and climate change is that, unlike urbanization during the early 20th century, which was mostly confined to developed countries, the fastest rates of urbanization are currently taking place in the least developed countries, followed by the rest of the developing countries (see Table 1.1), which now host nearly three-quarters of the world's urban population. In fact, more than 90 per cent of the world's urban population growth is currently taking place in developing countries.[5] This rapid urbanization of developing countries, coupled with the increased intensity and frequency of adverse weather events, will have devastating effects on these countries, which also have lower capacities to deal with the consequences of climate change.[6]

Third, while the populations of some cities are shrinking, the number of large cities and the size of the world's largest cities are increasing. The number of cities in the world with populations greater than 1 million increased from 75 in 1950 to 447 in 2011; while during the same period, the average size of the world's 100 largest cities increased from 2.0 to 7.6 million. By 2020, it is projected that there will be 527 cities with a population of more than 1 million, while the average size of the world's 100 largest cities will have reached 8.5 million.[7] However, it is significant that the bulk of new urban growth is taking place in smaller urban areas. For instance, urban centres with fewer than 500,000 people are currently home to just over 50 per cent of the total urban population.[8] The primary disadvantage of this development pattern is that these smaller urban areas are often institutionally weak and unable to promote effective mitigation and adaptation actions. However, there is a possible advantage to be gained here also, as the burgeoning development of these centres may be redirected in ways that reduce their emission levels to a desired minimum (e.g. through the promotion of mono-centric urban structures based on the use of public transportation), and their resilience and ability to cope with climate hazards and other stresses enhanced (e.g. through the development of climate-proof urban infrastructure and effective response systems).

Fourth, since urban enterprises, vehicles and populations are key sources of GHGs, gaining an understanding of the dynamics of the forces and systems that drive the urban generation of GHGs is fundamental in helping urban policy-makers, enterprises and consumers target the readily

Table 1.1

Urban population projections, by region (2010–2030)

Region	Urban population (millions)			Proportion of total population living in urban areas (%)			Urban population rate of change (% change per year)	
	2010	2020	2030	2010	2020	2030	2010–2020	2020–2030
World total	3486	4176	4900	50.5	54.4	59.0	1.81	1.60
Developed countries	930	988	1037	75.2	77.9	80.9	0.61	0.48
North America	289	324	355	82.1	84.6	86.7	1.16	0.92
Europe	533	552	567	72.8	75.4	78.4	0.35	0.27
Other developed countries	108	111	114	70.5	73.3	76.8	0.33	0.20
Developing countries	2556	3188	3863	45.1	49.8	55.0	2.21	1.92
Africa	413	569	761	40.0	44.6	49.9	3.21	2.91
Sub-Saharan Africa	321	457	627	37.2	42.2	47.9	3.51	3.17
Rest of Africa	92	113	135	54.0	57.6	62.2	2.06	1.79
Asia/Pacific	1675	2086	2517	41.4	46.5	52.3	2.20	1.88
China	636	787	905	47.0	55.0	61.9	2.13	1.41
India	364	463	590	30.0	33.9	39.7	2.40	2.42
Rest of Asia/Pacific	674	836	1021	45.5	49.6	54.7	2.14	2.00
Latin America and the Caribbean	469	533	585	79.6	82.6	84.9	1.29	0.94
Least developed countries	249	366	520	29.2	34.5	40.8	3.84	3.50
Other developing countries	2307	2822	3344	47.9	52.8	58.1	2.01	1.70

Source: UN, 2010; see also Statistical Annex, Tables A.1, A.2, A.3, B.1, B.2, B.3

available options to reduce those emissions at the same time that urban resilience to the impacts of climate change is enhanced. For instance, many cities exceed the recommended annual average figure of 2.2 tonnes of CO_2 equivalent value (CO_2eq) per capita.[9]

Fifth, cities are also centres of diverse kinds of innovations that may contribute to reducing or mitigating emissions, adapting to climate change, and enhancing sustainability and resilience. Mechanisms for that purpose include changes in transportation, land-use patterns, and the production and consumption patterns of urban residents. The economies of scale, as well as proximity and concentration of enterprises in cities, make it cheaper and easier to take the actions and provide the services necessary to minimize both emissions and climate hazards.[10]

Last, but certainly not least in importance, the dynamics of urban centres are intimately linked to geography. Latitude determines a city's need for more or less energy to run air-conditioning and heating systems within its buildings, industries and houses. However, cities also depend on biodiversity, clean water and other ecosystem services that they have developed over existing ecosystems or 'ecozones', such as coastal areas, wetlands and drylands.[11] Indeed, settling along large bodies of water such as seas, lakes and rivers has historically been a vital factor in the economic and demographic growth of cities, and this trend continues today. For instance, ecozones near water bodies (inland and coastal) have greater shares of population residing in urban areas than other ecozones (see Table 1.2). In developing countries especially, these urban centres are already faced with flooding resulting from a combination of factors (such as impermeable surfaces in the built environment, scarcity of green spaces to absorb water flows and inadequate drainage systems). There are also health-related risks that affect ecozones near water bodies. These include flood-related increases in diarrhoeal diseases, typhoid and cholera.

Many weather-related risks – which, as can be seen in Figure 1.1, already have an urban face – will be exacerbated as climate change progresses and hazards such as sea-level rise, saltwater intrusion and more intense storms become day-to-day realities for the poor and vulnerable populations that inhabit many of the most hazardous areas in urban centres. Drylands are also home to a considerable share of urban populations and, as will be illustrated later, these areas too will see an increase in climate-related impacts, especially in the western parts of the US, the northeast of Brazil and around the Mediterranean (see Table 1.2).

As illustrated in Figure 1.1, many urban dwellers and their livelihoods, property, quality of life and future prosperity are threatened by the risks from cyclones, flooding, landslides and drought: adverse events which climate change is expected to aggravate. Yet, urbanization is not only a source of risks. Certain patterns of urban development can increase resilience. For instance, while large population densities in urban areas create increased vulnerability, they also create the potential for city-scale changes in behaviour that can mitigate human contributions to climate change and encourage adaptation to the inevitable changes that climate change will bring. Furthermore, infrastructure developments can provide physical protection. As illustrated by Cuba's experience, well-designed communications and early warning systems can help to evacuate people swiftly when tropical storms approach.[12] Appropriate urban planning can help to restrict growth of population and activities in risk-prone areas.

Given the above, it is necessary to pay attention to the worsening global problem of climate change in relation to urban centres – the most local of the human systems on Earth – which concentrate more than half of the world's population and have significant potential to perform key roles in the climate change arena.

Many weather-related risks ... will be exacerbated as climate change progresses and hazards such as sea-level rise, saltwater intrusion and more intense storms become day-to-day realities

Appropriate urban planning can help to restrict growth of population and activities in risk-prone areas

Table 1.2

Urban population in different 'ecozones', by region (2000 and 2025)

Ecozone	Year	Share of urban population (%)						
		Africa	Asia	Europe	North America	Oceania	South America	World
Coastal	2000	62	59	83	85	87	86	65
	2025	**73**	**70**	**87**	**89**	**90**	**92**	**74**
Low-elevation coastal zone	2000	60	56	80	82	79	82	61
	2025	**71**	**68**	**85**	**86**	**83**	**90**	**71**
Cultivated	2000	38	42	70	75	67	67	48
	2025	**48**	**55**	**75**	**81**	**72**	**80**	**59**
Dryland	2000	40	40	66	78	49	61	45
	2025	**51**	**51**	**70**	**84**	**60**	**75**	**55**
Forested	2000	21	28	53	64	36	53	37
	2025	**31**	**41**	**59**	**72**	**40**	**68**	**47**
Inland water	2000	51	47	78	84	77	71	55
	2025	**62**	**58**	**82**	**88**	**80**	**83**	**64**
Mountain	2000	21	27	46	50	11	54	32
	2025	**30**	**40**	**53**	**60**	**13**	**67**	**43**
Continent average	2000	36	42	69	74	66	66	49
	2025	**47**	**55**	**75**	**80**	**70**	**78**	**59**

Source: Balk et al, 2009

EVIDENCE OF CLIMATE CHANGE: IMPLICATIONS FOR URBAN CENTRES

This section presents a brief overview of how the global climate system functions, and what is changing as a result of climate change. It also presents a brief summary of the characteristics of the main causes of climate change (i.e. the GHGs). The last part of this section takes a closer look at the main human activities that cause increasing GHG emissions.

How the climate system functions and what is changing

Several factors influence the climate of the Earth: the incoming energy from the Sun, the outgoing or radiated energy leaving the Earth, and the exchanges of energy among oceans, land, atmosphere, ice and living organisms (see Figure 1.2). Structure and dynamics within both the carbon cycle (see Box 1.1) and the atmosphere can be equally responsible for alterations in climate. Within the atmosphere, incoming solar radiation and outgoing infrared radiation are affected by some gases and aerosols (see Box 1.1). While most aerosols have some cooling effect, the amount of GHGs present in the Earth's atmosphere before human beings began the large-scale emission of these gases keeps the planet about 33°C warmer than it would be otherwise.[13] This natural greenhouse effect, by providing protection from the loss of heat, has made most life on Earth possible. The functioning of the carbon cycle has provided a good part of this protection; but human activities such as the combustion of fossil fuels, large-scale industrial pollution, deforestation and land-use changes, among others, have led to a build-up of GHGs in the atmosphere together with a reduction of the capacity of oceans and vegetation to absorb GHGs. This attack on the natural carbon cycle on two fronts has reduced the Earth's natural ability to restore balance to the carbon cycle and is now resulting directly in the current global changes in average temperatures.

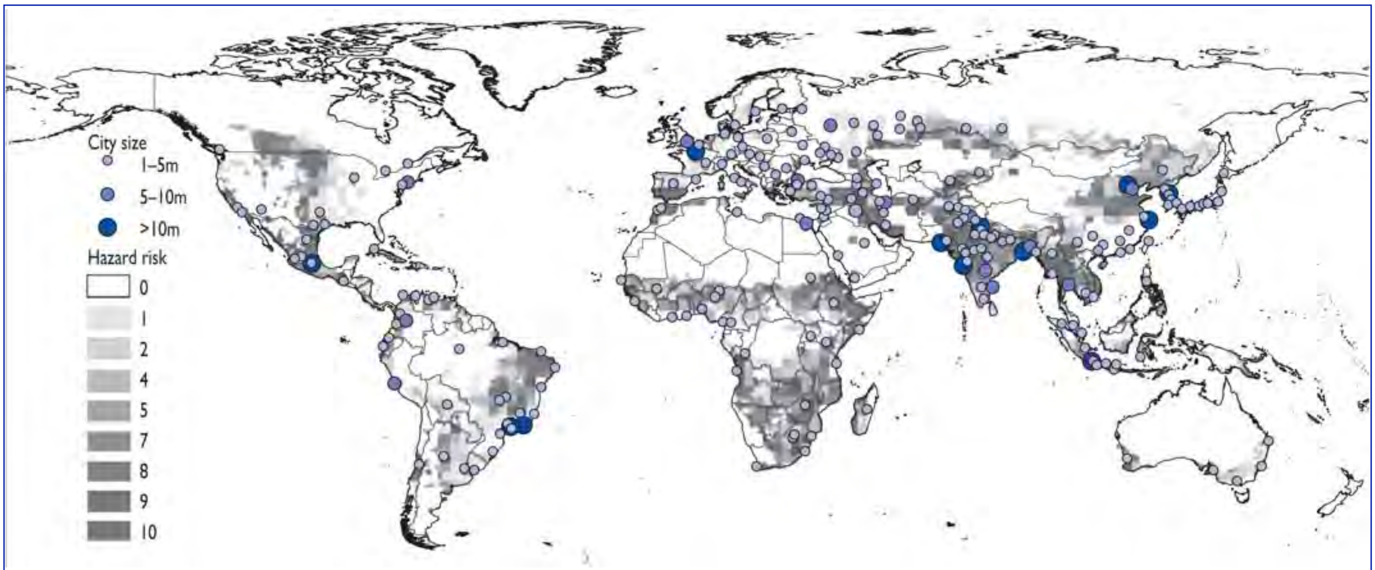
Looking back to the Earth's history, it is not surprising that its climate system has always changed.[14] Yet, a remarkable stability is also evident, with variations in temperature within a narrow range over thousands of years before the

Figure 1.1

Cities in relation to current climate-related hazards

Note: The urban areas included in this figure have populations greater than 1 million. The hazard risk represents a cumulative score based on risk of cyclones, flooding, landslides and drought. A score of '0' denotes 'low risk' and '10' denotes 'high risk'.

Source: based on de Sherbinin et al, 2007, Figure 1



Box 1.1 Climate change-related terminology

Adaptation: initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects.

Adaptive capacity: the whole of capabilities, resources and institutions of a country or region to implement effective adaptation measures. Adaptive capacity is the opposite of vulnerability (see below).

Adaptation deficit: the lack of adaptive capacity to deal with the problems associated with climate variability. Many cities, and at least some of their populations, already show adaptive deficits within the current range of climate variability without regard to any future climate change impacts. In many such cities and smaller urban centres, the main problem is the lack of provision for infrastructure (all-weather roads, piped water supplies, sewers, drains, electricity, etc.) and the lack of capacity to address this. This is one of the central issues with regard to adaptation because most discussions on this issue focus on adjustments to infrastructure – but infrastructure that is not there cannot be climate-proofed. Funding for 'adaptation' has little value if there is no local capacity to design, implement and maintain the needed adaptation.

Aerosols: airborne solid or liquid particles, with a typical size of between 0.01 and 10 micrometres (1 millionth of 1 metre) that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in several ways: directly through scattering and absorbing radiation, and indirectly through acting as cloud condensation nuclei or modifying the optical properties and lifetime of clouds.

Anthropogenic: resulting from or produced by human beings.

Carbon intensity: the amount of emission of CO_2 per unit of gross domestic product (GDP).

Climate change: a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural processes, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Carbon cycle: the flow of carbon (in various forms – e.g. as CO_2) through the atmosphere, ocean, terrestrial biosphere and lithosphere.

Carbon footprint: the total amount of emissions of GHGs caused by a product, an event and an organization. The concept of carbon footprint is a subset of the ecological footprint.

Carbon sequestration: the process of increasing the uptake of carbon-containing substances, in particular CO_2, by reservoirs other than the atmosphere, such as forests, soils and other ecosystems.

Climate variability: variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system, or to variations in natural or anthropogenic external forcing.

Ecological footprint: a measure of human demand on the Earth's ecosystems that compares human demand with planet Earth's ecological capacity to regenerate. It represents the amount of biologically productive land and sea area needed to regenerate the resources that a human population consumes and to absorb and render harmless the corresponding waste.

Energy intensity: the ratio of energy use to economic or physical output. At the national level, energy intensity is the ratio of total primary energy use or final energy use to GDP. At the activity level, one can also use physical quantities in the denominator (e.g. litres of fuel per vehicle kilometre).

Global warming: the documented increase in the average temperature of the Earth's near-surface air and sea surface temperatures based on records since the 1880s and the projected continuation of these increasing temperatures.

Greenhouse gases (GHGs): those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.

Greenhouse effect: the process by which GHGs trap heat within the surface–troposphere system.

Mitigation: technological change and substitution that reduce resource inputs and emissions per unit of output. Mitigation means implementing policies to reduce GHG emissions and enhance sinks.

Resilience: the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

Vulnerability: the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity.

Sources: based on IPCC, 2007b; European Commission, 2007; Nodvin and Vranes, 2010

industrial era.[15] Particularly striking about the current changes are the speed and intensity at which transformations in the greenhouse effect have been fostered by the exponential growth in concentrations of CO_2 and other GHGs during the industrial era: the increase of about 100 parts per million since the dawn of industrialization has led to a dramatic alteration of both the carbon cycle and the climate system.[16] An analysis of this period reveals that human actions are pushing the Earth's climate beyond a tipping point where changes in human behaviour and systems will no longer be able to mitigate the effects of climate change.

It is undeniable that the Earth's climate is warming. This is evident from models and observations at global and continental levels (see Figure 1.3), and from the work leading up to and including the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), according to which there was an increase of 0.74°C during 1906 to 2005. It has been further validated and strengthened by research published afterwards, according to which the observed increase in global mean surface temperature since 1990 is 0.33°C.[17] Since the onset of the industrial era, concentrations of CO_2 and methane (CH_4) have increased, with an increase of 70 per cent during the 1970 to 2004 period, and urban centres have played a key – though not yet fully understood – role in this process (see Chapter 3). Most important to this discussion, current research validates that there have been changes in the frequency and severity of

It is undeniable that the Earth's climate is warming

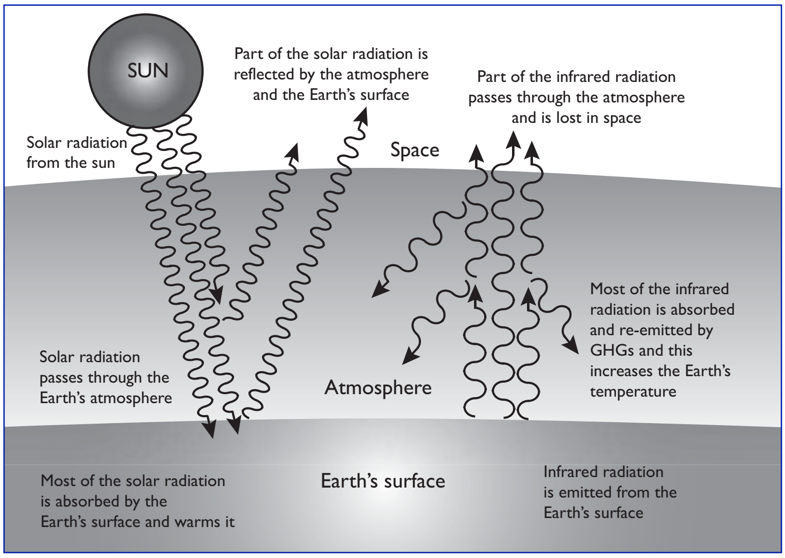


Figure 1.2

Schematic diagram of the greenhouse effect

Source: adapted from http://web.chjhs.tp.edu.tw/~j-bio/warmhouse/images/v1.gif

storms, precipitation, droughts and other weather extremes of relevance, all of which have impacts on urban centres (see Box 1.2).

The types of greenhouse gases[18]

Various human activities result in the production of GHGs. Water vapour is the most abundant GHG in the atmosphere; but its abundance means that human activities have only a small influence on its concentration. However, human action may generate feedback mechanisms that inadvertently have much larger effects on the concentration of this gas. The four most important types of GHGs produced by human activities are CO_2, methane, nitrous oxide (N_2O), and the halocarbons (hydrofluorocarbons and perfluorocarbons) and other fluorinated gases.[19] These GHGs are produced from various sources, but can also be removed from the atmosphere by various processes or activities, referred to as 'sinks'.

These gases do not all have the same impacts upon climatic change, so are often described using their CO_2 equivalent value (CO_2eq). This is a useful tool for comparing emissions, although it does not imply a direct equivalence because of the different time-scales over which these effects take place. Because of this, the gases may be allocated a global warming potential value that takes into account both the time for which they remain in the atmos-

Box 1.2 Recent changes in climate of relevance to urban areas

Rising temperatures

- 11 of the last 12 years rank among the 12 hottest years on record since 1850, when sufficient worldwide temperature measurements began. The eight warmest years have all occurred since 1998.[a]
- Over the last 50 years, 'cold days, cold nights, and frost have become less frequent, while hot days, hot nights, and heat waves have become more frequent'.[c]

Increasingly severe weather

- The intensity of tropical cyclones (hurricanes) in the North Atlantic has increased over the past 30 years, which correlates with increases in tropical sea surface temperatures.[a] According to several recent studies, the frequency of strong tropical cyclones has increased during recent decades in all world regions. Other studies suggest that the intensity of strong cyclones will further increase in the future.[b]
- Storms with heavy precipitation have increased in frequency over most land areas. Between 1900 and 2005, long-term trends show significantly increased precipitation in eastern parts of North and South America, Northern Europe, and Northern and Central Asia.[a]
- Between 1900 and 2005, the African Sahel, the Mediterranean, Southern Africa and parts of Southern Asia have become drier, adding stress to water resources in these regions.[a]
- Droughts have become longer and more intense, and have affected larger areas since the 1970s, especially in the tropics and subtropics.[a]
- More recent climate models point to the fact that the difference between humid and arid regions in terms of extreme events is projected to become even greater under a changing climate.[b]

Rising sea levels

- Since 1961, the world's oceans have been absorbing more than 80 per cent of the heat added to the climate, causing ocean water to expand and contributing to rising sea levels. Between 1993 and 2003, ocean expansion was the largest contributor to sea-level rise.[a] More recent figures on sea-level rise are substantially higher than the model-based estimates in the IPCC's Fourth Assessment Report, which did not include ice-sheet dynamics.[b]
- Melting glaciers and losses from the Greenland and Antarctic ice sheets have also contributed to recent sea-level rise (see below).[a]

Melting and thawing

- Since 1900, during winters in the Northern Hemisphere, there has been a 7 per cent loss in the seasonally average area covered by frozen ground. According to the United Nations Environment Programme (UNEP) and the World Glacier Monitoring System,[a] the average annual melting rate of mountain glaciers has doubled since 2000, in comparison with the already accelerated melting rates observed in the two decades before. Mountain glaciers and snow cover have declined worldwide.[b]
- Although the current and future contribution to sea-level rise from Antarctica is subject to large uncertainties, recent studies using extensive satellite observations found that loss of Antarctic sea ice increased by 75 per cent during the ten years between 1996 and 2006.[b]

Sources: a IPCC, 2007d; b Füssel, 2009; c IPCC, 2007d, p8

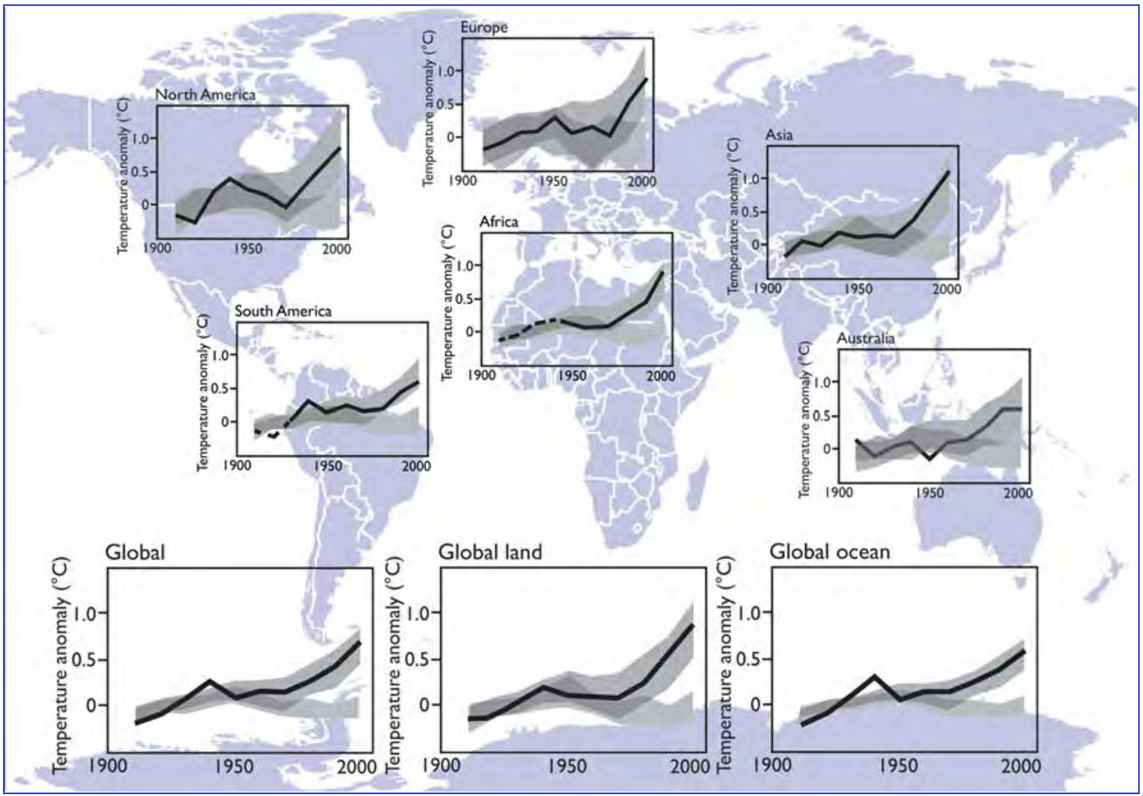


Figure 1.3

Global and continental temperature change

Note: The *black line* in the figures represents observed surface temperature changes. The *light grey band* represents how the climate would have evolved over the past century in response to natural factors only. The dark grey band represents how the climate would have changed in response to both human and natural factors. The overlap of the dark grey band and black line suggests that human activity very likely caused most of the observed increase since the mid 20th century. Lines are dashed where spatial coverage is less than 50 per cent.

Source: IPCC, 2007d, p11

phere and their relative effectiveness in causing the greenhouse effect. The global warming potential is a measure of the contribution that different GHGs make to global warming. It takes into account the extent to which these gases absorb warming radiation and the length of time that they remain in the atmosphere. The warming potential of CO_2 is used as the baseline against which this is measured (see also Table 1.3).

■ Carbon dioxide

Carbon dioxide (CO_2) is the most important anthropogenic GHG. Indeed, CO_2 emissions are often used synonymously with contributions to climate change. The main sources of atmospheric CO_2 are from the burning of fossil fuels, which is responsible for more than 75 per cent of the increase in atmospheric CO_2 since pre-industrial times. This energy from fossil fuels is used in transportation, heating and cooling of buildings, and manufacture of cement and other goods – all of which are substantial activities in urban areas. Land-use changes – deforestation and changing agricultural practices – account for the remaining 25 per cent of CO_2 emissions. Deforestation also reduces an important sink for the gas, as plants absorb CO_2 in the process of photosynthesis. The average annual CO_2 emissions from fossil fuels, cement production and gas flaring were 12.5 per cent greater during the period of 2000 to 2005 than during 1990 to 2000. The global atmospheric concentration of CO_2 in 2005 was approximately 379 parts per million – an increase from a pre-industrial value of about 280 parts per million. The approximate lifetime of CO_2 in the atmosphere is 50 to 200 years.

Carbon dioxide (CO_2) is the most important anthropogenic GHG

The main sources of atmospheric CO_2 are from the burning of fossil fuels … used in transportation, heating and cooling of buildings, and manufacture of cement and other goods

	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrous oxide (N_2O)	Halocarbons[a] CFC- 11	CFC- 12	HFC- 23
Atmospheric concentration: parts per million (ppm)/billion (ppb)/trillion (ppt):						
Pre-industrial times	280 ppm	715 ppb	270 ppb	–	–	–
1998	366 ppm	1763 ppb	314 ppb	264 ppt	534 ppt	14 ppt
2005	379 ppm	1774 ppb	319 ppb	251 ppt	538 ppt	18 ppt
Change in atmospheric concentration (%):						
Pre-industrial times–2005	+31	+147	+16	∞	∞	∞
1998–2005	+4	+1	+2	–5	+1	+29
Approximate lifetime in the atmosphere (years)	50–200	12	114	45	100	270
Global warming potential relative to CO_2 in 100 years	1	25	298	4750	10,900	14,800
Radiative forcing 2005 (watts per square metre)	1.66	0.48	0.160	0.063	0.170	0.0033
Change in radiative forcing 1998–2005 (%)	+13	–	+11	–5	+1	–

Notes: a For details on other halocarbons, see IPCC (2007d). ∞ = infinity.

Sources: Forster et al, 2007; IPCC, 2007d

Table 1.3

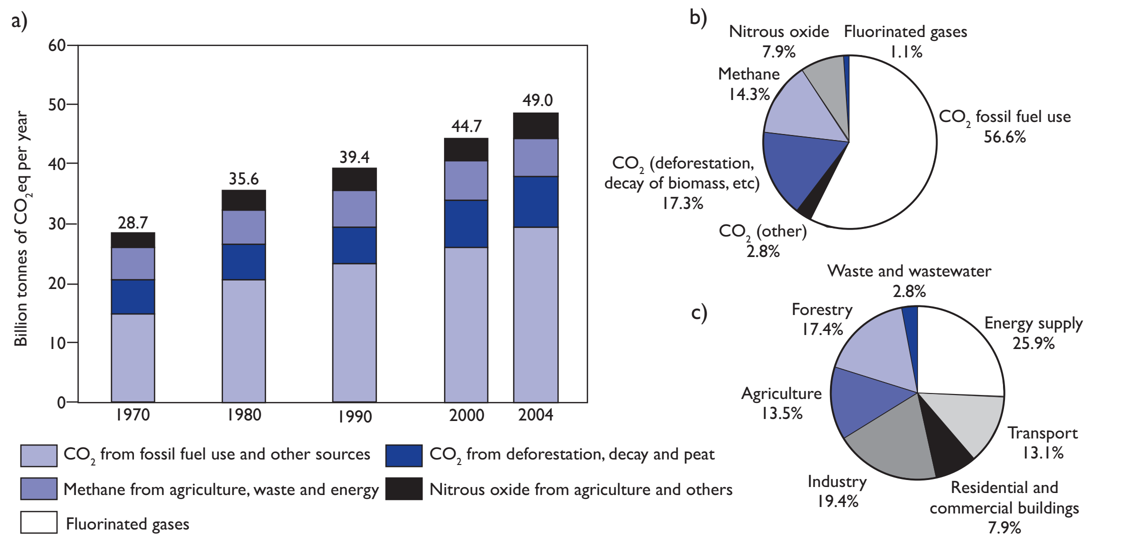
Major characteristics of the most important GHGs

Figure 1.4

Global anthropogenic GHG emissions

Notes: (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004; (b) share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2 equivalents (CO_2eq); (c) share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2eq (forestry includes deforestation).

Source: IPCC, 2007a



Methane

Methane is emitted into the atmosphere through a variety of human activities, including energy production from coal and natural gas, waste disposal in landfills, raising ruminant animals (e.g. cattle and sheep), rice cultivation and the burning of biomass. Wetlands are the main natural source of methane, although it is also emitted from the oceans and by the activities of termites. In 2005, methane accounted for about 1774 parts per billion of the atmosphere, more than twice its pre-industrial value – and these current levels are due to the continued human-induced emissions of the gas. Despite this apparently low concentration, methane is a powerful GHG that has a significant impact upon climate change. It is relatively short lived in the atmosphere with an approximate lifetime of 12 years. Over a 100-year period, it has 25 times the global warming potential of CO_2; but in the short term this is much stronger: it has a global warming potential 72 times that of CO_2 over a 20-year time horizon.

Nitrous oxide

Nitrous oxide is emitted from fertilizers and the burning of fossil fuels, and is also released by natural processes in soils and oceans. About 40 per cent of total nitrous oxide emissions result from human activities. In 2005, atmos-

Table 1.4

Total and per capita GHG emissions ('top 20 countries')

Country	GHG emissions (2005)[a] Thousand metric tonnes of CO_2eq	GHG emissions (2005)[a] Percentage of total CO_2eq	GHG emissions (2005)[a] Metric tonnes of CO_2eq per capita	CO_2 emissions (2007)[b] Thousand metric tonnes of CO_2	CO_2 emissions (2007)[b] Percentage of total CO_2	CO_2 emissions (2007)[b] Metric tonnes of CO_2 per capita	CO_2 emissions (2007)[b] Percentage change in CO_2 (2005–2007)
China	7,303,630	18.89	5.60	6,538,367	22.30	4.96	16.5
US	7,211,977	18.66	24.40	5,838,381	19.91	19.38	–0.1
India	2,445,328	6.33	2.23	1,612,362	5.50	1.43	14.3
Russian Federation	2,115,042	5.47	14.78	1,537,357	5.24	10.82	1.4
Japan	1,446,883	3.74	11.32	1,254,543	4.28	9.82	1.0
Brazil	1,079,576	2.79	5.80	368,317	1.26	1.94	5.2
Germany	972,615	2.52	11.79	787,936	2.69	9.58	–2.7
Canada	725,606	1.88	22.46	557,340	1.90	16.90	–0.5
UK	672,148	1.74	11.16	539,617	1.84	8.85	–0.8
Mexico	627,825	1.62	6.09	471,459	1.61	4.48	6.9
Indonesia	625,677	1.62	2.85	397,143	1.35	1.77	16.4
Australia	601,444	1.56	29.49	374,045	1.28	17.75	2.7
Iran	598,479	1.55	8.66	495,987	1.69	6.98	16.2
Italy	571,378	1.48	9.75	456,428	1.56	7.69	–2.5
France	542,980	1.40	8.92	371,757	1.27	6.00	–5.2
Republic of Korea	535,836	1.39	11.13	503,321	1.72	10.39	8.7
South Africa	499,842	1.29	10.66	433,527	1.48	9.06	6.2
Spain	457,776	1.18	10.55	359,260	1.23	8.01	1.6
Saudi Arabia	439,516	1.14	19.01	402,450	1.37	16.66	9.6
Ukraine	427,297	1.11	9.07	317,537	1.08	6.83	–2.8
Other developed countries	2,237,764	5.79	9.46	1,791,983	6.11	7.55	1.1
Rest of Asia and Pacific	3,527,583	9.13	3.51	2,460,617	8.39	2.37	7.3
Rest of Latin America and the Caribbean	1,329,867	3.44	5.04	749,694	2.56	2.77	10.0
Rest of Africa	1,659,120	4.29	1.90	699,867	2.39	0.77	4.1
World total	**38,655,189**	**100.00**	**6.00**	**29,319,295**	**100.00**	**4.45**	**6.0**

Note: The world totals include only emissions that have been accounted for in national inventories.

Source: a http://data.worldbank.org/indicator, last accessed 21 October 2010; b http://mdgs.un.org/unsd/mdg, last accessed 21 October 2010; see also Statistical Annex, Tables B.7 and B.8

pheric nitrous oxide levels were 18 per cent higher than pre-industrial levels, at 319 parts per billion. The gas has a lifetime in the atmosphere of 114 years, and over a 100-year period has a global warming potential that is 298 times greater than CO_2.

■ Halocarbons

Halocarbons – including chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) – are GHGs that are produced solely by human activities. CFCs were widely used as refrigerants before it was discovered that their presence in the atmosphere caused the depletion of the ozone layer. International regulations to protect the ozone layer – notably the Montreal Protocol of 1987 – have been successful in reducing their abundance and their contribution to global warming. However, the concentrations of other industrial fluorinated gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) are relatively small but are increasing rapidly. Although these gases occur in much smaller concentrations than CO_2, methane and nitrous oxide, some of them have extremely long lifetimes and high global warming potentials, which means that they are important contributors to global warming. For example, HFC-23 (CHF3) has a lifetime of 270 years and a global warming potential over 100 years 14,800 times greater than CO_2.

The causes of climate change

The main human sources of GHGs contributing to global warming are the dramatic rise in energy use, land-use changes and emissions from industrial activities (see Figure 1.4). Furthermore, between 1970 and 2004, changes in factors such as increased per capita income (up 77 per cent) and population growth (up 69 per cent) have favoured increases in GHG emissions. These have been, to a limited extent, offset by increases in efficiency and/or reductions in the carbon intensity of production and consumption; but the overall global trend has still been towards large increases in anthropogenic GHG emissions.

Not every country has contributed at the same level to global warming. In 2007, developed countries accounted for 18 per cent of the world's population and 47 per cent of global CO_2 emissions, while developing countries accounted for 82 per cent of the population and 53 per cent of CO_2 emissions.[20] Developing countries, therefore, generated only 25 per cent of the per capita emissions of developed countries. A select number of developed countries and major emerging economy nations are the main contributors to total CO_2 emissions (see Table 1.4). In fact, three developed countries (Australia, the US and Canada) have among the highest CO_2 emissions per capita, while some developing countries lead in the growth rate of CO_2 emissions (e.g. China and Brazil). These uneven contributions to the climate change problem are at the core of both international environmental justice issues and the challenges that the global community faces in finding effective and equitable solutions (see Chapter 2).

In this context, humanity is facing two main challenges that urban centres can to help address:

1. *There is a need to adapt*, at least to some amount of continued warming, because even if the concentrations of GHGs and aerosols are kept constant at year 2000 levels, 'a further warming of about 0.1°C per decade would be expected'.[21]
2. *There will also be a need to mitigate* – that is, to achieve development paths that bring about a peaking of emissions by 2015 and a stabilization of GHG concentrations in the atmosphere at about 445 to 490 parts per million by volume of CO_2 equivalents (CO_2eq) by the end of the century.[22] This path would keep global average temperature increases within 2°C to 2.4°C above pre-industrial levels, in keeping with the objective outlined in the United Nations Framework Convention on Climate Change, Article 2 (see Chapter 2).

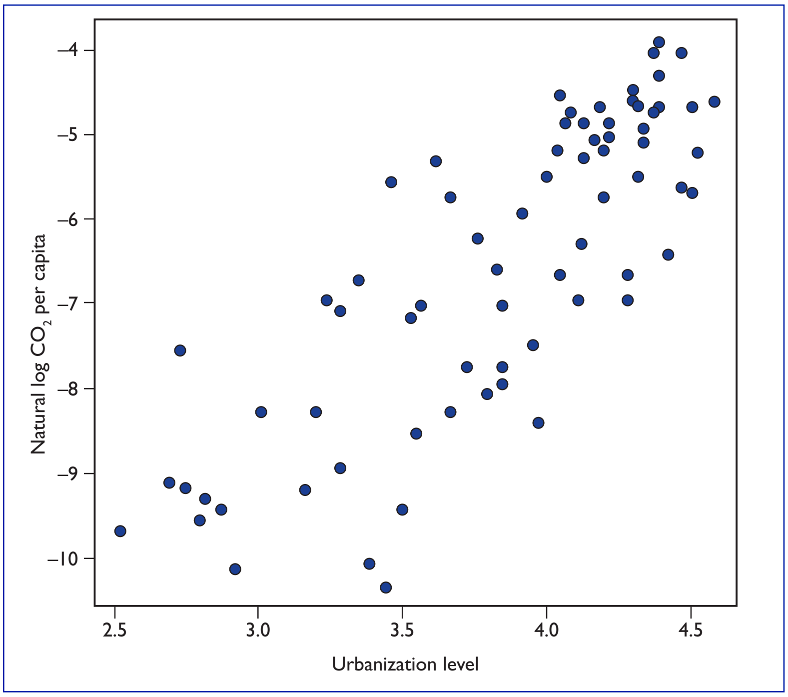


Figure 1.5

Relationships between urbanization levels and CO_2 emissions per capita

Source: Romero Lankao et al, 2008

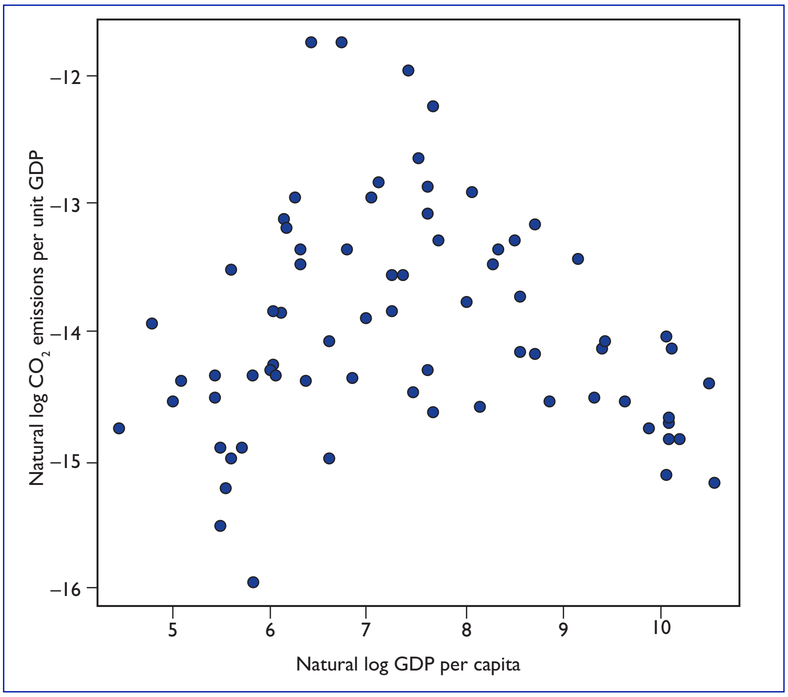


Figure 1.6

Carbon intensity and economic development (2003)

Source: Romero Lankao et al, 2008

Regarding the amount of GHG emissions that urban areas contribute to the atmosphere, it has been claimed (correctly or incorrectly) that although cities take up only 2 per cent of the Earth's land mass, they are responsible for as much as 75 per cent of the GHGs that are released into the atmosphere.[23] Indeed, many of the sources of these emissions are urban. The myriad of urban processes accounting for these emissions are combustion of fossil fuels by commercial and residential buildings or electricity generating plants for heating and air conditioning, the commercial and individual use of energy for running motor vehicles for transportation, and energy used in industrial processes. Urban households may also consume fuels more directly, in heaters and cookers, or indirectly in air conditioning or electric heating. Land-use changes induced by urban growth may lead to deforestation and reductions in the uptake of CO_2 by vegetation. Landfill sites taking up urban wastes also generate methane. Cement, as a construction material of primary importance to the development of urban infrastructure, as well as of commercial and residential buildings, also has a large carbon footprint due to an energy-intensive manufacturing process and high energy cost for transporting this dense material. Lastly, many activities, such as agriculture, livestock production, mining, timber collection and lumber production, increase GHG emissions as direct emitters or reduce the uptake of these gases by vegetation. While these are often undertaken outside the boundaries of urban centres, they are aimed at satisfying urban needs for food, raw materials, forest products and construction materials.

It remains unclear just how accurate existing figures on GHG emissions by cities are

Since the industrial revolution, urban centres have concentrated industries, construction, transportation, households and other activities that release large quantities of GHGs

The exploration of how urban centres contribute to climate change requires an understanding of how … urban activities and infrastructures act both as emitters and direct causes of climate change

As will be shown in Chapter 3, it remains unclear just how accurate existing figures on GHG emissions by cities are. Many different criteria have been used to measure these emissions, and the choice by researchers to use one or the other can greatly skew the final calculations on how large those contributions are.[24] For instance, if GHG emissions are allocated based on the generating activities within urban centres (the production-based approach), then these centres emit between 30 and 40 per cent of all anthropogenic GHGs. The proportion of GHGs that should be attributed to cities would be higher, however, if emissions were assigned to the consumers (i.e. to the home or business or organizational location of those whose demand for goods, services or waste disposal or travel creates the need for those goods or services that produce the GHG emissions). Under this consumption-based approach, cities' contribution to global GHG emissions would rise to almost half of all global emissions.

A dynamic, complex and strong link exists between economic development, urbanization and CO_2 emissions (see Figures 1.5 and 1.6). Urban contributions to CO_2 emissions seem to be based at least in part on the size of the national economy in which the urban centres are located (as measured by total GDP in constant US dollars) and the structure of that economy (i.e. whether it is predominantly industrial or service oriented). Although the relations between total emissions and the size of a country's economy have been weakening since the 1960s, there is still a strong correlation, with total emissions rising with the size of the economy (see Figure 1.6). Total energy used per unit of GDP went down by 33 per cent between 1970 and 2004, yet the rate of improvement has not been enough to globally reduce GHG emissions, which are rising beyond the worst-case scenario and have already resulted in an Earth that is 0.8°C warmer on average than it was in pre-industrial times. Based on the significant roles that they play in their countries' economies, urban areas can be seen as playing a major role in this connection.[25]

Nevertheless, the relationship between levels of urban development, as measured by GDP and levels of GHG emissions, is not so straightforward. It is clear that differences in GHG emissions result from the peculiarities and weight of different sectors, as shown in the next section.

FRAMEWORK FOR EXPLORING THE LINKAGES BETWEEN URBAN AREAS AND CLIMATE CHANGE

Reducing the contribution of cities to climate change, or mitigation, requires an adequate understanding of the drivers of urban GHG emissions, while effective adaptation must be based on a good understanding of what makes cities and their constituent socio-economic groups either vulnerable or resilient to climate change impacts. This section therefore focuses on the drivers of GHG emissions in urban areas and the concepts of vulnerability and resilience as frameworks for both analysis and for formulating mitigation and adaptation policy options.

Drivers of urban contributions to GHG emissions

Since the industrial revolution, urban centres have concentrated industries, construction, transportation, households and other activities that release large quantities of GHGs. Other sources that occur both inside and outside cities, but serve urban development, include deforestation and other land-cover changes, agriculture, waste disposal, power generation, and refrigeration and air conditioning. Chapter 3 presents findings from a wide range of urban emissions inventories to show how the data on urban emissions varies from place to place, and how the figures on emissions vary depending on the approaches used (i.e. consumption- or production-based approaches). It is therefore important to have a framework for understanding the levels and drivers of emissions by different demographic and economic sectors, buildings and infrastructures within, or serving, urban areas.

The exploration of how urban centres contribute to climate change requires an understanding of how transportation, heating and cooling systems, industries and other urban activities and infrastructures act both as emitters and direct causes of climate change. They create two main categories of impacts on the carbon cycle and the climate system:

1 *Changes related to the emission of aerosols, GHGs and solid wastes.* GHGs are the main source of changes in the climate system. Not only do they change the dynamics of the carbon cycle, but together with aerosols they also generate changes in the Earth's radiation that induce climate change.[26] Wastes affect the growth, function and health of vegetation and of ecosystems in general.[27]
2 *Land-use related changes.* Urbanization is a process that changes the uses of land and by creating impervious surfaces, filling wetlands and fragmentation of ecosystems has disproportional impacts upon the carbon cycle. The built environment of urban areas is also a forcing function on the weather–climate system of urban centres because it is a source of heat and a poor storage system for water.

Both within and across cities, different populations, economic activities and infrastructures contribute at different levels to global warming. Some studies point to the fact that *gender inequities* exist both in energy use and GHG emissions and that the differences are related not only to wealth, but to behaviour and attitudes. For instance, women tend to buy efficient electric appliances, while men tend to undertake efforts to insulate their houses. Men tend to eat more meat, while women tend to eat more vegetables, fruits and dairy products. Men tend to use more private motorized transport than women, and to use larger, more fuel-consuming vehicles.[28]

Urban centres in developing countries have lower levels of emissions per capita than cities in developed countries.[29] Houston and Washington, DC (US), for instance, have carbon emissions that are about 9 to 18 times higher than those in São Paulo (Brazil), Delhi and Kolkata (India) (see Chapter 3). Yet, other wealthy cities such as Stockholm (Sweden) and Barcelona (Spain) have lower levels of emissions per capita than some South African cities. This is because several *interrelated* factors shape or determine the patterns of energy use and emissions by different populations and sectors.

The *climate and natural endowments* of an urban area are significant factors shaping its energy-use pattern. A city located in high latitudes, for instance, might consume more energy to heat its buildings and houses than one situated in the tropics; and conversely, an urban centre located in the tropics might consume more energy for air conditioning. Thus, climate change will affect energy consumption behaviour in many urban areas of the world.

Weather undoubtedly plays a role in cities' carbon footprints, but does not act alone. For instance, many relatively colder urban areas in the northeast of the US have larger residential carbon footprints because they rely on carbon-intensive home heating fuels such as fuel oil. Warm areas in the south, likewise, have large residential carbon footprints because they rely on carbon-intensive air conditioning.[30] The carbon intensity of the fuels used is, hence, another key factor. For instance, the carbon intensity of coal is almost two times higher than the carbon intensity of natural gas.

The *economic base* of a city is another important factor. In Beijing and Shanghai (China), industry contributes 43 and 64 per cent of the total emissions, respectively.[31] Industrial emissions of GHGs in cities elsewhere are much lower: 28.6 per cent in Mexico City, 7 per cent in London (UK), 9.7 per cent in São Paulo (Brazil), and 10 per cent in Tokyo (Japan) and New York (US). This reveals that many cities have already transitioned to service-based urban economies and, thus, have been able to reduce their carbon footprints. The differences reflect a shifting international pattern in the location of industrial activities – a pattern determined by differences in profitability, costs and environmental legislation among cities.[32] The current pattern reflects the fact that China has become the main manufacturer of commodities for the world, allowing developed countries to shift responsibility for their own GHG emissions in spite of the fact that their consumer-driven impact upon the market has created much of the need for a high industrial output in China. This international shifting of the location of industrial production calls for the use of consumption-based approaches, and not only production-based ones, in the measurement of emissions in order to have a true picture of responsibility for industrial emissions among and within countries and urban areas.[33]

Affluence has been repeatedly acknowledged as a significant driver of GHG emissions and other environmental impacts; but again it does not act alone – rather, together with such factors as technology, natural endowments and equity. According to ecological modernization theory, environmental problems such as climate change are addressed by development or modernization. A structural change, or shift, to less carbon-intensive societies occurs at the macroeconomic level through the development of new and less carbon-intensive technologies whose use is induced by market mechanisms.[34]

As an economy develops (modernizes), sectors such as agriculture and fisheries are replaced by manufacturing industries and, with further development, service industries. Ecological modernization theorists argue that economic growth within developing economies will follow a natural path, driven by economic forces and market dynamics, from higher to lower states of environmental stress. The environmental impacts of economic growth, thus, increase in the early stages of development, but stabilize and then decline as economies mature. The process is depicted by an inverted U-shape curve, also known as the Environmental Kuznets Curve. Indeed, the relation between national carbon intensity and level of economic development has changed from essentially linear in 1965 to essentially curvilinear in 1990.[35] The tendency to an essentially curvilinear relation was still valid for the year 2003 (see Figure 1.6). A linear relation means that a one unit increase in GDP essentially translates to a similar increase in emissions, while in a curvilinear relation a one unit increase relates to a smaller than one unit increase in emissions. However, at least part of this tendency might be understood in terms of the shifting of manufacturing activity to other areas due to economic, political and environmental factors, as illustrated in the example of China given above. Because developed countries'

Gender inequities exist both in energy use and GHG emissions

Urban centres in developing countries have lower levels of emissions per capita than cities in developed countries

The international shifting of the location of industrial production calls for the use of consumption-based approaches … in the measurement of emissions … among and within countries and urban areas

economies have become service based and because their industrial production has been relocated to some developing countries, GHGs emitted by their urban areas have decreased. However, their responsibility for that percentage of the GHGs emitted in the industrial manufacturing countries producing goods for them should be accounted to them as the consumers creating the need for the goods and not to the manufacturing country.[36] Some researchers have suggested that this change in the attribution of GHGs would alter the features of the curve.[37]

The environmental burdens of affluence, such as climate change, can affect both rich and poor people around the globe; but … tend to fall disproportionately upon the poor

Affluence theory has empirical and political relevance for this Global Report for two reasons. While the 'environmental burdens of urban poverty primarily affect the poor living in the immediate locality', the environmental burdens of affluence, such as climate change, can affect both rich and poor people around the globe; but these also tend to fall disproportionately upon the poor.[38] The second reason, relevant to the debate around climate change impacts upon cities, follows from the fact that the very urban dwellers most at risk from local environmental degradation – the poor – seem also to be most at risk from floods, heat waves, storms and other climate-related threats.[39]

The size, growth, structure and density of population are key determinants of cities' GHG emissions

It can be misleading to concentrate on urban emissions per capita, as there are very large differentials within urban centres. Both gender and socio-economic equity is, therefore, a key dimension affecting GHG emissions by urban populations and activities. There is no adequate information to provide an accurate picture on the role of equity in determining different levels of emissions among demographic sectors of an urban area. Yet, some examples can be used to draw preliminary conclusions. According to a study on the per capita emissions footprints of single-person households in Germany, Norway, Greece and Sweden, on average men consumed between 6 per cent (Norway) and 39 per cent (Greece) more energy than women, and this gender difference is independent of income and age.[40] The per capita emissions of Dharavi, a predominantly low-income, high-density inner-city neighbourhood of Mumbai (India), are a tiny fraction of the per capita emissions of high-income districts of Mumbai, where a high proportion of the population commutes to work by car.[41]

According to human ecologists, the size, growth, structure and density of *population* are key determinants of cities' GHG emissions and other environmental impacts.[42] A negative correlation exists between population density and atmospheric GHG emissions; for instance, a 1 per cent increase in the density of urban areas would relate to approximately 0.7 per cent decline in carbon monoxide (CO) pollution at the city level, with other factors held constant.[43] Spatially compact and mixed-use urban developments have significant benefits in terms of GHG emissions.[44] However, attention also needs to be given to other explaining factors, such as land-use patterns and the layout of the transportation system.[45] Furthermore, urban density poses a dilemma: while 'tailpipe emissions and fossil-fuel consumption are greatly increased with urban sprawl', levels of human exposure to emissions of other pollutants (e.g. nitrogen dioxide) might actually increase with density if no measures are undertaken to reduce atmospheric emissions.[46] The implications of urban form on climate change mitigation and adaptation are discussed in Chapters 5 and 6.

Box 1.3 Mexico City: Environmental degradation and vulnerability

The water management system of Mexico City has developed features which do not allow it to cope with floods and droughts. It is overexploiting not only its water resources by between 19.1 and 22.2 cubic metres per second, but also the water of two providing basins (Lerma and Cutzamala). According to projections where no consideration is given to global warming, between 2005 and 2030 the population of Mexico City will increase by 17.5 per cent, while between 2007 and 2030 available water will diminish by 11.2 per cent. The situation might get worse if, as expected, climate change brings lower precipitation to this area. Those water users who already face recurrent shortages during the dry season, or when droughts hit Mexico City, will be especially affected. For example, 81.2 per cent of people affected by droughts during 1980 to 2006 live in Netzahualcoyotl, one of the poorer municipalities of the city.

This overexploitation of water resources creates two sources of vulnerability: first, problems of water availability (scarcity) that make water users (especially poor sectors already facing scarcity) vulnerable to the changes in the availability of water that are expected from climate change. Second, groundwater levels are continuously falling, which historically has caused subsidence (and continues to do so in some areas), thus undermining the foundations of buildings and urban infrastructure and increasing the vulnerability of these areas and the populations within them to such hazards as heavy earthquakes and rains.

Source: Romero Lankao, 2010

Urban vulnerability and 'resilience'

As described above, urban settlements are already at risk from sea-level rise, droughts, heat waves, floods and other hazards that climate change is expected to aggravate. Yet, a focus on the *exposure* to these hazards alone is insufficient to understand climate change impacts upon urban centres, their populations and economic sectors. Attention to urban resilience, development, socio-economic and gender equity, and governance structures as key determinants of adaptive capacity and actual adaptation actions is also necessary. Many scholars and practitioners view resilience in the context of responses to hazards and recovery from disasters.[47] In this view:

- Cities can increase or reduce the impacts of such hazards as floods and heat waves as a result of their socio-environmental history. Urban activities invariably alter their environment, but two results are possible: environmental degradation and reduced resilience (see Box 1.3), or urban populations' growing ability to repair damage, sustain the environment and increase cities' resilience.[48]
- Urban populations and the different tiers of government responsible for their well-being are resilient if they are able to build capacity for learning and adaptation, and even capitalize on the learning opportunities that might be opened by a disaster. The urban populations of Dhaka and other human settlements of Bangladesh offer an example of this (see Box 1.4).

The significance of urban vulnerability and adaptive capacity to climate impacts can be analysed on at least two distinct levels: from the perspective of the city as a whole and the way in which it develops; and from the perspective of the city as it can be broken down to reveal its different sociodemographic groups' access to the determinants of adaptive capacity.

Urban development can bring increased vulnerability to climate hazards

The concentration, in urban centres, of people and their homes, infrastructure, industries and waste within a relatively small area can have two implications for the urban impacts of climate change and other stresses. On the one hand, urban areas can be dangerous places in which to live and work; their populations can be very vulnerable to extreme weather events or other hazards, with the potential to become disasters. For instance, the urban concentration of these elements can generate risk when residential and industrial areas lack space for evacuation and emergency vehicle access (as in the case of slums), when high-income populations are lured by low-lying coastal zones or green areas (as in California or Florida in the US, or Melbourne, Australia), or when lower-income groups, lacking the means to access safer land, settle on sites at risk from floods or landslides (as in Rio de Janeiro in Brazil, Mumbai in India and many urban centres in developing countries).

Urban settlements can increase the risk of 'concatenated hazards'.[49] This means that a primary hazard (heavy storm) leads to secondary hazard (e.g. floods creating contamination of water supplies, or landslides destroying houses and infrastructures). Industrialization, inadequate planning and poor design are key determinants of secondary or technological risks. As illustrated by Bogotá (Colombia), Buenos Aires (Argentina) and Santiago (Chile), the populations of many cities are already at risk from exposure to high levels of pollution, exceeding World Health Organization (WHO) standards in particulate matter and nitrogen dioxide concentration in the air.[50] It is possible that the impacts of climate hazards such as heat waves will overlap with pollution events and the urban heat-island effect, and compound one another, making urban disaster risk management even more complex.

On the other hand, the same concentration of people, infrastructure and economic activities in urban centres also means economies of scale for many of the measures that reduce risks from extreme weather events. These economies of scale might manifest themselves in a reduced per capita cost of better watershed management, warning systems and other measures to prevent and lessen the risks when a disaster threatens or occurs. Furthermore, when provided with policies focused on enhancing sustainability and moving from disaster response to disaster preparedness, urban settlements can increase their effectiveness at coping with climate hazards.

Exposure to current climate hazards is, for many cities, a result of historical location factors and a long development process. Many cities have developed without consideration of the risks that climate change will induce. Most large cities have been built on sites that were originally chosen for trade or military advantage (e.g. Shanghai, China; New York, US; Cartagena, Colombia; and Cape Town, South Africa). In the majority of cases, this has meant that they were located on the coasts or near the mouths of major rivers where trade by sea with other coastal cities or by rivers with the interior hinterlands could best be accomplished. These urban centres then became the hubs of trade for their countries and, as such, greatly increased their wealth.

Box 1.4 Capacity to learn and adapt in Bangladesh

Bangladesh is situated in an area at risk from tropical storms, whose intensity and frequency have increased over the last years. A hurricane hit Bangladesh in 1991 killing at least 138,000 people and leaving as many as 10 million people homeless. Serious efforts have been undertaken, promoted by local and national governments and international organizations, to decrease the risk from tropical cyclones in the area. These efforts have included the development of an early warning system and the construction of public shelters to host evacuated people. These improvements were tested in 2007, when between 8 and 10 million Bangladeshis were exposed to Sidr, perhaps the strongest cyclone to hit the country since 1991. There was a 32-fold reduction in the death toll (i.e. 4234 people compared to 138,000) and Bangladesh's capacity for learning and adaptation was proven (see also Boxes 4.4 and 6.2).

Source: Paul, 2009

As this wealth continued to build, further development was fuelled and these areas became engines of economic growth for their countries, attracting more capital from private-sector investment and labour migration from rural areas and immigration from other countries. The movement to urban centres continues today and these areas have become magnets of industry and labour without regard to the many environmental risks that are endemic to these areas and the mounting hazards resulting from climate change.

Urban centres also means economies of scale for many of the measures that reduce risks from extreme weather events

Why are some sectors of the population more vulnerable?

Not all demographic segments of the urban population are equally affected by the hazards aggravated by climate change. The capacity of different urban populations to cope or adapt is influenced not only by age and gender, but also by one or a combination of some or many factors[51] (see Chapter 4). These factors include:

When provided with policies focused on enhancing sustainability and moving from disaster response to disaster preparedness, urban settlements can increase their effectiveness at coping with climate hazards

- Labour, education, health and the nutrition of the individuals (*human capital*). As a critical asset, labour is linked to investments in human capital. Health status determines people's capacity to work; education and skills determine the returns from their labour.
- The financial resources available to people (savings, supplies of credit – i.e. *financial capital*).
- The extent and quality of infrastructure, equipment and services (*physical capital*), some of which are owned by individuals (e.g. housing).
- Stocks of such environmentally provided assets as soil, land and atmosphere (*natural capital*). In urban areas, land for shelter is a critical productive asset.
- The quality and inclusiveness of governance structures and community organizations that provide or manage safety nets and other short- and longer-term responses, or *social capital* – an intangible asset defined as the rules, norms, obligations and reciprocity embedded in social relations and institutional arrangements.

Higher-income groups … have higher adaptive capacity

Women … can be particularly vulnerable to disasters

Children are more at risk of being affected by the adverse impacts of climate change

Poorer groups are most affected by the combination of greater exposure to a range of other possible urban hazards (e.g. poor sanitary conditions and lack of hazard-removing infrastructure such as drainage)

Wealthy individuals and households have many of the requirements for higher adaptive capacity. They have more resources to reduce risks – that is, safer housing, more stable jobs, safer locations to live in, and better means of protecting their wealth (e.g. insurance of assets that are at risk). Wealthier groups often have more influence on public expenditures. In many urban areas, middle- and upper-income groups have been the main beneficiaries of government investment in such determinants of adaptive capacity as infrastructure and services. If government does not provide these, higher-income groups have the means to develop their own provisions for water, sanitation and electricity, or to move to private developments which provide them. Wealthier groups, therefore, have higher adaptive capacity.

Although systematic evidence of the gender implications of climate change at the city level both among wealthy and poor sectors and countries is still lacking,[52] some evidence points to the fact that gender gaps exist in access to such assets and options as credit, services, education, information, decision-making power and technology. For instance, in sub-Saharan Africa, 84 per cent of women's non-agricultural employment is informal (compared to 63 per cent of men's).[53] The informal sector is also important in capital and large cities, where more than half of all women are employed in the informal sector (except in South Africa and Namibia), although informal employment is actually higher in small cities and towns and rural areas.[54] Due to this situation, women do not have adequate livelihood options and can be particularly vulnerable to disasters. As illustrated by Hurricane Mitch in Honduras and floods in Dhaka, Bangladesh, disaster warnings often do not reach women or are not understood by women. Furthermore, in many instances, women cannot evacuate without the authorization of their husbands.[55]

Scattered evidence points to the fact that children are more at risk of being affected by the adverse impacts of climate change.[56] There are several reasons for this: they are in a stage of rapid development which can be severely interrupted by the stress of severe weather events and climate hazards. They are relatively more vulnerable to warm spells and heat waves, heavy precipitation, droughts and other climate hazards because of their immature organs and nervous systems, limited experience and behavioural characteristics. This can be intensified by poverty and the difficult choices that poor households make as they cope with challenging situations. However, it is also true that 'with adequate support and protection, children can be extraordinarily resilient' when faced with hazards and stresses.[57]

Very elderly men and women can also be at risk, as illustrated by the high elderly mortality rates in the heat waves that hit Chicago (US) in 1995 and Europe in 2003. Indeed, as illustrated by research in the cities of London and Norwich (UK), the elderly might feel, falsely, that heat waves do not pose a significant risk to them personally.[58] The elderly can also be limited in their capacity to move rapidly away from rising floodwaters by their isolation, their health conditions or their perceptions.

The urban poor tend to be highly vulnerable, especially in developing countries, and may also fall into other disadvantaged categories that increase vulnerability by also being women, very young or very old. Many poor populations face additional risks: they live in informal settlements, live on floodplains, unstable slopes, over river basins and in other highly risk-prone areas, or work within the informal economy. They are also constantly faced with the possibility that governments may forcibly move them off land sites deemed to be vulnerable to weather risks, or they may be moved simply because other actors want the land they occupy for more 'profitable' uses, but with the consequence that they are also moved away from their means of livelihood.[59]

Furthermore, poorer groups are most affected by the combination of greater exposure to a range of other possible urban hazards (e.g. poor sanitary conditions and lack of hazard-removing infrastructure such as drainage). They have less state provision to help them cope, along with less legal and insurance protection. Low-income groups also have far fewer possibilities to move to less dangerous sites. This should not, however, lead to the conclusion that the poor are merely passive recipients of the risks of climate change and other hazards. As illustrated by Cavity City in the Philippines, or the *Baan Mankong* ('secure tenure') programme in Thailand,[60] many poor groups have developed mechanisms to adapt. It just means that the structural issues referred to here pose severe limits to their coping mechanisms and create constraints upon their adaptation options.

CONCLUDING REMARKS AND STRUCTURE OF THE GLOBAL REPORT

Urbanization and climate change are sources of both developmental and environmental challenges and opportunities. Industrialization and urbanization have been critical components of rapid economic growth and of technological changes that have contributed to improvements in the economy and the quality of life of many urban populations around the world. Both have also helped to decrease the carbon intensity and increase the efficiency of production and consumption. Yet, notwithstanding these socio-economic and technological achievements, poverty – which has increasingly been acquiring an urban face – remains a formidable challenge. 'The needs remain enormous, with the number of hungry people having passed the billion mark.'[61] Poverty alleviation thus remains the overarching priority, especially in developing countries.

Climate change, which is both a developmental and environmental issue, complicates the picture in several ways. The impacts of global GHG emissions are currently manifest in stronger and more frequent floods, droughts and heat waves, adversely affecting the industries, populations and governments of many urban centres. Therefore, urban populations and economic sectors are faced with two challenges: the need to adapt, at least to some amount of warming, and the urgency to mitigate the causes of global climate change.

Urban centres of developed countries and wealthy sectors within cities of developing countries must play a vital role in reducing their carbon footprints. Their actions cannot be reduced to technological fixes aimed at increasing energy efficiency and reducing the carbon intensity of cars, fabrics, utilities and other devices. Because goods, services, waste disposal and transportation are aimed at satisfying urban markets, the responsibility for the emissions produced in their manufacture, production and energy expenditures needs to be allocated to urban consumers, even when these goods and services are generated outside urban boundaries. This has very profound implications and difficulties for creating real mitigation strategies. A call for a change in consumption patterns and lifestyles away from a focus on more and bigger is, clearly, fundamental.

Actions to induce changes in the factors shaping population density, urban form, lifestyles, equity and other components of urban development are equally fundamental for mitigation, adaptation and sustainable development. Transport strategies, for instance, need to be consistent with the spatial structures of cities.

Urban development can also be a source of resilience. Population densities can create the potential for city-scale changes in behaviour that can mitigate human impacts upon climate and create opportunities for adaptation to floods, heat waves and other climate hazards. Properly designed infrastructure developments can provide physical protection; well-designed communications and early warning systems; can help people to deal with disasters; and appropriate urban planning can help restrict the growth of populations and activities in risk-prone areas.

Those urban centres with populations lower than 500,000 people will be faced with great difficulties in coping with the impacts of climate change, given their relatively low management capacity. However, they can also take advantage of their relatively small size to redirect their future growth in more sustainable and resilient ways that reduce their emission levels to a desired minimum and enhance their resilience and ability to cope with climate hazards and other stresses.

This Global Report is organized into seven chapters. Chapter 2 focuses on the international climate change framework and the implications, opportunities and challenges that it offers for urban action. It describes the process by which climate change became an international regime: the Climate Convention; the main mechanisms, instruments and financing strategies of the Climate Convention; and the main positions of the parties to the Kyoto Protocol. Aimed at providing policy-makers with a navigational tool to better steer a course through the complex universe of climate policy and action, the chapter presents various components of the multilevel climate change governance elaborated upon throughout the report and describes the main actors, components and actions of climate governance at the international, supra-national (regional), national, and sub-national levels.

Chapter 3 examines the contribution of urban areas to climate change. It discusses the main protocols and methods for measuring GHG emissions and examines transportation, industry, buildings and other sources of GHG emissions in more detail. A summary of the scale of urban emissions and how they vary between countries at different stages of economic development is provided. The chapter illustrates how the total volume of emissions is strongly shaped by such factors as a city's geographic situation, demographic situation, urban form and density, and economic activities. It includes a discussion of both the main factors and underlying drivers influencing emissions.

Climate impacts and vulnerabilities are the main focus of Chapter 4. The chapter describes how climate change may exacerbate the physical, social and economic challenges that cities are currently experiencing. First describing the physical climate change hazards facing urban centres, it goes on to look at how the direct and indirect physical, economic and social impacts of these changes vary with disparities in existing vulnerabilities within and across cities, identifying specific urban populations, regions and cities that are particularly vulnerable to climate change and the reasons why this is so. The chapter ends with concluding remarks on the impact of climate change in cities and the lessons for policy.

Chapter 5 focuses on mitigation, one of the two main responses to climate change. It describes the mitigation policy responses and initiatives that are currently taking place in cities in the areas of urban planning and infrastructure development, transportation, the built environment and carbon sequestration. It examines how such strategies and measures have been undertaken through different modes and mechanisms of governing (e.g. provision, regulation, self-governing and enabling), and explores the factors shaping urban mitigation in institutional, economic, technical and political terms (e.g. individual and institutional leadership, knowledge and institutional capacity). Finally, the chapter provides a comparative analysis of emerging trends in mitigation responses.

Chapter 6 looks at adaptation to climate change from the fundamental position that because the international community has been unable to effectively respond to the challenge of reducing GHGs to a level that would avoid dangerous interference with the climate system, adaptation responses over the next decade will be critical. The chapter starts by defining urban adaptation and adaptive capacity, followed by a review of some existing coping and adaptation experiences by individuals, households, communities and urban governments, and then examines the relative roles and potential partnerships between stakeholders, and looks at some mechanisms for financing adaptation.

Chapter 7 summarizes the key findings and messages of the report, and proposes a set of integrating themes with respect to urban areas facing climate change challenges. The chapter first looks at the constraints and challenges to, and opportunities from, mitigation and adaptation actions, along with some of the linkages among drivers and vulnerabilities. It then goes on to highlight a variety of synergies and trade-offs between mitigation, adaptation and urban development. After briefly describing the current state of knowledge along with the gaps, uncertainties and challenges, the chapter provides a series of suggestions on future policy directions in terms of local, national and international principles and policies to support and enhance urban responses to climate change.

Urban development can … be a source of resilience

Properly designed infrastructure developments can provide physical protection … and appropriate urban planning can help restrict the growth of populations and activities in risk-prone areas

Urban centres with populations lower than 500,000 people … can … take advantage of their relatively small size to redirect their future growth in more sustainable and resilient ways

NOTES

1 UN, 2010.
2 Due to increasing CO_2 concentrations.
3 The low-elevation coastal zone is the contiguous area along the coast that is less than 10m above sea level (IPCC, 2001b).
4 UN, 2010.
5 UN, 2010.
6 IPCC, 2007b; Satterthwaite et al, 2007b, 2009c.
7 UN, 2010.
8 UN, 2010. See also Statistical Annex, Table A.4.
9 See Chapter 3 and Tables 3.5, 3.11 and 3.12.
10 Dodman, 2009; Romero Lankao et al, 2008, 2009a.
11 McGranahan et al, 2005; Balk et al, 2009.
12 See UN-Habitat, 2007, p319.
13 Le Treut et al, 2007.
14 Ammann et al, 2007.
15 Sabine et al, 2004.
16 Sabine et al, 2004; Raupach et al, 2007.
17 Füssel, 2009.
18 The data in this section are derived from IPCC (2007d).
19 For a full list of gases to be assessed in national GHG inventories under the Kyoto Protocol, see the note in Table 3.1.
20 See Table 1.4; UN, 2010.
21 IPCC, 2007d, p12.
22 IPCC, 2007d.
23 Examples include the Clinton Foundation, Nicolas Stern, and Munich Insurance. See Satterthwaite, 2008a; Dodman, 2009; and Chapter 4.
24 Satterthwaite, 2008a; Dodman, 2009.
25 Zhang, 2010.
26 IPCC, 2007b.
27 Alberti and Hutyra, 2009.
28 Alber, 2010, p21.
29 Romero Lankao, 2007a; Satterthwaite, 2008a. See also Chapter 3.
30 Brown et al, 2008.
31 Ru et al, 2009.
32 Satterthwaite, 2007; Romero Lankao et al, 2005.
33 See Chapter 3.
34 Murphy, 2000; Gibbs, 2000.
35 Roberts and Grimes, 1997.
36 See Chapter 3.
37 Bin and Harris, 2006.
38 Satterthwaite, 1997a; McGranahan et al, 2001, p15;.
39 Parry et al, 2007a; Wilbanks et al, 2007; Satterthwaite et al, 2007b; Romero Lankao et al, 2008.
40 Räty and Carlsson-Kanyama, 2010.
41 Satterthwaite, 2008a.
42 Walker and Salt, 2006.
43 Romero Lankao et al, 2009a.
44 See Chapter 3.
45 Other determinants of transportation emissions are transit accessibility, pedestrian friendliness and local attitudes and preferences, which also influence driving behaviour. Handy et al, 2005.
46 Marshall et al, 2005, p284.
47 Vale and Campanella, 2005.
48 This can be done through two mechanisms: patterns of use that do not overexploit local resources and go beyond the carrying or absorbing capacity of local ecosystems; and the ability and power to import resources from, or export emissions to, surrounding and remote areas and to make up for the impact (i.e. avoid local overexploitation and pollution). See Turner et al, 2003.
49 Allan Lavell, cited in Satterthwaite et al, 2007b.
50 Romero Lankao et al, 2009b.
51 Moser, 2008; Moser and Satterthwaite, 2010; Harlan et al, 2006; Romero Lankao and Tribbia, 2009.
52 Alber, 2010.
53 UN-Habitat, 2008c; Alber, 2010 (citing WIEGO and Realizing Rights: The Ethical Globalization Initiative, 2009).
54 UN-Habitat, 2008c.
55 Alber, 2010.
56 Bartlett, 2008.
57 Bartlett, 2008, p1.
58 Wolf et al, 2010.
59 Satterthwaite et al, 2007b.
60 Satterthwaite et al, 2007b.
61 World Bank, 2009c, p1.