Part III

Urban sectors

4

Climate change and urban energy systems

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4.1 Introduction

The energy systems that provide the "life blood" to cities are as complex and diverse as cities themselves. Reflecting local natural resource and economic conditions, supply chains that may extend globally, historic investments in technology, and cultural and political preferences, urban energy systems serve as either a key accelerator or brake on the vitality and prospects of a city or urban region. Because of this, the local energy system can be of great interest to policymakers in a city, and many have begun to develop plans that seek to change one or more aspects of this system over the coming decades.

Climate change concerns are increasingly a key driver behind these changes, with local authorities seeking to reduce their city's current level of contribution to global climate change. Climate is not the only reason local authorities engage on energy issues, however. In some cases, cities are seeking to ameliorate pollution attributable to local energy use, while in other cities, economic development is a key concern. The latter is particularly prominent in developing countries, where a lack of access to adequate, reliable energy services continues to impede the economic growth of many cities (UNDP/WHO, 2009). In these situations, climate-related concerns are often secondary to efforts to improve access to modern energy services to reduce poverty, allow for new types of economic activity, and improve public health.

Looking to the future, climate change may stress local energy systems in many different and profound ways. The level of impact will vary significantly based on the age of the system, the ease with which the underlying technology or fuels can be changed or made more climate resilient, and the nature and severity of the climate change-related impacts likely to occur in that city. The capital-intensive nature of energy technology, and the decades-long lifespan of much of the energy supply and distribution infrastructure serving most cities, compounds the challenge of addressing climate change in a comprehensive manner. To date, relatively few cities have systematically explored how or whether their energy system must change to adapt to new climatic conditions.

This chapter explores these issues, weaving in examples and data from a range of types and sizes of cities around the world. The chapter begins with a generalized discussion of how cities obtain and use energy and govern energy matters. Although this discussion is somewhat lengthy, it is important to understand energy system and market fundamentals because they are so relevant to the subsequent discussion about climate change stresses and current policymaking efforts. The chapter concludes with commentary on areas for future research and potential policy changes that can help cities improve their management of local energy systems in the coming decades.

4.2 The urban energy system: technology choices, market structure, and system governance

Because there are so many issues that relate to how a city obtains or uses energy – including land use and mobility policies and practices, waste management collection and disposal practices, and the type and level of local economic activity – urban energy systems can be defined in either broad or narrow terms. Issues such as transportation and land use are taken up in other chapters of this assessment report, as they are significant enough to warrant detailed attention. Other topics by necessity fall outside the scope of this report given limited time and resources. For the purposes of this chapter, however, the analysis will focus on electricity and thermal energy supply and distribution systems, as these link to the bulk of the energy used in most cities.

4.2.1 System overview

"Centralized" electricity systems are commonplace in cities, involving large power plants generating power which is then distributed to users through a complex web of high- and low-voltage wires crossing a city. Centralized generation takes advantage of the economies of scale offered by large power plants, which can be fueled by a variety of different sources, including coal, natural gas, biomass, solid waste, or nuclear fuels. Even large renewable energy systems, including large wind farms, geothermal power plants, or concentrating solar "power towers" can be sized at scales equivalent to "traditional" power plants, allowing them to fit relatively easy into the central generation and distribution model.

Power plants linked to this system can be located either within a city's borders or at locations quite remote from the urban core. Locations within cities have proven less desirable in many locales because of concerns over the emissions from these plants, creating public health concerns and dampening real estate values in adjacent neighborhoods (Farber, 1998; Abt Associates *et al*., 2000). The advent of comprehensive state, national, or trans-national grids has allowed many cities to increasingly rely on out-of-city power sources, lessening the severity of the problem and the political challenges associated with siting new in-city power plants; although the siting of transmission lines has become problematic in many locations as well.

"Distributed" forms of power generation and distribution (also known as DG) refer to systems with much smaller power production units that are located at or near the point of energy use. DG systems enjoy certain advantages, such as the fact that because they link directly to the electric wiring system within the host building, they tend to suffer from less "transmission loss." These losses occur due to Joule heating of power lines and when electricity voltage levels are "stepped" up or down at different points in the transmission and distribution network (Lovins *et al.*, 2002). DG systems may also allow a building or user to avoid certain design or service deficiencies involving the citywide distribution grid, such as poor power "quality" or vulnerability to blackouts or other types of service disruptions (Lovins *et al.*, 2002). Finally, DG systems may allow buildings to utilize certain types of power more easily or cheaply, such as electricity generated from renewable sources such as wind or solar power or technologies such as combined heat and power (CHP) units that enjoy high rates of energy efficiency.

Thermal energy use in cities – that is, energy used for space, water, or process heating or cooling – can also be produced in a centralized or decentralized manner. Centralized (or "district") thermal energy systems, tend to be more common in cities with extreme temperatures in winter or summer months. For cost or pollution reasons, local authorities and/or utilities in many cities have found there are benefits to producing steam or hot (or cold) water centrally, and then distributing this thermal energy to users via a network of underground pipes (see Table 4.1). Because of the cost of installing and maintaining the pipeline network, some minimum population density or level of demand is necessary to make these systems cost effective (Gochenour, 2001). District heating and cooling systems can be fueled by a range of energy sources, such as coal, natural gas, biomass, nuclear power, and geothermal sources. In some cases, the plants producing the thermal energy may operate as co-generation facilities, simultaneously producing electricity for use around the city.

The alternatives to district thermal systems are building-based thermal technologies such as gas-powered stoves, boilers, furnaces, or ground source heat pumps. Some buildings employ combined heat and power technology, satisfying some or all of the building's thermal and electricity needs.

Although decentralized in function, building-sited thermal systems may nonetheless involve linkages to citywide fuel networks delivering natural gas or coal gas around a city. Building-sited thermal systems may also rely on fuel oil or liquid petroleum gas tanks located within the building that are refilled on an as-needed basis. Other buildings or homes rely on supplies of solid energy feed stocks, such as coal, kerosene, charcoal, biomass, or animal dung, which are burned in a boiler or cookstove to produce space or process heat. These latter systems may involve some type of formal supply chain, or less formal scavenging processes involving the building owner or dwelling occupant. In developing countries, these supply chains can create important opportunities for local economic development (Clancy *et al.*, 2008).

The thermal systems employed may have significant health impacts within or near the home, because of differing levels of smoke or other pollutants emitted while operational. Households in cities in developing countries are far more reliant on solid fuels for cooking than urban dwellers in developed countries (UNDP/WHO, 2009; see Figure 4.1) This is testament to both differing levels of energy infrastructure in these cities, the price of the different fuels, and difficulties obtaining interconnections to formal distribution networks (Dhingra *et al.*, 2008, Fall *et al.*, 2008).

A corollary to the thermal system discussion is the fact that, in many cities around the world, there may be heavy reliance on electric heating and cooling systems. Electric air conditioners are well-known features in many homes and businesses in warmer climates, but – especially in cities with historically cheap electricity sources such as nuclear or hydropower – there were many decades during the twentieth century when electric space

Table 4.1: *Selected urban district energy systems.*

City	Thermal application	Approx. energy production (GWh/yr)	Number of people served	Number of buildings served	Percentage of district served	Use co-generation?	Fuel Sources
Copenhagen, Denmark	Space heating	5,400	500,000	31,300	98%	Yes	Coal, natural gas, biomass
Seoul, South Korea	Space heating and cooling	10,600	>1,000,000	N/A	25%	Yes	Natural gas, oil, landfill gas
Austin, USA	Space heating and cooling	350	75,000	200	100%	Yes	Natural gas
Goteborg, Sweden	Space heating and cooling	4,000	300,000	N/A	64%	Yes	Natural gas, biomass, biogas
New York City, USA	Space heating and cooling	7,600	N/A	1,800	<10%	Yes	Natural gas, oil
Paris, France	Space heating	5,000	N/A	5,774	N/A	Yes	Natural gas, biomass, coal, oil

Sources: NYC SBD Task Force (2005), Toulgoat (2006), Elsman (2009), Goteborg Energi (2009), Ontiveros (2009), Won and Ahn (2009).

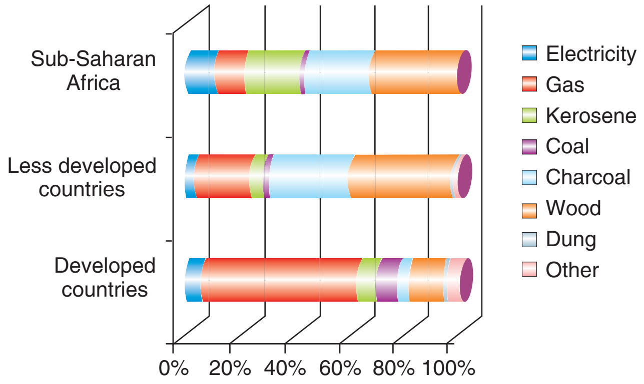

Figure 4.1: *Share of urban population relying on different cooking fuels.*

Source: UNDP/WHO (2009).

heating, water heating, or cooking systems were aggressively promoted as preferred technologies (Hannah, 1979; Platt, 1991; Nye, 2001). Electric thermal systems remain popular in homes in many cities around the world, because of lack of access to gas supply lines or because builders did not want to incur the cost of installing the necessary feeder pipes.

Climatic conditions and the local economic base also figure decisively in local energy technology choices and usage levels. In China, for example, the colder and more heavily industrialized west has vastly different energy needs than the warmer and more service sector-focused coastal cities in the east and southeast (Dhakal, 2009). The "new" cities of coastal China also tend to have more modern buildings that are home to wealthier families, both of which contribute to different types of energy usage patterns (Chen *et al.*, 2010).

These technology and fuel choices made years ago in cities create a path dependency that shapes current climate change mitigation and adaptation policymaking efforts. The embedded system assets – the massive technology investments in power plants and pipes and wires – are costly to replace or upgrade, and they may provide energy to homes and businesses at a market price lower than newer, more "climate friendly" technologies (Unruh 2000, 2002). This raises important questions for local authorities about how aggressively to promote new technology adoption, including whether existing system assets should be replaced before the end of their useful life. In cities in less-developed countries, the question may focus on whether more advanced energy systems can be cost effectively deployed as part of the overall infrastructure system development efforts sought in these cities.

4.2.2 Energy market structure

"Modern" energy systems[1] involving gas and electricity supply chains were eventually recognized as operating most efficiently as natural monopolies, reducing the need for redundant gas and electricity supply lines across a city (Hannah, 1979; Platt, 1991). In some cases, monopoly rights were expanded vertically with a single entity holding responsibility for both the supply and distribution of energy around some or all of a city. Ownership responsibilities for these system assets were largely dictated by state or national market regulatory preferences, with different assets owned and operated by either government, private firms, or some type of public–private partnership. Government ownership can take the form of nationalized utilities or municipally owned utilities, where local government has direct control over the management and operations of the local energy system.

In the 1980s and 1990s, when energy market liberalization efforts took off around the world, some cities began to see significant changes in who owned and operated these systems. In many cases, ownership responsibilities became more fragmented, with supply and distribution responsibilities broken apart in the name of competition and economic efficiency.

In cities with large informal settlements with less comprehensive or technically advanced energy system infrastructures, market structures may look very different. Many households are unable to afford clean-fuel cookstoves or appliances (UNDP/WHO, 2009); households may also be unaware of the ill effects caused by pollution from certain types of solid fuels (Viswanathan and Kavi Kumar, 2005). Supply chains may therefore focus on delivering fuels that can be used in very low-tech ways, satisfying heating and cooking needs. Developing country cities may also experience high levels of utility "theft," with homes and businesses illegally (and dangerously) tapping into local electricity distribution systems (USAID, 2004).

These different energy market circumstances all make addressing the issue of climate change a challenging one, as responsibilities for energy system planning – and payment for any system upgrades – may be divided among a very diffuse set of stakeholders.

4.2.3 Energy system governance

Technology choices, market structures, and ownership responsibilities are all important considerations as we look towards a future involving changing climatic conditions. The ability of cities to influence the design or operation of the local energy system varies widely, however, linked to a much broader set of governance questions discussed in Chapter 9 of this report.

In analyzing energy governance in cities, span of control (also known as agency or policy competency) is the critical factor. Span of control refers to the fact that energy policy is traditionally considered a supra-local issue, controlled at the state/provincial, national, or trans-national level (Bulkeley and Betsill,

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[1] Although cities have long relied on energy supply chains (primarily for biomass/charcoal imported to cities for use as a thermal energy source), we refer to the modern energy sector as the systems that began to develop widely in the mid to late 1800s, when gas and electricity supply and distribution markets began to become increasingly prominent in cities.

2002). This is a reversal of the situation in the mid to late 1800s, the era when gas and electricity use first became prominent in cities. At that time, electricity and gas utilities were frequently under local authority control, a function of the technology in use at the time. Over time, however, as local networks were linked into ever-larger systems serving entire states or countries and concerns arose over corrupt local oversight practices, regulatory oversight for these systems was transferred to state/provincial or central government agencies (Hughes, 1983).

As markets for certain forms of energy became global, and as energy-related pollution or other externalities crossed country boundaries, international agreements or treaties shifted certain policy control powers yet again, to trans-national organizations such as the European Union or United Nations (Bulkeley and Betsill, 2002).

Today, we are increasingly seeing a re-engagement on energy policy matters by local authorities in both developed and developing countries (Keirstead and Schulz, 2010). Capello *et al.*(1999) note that the focus is on land use planning and building regulations, energy conservation policies, market or behavioral stimulation programs (e.g., grants and information campaigns), and support for technical innovations. Cities also have significant control over energy use in local authority-owned buildings and in the type of energy or technology used in publicly managed services such as mass transit, waste disposal or treatment, and water supply systems.

Because key regulatory control powers still reside at the state or national level, however, most local authorities lack the ability to force fundamental changes in the technologies that utilities employ or their efforts promoting energy conservation or efficiency. Energy or carbon taxing powers also tend to be within the prerogative of national governments, and their availability locally varies significantly from city to city (for example, see European Commission, 2007b).

Other policy options may be unavailable to cities owing to the high costs of entry, such as funding for major research and development projects. Some areas where cities can act, such as planning and building codes, may be constrained by institutional capacity. An innovation such as the Merton Rule,[2] which promotes the increased use of renewables in buildings in London (House of Commons, 2007), requires adequately trained officials for plan approval and enforcement. Building codes exhibit this principle more generally; municipal governments in developing countries can often influence energy use through building codes, but the effectiveness of these measures is highly variable, depending on the resources available for application and enforcement. In China, enforcement of local buildings codes varies across cities and across different stages of design and construction (Shui *et al.*, 2009).

4.3 Energy use in cities

Cities play a central role in driving global energy demand, but historically there has been relatively little information published on energy use in individual cities or urban areas. The OECD (1995) was one of the first organizations to estimate total urban energy demand around the world (74 percent), although the methodology supporting this estimate is unclear. More recently, the focus of aggregate urban-scale analysis has shifted to the level of greenhouse gas emissions attributable to cities, based largely on calculations of energy use in these cities.

In most cities around the world, data on local energy consumption or supply levels either have not been compiled or provide only a partial picture of the local situation. In the case of the latter, this is partly a function of the underlying goals of some of this research – it may be a residential sector-focused analysis, for instance – but it also reflects the many challenges inherent in obtaining these data. These include difficulties accessing proprietary market data held by the private companies serving a city and definitional questions related to what actually constitutes energy use resulting from activity in a city. Analyses may also focus narrowly on marketed fuels and technical energy, while fuels such as biomass and charcoal and non-technical sources (such as draft animals or other non-motorized transport modes in general) may be under-documented despite representing a large share of total local energy use.

There is also the issue of whether the urban system is defined as a spatial territory or functional unit and whether cities must account for all primary and/or embodied energy consumed within their borders (Parshall *et al.*, 2010; Kennedy *et al.*, 2009a). The notion that cities are ascribed responsibility for this use is considered problematic by some, arguing that such views diminish the energy efficiency benefits offered by urban lifestyles, given smaller dwelling sizes, reduced travel distances, increased access to public transportation, etc. (Satterthwaite, 2008; Dodman, 2009). The notion of holding a city accountable for local energy use can also be seen as problematic, as it is the *behavior* of individuals or institutions in cities that is at the root of this level of energy usage, rather than the city itself.

This argument speaks to the fact that analyses of urban energy usage are helpful primarily because of the spotlight they shine on the need for energy and climate policies that respect the unique attributes of urban areas. City-specific analyses focus even more directly on this point, using local energy supply and use data to inform local energy efficiency strategies or climate change mitigation or adaptation plans. In some cases, cross-city comparisons are employed because they provoke questions among local policymakers about how they can attain energy use or emission levels comparable to those in other cities. Per capita electricity

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[2] Named after the London borough where it was first established in 2003, the “Merton Rule” required that new development projects generate at least 10% of their energy needs from on-site renewable energy equipment. The Mayor of London subsequently adopted the rule as part of his climate change initiatives, along with many other local authorities around the UK. In 2008, the UK government published new planning guidance requiring all UK local planning authorities to adopt a “Merton rule” policy.

[MITIGATION] Box 4.1 Managing CO_2 emissions from buildings: Lessons from the UK, USA, and India

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This synopsis is based on the research paper commissioned by the World Bank and presented in the 5th Urban Research Symposium on Cities and Climate Change held at Marseille in June 2009.

In 2002, buildings were responsible for 7.85 Gt, or 33 percent of all energy-related CO_2 emissions worldwide and these emissions are expected to grow to 11 Gt (B2 scenario) or 15.6 Gt (A1B scenario) by 2030 (IPCC, 2007). However, as the housing market in the UK, USA, and several other developed countries has gone into deep and prolonged recession, the opportunity for very substantial investment into improving the existing building stock has opened up. In fact according to the Fourth Assessment Report (AR4) of the IPCC (2007), approximately 29 percent of CO_2 emissions can be saved economically, or at a net benefit to society, even at zero carbon price. Mitigation measures in the residential and commercial sectors can save approximately 1.6 billion and 1.4 billion tons of CO_2 emissions, respectively, by 2020 (Urge-Vorsatz *et al*., 2007). While the magnitude of these large potentials that can be captured has been known for decades, many of these energy efficiency possibilities have not been realized. This is because of certain characteristics of markets, user behavior, and a lack of critical evaluation of the available tools and models that could be used by planners, building designers, and policymakers to measure, benchmark, target, plan, and monitor energy-related CO_2 emissions and forecast reductions from existing buildings. This research paper therefore comparatively evaluates the building-related CO_2 measurement, benchmarking, and reduction approaches available in the USA, UK, and India, to share the lessons learnt in implementing CO_2 reducing policies in each of these countries, by:

- Establishing what tools, approaches, and methodologies are available for measuring energy use and CO_2 emissions from existing buildings in the UK, USA, and India.
- Reviewing and comparing benchmarks of annual energy consumption (kWh/m^2 per year) and CO_2 emissions (kgCO_2/m^2 per year) from buildings-in-use in the case study countries.
- Developing more rigorous standards for existing buildings (to reduce their energy consumption), which could be adopted by developed and rapidly developing cities taking account of building type, local climate and occupancy.
- Evaluating various strategies and measures available for maximising CO_2 emission reductions in existing buildings (above 80 percent in developed countries) through improved energy efficiency, low and zero carbon technologies, as well as non-technical solutions (education and awareness, behavioral change), and to identify barriers for their implementation.
- Finally, recommending policy measures that would increase uptake of the selected CO_2 reduction strategies in existing buildings.

A comparative analysis is undertaken to evaluate the strengths and weakness of methods such as BREEAM/CSH in the UK, LEED in the USA, and TERI-GRIHA and LEED-India in India. Robust performance-based standards (in terms of kWh/m^2 per year or kgCO_2/m^2 per year) are recommended for reducing the energy consumption of existing buildings present in both developed and rapidly urbanising cities. A range of policy instruments and measures are suggested to remove or lower barriers and encourage uptake of various CO_2 reduction strategies in existing buildings. Among these are: appliance standards, building energy codes, appliance and building labelling, pricing measures and financial incentives, utility demand-side management programs, and public sector energy leadership programs including procurement policies. Because culture and occupant behavior are major determinants of energy use in buildings, these policy approaches need to go hand in hand with programs that increase consumer access to information, awareness, and knowledge. At present, however, there is particularly a lack of accurate information about exactly how much variation occupant behavior introduces to a building's energy consumption.

It is realized that the UK is world-leading in its CO_2 reduction policy for buildings but lacks good-quality bottom-up data sets of real energy consumption and CO_2 emissions in buildings. The USA on the other hand has excellent data sets by EIA and DoE, but needs to have national-level policies and targets for CO_2 reduction from buildings. India is working on both policy and data collection given that the energy data are quite polarized between the urban and rural. In fact the Bureau of Energy Efficiency is working with USAID's ECO-III program to benchmark a range of commercial and institutional buildings – although the focus is primarily on energy efficiency and not CO_2 reduction. Hopefully, robust targets for CO_2 reduction and policies to achieve those targets will be set soon.

The role of data and analysis is particularly emphasized, since the building sector is not considered as an independent sector and there is a lack of consistent data, which makes it difficult to understand the underlying changes that affect energy consumption in this sector. It is essential to make available comprehensive building energy information to allow suitable analysis and efficiently plan energy policies for the future. In fact, regularization of data collection and analysis for the building sector can help quantify technology performance, its cost-effectiveness, role of barriers, identification of beneficiaries, and targeting of government and industry policies, programs, and measures. In that respect, studies developed by the EIA on the energy consumption of residential and commercial buildings in the USA are a valuable reference (EIA, 2001, 2003, 2006, 2008a, b).

It is hoped that findings from this project will help to expedite the process of achieving significant reductions in energy use and CO_2 emissions from the existing building stock by formulating policies that address the conventional barriers to implementation and increase the uptake of low carbon systems (heat pumps, solar hot water, solar PV, micro-combined heat and power, micro-wind) in buildings and cities. There is a need for adaptive policies to be mainstreamed through all development and environmental policies such as retrofitting existing building stock to ensure that it remains resilient to climate change impacts. On the longer term, the data archive of this study will be of immense value to all those with a stake in a low-carbon future, be it policy, practice or academic understanding. No doubt the ultimate aim is to make the global building stock become low-energy, low-carbon and more resilient to climate change effects.

use is a metric commonly employed to highlight such comparisons between cities (see Figure 4.2), although such comparisons are most useful if they account for differences in climate or level of economic development.

Tracking urban energy consumption

Despite these challenges, there are several studies that have sought to examine urban energy consumption at different scales.

In 2008, the International Energy Agency (IEA) calculated global urban energy use, concluding that 67 percent of global primary energy demand – or 7,903 Mtoe – is associated with urban areas (IEA, 2008; see Table 4.2). By 2030, urban energy consumption is expected to increase to 12,374 Mtoe, representing 73 percent of global primary energy demand and reflecting dramatic anticipated growth in urban population levels around the world.

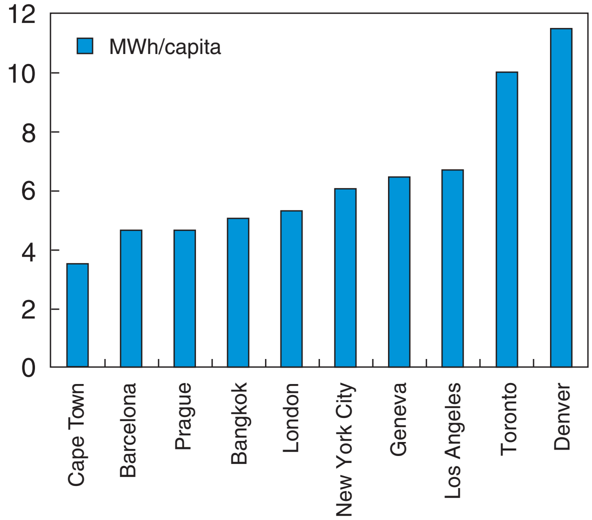

Figure 4.2: *Per capita electricity consumption in MWh/capita.*

Source: Kennedy et al., *(2009b).*

Regional or country specific analyses have also focused on aggregate urban scale energy consumption. Dhakal (2009) estimated that the urban share of total commercial energy use in China is 84 percent, while in the USA, urban areas are responsible for between 37 and 86 percent of national direct fuel consumption in residential, commercial, and industrial buildings, and between 37 and 77 percent of national on-road gasoline and diesel consumption (Parshall *et al.*, 2010).[3] Such studies frequently contrast energy use in urban and non-urban areas of a country. For example, a Brookings Institution study showed that large metropolitan areas in the USA have smaller per-capita energy consumption and carbon emissions compared with the national average (Brown *et al.*, 2008). By contrast, Dhakal (2009) found dramatically higher rates of energy use in Chinese cities compared to rural areas.

Other studies focus narrowly on detailing the fuel mix in specific cities. ICLEI (2009b) compiled energy use data in 54 South Asian cities, identifying the absolute quantities of each fuel type broken out by sector (see Table 4.3). Kennedy *et al.* (2009a, 2009b) compared energy use and emissions data in ten cities in Africa, Asia, Europe, and North America, while other individual local authority analyses have been published as part of each city's sustainability or climate initiatives or as part of ongoing public reporting efforts on different key performance indicators (for example, see Mairie de Paris 2007; Shanghai Municipal Statistics Bureau, 2008).

There is information that is less commonly available that is helpful when crafting city-specific mitigation and adaptation policies. New York City's sustainability plan breaks out building-related energy use by function and sector; that is, how much energy is expended on lighting versus heating, cooling, and other types of specific energy demand in different types of buildings (see Table 4.4). This information is useful because it can help a local authority prioritize its scarce time and financial resources when implementing a sustainability plan. Diurnal information, or a further breakdown of how energy is used by different applications (e.g., heating, lighting, etc.) over the course of the day, can also be helpful in highlighting opportunities to employ different types of energy efficient technology within a building or on a citywide scale (Parshall, 2010).

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[3] The wide range reflects different boundary assumptions employed in the analysis.

Table 4.2: *World energy demand in cities by fuel.*

	2006		2015		2030		
	Mtoe	Cities as percentage of global demand	Mtoe	Cities as percentage of global demand	Mtoe	Cities as percentage of global demand	2006–2030[a]
Coal	2,330	76%	3,145	78%	3,964	81%	2.2%
Oil	2,519	63%	2,873	63%	3,394	66%	1.2%
Gas	1,984	82%	2,418	83%	3,176	87%	2.0%
Nuclear	551	76%	630	77%	726	81%	1.2%
Hydro	195	75%	245	76%	330	79%	2.2%
Biomass and waste	280	24%	358	26%	520	31%	2.6%
Other renewable	48	72%	115	73%	264	75%	7.4%
Total	7,908	67%	9,785	69%	12,374	73%	1.9%
Electricity	1,019	76%	1,367	77%	1,912	79%	2.7%

Source: IEA (2008).

[a] Average annual growth rate.

4.4 Climate risks to urban energy systems

While the contribution of energy use to global climate change has been extensively studied, the literature on the impacts of climate change *on* urban energy systems is still in its infancy. What is clear, however, is that because cities are so reliant on energy sources and system assets based *outside* of the city, any discussion must examine climate change-related impacts at multiple levels of the energy supply and demand chain.

Figure 4.3 provides a schematic of how different climate change hazards projected for cities (Column 1) link to both physical (Column 2) and institutional risks (Column 3) for different segments of the energy system. All of these impacts could threaten the wider economic vitality of urban centers, as damaged or inoperable energy system assets jeopardize public health, commerce, and private property interests. Changing climate patterns may also have a big impact on energy system asset requirements and operating costs, driving up fuel prices, imposing changed maintenance regimes or operating practices, or requiring significant capital expenditures to adapt the system to these threats. This chapter does not address all of the impacts cited in Figure 4.3, but focuses on the areas of greatest significance.

4.4.1 Energy demand impacts of climate change

There is a rich literature detailing the link between climatic variables and changes in energy demand. Research has examined this issue at a variety of different scales, primarily for utility or government planning purposes, to assess the adequacy of overall energy system capacity to meet demand at different times of the year (Amato *et al.*, 2005).

A different set of literature examines the link between "urban heat islands" and energy demand (Taha *et al.*, 1999; Akbari and Konopacki, 2005; Rosenzweig *et al.*, 2009). Urban heat islands refer to the fact that cities are full of impervious surfaces that trap heat, leading to elevated air temperatures. In the summertime, heat island conditions can significantly increase local electricity demand for space cooling. For example, a study of Athens found that due to the heat island effect, a building in the urban core would have approximately twice the cooling load of an equivalent building located on the city's outskirts (Santamouris and Georgakis, 2003).

Global climate change is expected to increase temperature at the regional scale, which may exacerbate heat island conditions in cities. Whether a city's *net* energy demand increases or decreases will vary by location. Areas where energy demand peaks in the winter will experience a reduction in overall energy consumption if anticipated thermal load savings exceed anticipated summertime power load increases. Conversely, areas with summer peaks will see net demand increases if rising air conditioner loads exceed decreases in heating requirements (Scott and Huang, 2007).

No information was found that directly addressed the impacts climate change could have on other thermal loads in cities (e.g., cooking, water heating, or process energy requirements). However, to the extent these loads are supplied by the same fuels used for space conditioning, they will also be affected by changes in market supply conditions.

Looking strictly at electricity demand, it is important to distinguish between the impact on cumulative power requirements (i.e., the annual demand measured in MW or GW hours) and peak demand impacts (i.e., point-in-time demand measured in MW_p). Both can have significant financial implications around a city,

Table 4.3: *Energy use in selected cities in South Asia.*

		Agra, India	**Chennai, India**	**Kolkata, India**	**Mysore, India**	**Chittagong, Bangladesh**	**Thimphu, Bhutan**	**Kathmandu, Nepal**	**Colombo, Sri Lanka**
		Population 1.27 million	Population 4.34 million	Population 4.57 million	Population 750,000	Population 2.53 million	Population 90,000	Population 700,000	Population 640,000
Residential	Electricity (million kWh)	414	589	1,196	238	60	81	287	419
	LPG (metric tons)	10,014	197,748	75,997	2,398	N/A	N/A	25,386	6,876
	Kerosene (kL)	33,408		292,240	32,604				
	Fuel wood (metric tons)				12,400				
Commercial	Electricity (million kWh)	115	176	985	92	15	21	89	19
	LPG (metric tons)	N/A			8,349		N/A	1,148	N/A
Industrial	Electricity (million kWh)	53	78	503	380	102	4	54	455
	LPG (metric tons)				1,057		N/A	2,762	
	Coal/wood			2,929,348					
	Furnace oil (kL)								68,153
Transportation	Diesel (kL)	50,442	346,180	488,955	51,000	4,855	7,002	32,707	72,280
	Petrol (kL)	49,376	178,970	117,987	30,800	42,098	5,042	31,785	51,218
	CNG (kg)	930,271							
	Other (kL)					31,512 (octane)			8,224 (kerosene)
Other	Electricity (undefined user) (kWh)	318	1,850		273	35	25	62	219
	Fuel wood (metric tons)	7,200							

Source: ICLEI, 2009b.

Table 4.4: *Energy usage by building type in New York City as percentage of total energy in British Thermal Units (BTU).*

Building type	Heat	Hot water	Lighting	Appliances[a]	Cooling[b]	Other	Total
1–4 family residential	7.6%	2.6%	1.7%	2.2%	0.6%	0.0%	14.7%
Multi-family residential	7.4%	7.4%	3.0%	3.9%	1.2%	0.0%	22.9%
Commercial	8.5%	2.8%	10.2%	4.5%	4.5%	0.9%	31.4%
Industrial	2.6%	2.1%	4.0%	3.3%	1.1%	0.2%	13.3%
Institutional/government	6.3%	4.0%	3.6%	1.7%	1.4%	0.9%	17.9%
All types	**32.4%**	**18.9%**	**22.5%**	**15.6%**	**8.8%**	**2.0%**	**100.0%**

Source: City of New York (2007).

[a] Appliances including electronics and refrigerators as well as other appliances.

[b] Cooling includes ventilation as well as air conditioning.

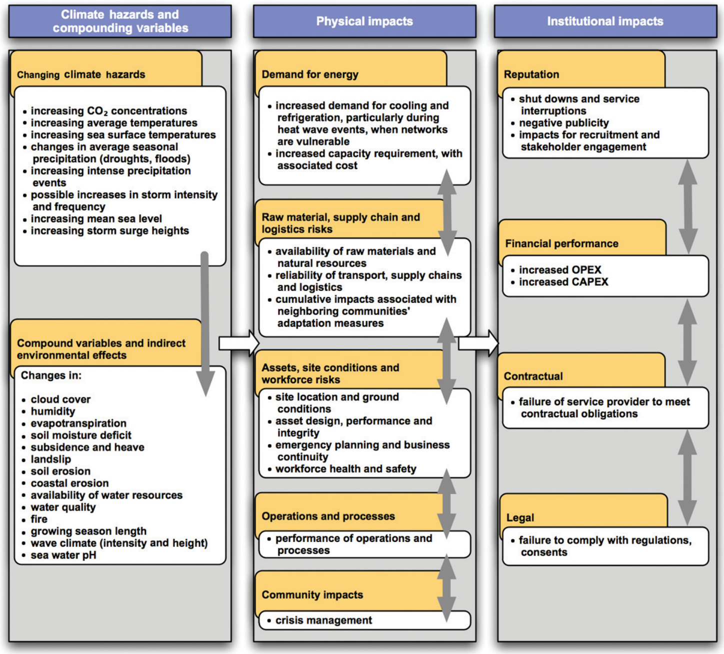

Figure 4.3: *Impacts of climate change on urban energy systems.*

Source: Adapted from Acclimatise (2008).

but they vary in terms of whether additional generation capacity must be deployed or if existing capacity is utilized more often. This occurs because warmer nights and longer cooling seasons can generally be served by a city's existing power generation capacity, which is sized to meet the highest summertime peak demand. By contrast, when peak demand growth outpaces total demand growth, spare capacity is in short supply, increasing the risk of blackouts and brownouts (Miller *et al.*, 2008).

To date, there have been several studies analyzing how climate change will affect energy demand, although most have examined this issue at a state or national scale (Smith and Tirpak, 1989; Baxter and Calandri, 1992; ICF, 1995; Franco and Sanstad, 2008). The analyses generally conclude that for the regions examined both total electricity demand and peak electricity demand will increase as a result of climate change, although peak demand will increase at a much faster rate.

There is a slimmer body of research examining how climate change will influence energy demand in cities. In Boston, climate change is expected to boost per capita energy demand in 2030 by at least 20 percent compared to the 1960–2000 average (Kirshen *et al.*, 2008). In New York, two different studies looked at climate change impacts on the wider metropolitan region. A 1987 analysis concluded climate change would increase peak electricity demand 8–17 percent by 2015, whereas overall demand would have a much slower 2 percent growth rate (Linder *et al.*, 1987). Hill and Goldberg (2001) looked at the peak demand impacts of climate change, projecting that by the 2020s climate change-induced demand growth would total 7–13 percent, reaching 12–17 percent by the 2080s. An analysis by Scott *et al.* (1994) examined the impacts of climate change on projected energy use in commercial buildings in four US cities (Phoenix, Seattle, Minneapolis, and Shreveport), finding widely variable – but uniformly positive – demand increase in each city.

Scott *et al.*'s conclusion stems from the fact that (i) a sizable percentage of the energy demand in commercial buildings is tied to space cooling (EIA, 2009), and (ii) air conditioning deployment (aka "saturation") levels vary widely by city (see

Table 4.5: *Air conditioning (AC) saturation rates in US cities.*

City, state	Percentage of buildings with window AC units	Percentage of buildings with central AC systems	Total
Los Angeles, CA	27.3%	23.9%	51.2%
San Francisco, CA	6.0%	15.0%	21.0%
Sacramento, CA	22.1%	62.7%	84.8%
New York, NY	53.1%	10.1%	63.2%
Rochester, NY	25.6%	17.5%	43.1%
Buffalo, NY	16.3%	8.8%	25.1%
Columbus, OH	21.4%	56.1%	77.5%
Cincinnati, OH	32.3%	50.9%	83.2%
Cleveland, OH	25.7%	34.2%	59.9%
Houston, TX	14.7%	78.9%	93.6%
San Antonio, TX	27.8%	60.6%	88.4%
Dallas, TX	17.3%	78.5%	95.8%

Source: Sailor and Pavlova (2003).

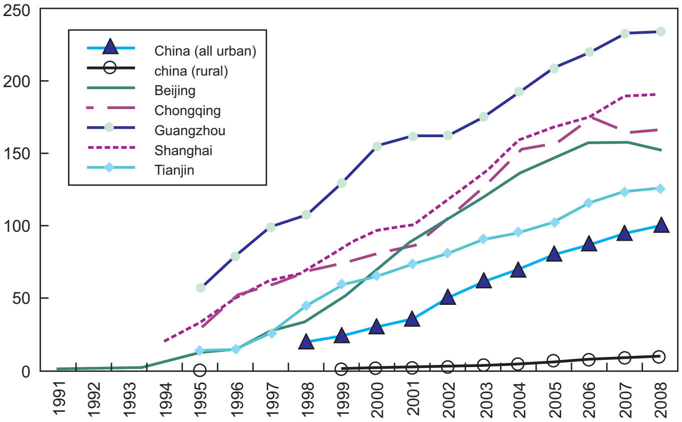

Figure 4.4: *Number of air conditioners per 100 households in selected Chinese cities.*

Source: CEIC (2010).

Table 4.5). Saturation levels are important because they hint at the level of demand growth that could occur as temperatures rise in a city. Cities with low saturation rates might experience higher rates of demand growth as buildings lacking air conditioning systems install them. Cities with high saturation rates could still experience demand growth, but at a slower pace as the percentage of buildings lacking air conditioning units approaches zero.

In China, air conditioner ownership rates have increased dramatically in the past 15 years, with rates of ownership in urban households exceeding an average of one unit per household in most urban areas. This contrasts markedly with rates of use in rural areas of China (see Figure 4.4). More research is necessary to tell us the actual level of use, however, or whether urban areas in China have markedly different saturation rates.[4]

4.4.2 Energy supply chain and operations risks and vulnerabilities

Climate change may affect the urban energy supply chain in three principal ways: through impacts on primary energy feedstock production or supply networks delivering these feedstocks to power plants; impacts on power generation operations; and via impacts on the energy transmission and distribution network. Our understanding of these risks varies widely, as does the severity each risk presents to cities around the globe.

4.4.2.1 Energy resource production and delivery

Primary energy fuel stocks tend to be found away from urban areas, but the impacts of climate change on the sourcing and processing of these materials would nonetheless be felt in urban areas, albeit in an indirect manner as cost impacts ripple across national or global economies.

For example, the US Climate Change Science Program (Bull *et al.*, 2007) has noted the vulnerabilities of oil and gas drilling platforms and refineries along the Gulf of Mexico coast to flooding and high winds associated with extreme weather events. Closure of these facilities and fuel terminals during and after Hurricane Katrina were linked to fuel price increases across the USA. Extreme weather events in non-coastal areas can also affect primary energy supply chains, as we saw in 2008 when heavy snows in central and southern China blocked rail networks and highways used for delivering coal to power plants in these regions. Seventeen of China's 31 provinces were forced to ration power, affecting hundreds of millions of people in cities across the country (French, 2008). Climate scientists have been wary of attributing these snowstorms to climate change (Perry, 2008), but others note they represent the type of extreme weather event related disruptions that may be more prevalent in the future (Pew Center on Global Climate Change, 2008).

Larsen *et al*. (2008) note that Arctic transport routes and energy infrastructure critical for moving oil and gas across Alaska are located across areas at high risk of permafrost thaw as temperatures rise. Potential vulnerabilities include structural failure and distribution problems as oil and gas pipelines fracture; reduced access and increased transport costs due to a shorter winter season for ice roads, and increases in repair and maintenance costs. System stresses such as these will produce *indirect* impacts on cities, generally in the form of higher energy prices.

In developing countries, areas heavily dependent on different types of biomass may be vulnerable to the extent certain climate change risks affect the availability of the material or the transport routes delivering this material to cities. For example, changing temperature levels may reduce biomass availability if plants reach the threshold of their biological heat tolerance or if storms or drought reduce plant or tree growth levels (Williamson *et al.*, 2009). The extent of these problems will be localized based on how biomass materials are sourced in different urban areas.

4.4.2.2 Impacts on power generation

Chapter 3 documents the risk to cities from rising sea levels and storm surges associated with climate change. There is little within this growing literature, however, that draws specific links between anticipated coastal threats and energy system assets located along or near threatened coastlines. Potential risks exist because many power stations were historically sited along waterways, a legacy of the need for cooling waters that were integral to the design of older thermoelectric power plants. Many facilities also relied on barge deliveries of their coal supply. Given the decades-long lifespan of most large power plants, they now face risks from anticipated sea level rise or more extreme weather events.

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[4] The Chinese government's approach of tracking air conditioning unit ownership rates tell us little about deployment patterns, as high-income households may deploy multiple units, skewing local saturation rates.

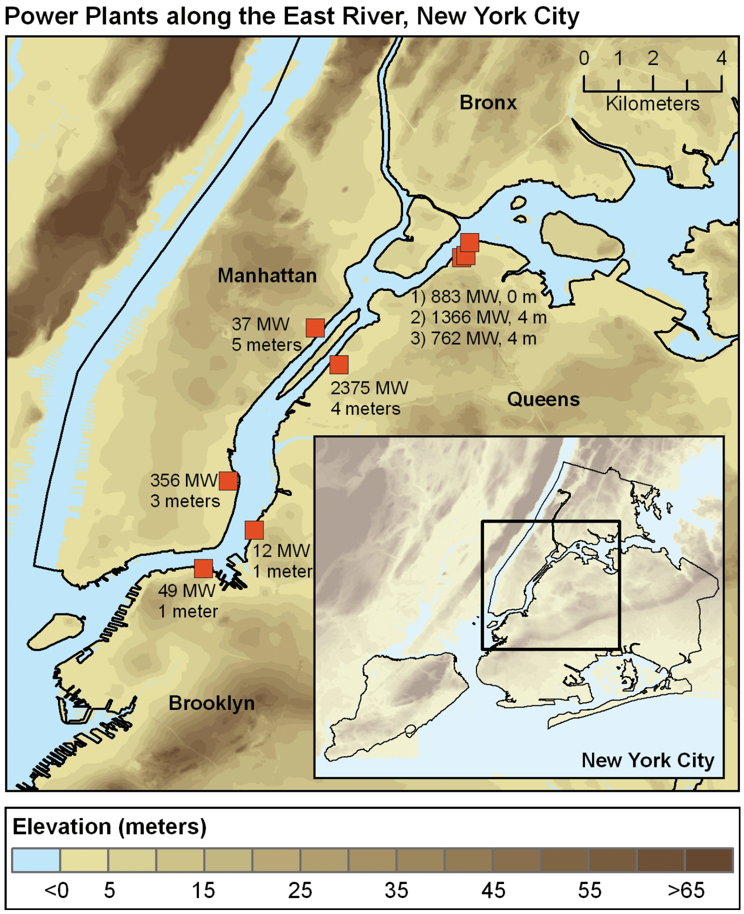

Figure 4.5: *Location and elevation of power plants along the East River in New York City. Power plant data for 2000 from eGRID (USEPA, 2002) to reflect with recently retired plants deleted. New York City digital elevation model is from the USGS (1999), which has a vertical error of approximately +/–4 feet.*

Whether a given power plant (or fuels temporarily stored on-site at or near these plants) is vulnerable to flooding problems is a function of the elevation of the facility, the facility design (e.g., surrounded by berms, etc.), and its proximity to any path that storm-linked tidal surges would follow during extreme weather events. Hurricanes Katrina, Rita, and Ike in the Gulf of Mexico were recent examples where coastal power plants were damaged by storm surges, with several facilities serving New Orleans, Houston, and Galveston forced to shut down due to anticipated flooding. Some remained closed for several days after the storms had passed, suffering extensive wind and water damage (Jovetski, 2006; McKinley, 2008).

Figure 4.5 displays the potential vulnerability of power plants along the East River in New York City to similar storm surges, highlighting the vulnerability of 5,840 MW of power generation capacity at an elevation of less than 5 meters, the height of the storm surge expected in some areas if a Category 3 hurricane directly hits the city.

A different type of risk arises from the fact that cooling waters needed to exhaust waste heat from older thermoelectric power plants may be less able to satisfy their cooling function in the future. Warmer ambient air temperatures and decreased stream flows attributable to climate change increase the risk that power stations will run afoul of rules restricting (ICF, 1995):

- The absolute temperature of water discharged from a power plant
- The absolute temperature of water downstream from power plants and/or
- The temperature rise of waters receiving cooling water effluent from power plants.

Water-cooled power plants are subject to one or more of these standards designed to protect aquatic life, with the exact rules varying by location. To prevent violations, power stations could be forced to scale back their operation or shut down entirely. Such was the case in Europe's deadly heat wave in 2006, when nuclear power plants in Spain and Germany were temporarily shut or forced to scale back operations due to high receiving water temperatures (Jowit and Espinoza, 2006). Little research has been done to date exploring the overall vulnerability of the energy system to this problem, and doing so – particularly from a city-level perspective – could be difficult, because climate models currently in use cannot be downscaled with pinpoint accuracy to a specific location on a river or bay.

Power plant operations may also be vulnerable to changes in air temperature and air density arising from climate change. The UK Met Office surveyed power plant operators around the UK in 2006, ultimately reporting operator concerns that combined-cycle gas turbines could experience decreased output as temperatures rise and air density decline (Hewer, 2006). Others discount the extent of this problem, however, noting that output reductions will be minor, totaling less than 1 percent under most climate scenarios (Linder *et al*., 1987; Stern, 1998; Bull *et al.*, 2007), or concluding that it will require systems to be upgraded 1–2 years earlier than otherwise would have been required (Jollands *et al.*, 2007). To the extent these problems do occur, they would apply to both central station power plants and district energy facilities. No data have been published thus far exploring such impacts on small-scale (<10 MW) cogeneration systems commonly deployed in many cities as a distributed power generation source.

Although this discussion has thus far focused on traditional thermoelectric power stations, power generation facilities reliant on renewable resources may also be affected by climate change. For instance, hydroelectric facilities fed by glacial and snow melt have historically benefited from the ability of glaciers to regulate and maintain water levels of rivers and streams throughout the summer – a time in many of these regions when precipitation-fed water sources often run low or dry. With increasing temperatures, however, snow levels are decreasing and glaciers are shrinking, jeopardizing the amount of hydroelectric production available to serve many urban areas (CCME, 2003; Markoff and Cullen, 2008; Madnani, 2009).

Changing climate patterns may also affect the timing and level of precipitation available to feed many hydropower systems. For example, although changing precipitation patterns are expected to increase hydropower production by roughly 15–30 percent in northern and eastern Europe by the 2070s, a 20–50 percent decrease in hydropower potential is projected for the Mediterranean region over the same period (Lehner *et al.*, 2005). Problems could arise depending on whether the precipitation falls as rain or snow and at which elevation, because snow serves as a secondary water reservoir, gradually releasing water over the spring and early summer. The elevation at which precipitation occurs is key, because retention dams serve different functions (e.g., water supply, flood control, power generation) based on their elevation and thus have different water release rules. This could affect the availability of power at different times of the year (Linder *et al.*, 1987; Aspen Environmental Group and M Cubed, 2005; Franco, 2005; Vine, 2008).

Whether cities are highly vulnerable to these problems is a function of the type and magnitude of impact of climate change on regional hydrologic conditions and their overall reliance on hydropower. The city of Seattle, Washington, obtains fully 50 percent of its electricity from a network of hydropower dams around the northwestern USA (Seattle City Light, 2005). Projections are that reductions in annual hydropower output in the region are likely by 2080 (Markoff and Cullen, 2008), putting that city's power supply at risk. Seattle's municipally owned utility has already begun investing in wind farms on the state border with Oregon to hedge its power generation bets (Seattle City Light, 2005).

Even cities that do not directly rely on hydropower for the electric supply may feel the pinch of declining hydropower availability in their region. Hydropower is generally a low-cost power source, so decreasing availability means it will be replaced by higher cost forms of power, driving up prices as the regional supply market tightens during low-water months or years (Morris *et al.*, 1996).

The impacts of climate change on two other important types of renewable power generation in cities – solar and wind power – are far less definitive. One study examining solar levels in the USA through 2040 projects increased cloud cover resulting from higher CO_2 level concentrations could cut solar radiation by 20 percent (Pan *et al.*, 2004). A Nordic study estimates that a 2 percent decline in solar radiation levels could cut solar photovoltaic system output by 6 percent (Fidje and Martinsen, 2006). To the extent cities around the world are seeking to significantly expand deployment levels on local homes and businesses, this could be problematic as long-term power output levels could be less than anticipated. However, because current in-city solar deployment levels are so small compared to overall urban power demand, it will likely be some time before such a decline in solar production becomes significant enough to create major problems. Whether large new concentrating solar facilities recently installed in many parts of the world will suffer degraded output levels is unclear. Several utilities serving urban areas in Spain and the southwestern USA have invested in these projects in rural areas outside of the city (Philibert, 2004), dramatically boosting the level of renewable power feeding the local power system.

Wind patterns (wind speed, duration, and direction) may also change as a result of climate change, although the projected impacts will likely vary seasonally and differ widely from region to region. Research on the Baltic Sea region finds no clear signal on future wind resource levels (Fenger, 2007), while in the UK and Ireland, onshore wind speeds are expected to decrease in the summer and increase in winter (Harrison *et al.*, 2008). Fenger (2007) notes the likelihood that system efficiency levels will increase in Scandinavia during the winter months because of reduced turbine blade icing attributable to warmer temperatures. Research on US wind patterns projects speeds will decline 1 to 15 percent over the next 100 years, depending on which climate models are used (Breslow and Sailor, 2002).

No studies have been identified to date that examine potential wind pattern changes in cities attributable to climate change. Cities are already recognized as being a challenging locale for deploying wind power systems due to the turbulence created by the built environment (Dutton *et al.*, 2005); the extent to which this may change is unknown and a good area for future research.

[ADAPTATION] Box 4.2 Cooling waters and nuclear power in the USA

Michelle Colley

Acclimatise

Morgan Herve-Mignucci

CDC Climat

An August 2007 heat wave forced the shut-down of a reactor unit at the Browns Ferry nuclear power plant in Alabama, USA, leading to international debate about the feasibility of nuclear power in warming temperatures. The Browns Ferry plant uses cooling water drawn from the Tennessee River to condense and cool the steam generated by the plant for its turbines. State environmental regulations impose a 90 °F (32 °C) cap on the river temperature downstream of the plant to minimize stress to aquatic ecosystems, and typically the plant increases the river's temperature by 5 °F (3 °C). During the heat wave, the upstream river temperature was often at, or above, 90 °F and the plant then became constrained by regulatory limits preventing it from raising the river's temperature further. As a result, one unit at Browns Ferry was shut down and power production from another two plants was decreased to reduce the quantity of process steam generated. This allowed the abstracted river water to condense the steam and pass back into the Tennessee River without violating the regulatory limits.

Plant operations were also affected by intake temperatures. In engineering terms, the plant can operate at 100 percent power output with river temperatures up to 95 °F (35 °C), leaving a 5 °F margin between the environmental cap and the engineering threshold. As river temperatures rise, the river water's ability to condense the steam that drives the turbines drops rapidly, requiring the plant to operate at reduced power outputs. Heat waves increase demand for air conditioning, so Browns Ferry is prone to shut-down when electricity demand is highest.

Source: Fleischauer, E. (2007). 'Heat Wave Shutdown at Browns Ferry Stirs Nuclear Debate,' September 2, 2007. Available at the Climate Ark website: http://www.climateark.org/shared/reader/welcome.aspx?linkid=83238&keybold=climate%20blogs (accessed July, 2009).

4.4.2.3 Climate impacts on energy transmission and distribution

To the extent temperatures are expected to rise as a result of climate change, there may be impacts on the local power grid. In general, transmission and distribution lines and electrical transformers are "rated" to handle a maximum amount of voltage for a fixed period of time before they fail. Changing climatic conditions can lead to such failure by pushing power demand beyond equipment rating levels. In California, for example, a summer 2006 heat wave led to blackouts across the state, as sustained high nighttime temperatures prevented the transformers from cooling down before demand increased again the next morning. Insulation within the transformers burned and circuit breakers tripped, knocking out power for more than one million customers (Miller *et al*., 2008; Vine, 2008).

Related to the previous discussion on the impacts of rising temperature levels on power plant output is the issue of how temperature changes will affect the power throughput of electricity transmission and distribution lines. When electric current flows through power lines, it encounters resistance from every system component it flows through, which produces heat and results in efficiency losses. These losses normally range from 6 to15 percent of net electricity produced, depending on the age of the system and the degree of electric loading on the lines (EIA, 2009; Lovins *et al.*, 2002; IEC, 2007). The effect on above-ground lines is moderated by the cooler ambient air, while wires below the ground are cooled by moisture in the soil. As temperatures increase, the cooling capacity of the ambient air and soil declines, conductivity declines, and lines may begin to sag or fail altogether (Hewer, 2006; Mansanet-Bataller *et al.*, 2008). Because distributed generation systems tend to involve minimal wiring exposed to the elements, they may be less vulnerable to these problems than central station-based power networks commonly deployed around cities.

Transmission and distribution networks may conversely experience reduced vulnerability as a result of anticipated temperature increases during the winter months, when they are more subject to damage or failure caused by ice or snow storms. Whether cities will be affected by this change will hinge on their general vulnerability to snow and ice storms, the extent to which these patterns change, and their level of reliance on power delivered by these sources. The severe snowstorms plaguing China in 2008 also brought down power lines in many cities and rural areas, compounding the power outages brought about by diminishing fuel stocks (French, 2008).

Electricity transmission and distribution networks may also be vulnerable to storm surges, rising sea levels, and high winds associated with extreme weather events (McKinley, 2008). Whether cities employ above- or below-ground electric wiring systems is largely a legacy of investment or operating decisions made long ago; a blizzard downing wires across the city led local authorities in New York City to move to bury electric wiring in 1888 (New York Times, 1888). Although this tends to eliminate snow and icing problems, it does make the city's underground transformers and substations more vulnerable to flooding. The local utility in New York is moving to address this problem by installing salt-water submersible transformers in Category 1 flood zones around the city (New York State Department of Public Service, 2007).

Thermal power systems and fuel storage tanks located in buildings may also be vulnerable to sea level rise or storm surges, depending on where they are situated. In many areas, local authorities issue warnings during anticipated flooding events about the need to anchor fuel tanks so they do not shift or flip, spilling their contents and contaminating the building (for example, see State of Maryland (undated)).

4.5 Efforts by cities to reduce greenhouse gas emissions and adapt local energy systems

Local-level policy engagement on energy matters has historically ebbed and flowed, with most action resulting as a response to some tangible crisis or vulnerability. In many parts of the world, the 1970s were a period of heightened local energy policymaking activity, as cities sought to protect themselves from shortages and price increases brought on by the OPEC oil embargo. Many other cities took action in response to growing public engagement in the nascent environmental movement and its "think globally, act locally" mantra.

Other cities have sought to influence the local energy system because of concerns over fuel poverty; lack of public access to safe or reliable energy supply; the adverse impact local energy prices or energy system reliability are having on the city's economy; public health concerns related to local energy emissions; and concerns about the long-term energy security of the city (for example, see San Francisco Public Utility Commission, 2002; Greater London Authority, 2004; New York City Energy Policy Task Force, 2004; City of Cape Town, 2006; City of Amsterdam, 2007; City of Toronto, 2007, Mairie de Paris, 2007; Ciudad de Mexico, 2008).

Climate change began to influence local energy policy efforts in the early 1990s, an outgrowth of the Local Agenda 21 (LA21) movement emanating from the Rio de Janeiro "earth" summit. LA21 plans were conceived of as a means of rallying local support for policy and program initiatives designed to improve local "sustainability." Sustainability was broadly interpreted, but concerns about global climate change and the need to shift to alternative energy sources were clearly articulated as an important element of any local plan. The international non-governmental organization ICLEI was created at around this time, specifically with a goal of providing information and technical support to cities interested in developing these plans (ICLEI, 2000, 2009a).

Over the following decade, other similar organizations and initiatives were established, including Energie-Cités and the European Union-sponsored Covenant of Mayors in Europe; C40-Large Cities Climate Group; World Mayors Council on Climate Change; and climate-related programming by United Cities and Local Governments and Metropolis. The exact structure and purpose of these organizations and initiatives varies slightly, but most tend to provide policymaker education and training, information exchange, technical support, and recognition programs. Membership requirements, costs, and performance obligations vary widely across these initiatives.

Other information and technical support initiatives focused on local-level energy and climate change initiatives have also cropped up in recent years, sponsored by various non-governmental organizations, academic groups, international development banks, and private consultants (for example, see European Commission, 2007a; Natural Capitalism Solutions, 2007; ISET, 2009; Prasad *et al.*, 2009; Suzuki *et al.*, 2009; US Conference of Mayors, 2009). The visibility of these initiatives has grown considerably, particularly as local action has become identified as a counterweight to inaction on climate change by national governments (Grunwald, 2007; City of Copenhagen, 2009).

The number of cities enrolling in these initiatives is sizable,[5] although the results of this activity or participation are poorly documented.

4.5.1 Policy and program initiatives

The type of initiatives undertaken by cities around the world or endorsed by these technical assistance organizations varies widely, reflecting local climate, economic, and political conditions; available local authority resources; local authority political and policy preferences and span of control; the design of the energy system, including its age and breadth of geographic coverage; and sense of urgency by key stakeholders.

Structurally, these policy and program initiatives fall into three broad categories: energy and climate planning and governance, specific mitigation policies and programs focused on reducing the local energy system's contribution to climate change, and adaptation efforts dealing with the consequences of climate change. A review of climate action plans and other documentary evidence has found that the majority of cities engage in the first two categories of activities, emphasizing climate change planning and mitigation-focused initiatives. Adaptation planning is still a relatively new concept, more the exception to local authority efforts than the rule (Carmin *et al.*, 2009).

In many ways, the programmatic emphasis seen to date mirrors the type of consultation and advice provided by many of the technical assistance initiatives cited above. Early handbooks and other guidance documents prepared to aid local authorities tended to be very mitigation focused. More recent initiatives appear to be more evenly balanced in their coverage or focus entirely on bolstering local resiliency to the impacts of climate change. Even in these documents, however, the sections on how local energy systems must adapt are still poorly developed, as will be discussed below.

4.5.1.1 Climate planning and governance efforts

Many cities treat energy and climate planning as a major initiative, involving a range of stakeholders in and outside of

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[5] For example, as of December 2010, 1,044 cities have signed on to the US Conference of Mayors Climate Protection Agreement (US Conference of Mayors, 2010), while 2,181 cities from around the world have signed on to the European Union's new Covenant of Mayors initiative (European Commission, 2010). Globally, ICLEI has more than 1,200 local authority members (ICLEI, 2010). The extent to which there is overlapping membership in these counts is unclear, as membership information is not made publicly available by ICLEI.

[MITIGATION] Box 4.3 Seoul's efforts against climate change

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Young-Soo Choi

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In April 2007, the City of Seoul announced the Seoul Environment-friendly Energy Declaration, which promotes energy savings and efficiency, expansion of renewable energy and reduction of greenhouse gas emissions. The objective of the program is to actively cope with climate change, the energy crisis caused by excessive consumption of fossil fuels and the exhaustion of unstable energy supplies caused by oil price changes. Seoul is implementing a variety of measures to improve the city's self-reliance on energy, including establishing an objective of 15% energy reduction and 10% renewable energy use by 2020, compared to a year 2000 baseline.

To support this program, Seoul announced new Environment-friendly Building Criteria. Buildings use 57% of energy and produce 65% of greenhouse gas emissions in Seoul.

When the criteria are fully implemented, energy use and greenhouse gas emissions will decrease by at least 20% in new buildings and 10% in existing buildings. The city will require all public buildings to observe the criteria and actively encourage private buildings to follow the guidelines. Specific elements of the criteria include promotion of transit-oriented development (i.e., development near subway and bus transport); promotion of bike lane development; and the promotion of energy efficiency initiatives and the increased use of renewable energy.

In 2010, the Environment-friendly Building Criteria were enhanced to require more direct action. Buildings in Seoul must now achieve second class or higher performance in terms of energy efficiency. In particular, high-rise residential buildings (with 100 or more households) will only receive a construction permit if designed to satisfy 3% of the buildings' energy demand through the use of on-site renewable energy technology. Insulation for outer walls must also be enhanced, and automatic standby power cut off systems should also be installed on more than 80% of the facilities of the buildings.

Seoul is also undertaking a variety of other initiatives including:

- Developing a climate and energy map to show Seoul's climatic characteristics and energy usage patterns in each district around the city. The climate and energy map will aid local urban planning initiatives and provide an opportunity for the citizens to join activities to address climate change, such as energy saving.
- 79% of the city's transport-related greenhouse gas emissions are from automobiles. To address this problem, Seoul collects a 'congestion charge' from cars entering downtown Seoul through Namsan Tunnels No. 1 and No. 3. (There are several routes drivers can take to enter downtown Seoul, but Namsan Tunnels No. 1 and No. 3 offer the shortest routes into the city, saving time on the road.) The congestion charge allows smoother traffic flow, diminishes atmospheric pollution and makes efficient use of traffic facilities. The congestion fee is 2,000 Korean won (approximately US$1.60) per vehicle with less than 3 passengers. Ultimately, Seoul may seek to impose congestion charges on all routes entering downtown Seoul, but there is currently a lack of consensus among the citizens about this issue.
- Seoul also introduced a No-Driving Day scheme on weekdays. In this scheme, people voluntarily determine a day when he or she will abstain from driving his/her car. Compliance is monitored using a RFID system. There are currently 2.95 million vehicles registered in Seoul and 968,000 cars are participating in the No-Driving Day program. The program is estimated to reduce local CO_2 emissions by 246,541 tons annually. Participants in the program receive a 5% discount on vehicle tax, a 10% discount on the local congestion charge, and 30% discount on public parking fees. There are no penalties imposed on the drivers caught driving on their specified day, but drivers caught cheating more than three times per year will be banned from the benefits provided by the No-Driving Day program.
- In 2009 the Seoul Metropolitan Government launched the Eco-mileage program to encourage citizens to take an active role in reducing greenhouse gases. The program provides incentives to households that reduce their electricity, water, and gas consumption by 10% compared to their consumptions levels over the two prior years. As of the first half of 2010, 186,000 households have joined the program and 70,742 tons of CO_2 were reduced over the past 6 months. Participating households receive green consumer goods discounts worth US$50, tree planting vouchers, energy auditing services, etc. Groups (such as schools or apartment complexes) can receive subsidies for different greening projects worth approximately US$10,000.
- Seoul also established the *Low CO_2 Green Bank Account*, a green financial mechanism, to raise funds for use in responding to climate change. Citizens can be offered discount commission benefits when they open an account with Wooribank, a private Korean bank. This account is similar to other private bank accounts, except all profits yielded from the account will be directed to a new Seoul Climate Change Fund. This fund will then be used on a range of low carbon projects, including providing eco-friendly consumer goods to low income households.

local government. The effort is generally managed by local authority staff, although key support roles may be played by outside NGOs such as ICLEI-Local Governments for Sustainability, private consultants, academic researchers, or representatives from the general public or local private companies with special knowledge or interests in the outcome of the planning work. The extent of external involvement also varies depending on the desired scope of the planning exercise. Efforts focused on reducing energy use or greenhouse gas emissions solely from local authority operations (i.e., so-called "corporate" emissions) primarily involve officials from agencies responsible for these emissions. Broader efforts seeking to reduce emissions from other sources around the city (e.g., homes or local businesses) often include more external stakeholders. Another key scoping decision shaping local planning efforts is the decision over whether to target energy use or greenhouse gas emissions from new or existing buildings, as each requires a dramatically different policy orientation.

[MITIGATION] Box 4.4 Cities for Climate Protection (CCP) Campaign of ICLEI–Local Governments for Sustainability

Yunus Arikan

ICLEI-Local Governments for Sustainability

This case study summarizes information available on the ICLEI website, at www.ICLEI.org.

The Cities for Climate Protection (CCP) Campaign[6] assists cities and local governments to adopt policies and implement quantifiable measures to reduce local greenhouse gas emissions, improve air quality, and enhance urban livability and sustainability.

BACKGROUND

In 1993, at the invitation of ICLEI, municipal leaders met at the United Nations in New York, for the 1st Municipal Leaders Summit on Climate Change, and adopted a declaration that called for the establishment of a worldwide movement of local governments to reduce greenhouse gas emissions, improve air quality, and enhance urban sustainability. The result was the CCP Campaign, today recognized as the longest running climate change mitigation campaign globally.

FIVE MILESTONE PROCESS

The CCP Campaign follows a five-step course of action (milestones) providing a simple, standardized way to reduce greenhouse gas emissions and to monitor, measure, and report performance. The milestones allow local governments to understand how municipal decisions affect energy use and how these decisions can be used to mitigate global climate change while improving community quality of life. ICLEI has developed several software tools that help cities comply with the methodology.

THE FIVE MILESTONES ARE:

Milestone 1. Conduct a baseline emissions inventory and forecast. Based on energy consumption and waste generation, the city calculates greenhouse gas emissions for a base year and for a forecast year. The inventory and forecast provide a benchmark against which the city can measure progress.

Milestone 2. Adopt an emissions reduction target for the forecast year. The city establishes an emissions reduction target for the city. The target both fosters political will and creates a framework to guide the planning and implementation of measures.

Milestone 3. Develop a Local Action Plan. Through a multi-stakeholder process, the city develops a Local Action Plan that describes the policies and measures that the local government will take to reduce greenhouse gas emissions and achieve its emissions reduction target. Most plans include a timeline, a description of financing mechanisms, and an assignment of responsibility to departments and staff. In addition to reduction measures, most plans also incorporate public awareness and education efforts.

Milestone 4. Implement policies and measures. The city implements the policies and measures contained in their Local Action Plan. Typical policies and measures implemented by CCP participants include energy efficiency improvements to municipal buildings and water treatment facilities, streetlight retrofits, public transit improvements, installation of renewable power applications, and methane recovery from waste management.

Milestone 5. Monitor and verify results. Monitoring and verifying progress on the implementation of measures to reduce or avoid greenhouse gas emissions is an ongoing process. Monitoring begins once measures are implemented and continues for the life of the measures, providing important feedback that can be use to improve the measures over time.

ACHIEVEMENTS

Since its inception, the CCP Campaign has grown to involve more than 1,000 local governments worldwide that are integrating climate change mitigation into their decision-making processes, covering around 10 percent of the world's urban population and including approximately 20 percent of global urban anthropogenic greenhouse gas emissions.

Following the achievements in North America, Australia, and Europe in the early 2000s, CCP is recognized as the only local government climate mitigation campaign taking place in developing countries in Latin America, South Africa, South Asia, and Southeast Asia.

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[6] www.iclei.org/climate

Specific regional/national achievements are:

SOUTH ASIA

In 2009 ICLEI South Asia published *Energy and Carbon Emissions Profiles of 54 South Asian Cities*, a comprehensive account of corporate and community emissions from 54 local authorities from India, Bangladesh, Bhutan, Nepal, and Sri Lanka, compiled by ICLEI South Asia. The report is recognized as one of the most comprehensive compilations of greenhouse gas emissions of cities in developing countries.

USA

In 2009 ICLEI USA welcomed Oklahoma City as the 600th member of its national CCP Campaign. Around 200 local governments have completed their greenhouse gas baseline inventory and at least 155 have committed to emissions reduction targets. The projected greenhouse gas emissions reduction from these targets is expected to add up to more than 1.36 billion tonnes CO_2-eq by 2020 – the equivalent of taking 25,000,000 passenger vehicles off the road for the next 10 years.

NEW ZEALAND

Communities for Climate Protection: New Zealand, Actions Profile 2009 summarizes greenhouse gas emissions reduction data from 34 councils covering 83 percent of the New Zealand population. The total of reported and quantifiable emissions reductions from CCP-NZ council activities, since councils' inventory base-years (starting from June 2004) to June 2009, has been conservatively calculated to be more than 400,000 tonnes CO_2-eq.

AUSTRALIA

CCP Australia was launched in 1997 and as of 30 June 2008 had 233 participating councils, representing about 84 percent of the Australian population. In 2007/2008 over 3,000 greenhouse gas abatement actions were reported by 184 councils across Australia. Collectively these actions prevented 4.7 million tonnes CO_2-eq from entering the atmosphere – the equivalent of taking over a million cars off the road for an entire year. Since the start of reporting in 1998/1999, 18 million tonnes CO_2-eq have been abated by Australian cities within the CCP Campaign.

IMPACTS

Following the success achieved through the implementation of CCP, ICLEI and local government networks are able to advocate for more ambitious greenhouse gas reduction policies at the national and international level. CCP enhances cities' access to carbon financing and improves standardization of urban greenhouse gas accounting. Based on the experience of the five-milestone process, ICLEI further developed innovative actions in adaptation to climate change at the local level.

The local climate planning process often begins with a data gathering and analysis exercise to track local greenhouse gas emissions. As noted in Chapter 8, this analysis can be difficult to conduct. Emission reduction targets set decades into the future are frequently established, in many cases at levels suggested by different climate policy networks or technical assistance initiatives. For example, the US Conference of Mayors Climate Protection Agreement launched in 2005 sought to convince mayors to commit to a 7 percent reduction in their city's emission levels by 2010, the same level called for by the USA as a whole under the Kyoto Protocol (US Conference of Mayors, 2010).

The lifespan of these planning initiatives varies. Some cities have designed them as ongoing initiatives, with regular reporting on results and updating of plans to reflect implementation progress, new knowledge, or changing local conditions.

4.5.1.2 Greenhouse gas mitigation policies and programs

Although many factors affect the exact policy and program prescriptions contained in local climate plans, it is common to see plans emphasizing specific policies and programs targeting the largest emission sources identified by the local greenhouse gas emission inventory. In London, for example, the local climate plan projects how specific proposed strategies will collectively shift the city from its current business-as-usual greenhouse gas emissions path (see Figure 4.6).

Existing technology choices directly influence the content of a city's plan. For example, cities receiving the bulk of their electricity supply from low- or non-greenhouse gas emitting sources such as hydropower or nuclear power (e.g., Paris) tend to focus their policy attention to thermal or transport-related energy use, essentially viewing electricity consumption as a less problematic issue.

Cities reliant on carbon-intensive power sources frequently emphasize fuel switching or technology switching as a means of driving down emission levels. Strategies include increasing the use of renewable power generated within or imported to the city, or the replacement of existing large power plants with more energy efficient turbine designs (San Francisco Public Utility Commission, 2002). Combined heat and power technology deployment or district energy system expansion may also be advocated, because these technologies can both heat homes and power steam chillers that replace electric powered air conditioning units. In New York City, it is estimated that such chilling units and other technologies connected to the district steam system displace nearly 375 MW of electric demand around Manhattan (City of New York, 2007).

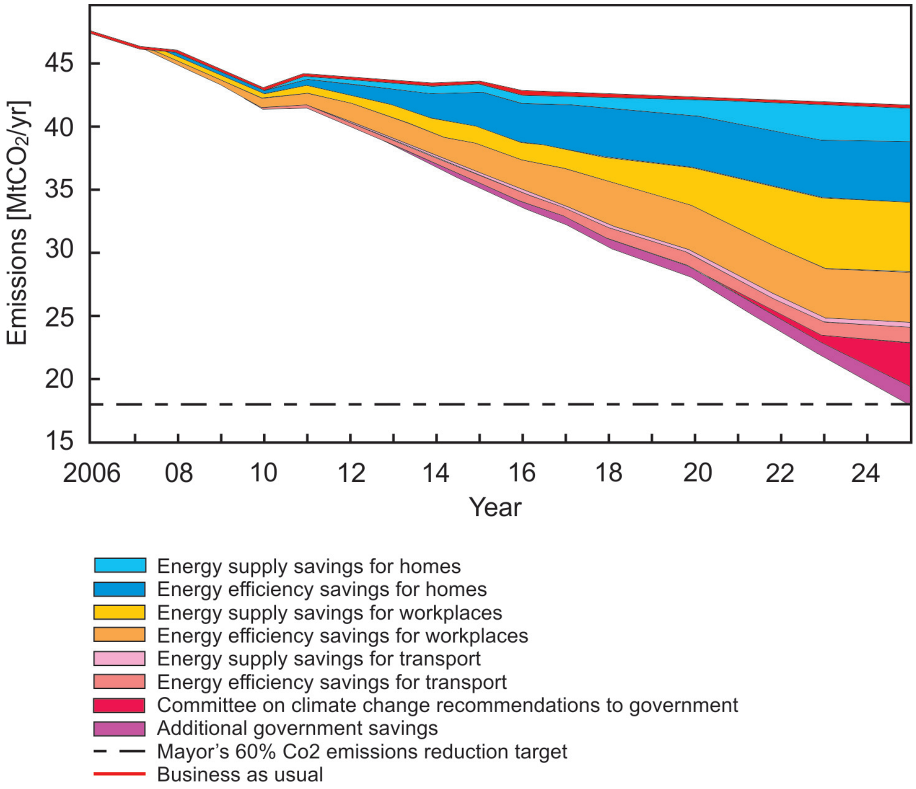

Figure 4.6: *Projected emission impacts of selected climate mitigation strategies contained in London Climate Change Action Plan.*

Source: Greater London Authority (2007).

Other strategies emphasize demand-side initiatives to reduce overall energy use around the city, including efforts promoting the use of more efficient lighting systems on roadways and in homes and businesses. Because peak power demand in many cities is linked to air conditioning use on hot days, efforts to reduce solar gain within buildings on hot days often find a home in local climate plans. Strategies promoted include green roofs, cool roofs, enhanced wall or ceiling cavity insulation, or landscaping programs planting trees on the sunny side of buildings. Electricity-intensive businesses or business units such as computer data centers may also be the target of policymaker interest.

There is a lengthy literature of technical assistance documents that have been developed over time advising cities on "best practice" initiatives (Natural Capitalism Solutions, 2007; US Conference of Mayors, 2009); some of these best practice claims are better documented than others. One of the biggest challenges local authorities face when considering these many ideas is assessing whether ideas deemed effective in one city can be effectively translated to a completely different local context. This problem is most pronounced in cities in less-developed countries, where the challenge of providing even the most basic type of energy infrastructure system has proven vexing (USAID, 2004).

A closely related point local authorities must consider is which type of policy instruments will prove most effective at delivering on their policy goals. In many cases, cities lack relevant local evidence, and must rely on outcomes achieved in other cities where the underlying economic or policy conditions could be completely different. Policymakers may also have strong ideological preferences that shape their policy decisions, preferring mandates to incentives or vice versa.

Energie-Cités (2009) identifies ten different functions or roles for local government, each of which creates specific policy and program opportunities to influence local carbon emission levels.[7] Hammer (2009) argues that these functions can be collapsed into five unique types of policy levers that generally fall under mayoral control, each of which can contribute towards a comprehensive local mitigation policy:

- Rulemaking – regulatory or policymaking powers, including the ability to impose land use controls that reduce the need for private vehicle use; environmental standards; or clean energy technology requirements
- Regulatory oversight – responsibility for the enforcement of standards established by other governmental entities (such as building codes promoting energy efficiency)
- Direct expenditures/procurement – use of local purchasing powers to procure efficiency upgrades that reduce the local authority's own energy expenditures
- Financial incentives – tax breaks, permitting rule modifications, or cash subsidies or financial penalties designed to

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[7] These roles include consumer, service provider, model, planner, developer, regulator, advisor, motivator, producer, and supplier.

promote energy efficiency or clean energy investments and behavior
- Information/advocacy – use of local government's highly visible platform to speak out on local energy issues or convene stakeholder meetings to move projects forward.

Regardless of which instrument(s) local authorities choose to employ, officials must assess how long they will stick with a certain policy approach, and when they should shift to an alternative strategy if the original policy is proving less effective than first hoped. The fact that the greenhouse gas emission reduction targets established by most cities are aspirational, rather than obligatory, means there may be some laxness about shifting away from unsuccessful policy approaches. The long time horizon of most emission reduction targets also makes accountability difficult, as these targets generally extend far beyond the average mayor's term of office.

Their limited policy control powers also highlight the need for local authorities to structure their mitigation efforts in more holistic or cross-cutting ways that leverage support and involvement from other key stakeholders and levels of government. Some cities do this by articulating advocacy strategies designed to win changes giving local officials additional financial resources or more policy control powers (Greater London Authority, 2004). Others emphasize information and education campaigns that inform local energy users about financial or technical assistance resources available from state or central government.

4.5.1.3 Climate change adaptation policies and programs

Compared to efforts to mitigate the role of local energy systems in global climate change, efforts to adapt local energy systems to changing climatic conditions are much more difficult to identify. A scan of many local climate plans finds energy system adaptation rarely mentioned, or defined only in terms of a single type of climate risk, such as vulnerability to coastal flooding (Webster and McElwee, 2009).

Part of the problem is that local understanding of the climate impacts a specific city will face has historically been poor; efforts to downscale global climate models described earlier in this report are only now being employed in cities around the globe. Cities can use past extreme weather events as proxies, with the assumption that climate change will exacerbate the frequency or scale of these events. Even this approach, however, does not fully explain which of the many possible climate-related impacts identified earlier in Chapter 3 are most relevant to the local energy system over different timescales.

Another factor potentially impeding local authority engagement is their limited "ownership" of the solutions to this problem. The majority of the impacts cited in Chapter 3 affect long-embedded central energy system assets that fall outside of the direct jurisdiction of local officials. This fact forces local authorities to develop an advocacy, education, or partnership agenda, seeking to engage other key stakeholders such as utility owners and

[ADAPTATION/MITIGATION] Box 4.5 Adaptation and mitigation of climate change impacts in Kampala, Uganda

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Climate change, now a reality, is influencing realignment of global and country policies towards adaptation and mitigation (Prasad *et al.*, 2009). The effects of climate change are now being felt, with Africa as the most vulnerable region (UN-HABITAT, 2008). This is due to Africa's multidimensional unpreparedness, yet the continent is unequivocally urbanizing faster than any region globally, exposing inland and coastal cities to risks. Cities are both contributors to and vulnerable to climate change, but the effects of climate change are exacerbating the already grim environmental, social, and economic challenges heightening the risk to the urban poor (UN-HABITAT, 2008). Urban vulnerabilities are manifest in several areas including housing, energy, food security, water resources, health, transport infrastructure, environmental services, and economic productivity. This box highlights findings of climate change effects, and strategies for mitigation and adaptation in Kampala. Under the Sustainable Urban Development network (SUD-Net), the Cities in Climate Change Initiative (CCCI) of the UN-HABITAT is aimed at raising awareness, developing tools, and building capacity for municipalities and intensification of adaptation and mitigation activities through demonstration projects. The CCCI is building on existing climate change mitigation and adaptation measures at national and city levels by providing frameworks for urban vulnerability assessment, identifying scalable adaptation and mitigation measures implemented at community to city levels through Local Climate Change Plans.

Applying a multi-faceted methodological approach that utilized geospatial analysis integrating demographic, social, economic, and environmental data complemented with meta-evaluation of climate change projects, findings show that the impacts are increasing. In Uganda, there has been recorded variation in average temperatures that correlates with an estimated increase of 1.5 °C in the next 20 years and by up to 4.3 °C by the 2080s, although recent scientific studies indicate that the globe could warm by 4 °C by 2050. Significant observed changes in rainfall patterns and temperature continue to pose vulnerabilities to urban areas in Uganda. The most significant impact to Kampala is flooding due to increased rainfall that is spread over relatively short or extended periods. Increase in runoff has made flooding the most serious threat to humans, livelihoods, the urban system, and the economy. On the other hand, changes in temperature regimes have affected urban livelihoods and food security.

Kampala city is the primary city, with 39.6 percent of the national urban population. Located along the shores of Lake Victoria, a region with evidence of increased precipitation, the challenge of surface runoff coupled with non-robust drainage systems has increased the vulnerability of Kampala city's infrastructure, housing, social services, and livelihoods. Between December 2006 and February 2007 there was serious damage to housing and schools and disruption of livelihoods from excessive rainfall. These vulnerabilities are felt variably in a city "region" of Kampala spanning an estimated surface area of 1,895 sq km with a spatial connectedness of economic, social, and environmental processes (Nyakaana *et al.*, 2004). The various urban sectors of the city are affected in different ways, so that sector-specific vulnerability analysis provides better clues on mitigation and adaptation measures. Energy is an important sector with heavy reliance on biomass energy for domestic and institutional use. About 75 percent of Kampala's population use wood fuel and will use an estimated 535 metric tons annually by 2007 (Mukwaya *et al.*, 2007). This is coupled with increases in motorized transportation and consumption of petroleum products leading to greenhouse gas emissions. Although the contribution of Uganda to CO_2 emissions is low, adapting urban transportation for energy efficiency is important. Another sector associated with energy is housing, with two roles: protection of inhabitants from climate change impacts; and contribution of buildings to emissions. Analysis shows that existing buildings are neither energy efficient nor protective to inhabitants. Low- or neutral-energy housing is needed and a housing code that is energy efficient is to be developed under the CCCI.

Urban water is an important sector vulnerable to climate change. Safe urban water supply reaches only 67 percent of the population in Kampala, with the large population left out being the urban poor. Climate change impacts around Lake Victoria have led to decrease in the water levels and affected supply for 2.5 years. Climate change is likely to worsen the situation for the urban poor. In respect to solid waste collection, transportation, and disposal, the principle of "generator pays" is the basis of solid waste management, but despite the initiative, solid waste management practices are deplorable. The city has not benefited from the Clean Development Mechanism (CDM) of trading carbon credits from landfill gas capture. Local-level innovative ways of utilizing waste for energy with the potential to reduce landfill emissions is yet to be scaled up. The linkage between solid waste management, energy, and flooding has increased the vulnerability of the city's population to health hazards. Infectious diseases, especially water-related and air-borne, are prevalent in many of the neighborhoods of Kampala: disease outbreaks occurred in 1997, 1999, 2004, 2006, and 2008 due to the increased floods (KCC and BTC, 2008). With these impacts, urban health services become overstretched to meet the challenges of high service demand. The ecosystem of the city region is also under threat with wetland destruction, biodiversity loss and soil erosion augmented by clearance of vegetation, and ecosystem services decline. Ecosystem conservation and management remains an important component for climate change adaptation and mitigation. A gender perspective of climate change vulnerability has informed the initiative to be responsive by analyzing effects on different gender groups and strategies that address the needs of women and children.

SUD-Net CCCI has initiated awareness-raising campaigns, which will be followed by development of tools to enable different stakeholders to develop climate change plans. Drawing on the National Adaptation Program of Action (NAPA) and the Initial Climate Communication tool, the CCCI is enabling amplification of the role of urban areas in climate change adaptation and mitigation (Isabirye, 2009). A platform to enable engagement of stakeholders is envisaged to highlight vulnerability for policy action. Various demonstration projects, including city greening, alternative energy briquette utilization, clean wood fuel use, climate proofing of infrastructure, and designing energy efficient urban transport systems, are underway for long-term response to climate change. A key aspect of this program is building institutional resilience and adaptation to climate change by investing in action research that brings together different stakeholders. There is much needed knowledge to inform climate change policy, a wealth of which exists but is not widely disseminated. This necessitates innovations in enabling information flow for up- and out-scaling of innovations. Thus, information sharing is important and provides an opportunity for communicating and networking on climate change. UN-HABITAT under the SUD-Net is supporting a Local Urban Knowledge Arenas (LUKAS) platform through which climate change information at city and national level will be exchanged.

regulators in a way that will advance the city's interest in a more robust and resilient energy system.

This is not to say there has been no progress on this issue. New York, London, and Chicago all have active energy system adaptation initiatives underway, working closely with key energy system stakeholders and regulators (Chicago Climate Task Force, 2007; Greater London Authority, 2008; City of New York, 2008). Other cities have also identified steps they would like to take to adapt the local energy system to climate-related impacts, while researchers and non-governmental organizations are coming up with their own guidance documents (Neumann and Price, 2009; Williamson *et al.*, 2009). Many of these emphasize the synergistic nature of mitigation and adaptation strategies, with system changes intended to reduce greenhouse gas emission levels whilst simultaneously enhancing the resilience of the system to climatic changes (Laukkonen *et al.*, 2009).

It is possible to categorize adaptation initiatives in various ways, including those that reduce sensitivity, alter exposure, or increase resilience to changing conditions (Adger *et al.*, 2005). As discussed above, it also helps to categorize strategies as relating to either energy supply or demand. Examples of different energy system adaptation strategies are found in Table 4.6, broken out by these two classification systems. In some cases, individual policy and program strategies provide benefits in multiple impact categories.

Cities opting to pursue adaptation initiatives will likely find that grappling with uncertainty over the nature, scale, and timing of the impacts will be a significant challenge. Part of the problem arises from the fact that the energy system itself is constantly changing, reflecting technological and market innovation and growing demand levels. Each segment of the system also has a natural lifespan, creating opportunities to upgrade the system or enhance its climate resiliency as part of the natural life cycle of the equipment (Neumann and Price, 2009). By themselves, these factors make system planning a highly complex endeavor; adding climate change to the mix only compounds the difficulty (Linder *et al*., 1987; ICF, 1995; Scott and Huang, 2007). Equally challenging is the fact that many energy companies have a relatively short capital investment horizon, potentially limiting their interest or ability to take actions whose benefits may only be realized over a much longer timescale.

Local authorities seeking decision rules to rank their adaptation options or manage risk have several options. It may be helpful to apply scenario analysis to the problem, selecting the option(s) that result in the least sensitivity to future climate conditions (Lempert and Collins, 2007). Hallegatte (2008) suggests that "no-regret" or "reversible" policies be considered. No-regret strategies are those yielding benefits even if impact projections prove overblown; energy efficiency initiatives are "no-regret measures par excellence" (Mansanet-Bataller *et al*.,

Table 4.6: *Examples of energy system adaptation strategies.*

Impact category	Energy supply	Energy demand
Reduce sensitivity: alter the scale or type of local energy system assets or markets to minimize the effects of reduced system output or failure	• Reduce supply sensitivity to loss of hydropower availability by increasing reservoir system capacity (Adger *et al.*, 2005) • Install in-building supply systems (thermal or power) at elevations above anticipated flooding levels (Adger *et al.*, 2005) • Construct additional or redundant transmission or distribution line capacity to offset anticipated efficiency losses (Hill and Goldberg, 2001) • Establish new coastal power plant siting rules to minimize flood risk (Stern, 1998) • Install solar PV technology to reduce effects of peak demand (Franco and Sanstad, 2008)	• Install steam-powered chillers to reduce burden on local power system on hot days • Establish or expand demand-response programs which encourage consumers to voluntarily reduce power consumption during peak demand events (Stern, 1998)
Alter exposure: take steps that reduce opportunities for the local energy system to experience damage or problems resulting from climate change	• Upgrade local transmission and distribution network to handle increased load associated with higher temperatures (Hill and Goldberg, 2001) • Protect power plants from flooding with dykes/berms (Mansanet-Bataller *et al.*, 2008) • Expand hazard preparedness programs (Adger *et al.*, 2005) • Install solar PV technology to reduce effects of peak demand (Franco and Sanstad, 2008) • Require utilities to develop storm hardening plans on a regular basis (Neumann and Price, 2009) • Retrofit power plants so they use less cooling water (Neumann and Price, 2009)	• Install steam-powered chillers to reduce burden on local power system on hot days • Establish or expand demand-response programs which encourage consumers to voluntarily reduce power consumption during peak demand events (Stern, 1998) • Improve and rigidly enforce energy efficient building codes (Morris and Garrell, 1996)
Increase resilience: enhance ability of city to recover from losses by reducing overall need for energy services or enhancing speed with which system can recover	• Automate restoration procedures to bring energy system back on line faster after weather-related service interruption (Overbye *et al.*,2007) • Expand refinery capacity in less vulnerable areas (Neumann and Price, 2009) • Provide additional support for distribution generation systems to spread climate risk over a larger area (Neumann and Price, 2009)	• Establish public education programs to promote lifestyles that are less energy-dependent • Employ passive building design strategies (e.g., larger windows, extra thick walls, flow-through ventilation, natural shading, etc.) to maintain minimum comfort or lighting levels even in situations where energy system losses occur (Commonwealth of Australia, 2007; Miller *et al.*, 2008) • Reduce or eliminate energy subsidies so prices reflect true cost (Stern, 1998)

2008) because they deliver cost-saving benefits regardless of what happens with climate change. Reversible policies allow a local authority to swiftly change course if anticipated problems do not arise or if the policy proves ineffective. Hallegatte (2008) also proposes that local authorities account for uncertainty over climate change by pursuing investments with a shorter projected lifespan. Such a strategy allows the local authority to exploit the replacement cycle for these investments, incorporating the latest scientific knowledge into the procurement process.

4.6 Conclusions, policy recommendations, areas for future research

This chapter makes clear the complexity of urban energy systems. Market structures vary across cities and countries, as do current-day economic and climatic conditions. Technology decisions made long ago that reflect past market and policy/regulatory realities continue to influence choices made today and plans looking toward the future.

The result is that urban energy consumption, the impacts of that consumption, and the vulnerability of urban energy systems to climate change will vary significantly across locales. This local context needs to be well understood, both to elucidate the vulnerabilities and challenges facing a particular city as well as to clarify the options available to combat these threats. Because of the unique circumstances facing each city, there is little evidence on how strategies promoted as "best practice" in one city can be effectively transferred from one city to another. It is also difficult to pinpoint one single energy system type as being more or less vulnerable to the impacts of climate change than another.

Localized climate change studies offer clear benefits, employing downscaled GCMs to establish a scientific justification for local action. Energy supply and demand or greenhouse gas emission inventories also set the stage for comprehensive policymaking efforts.

Local authorities drawing on these facts have many intervention strategies they can employ to influence local energy use or enhance the climate resilience of urban energy systems. Section 4.5 looked at initiatives including public information campaigns, building regulations, and market and policy changes. However, because cities often have a limited span of control, working with partners is vital, including the public, non-governmental organizations and other civil society groups, the private sector, and different scales of government. There is evidence that cities have already recognized this and such collaborations are becoming increasingly common.

4.6.1 Knowledge gaps

Much of the research cited in this report is quite recent. Work in this area continues to evolve and, while some of the basic issues are now well-understood, a number of knowledge gaps remain. These include:

- *Limits on structural or systemic change*: Section 4.2 highlighted the key drivers of urban energy consumption. Although many local action plans seek modest or incremental change to the current energy system, there is a larger question of whether cities can overcome their path dependency to implement large-scale overhauls, dramatically altering the way they make or use energy, and under what timescale this might be possible. In Denmark, cities in the Copenhagen region banded together to completely overhaul the way buildings in the city are heated, installing a comprehensive district energy system that reached into nearly every home and business in just a few years (Manczyk and Leach, 2002). Is such a model transferable to other cities, employing the same or other types of energy technologies? Research authoritatively evaluating all that was done to deliver this change in Copenhagen and its relevance to other cities might go far in helping local authorities move beyond their current energy or climate policymaking comfort zone.
- A corollary to that question is our lack of understanding of the point at which local features of climate, geography, and history are immutable facts that undercut our goals for system transformation. In other words, when do aspirational climate or energy goals become unattainable, and what can be done to identify the realistic limits on change so this can be directly woven into the local planning process?
- *Demand-side projections*: There is little evidence to date on what climate scenarios mean for local energy demand in different cities. Storm and flooding risks are more likely to be known, based on historical experience. Far less understood, however, is the issue of consumer behavior and local price elasticity of demand. If cities start to get hotter, at what point will consumers increase their adoption of air conditioning, and how much will they use it each day? This knowledge is critical because it leads to questions of market pricing, demand-side management, and (potentially) the need for new peak-load generation capacity.
- *Energy supply chains in developing countries*: Little is known to date about how climate change will affect the informal energy systems of developing countries. Because some of these cities are rapidly growing, it will be important to understand whether climate-related system vulnerabilities may be outpaced by a transition to cleaner fuels or by efforts to expand grid access in these cities.
- *Multi-level government policy coordination*: A gaping hole in the urban energy and climate literature is an understanding of the proper role of national and transnational governments in urban energy system governance. Local authorities have their own vision in terms of policy coordination and resource support (see City of Copenhagen, 2009), but more fundamental questions about power sharing or the devolution of power from central/state government have not been examined in meaningful ways. A related question involves market restructuring efforts. Increased competition in supply has led to significant changes in technology deployment and energy planning responsibilities, but transmission and distribution

functions are still largely regulated monopolies. In both cases, are these regulatory systems structured in ways that they can meaningfully address that challenges presented by climate change? Moreover, are regulators informed about how climate change may manifest itself in different cities under their jurisdiction, and on what time frame? Have they begun to weave these facts or projections into their regulatory decisions, such as whether to allow utilities to receive rate recovery for climate resiliency investments?

- *Future-proofing*: Hallegatte's "no-regrets" strategy (Hallegatte, 2008) provides guidance on adaptation strategies cities can pursue with little concern for how climate change actually plays out, because the environmental or efficiency benefits of these strategies will always be valued. Uncertainty also exists, however, in the form of future national-level climate change mitigation policies and technological innovation. How can local authorities craft policies that will serve their long-term energy and climate interests without a full understanding of whether breakthrough technologies may fundamentally change how energy must be generated, imported, or used within a city? Local authorities would benefit from such guidance, particularly because it is likely that central and state governments will be increasingly active on climate change mitigation efforts in the coming years, leaving local authorities to play catchup.

4.6.2 Where do cities go from here?

While there are clearly a number of challenges facing urban governments, they need not respond passively to signals from higher level governance and broader trends. Indeed, there are a number of activities where cities can show leadership and promote better understanding in this area.

- *Climate planning and policy/program implementation*: Local authorities should establish or continue their efforts to both mitigate and adapt to the impacts of climate change. Working through local government networking organizations, such as ICLEI, Metropolis, the C40, and others, cities should share both their successes and failures as a means of advancing international knowledge and best practice on these issues.
- *Advocacy*: Local authorities need to continue their participation in both city networks and global discussions (e.g., the Mayor's Climate Summit at the Copenhagen Climate Summit in December 2009) as a reminder to national governments about their central global role and unique local risks and needs.
- *Data collection*: Understanding the problem is the first step. The IEA (2008) and other reports are helping to establish baseline estimates of total urban emissions, but data collection efforts should continue to facilitate comparative analyses and informed policymaking at the local, state/national, and international level. This might benefit from the adoption of clear urban energy and emissions accounting standards (see Kennedy *et al.*, 2009a).
- *Awareness*: Local authorities can begin or expand outreach to the public on these issues to heighten awareness of the unique challenges facing "their" city and the role that citizens can play in ensuring the success of local energy and climate initiatives.
- *Academic research*: To support the broad research agenda outlined above, local authorities should work closely with research institutions to provide access to data and collaborate on long-term planning and assessment efforts.

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