Sustainable Urban Infrastructure

London Edition – a view to 2025

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Foreword

It is increasingly clear that the battle for environmental sustainability will be won or lost in cities. Over half of the world's population now live in urban areas, a figure which will reach almost 60% by 2025. Already, cities account for a disproportionate share of greenhouse gas emissions. Issues of water and waste management in cities are inter-related with carbon ones, as well as having their own important impact on the environment and quality of life. As highlighted in this report's predecessor, *Megacity Challenges*, the large cities of the world recognise these challenges and place a high importance on environmental issues. However, if a choice needs to be made between the environment and economic growth, it is still the latter that often wins out.

This report describes a series of technological levers of varying effectiveness, and with different cost implications, which can all contribute to greater environmental sustainability in cities, focusing in particular on the example of London. In so doing, it aims to provide necessary clarity about these levers to policy makers, planners, businesses, consumers and concerned individuals—in short society as a whole. The encouraging message is that many of the levers to reduce energy and water consumption and improve waste management in urban agglomerations not only help protect the environment, but also pay back from an economic point of view.

City governments have recognised the challenge. Many are not only committed to change, but are working together. The C40 initiative and the Local Governments for Sustainability association (ICLEI), for example, aim to share best practice and exert joint influence. Cities do have certain natural advantages in their efforts. For example, the population density, which is the defining feature of urban life, provides efficiency opportunities in a host of environmental areas. Cities also have the flexibility to devise new ways to promote sustainable technological or behavioural change through a range of planning, policy and procurement instruments. Urban areas, particularly national or regional capitals, often house academic and industrial centres that shape technology and policy. Finally, their actions and strategies can attract the attention of, and affect the sustainability debate in, other cities and countries, as well as among their own residents. In other words, they can be a laboratory of environmental sustainability.

However, cities also face specific challenges. The very density that provides opportunities also causes problems, such as congested traffic, the trapping of heat by buildings, and a high share of the ground surface covered by man made materials, which makes sophisticated drainage essential. Moreover, as at any level of government, cities must balance environmental concerns and other development goals such as economic competitiveness, employment, and social services like public health and education. This need not always involve trade-offs between these but it does at the very least involve resource allocation issues.

This report seeks, through a detailed analytical approach to available technologies, to help decision makers, both public and private, take informed decisions when navigating the opportunities and challenges they face. To do so, it introduces a methodology to:

➔ Quantify the current and likely future carbon, water and waste challenges of a city, using London in this instance as an extended case study;
➔ Put the challenges in perspective through comparison with the performance of other cities;
➔ Analyse the costs and improvement opportunities of different technological options;
➔ Finally, better understand the financial and other implementation barriers to these technologies, as well as highlight selected strategies to overcome them.

The report's holistic perspective, rigorous quantification, common methodology applied to different areas of sustainability, and consideration of a comprehensive set of potential technological options for improvement – including their economic dimensions – make it unique. Its focus on some key determinants of urban environmental performance also provides insights for other mature cities.

It does not pretend to simplistically "solve" climate change or other environmental challenges, issues replete with uncertainties as well as ethical, social and economic ramifications. We hope, however, that it will provide a useful tool to address some of the most urgent questions of today in a better way.

Table of contents

01

What happens in cities will to a large degree decide whether humanity can lower its common environmental footprint, or whether it will face a greater risk of substantial climate change and other daunting ecological problems. The United Nations Population Division estimates that over half of the world's population lives in urban centres today, a number likely to grow to almost 60% by 2025 and to 70% by 2050. Today's cities are already responsible for about 80% of greenhouse gas emissions, according to UN-Habitat, making them in carbon terms a highly inefficient way to live. This need not be. Cities have built-in economies of scale which should allow much lower average environmental footprints for residents. Achieving these savings, however, means taking challenges like global warming, water use or waste seriously—in particular creating and modifying infrastructure elements as well as incentives to make greener lifestyles viable. This study looks at some of the options available in creating more sustainable urban infrastructures.

Sustainability is a wide-ranging concept. This research focuses specifically on technological levers that could help make an environmental impact – reduce greenhouse gas emissions, water usage and waste disposal in landfill – and that would have an effect before 2025 without any compromise in lifestyle. It does not deal with social or economic aspects of sustainability. Nor does it consider behavioural change, except to the extent that the decision to purchase a new technology is in itself a behavioural step. Broader behavioural change is, of course, important, but its effect has not been specifically calculated for this report (see Methodology for full details of the approach taken).

This research centres on London as a case study. Differences exist between all cities. London, for example, has a smaller environmental footprint than New York in certain areas, such as

Executive summary

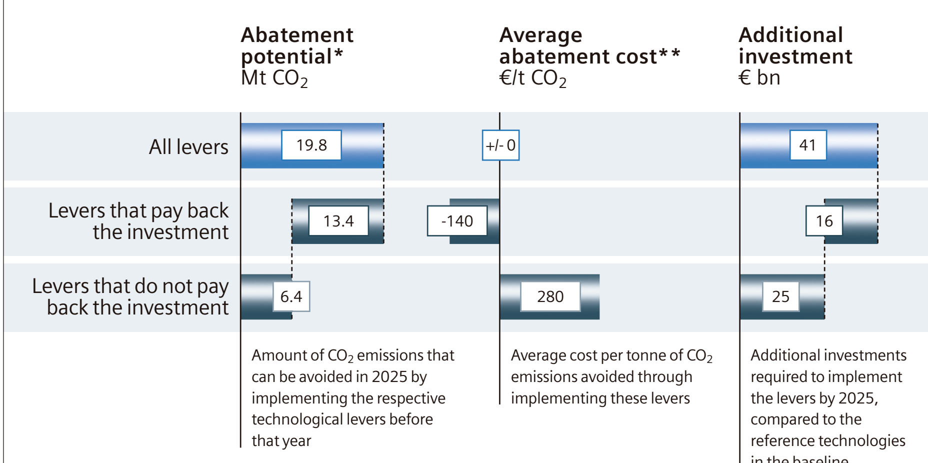
air pollution, buildings and water use, while other cities, such as Tokyo, Rome and Stockholm, show that London has room for improvement. Whatever its relative performance, many of the city's environmental challenges share much in common with those facing comparable large urban centres. London is also a particularly helpful case because of its efforts to take a lead on many of these issues.

Key findings of the study include:
London can meet international greenhouse gas targets without a massive shift in its citizens' lifestyle. All of the carbon abatement needed to meet London's proportional contribution to major international carbon reduction targets, as well as the majority of London's own 2025 goal, can come from exploiting existing technology without compromising the way its inhabitants live. Technological levers identified in this report, if fully adopted, would lead to a cut of almost 44% from 1990 levels by 2025—thereby reducing London's total carbon dioxide (CO_2) emissions from over 45 megatonnes (Mt) in 1990 to less than 26 Mt in 2025. This comfortably exceeds the necessary cuts mandated at Kyoto (12.5% by 2012), by the EU (20% by 2020) and by the British government (30% by 2025). The London Climate Change Action Plan, however, is more ambitious, aiming at a reduction of 60% by 2025. Still, these measures will take London a large way to that target, even exceeding what the London Action Plan assumes is attainable by technological means alone.

However, to fully meet the 60% reduction aspired to by London, a combination of regulatory change, lifestyle change brought about by other means, and future technological innovation will have to account for the additional cuts required over those provided by existing technological levers.

About two-thirds of these solutions will pay for themselves. Some of these technological shifts would cost more than remaining in the status quo, but the majority would save money over time for those who invest in them, largely by reducing energy costs. The money-saving technologies, which should for that reason be the easiest to convince people to adopt, make up almost 70% of the potential abatement and would provide net savings of more than €1.8bn per year by 2025 for those implementing them. Adopting all of the levers identified to eliminate 19.8 Mt annually from London's emissions by 2025 would take an incremental total investment of about €41bn over a 20-year period—or less than 1% of London's total economic output. This amounts to less than €300 per inhabitant per year, around half of the average Londoner's annual bill for gas and electricity. In the year 2025, the resulting average net cost of reducing a tonne of CO_2 through these technologies would be around zero. The savings on those technologies that do pay back their investment could theoretically subsidise the costs of those levers that don't pay back. Unfortunately, this is difficult to achieve in real life, as the savings from different levers don't necessarily accrue to the same investor.

Overview of identified potential, costs and investments for greenhouse gas reduction – London



* Annual abatement by 2025; ** Decision maker perspective

Economically profitable strategies also exist to substantially reduce water usage and waste to landfill. London currently loses 33% of its water production through leakages in the distribution system. The implication is that for every litre of water saved by consumers, almost one and a half litres less needs to be filtered and pumped into the system. This makes demand reduction highly effective. This report identifies levers that can reduce water demand by about 20% or 100 million cubic metres per year by 2025. Most of these measures would yield savings for consumers if they paid for their water use by volume rather than by fixed annual fee. This calculation does not assume any further repairs to the distribution system that might come on top of these savings, as fixing the leaks is hugely expensive and arguably requires replacement of the city's entire Victorian-era piping system. On the waste front, London currently sends 64% of its municipal waste to landfill. Not only is this one of the least environmentally sustainable options for dealing with waste, but it is increasingly expensive due to the high and rising landfill tax. All alternative approaches to waste treatment – from improved recycling to composting – would be cheaper and more environmentally friendly over the forecast period.

Simple steps can have a big impact. Across all infrastructure areas, there are some relatively simple and often highly economical levers that can substantially reduce carbon emissions.

→ **Buildings:** The single biggest possible lever for CO_2 in London is a basic one—better insulation. This on its own could take 4.5 Mt, or 10%, out of the city's annual carbon output by 2025. It could also save the investors about €150m per year in energy costs net of investment by 2025. Measures relating to more efficient heating of buildings, such as condensing boilers, the

recovery of heat and an optimisation of controls, could add another 2.7 Mt of reductions, saving almost €400m for the investors by 2025. Similarly, energy-efficient lighting could eliminate 1.4 Mt per year, and save money for the investors (around €170m annually by 2025). Replacing old appliances with more energy-efficient ones in homes and offices could cut a further 1.3 Mt of CO_2 emissions.

→ **Transport:** With over half of London's transport-related greenhouse gas emissions coming from cars, cost-efficient measures to improve automobile fuel efficiency are the cheapest and most promising technological innovations, with a potential of abating 1.2 Mt of CO_2 and savings in the order of €400m for the investors by 2025. While these measures relate to individual car owners, city government can also make a difference: hybrid buses would reduce an additional 0.2 Mt, leading to annual savings of around €50m. Both of these technological options would pay back the required investments due to fuel savings.

→ **Energy supply:** In the context of energy supply, there are fewer obvious options. However, there are several levers that can make a major impact on carbon abatement which are well understood. At the local level, gas-engine combined heat and power (CHP) systems offer the largest overall abatement potential (1.3 Mt of CO_2)—and would generate around €200m in savings per year for the investors by 2025. When combined with other CHP systems, a total of 2.1 Mt could be cut, at an overall benefit to investors. While CHP is a promising technology, its total carbon abatement potential for London is limited because the city is constrained in the number of suitable sites for installing the technology. At a national level, an increased switch in the electricity supply from coal to gas would cut 1.5 Mt of carbon from London's share of the country's total by 2025. However, this would

Overview of identified greenhouse gas abatement levers – London 2025

	Levers	Abatement potential[1] Mt CO_2	Average abatement cost[2] €/t CO_2	Additional investment € bn	Abatement/investment ratio kg CO_2/€	Decision maker
Buildings	Insulation	4.5	-30	10.4	0.4	• Individuals (70% of potential) • Businesses/city (30% of potential)
	Heating efficiency	2.7	-150	1.0	1.9	
	Lighting	1.4	-120	0.9	1.5	
	Appliances	1.3	-190	0.8	1.6	
	Other	0.7	460	7.3	0.1	
Transport	Higher car efficiency[3]	1.2	-320	2.4	0.5	Individuals[4]
	Biofuels	0.5	140	–	n/a	National level
	Hybrid passenger cars	0.3	1,700	5.3	0.1	Individuals
	Hybrid bus	0.2	-240	0.5	0.4	City
	Other	0.8	230	4.3	0.2	Various
Energy	Grid mix	3.7	40	1.1[5]	3.4	National level
	CHP	2.1	-90	4.0	0.5	Businesses
	Other	0.4	570	3.5	0.1	Individuals/businesses

1) Abatement by 2025; 2) Decision maker perspective; 3) Economical levers only; 4) Assuming car manufacturers follow individuals' demand; 5) Pro rata share of total investment at national level

come at a cost of more than €40 per tonne of CO_2 abated for the investors.

➔ **Water:** More efficient washing machines, dish washers, aerated taps, and even dual flush toilets, would not only save money, but could collectively reduce London's water usage by more than 60 million cubic metres by 2025.

➔ **Waste:** Recycling is the least expensive, most sustainable and simplest way to get waste out of landfill. For the balance that can't be recycled, there are various treatment technologies available. Anaerobic digestion, which turns biodegradable waste into biogas, currently seems to be the most efficient option for what is not recycled. That said, even simply burning everything possible is becoming cheaper than landfill, given rising taxes on the latter.

Fashionable solutions are often an expensive means of reducing carbon emissions. Some technologies, despite being perceived at the cutting edge of green, are not (yet) capable of reducing carbon emissions in a cost effective way. Home or office solar heating (around €900 per tonne of CO_2 abated) and photo-voltaic (PV) cell electricity generation systems (over €1,000), as well as hybrid cars, whether petrol-based (€1,500) or diesel (€2,000), are all still more expensive than other approaches to buildings' energy management, energy generation, or transport respectively. Of course, technological development is rapid. Between 1975 and 2003, for example, the cost per kWh of solar PV dropped by over 90%. Nevertheless, many fashionable green technologies are likely to remain expensive choices in this forecast period.

Most of the choices are in the hands of individuals. The proportion of these technological changes which are controlled by consumers – whether people or businesses – is about three-quarters. City government efforts, at whatever level, therefore need to address not only what they can do directly to reduce carbon emissions, but also how they can promote greater adoption of these technologies by consumers. Depending on the technology, this can come through changes in regulation, taxes, subsidies, access to capital and provision of trusted information, as well as marketing and campaigning to raise the awareness and encourage consumers to make choices that are both economically and environmentally sound. Cities could also help bring together different stakeholders that need to act jointly to make change happen.

Overview of identified levers in water and waste – London 2025

	Levers	Reduction potential[1] million m^3	Reduction cost[2] €/m^3	Decision maker
Water	Increasing meter penetration	30.0	0.9	Individuals
	Aerated taps	29.6	-1.0	
	Washing machines	17.2	-1.5	
	Dual flush toilets	15.2	-1.2	
	Other	10.4	2.1	

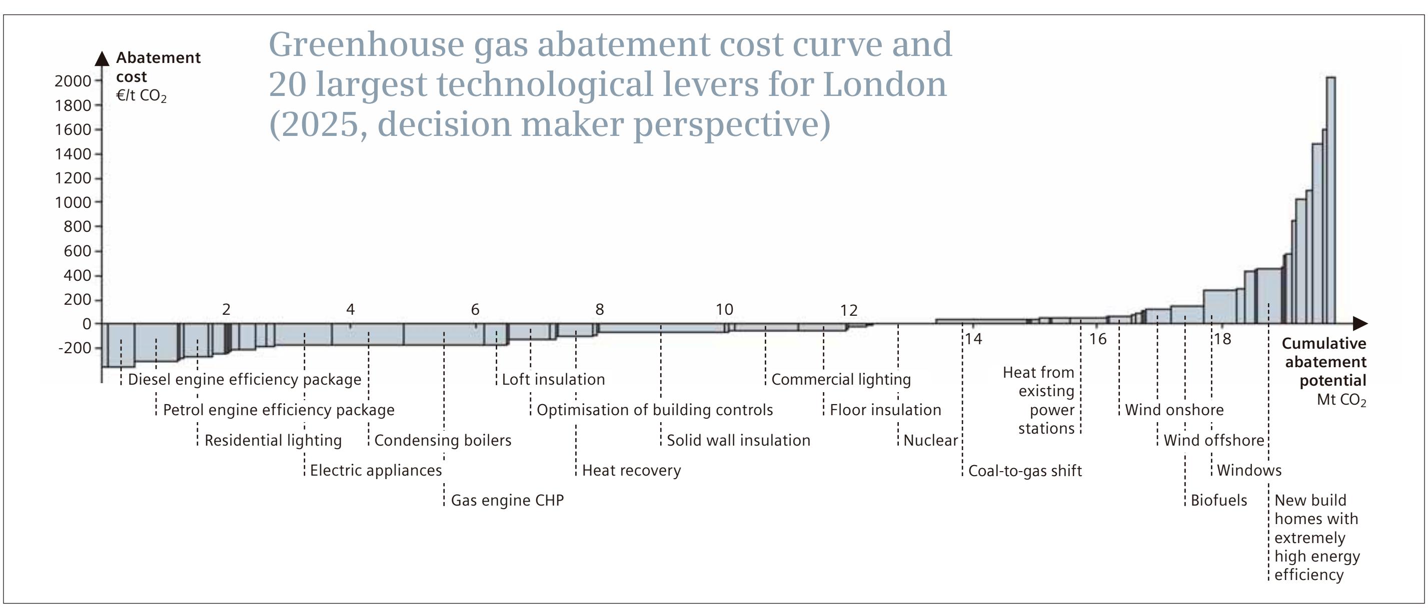
	Alternative treatments (after sorting and recycling)	Landfill avoided Percent	Cost[4] €/t	Decision maker
Waste	Anaerobic digestion	77	25	City/boroughs
	In-vessel composting	80	29	
	Anaerobic digestion/RDF[3]	77	48	
	Mass-burn incineration	66	79	

1) Reduction of demand by 2025; 2) Decision maker perspective; 3) Refuse-derived fuel; 4) Cost of treatment combined with prior sorting/recycling and landfill of residual

A frequent barrier to consumers selecting more environmentally friendly options is a disconnect between those making the investment and those reaping the benefits. This is particularly true in the area of water use, where only 22% of all London households are on water metering rather than paying a set annual fee. Nearly 8 in 10 residents therefore have no financial incentive to reduce water consumption: should they spend anything in this area the only economic impact is to reduce the water company's costs. The effects are striking: metering reduces average household water consumption by over 12% and an expected increase in meter penetration to about 55% by 2025 on its own should reduce the city's total water use by 4%. Another example of this disconnect arises from patterns of house ownership: in 2006 42% of London households did not own their homes. For these households, landlords are typically responsible for spending on improvements such as insulation, but the immediate benefit accrues to tenants, who usually are responsible for utility bills.

Sustainability issues need to be seen holistically, not in silos. Many sustainability challenges are interconnected in surprising ways, requiring complex thinking about solutions. One example for London is in the area of traffic management. More efficiency here would improve the flow of vehicles and could potentially remove 0.1 Mt of CO_2 emitted, all of which would pay a higher return than the total investment. On the other hand, making roads easier to navigate might lure users of public transport back into their cars. Of course, making public transportation more attractive or discouraging individual transportation through toll systems can prevent this from happening, as London has shown. Similarly, although gas-powered CHP is currently the most promising decentralized energy generation technology for London, its utility depends on the carbon intensity of the alternatives available. In fact, if the carbon emissions from electricity generation for a country are below 0.22 t/MWh, then gas-powered CHP would provide no carbon benefit at all, although this is unlikely to be an issue in the UK for the foreseeable future. A similar, but positive, connection is seen in waste: using advanced waste treatment such as anaerobic digestion not only reduces the need for landfill, but also reduces the methane (a greenhouse gas twenty times stronger than CO_2) emitted from dumps and creates biogas that can be used to replace other fossil fuels.

Greenhouse gas abatement cost curve and 20 largest technological levers for London (2025, decision maker perspective)



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Methodology

Sustainability's terminology can be a minefield. Rather than suggesting any new definition, this report follows the frequently cited Brundtland Commission Report, Our Common Future (1987), in treating sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

This report concentrates on the ecological side of sustainability, covering greenhouse gas emissions, water use and waste in cities. In doing so, it focuses on an urban area's direct impact, rather than its total one—it does not attempt to calculate indirect carbon emissions, such as those embedded in manufactured goods that are consumed in the city but produced elsewhere. Also, it does not cover every environmental issue – noise and electromagnetic pollution, for example – nor does it examine the broader economic or social aspects of sustainability and attendant considerations, such as poverty, inequality, health or human rights. Instead, it aims to provide a clear environmental profile of where the city stands today, and how it can use a variety of technologies to achieve key sustainability goals by 2025.

In considering these issues and ways in which to address them, the report uses three main methodological concepts:

1. It establishes quantifiable sustainability metrics. The report develops specific, quantifiable metrics that measure the environmental sustainability performance of a city and allow comparison with the results from other metropolitan areas. There are three types of these:

➔ *Per capita environmental footprint.* These indicate each inhabitant's consumption of a particular resource or the emission of specific pollutants resulting from such consumption. For example, the average per person CO_2 emissions from transport.

➔ *Demand.* These metrics quantify the volume of demand for specific goods or services. For example, passenger kilometres travelled per person.

➔ *Overall efficiency.* These measurements assess the efficiency with which such demand is met in the city. For example, CO_2 emissions per passenger kilometre travelled.

2. It sets a baseline forecast. To assess the value of adopting possible ways of improving sustainability performance over time, the report projects a likely scenario, or baseline, for each sustainability area, through to 2025. It uses a "constant technology adoption" approach, which makes the following assumptions:

➔ The level of adoption of relevant technologies will remain unchanged from today into the future. For example, the energy efficiency of newly built houses will stay the same as it is for newly built homes today, and people will keep buying appliances with the same energy efficiency as the appliances bought today. Similarly, the installation rate of new water meters will remain constant. Consequently, the baseline takes into consideration the increased adoption of today's technologies in the stock (e.g. of buildings or cars) but does not reflect any expected future efficiency improvements.

➔ No additional measures will be taken in the fields under discussion beyond those already decided upon or implemented. The calculations therefore take into account likely changes, such as the impact of power plants currently under construction that will come online during the forecast period. However, it does not do so in the case of political statements of intent without detailed decisions in place to back them up.

3. It determines technology cost curves for each area. For all the infrastructure areas outlined in this report, barring waste, the report provides an abatement cost curve. This is a graphical representation of the improvement potential and associated average improvement cost of all the possible technological options, or levers. In the cost curve, each individual column shows the impact of a particular technological lever.

The width of each column indicates the amount of annual improvement (carbon abatement or water reduction) that would come from that technology's adoption beyond the baseline by 2025. This improvement potential reflects interdependencies in order to avoid overstating the savings potential and double-counting. For example, the abatement potential from electricity supply has been calculated under the assumption that all levers for reducing electricity demand have already been implemented. Similarly, the effects of different insulation measures have been calculated sequentially with increasing costs, so that the abatement potential and efficiency of levers further to the right-hand side of the cost curves

is lower than if implemented by themselves. The column's height shows the costs or net savings per unit of improvement (for example, per tonne of CO_2 abated). This is calculated as a comparison to the reference technology in the baseline. All calculations take into account both the investment and running costs of a particular lever and its reference technology. Accordingly, when a lever is shown below the x-axis, this implies that the benefits associated with its implementation (energy savings, lower maintenance costs, etc) are greater than those of the reference technology—it provides a net saving over the forecast period. Accordingly, the area of each column represents the total cost (or saving) of implementing that particular lever in the year 2025 when compared to the base case. The levers are ordered from left to right by increasing improvement costs. This is not necessarily a recommendation with respect to the order in which they should be implemented.

It is important to note that this report takes a decision maker perspective—it calculates the costs and savings for the individual or entity that makes the investment decision, assuming different discount rates and investment horizons for different decision makers (e.g., individual homeowners, businesses, etc) and taking into account taxes, subsidies or duties. As a consequence, the figures cannot be used to calculate a "social cost" or "social benefit" for any of these levers for London or for society as a whole.

For all calculations, certain assumptions had to be made regarding prices, including the world market price for oil. This report assumes a relatively stable price of around US$60 per barrel of oil over the period from 2005 to 2025, based on a forecast by the International Energy Agency IEA (see Appendix 2 for key data). Sustained higher energy prices would not change the carbon abatement potential of the technological levers, but would reduce their abatement costs and make them economically more attractive than actually shown in this report.

Similarly, it is important to note that all investments calculated in this report indicate the additional capital expenditure required over and above the baseline assumption of constant technology adoption. In some instances (for example, insulation) there is no investment assumed in the baseline at all, so the figures refer to the total investment for implementing the lever (e.g., installing the insulation). In other instances (for example, energy-efficient appliances or the shift from coal to gas in electricity production) where investments will occur over the forecast period anyway (but on an alternative technology), the investments detailed are the difference between what is spent in the baseline and the additional capital costs required for the more efficient technology.

In total, the report identifies more than two hundred technological levers for greenhouse gas reduction across buildings, transport and energy supply. It also suggests levers for the reduction of water demand and possible strategies for dealing with waste reduction and treatment. In selecting all these, it uses the following criteria:

➔ It only considers technological solutions that – according to current knowledge – could have an effect by 2025. It therefore does not look at emerging technologies, where costs and benefits cannot (yet) be reasonably assessed. However, each section includes a brief technology outlook highlighting some technologies currently being considered or developed.

➔ It ignores behavioural change in terms of people having to change their normal habits (for example, turning down their thermostats or changing their style of driving), as such activity cannot be subjected to the same rigorous and objective analyses as technological levers. The only behavioural change required is that associated with making purchasing choices (for example, choosing to change a boiler or buy a car with better fuel consumption).

➔ It makes certain assumptions about a realistic implementation rate for the technologies, such as the proportion of cars that will be powered by hybrid engines by 2025.

The report applies this methodology using London as a case study, while also making some comparisons to other cities. London was chosen for its high aspirations and leadership in the field of sustainability. The selection of any one city inevitably means that certain environmental issues – for example, access to potable water – will not be relevant here, although they might be very important in other cities. Their absence should not obscure the fact that the same overall approach can be used to assess the environmental sustainability of cities at any stage of development.

02

An urbanising world. The growth of cities will be a dominant demographic trend of the coming decades. The current proportion of the world's population living in urban areas just passed the halfway mark. The United Nations expects the number to rise to almost 60% by 2025, and to reach 70% around 2050. The fastest growth will occur in what are already some of the largest cities. Although this will happen mostly in developing countries, it will not do so exclusively.

Urban areas are part of today's environmental problems. According to the United Nations, cities account for roughly 75% of global energy consumption and 80% of greenhouse gas emissions, giving them much higher per capita figures than rural areas. Trying to stem the migration towards cities would be futile, and probably not accomplish anything on its own. Instead, people will need to make urban areas more sustainable if humanity is to master the global environmental issues it faces.

The population density of cities creates a number of specific problems, ranging from potential water shortages to trapped heat between buildings. The challenge is, however, not insurmountable and can create opportunities. Simon Reddy, Director of the C40, a group of the world's largest cities tackling climate change, argues that cities need to look more at the way they operate. "For example, in many cities we have ignored CHP [combined heat and power]. It is crazy that two-thirds of the [energy] going into a coal-fired station goes up the chimney in the form of waste heat. In cities there is so much opportunity to reduce emissions in terms of transport, building design and retrofitting, efficient power generation, the list is endless."

City administrations have been taking note. Many have been thinking about the challenge from a global perspective, while acting locally, with diverse sustainability initiatives. A number

Introduction

of cities have banded together into various organisations aimed at sharing best practice, such as the ICLEI – Local Governments for Sustainability – and the C40.

The political dynamics of city government holds advantages and disadvantages in pursuing these efforts. On the one hand, as Mary MacDonald, Climate Change Advisor to Toronto's Mayor David Miller, explains, municipal governments can work together "in a way very different from the heavy diplomatic interactions between national governments. It allows them to be the first wave of government to understand when people are concerned about something." Cities have therefore become the laboratory, or seedbed, of sustainability practice. Even smaller local authorities have played this role. Tariq Ahmad, the Cabinet Member for Environment in London's Merton Council, says that the borough is proud of how the "Merton Rule" – mandating that any new development use renewable energy for a certain proportion (typically 10%) of its needs – has spread throughout the UK.

The difficulty for urban centres is that the levers which they have to address sustainability issues only go so far. First, they have limited resources and must deal with a host of issues. A poll of urban decision makers last year for Siemens' *Megacity Challenges* report put environmental issues high on the list of areas with investment needs. However, if a choice needs to be made between the environment and economic growth, it is still the latter that often wins out.

Second, when able to focus on sustainability, the powers that cities wield vary enormously, from almost none to full sovereignty for a handful of city-states like Singapore. One thing, however, is consistent everywhere: the city government is not the single, or even the overwhelming dominant player. Charles Secrett, Special Advisor to the Mayor of London on

> "Big cities present many obvious environmental problems, but the challenge of energy efficient housing is actually easier to tackle in compact urban areas than in loosely structured, low density suburbia."
>
> **Jonathan Porritt, Founder Director of Forum for the Future and Chairman of the UK's Sustainable Development Commission**

Climate and Sustainability issues from 2004 – 2008, explains that "people don't really appreciate how little actual power the London mayor has had." Although legislation recently increased this authority, it has not changed the basic truth that many stakeholders influence urban sustainability, including:

➔ national or supra-national political bodies – such as the EU – in areas of their jurisdiction. This ranges from the large scale, such as the national power grid's fuel mix, to lower-level details, such as regulations on packaging and vehicle fuel efficiency;

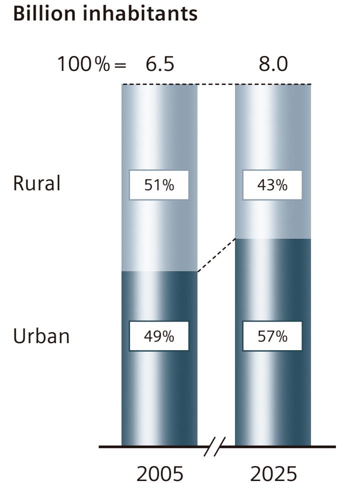
➔ private firms with their own agendas – such as the national utilities or Thames Water which provides water services to London; and

➔ residents, both as citizens and consumers, who make a host of decisions, such as whether to recycle, take public transport or insulate their houses.

Equally important, where cities do exercise their powers, they must often act in conjunction with other stakeholders. The City of Toronto, for example, owns Toronto Hydro, the local electricity distributor. The latter's renewables policy is also controlled, however, by the regulators from the Ontario provincial government. The reality is that cities only have certain ability to act and influence at a national scale. They have to act within the limits of their powers. However, the large number of actors can also have its advantages. Each brings strengths to the table. National governments, for example, can provide a broader perspective and business can bring a capacity for agility or innovative research and development (R&D). Meanwhile, individuals can bring about large-scale change.

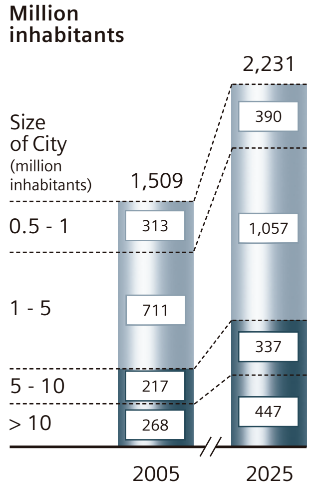
Moreover, the powers that cities do possess should not be completely discounted. They usually give some leverage in efforts for sustainability, for example, through building and transport

Global population



Source: UN

Population of large cities



Source: UN

regulation. Purchasing is another area of potential influence. The C40, in conjunction with the Clinton Climate Initiative, has helped arrange procurement initiatives for the C40 cities on goods and services for reducing greenhouse gas emissions. "If 40 of the world's largest cities want products such as LED traffic lights and street lighting, it's a strong indicator to the manufacturers of such products where the market is going," says Mr Reddy.

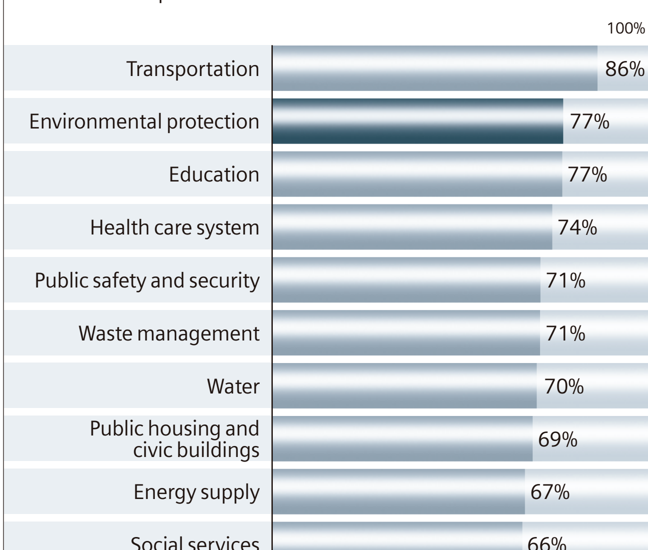
In this context, cities can lead change through example and dialogue. Ms MacDonald notes that implementation of Toronto's Climate Change, Clean Air and Sustainable Energy Action Plan, began with the city first doing what it could do by itself and then using the plan's targets to "engage the community, as well as big and small business". She adds, "In cities, if you want dramatic changes, they often come as a combination of big bold moves by the city, and thousands of choices by individuals."

Local administrations, particularly of large cities, also often have what Americans refer to as a "bully pulpit" – the ability to be heard when speaking on an issue. Given the number of stakeholders involved in efforts against climate change, this is an essential tool to exploit on a variety of levels. For residents, the city can provide trusted information in an often confusing field. This influence also gives cities a strong convening ability, bringing other stakeholders – business, NGOs or other levels of government – into discussions and programmes that lead to joint solutions that recognize the respective powers of each.

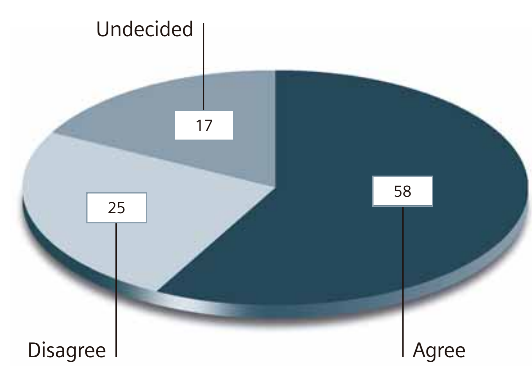
Perhaps most important, cities have the ability to see things holistically. Mr Secrett argues that the biggest challenge is the need to move from a silo-based set of policies to a truly integrated development strategy. "Then you can escape the trap of playing off progress in one area against progress in another, and put

Need for investment in environmental protection and trade-off with other goals

Investment area with highest need for investment
Percent of respondents*



City will increase infrastructure at expense of environment
Percent of respondents*



* Survey among 522 stakeholders in 25 large urban agglomerations worldwide

Source: Siemens Megacity Report (2007)

> ”The public sector has great difficulty because, traditionally, departments of transport, environment, those addressing social issues in cities and in regions, economic departments, have all operated independently. Very rarely are they able to look at joined up policy.”
>
> **Peter Head, Director and Leader of Global Planning Business, Arup**

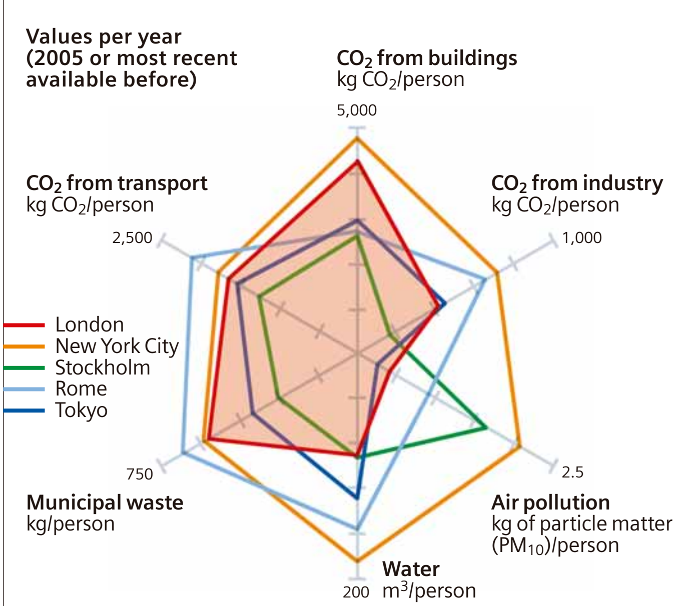
together a development plan that demonstrates how the rapid transition to a low carbon/low waste economy can be achieved, to the benefit of companies and households across the capital.” This broad view also helps those trying to make sense of policy. Matthew Farrow, Head of Environmental Policy for the Confederation of British Industry (CBI), explains that because climate change is so “wide reaching, politicians have started to throw policies at problems without thinking how they relate to each other. Companies say they face contradictory or multiple reporting requirements. This takes time and is not helpful.”

Sustainability in the context of London. To put all of this into context, this report draws extensively on the experience of London, as a primary case study. The UK’s capital is a significant developed-world city, has a range of sustainability issues common to many similar urban areas, and has aspirations not only to addressing these but in taking a leading role in international efforts against them. Numerous other cities have also been referenced throughout the report, particularly where they provide examples or best practices that are potentially relevant to London or cities like it.

It is useful to begin by comparing London with a few other large cities. For the purpose of this report, it has been compared against a selection of prominent developed-world cities, including New York, Tokyo, Rome, and Stockholm, in terms of its environmental footprint. Overall, New York is the only one with a larger environmental footprint across the board. London has relatively low levels of air pollution and water usage – the latter despite a literally leaky infrastructure. On a variety of other issues, however, the city has room for improvement (see box London’s sustainability performance).

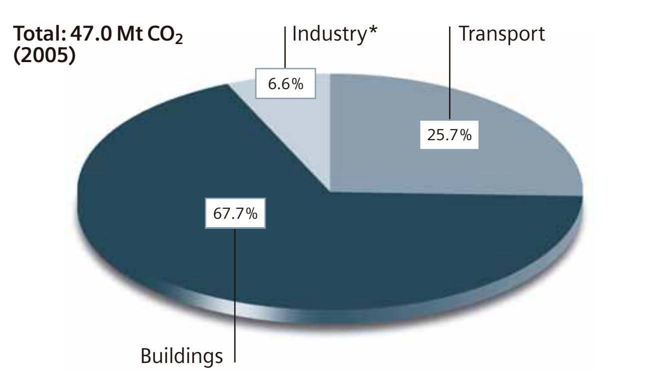
On the other hand, London is far advanced, relative to other cities, on sustainability policy.

Comparison of cities’ environmental footprint



Source: © Copyright 2008 McKinsey & Company

Composition of London’s greenhouse gas emissions



* Mainly stemming from industrial buildings, so subsumed in the ”buildings” section in the following

Source: GLA; McKinsey & Company

London's sustainability performance

An ideal environmental footprint would be as small as possible – a city where emissions per capita are absorbed by the green areas, where water usage is below the natural replenishment rate of the area and where all waste is reused or recycled. But rather than trying to assess performance in absolute terms, it can be more instructive to review relative performance. Here, a good result does not mean that there is no room for improvement, merely that you are ahead of the pack. The following points outline London's environmental sustainability performance in comparison with a few of its international peers:

➔ **Overall carbon emissions:** London produced a total of 47 Mt of CO_2 in 2005, which is accounted for by the energy use within buildings, transport and industry. This translates into 6.3 tonnes of emissions per person, compared to 7.3 in New York, 4.9 in Tokyo, 5.5 in Rome and 4.0 in Stockholm.

➔ **Carbon emissions from buildings:** Most of London's CO_2 emissions come from its buildings. Annual per capita CO_2 emissions from these are 4.3 tonnes, against 4.8 in New York but 2.9 in Tokyo, 2.7 in Rome and 2.6 in Stockholm. London's low performance arises mostly from wasted heating energy, which results in the city emitting more CO_2 per person than Stockholm, despite its milder climate.

➔ **Carbon emissions from transport:** On annual transport-related CO_2 emissions, London compares more favourably. Its 1.6 tonnes per person are slightly more than Tokyo's 1.5, but less than New York's (1.8) and Rome's (2.1). Only Stockholm has considerably lower emissions at 1.3 tonnes. London's lower emissions can be attributed to a well-developed public transportation system and road traffic that emits less than in New York.

➔ **Carbon emissions from industry:** Carbon emissions from industry in all of these cities are relatively low, ranging from just 0.2 to 0.7 tonnes per capita. This is due to the fact that these cities are not home to large, high energy-using, industrial sites. Also, most of these emissions come from industrial buildings rather than processes and are therefore included as part of the total for buildings in the following. Accordingly, this report does not specifically examine London's industry emissions in greater detail. However, for some cities, industry is the leading carbon emitter.

➔ **Air pollution:** For Londoners, the emission of particles into the air – 0.4 kg per person annually – is lower than any of the other cities but Tokyo and looks set to continue on its current decline, especially as a result of regulation. Therefore, this report will not discuss air pollution further, but for cities at a different stage of development, such as Shanghai, they represent a very serious sustainability challenge.

➔ **Water:** For each Londoner, 91 cubic metres of water are produced per year, about the same as for residents of Stockholm, but less than half the 186 produced for New Yorkers, and significantly less than the figures for Rome (156) and Tokyo (128). London's performance is surprising because its aged water infrastructure has an extremely high leakage rate which dramatically increases the production needed to satisfy actual consumption. Therefore, the latter is even lower compared to other cities than these figures suggest.

➔ **Waste:** London residents annually produce 577 kg of municipal waste per person, compared to 663 for Rome, 583 for New York, 400 for Tokyo, and 301 for Stockholm. Although waste production is mid-range, a much higher proportion of London's waste goes to landfill – 64% – making it a significant environmental challenge.

> ”You can’t see sustainability as a premium product: you need to make it something in day to day business.”
>
> **Shaun McCarthy, Chairman of Sustainable London 2012**

Its targets, notably in the London Climate Change Action Plan, surpass national ones, and the city not only collects key environmental data but also makes it available to the public. Even in terms of considering sustainability holistically, London is well on the way: its overarching sustainability planning documents integrate more specific documents, such as its Climate Change Action Plan.

Current programmes and initiatives show the overall direction. In transport, the congestion charge, introduced in 2003, has successfully influenced consumers to switch from cars, leading to a 16% decrease in traffic within the zone during its hours of operation. Similarly, the Low Emission Zone, introduced in February 2008, attempts to reduce the level of particulate matter in the inner city via a daily charge on heavy vehicles. In city planning, London has also made a conscious decision not to let itself grow beyond its current boundaries, despite the fact that its population is expected to grow by almost one million by 2025. The city thereby preserves the “green belt” of relatively undeveloped land around it and plans to reclaim currently derelict brown field sites, such as in Lower Thames and Docklands. The city also realises the importance of reducing CO_2 emissions from existing building stock, and is trialling BEEP (the Buildings Energy Efficiency Programme) to encourage retrofitting. The highest profile sustainability effort, however, is the city's plan to host the world’s “first sustainable Olympic Games” in 2012 (see box Sustainability and London’s 2012 Olympics).

Technological levers for change: the big picture. This report has specific chapters addressing buildings, transport, energy, water and waste in detail. Across all specific areas, however, a number of broader insights emerge.

Most striking is the contribution which tech-

London policy documents

Area	Core policy documents	Selected objectives
General	The London Plan (2008*)	• Summary of objectives in individual strategy plans
CO_2	London Climate Change Action Plan (2007)	• 60% reduction of emissions below 1990 baseline by 2025
	Energy Strategy (2004)	• No housing with Standard Assessment Procedures (SAP) rating below 30 by 2010 and below 40 by 2016 • 665 GWh of electricity and 280 GWh of heat generated by decentral renewable energy installations by 2010
	Transport Strategy (2006)	• Shift of car travel from 41% to 32% of journeys by 2025 • Increase of public transport from 37% to 41% of journeys by 2025
Air	Air Quality Strategy (2002)	• Annual mean of less than 40 mg/m^3 of PM_{10} by 2005
Waste	Municipal Waste Management Strategy (2003)	• 60% of municipal waste recycled by 2015 • 85% of waste treated within the city by 2020
	Business Waste Management Strategy (2008**)	• Recycling or reuse of 70% of commercial/industrial and 95% of construction/demolition waste by 2015
Water	Water Strategy (2007**)	• Reduce demand in new developments to 110 litres per day and person

* Consolidated with alterations since 2004, ** Draft for consultation

Source: Mayor of London

Sustainability and London's 2012 Olympics

Shaun McCarthy, Chairman of Sustainable London 2012 – the independent watchdog overseeing the Games' environmental and social performance – recalls that "Sustainability was the centrepiece of the bid." Even having a watchdog assure success in these goals is something of an innovation. Overall, the London organisers have made a variety of challenging commitments, including:

➔ Homes in the Olympic Village will be built to the Code for Sustainable Homes Level 4 standard – which require 44% lower carbon emissions compared to the 2006 Building Standards Target Emission Rate, as well as reduced water requirements;

➔ 20% of the energy used during the Games will come from new local renewable energy sources. This is particularly challenging as the Olympics invariably lead to a temporary spike in demand at the host site, usually met by temporary gas or oil generators;

➔ Zero waste will go to landfill during the games, and 90% of demolition waste during construction will be reused or recycled.

Although preparations for the Games are still at a very early stage, Mr McCarthy notes some "good successes" in several areas. For example, the site is currently exceeding its 90% reuse or recycling target in construction. Moreover, the various bodies involved – the London Organising Committee of the Olympic Games (LOCOG), the Olympic Delivery Agency (ODA), and the London Development Agency (LDA) – all have knowledgeable sustainability departments.

Just as with many city governments, much of the difficulty lies in seeing the big picture and ensuring various disparate efforts are properly linked. This is, however, "where things are falling down a little bit", says Mr McCarthy. "Each organisation has got good expertise but where we are missing a dimension is the ability to join up some of the thinking." His commission has therefore encouraged the treatment of carbon as a strategic issue and consideration of more than energy use at the site, including questions ranging from the impact of flights by athletes and visitors to the implications of "300 million people in China putting the kettle on at the same time" after an event finishes.

One example of this approach is waste treatment that is coupled with energy generation. Until recently, Mr McCarthy notes, there was "a bold objective to act as a catalyst for good waste management practice, but nobody was building or planning the facilities to take the waste away." Now, the LDA is investigating an anaerobic digestion system with a pipeline to bring biogas back to the site. This would deal with the waste and help meet the renewable energy commitment.

Although London is going into uncharted waters in putting together sustainable Games, there is a limit to how far it will go in trying out untested technologies. That does not mean a lack of innovation. In the procurement process, the responsible agency signalled that carbon embedded in concrete would be relevant in choosing a successful bidder. As a result, the Games obtained material that involved 50% fewer emissions in its creation than the concrete used at the recent build of Heathrow Terminal 5.

On the other hand, the lower carbon concrete is now prominently featured as a concept for other projects. This fits into the goal of the Games to provide a legacy for sustainability. Mr McCarthy hopes that this will not merely mean a sustainable site. He spends a lot of time encouraging professional bodies, such as for architecture, to get involved, so that "organisations around the edge of the Olympics can suck as much learning and knowledge as possible out and share it as widely as they can."

The perennial concern with a project like the Olympics is cost. For Mr McCarthy, creativity, rather than money, will deliver more sustainable Games. "If we manage it effectively, and join up thinking, I think we can deliver a very good sustainability performance for the Olympics without hurting the budget. You can't see sustainability as a premium product: you need to make it something in day to day business."

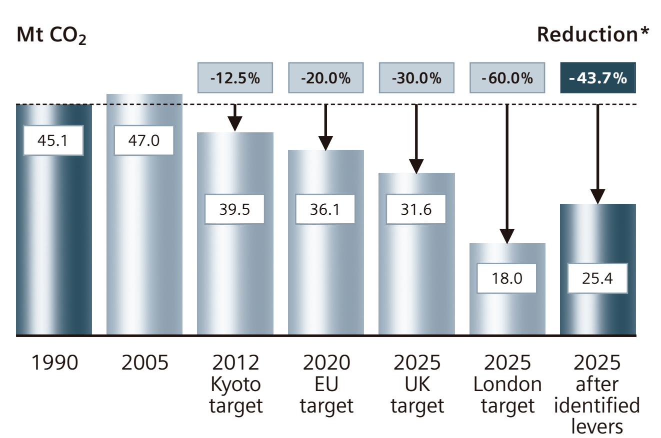
> ”[In this] muddled marketplace, you will see a much greater take up for people wanting to go to a deeper green level if you make information on how and why to do so widely available, and help them make the change through supportive audit, advice and financial assistance programmes.”
>
> **Charles Secrett, Special Adviser to the Mayor of London on Climate and Sustainability issues from 2004-2008**

nology, without any need for lifestyle change, can make to carbon reduction. Levers identified in this report, if fully adopted, would cut greenhouse emissions by almost 44% from 1990 levels. To put this in context, at Kyoto the British promised a 12.5% drop by 2012; the EU's recent target is 20% by 2020; and the UK government is looking to reduce emissions by 30% by 2025. The London Climate Change Action Plan, however, is even more ambitious. It seeks a reduction of 60% from 1990 emissions by 2025. Although technology levers alone can take the city a long way towards this goal, regulatory change, behavioural change brought about by other means, or currently unforeseeable rapid technological development will have to account for the additional 16%. The levers analysed still, however, deliver the most of the gains required. They also show policy makers, and the public, how much of a difference they can make through their decisions with respect to sustainability. Importantly, they do so at a manageable cost. In London, as elsewhere, some of these technological shifts would cost more than the status quo, but others would save money over time. It turns out that there is a large number of the latter. For all the levers identified in the report combined, the incremental investment required beyond the base case would be about €41bn until 2025. This is slightly less than 1% of the Gross Value Added of the London economy until 2025—i.e. of all economic activity in the city during the period. This amounts to less than €300 per inhabitant per year, around half of the average Londoner's annual bill for gas and electricity. By 2025, the average annual net costs from implementing these levers would theoretically be around zero, i.e. the savings from technologies that pay back their investment would theoretically compensate for those that do not. It is worth noting, however, that almost 70% of the abatement potential is made up of technology levers that would collectively provide net savings of more than €1.8bn per year by 2025 to the investors. To a degree, this is a function of what Londoners have not already done. Better insulation of buildings, for example, would not only achieve the single biggest carbon reduction (4.5 Mt), it could also save around €150m annually by 2025 for the investors due to lower energy bills. More efficient cars, appliances and lighting could all save even more money. This is true not just of London or the UK. Daryl Sng, Deputy Director (Climate Change) in Singapore's Ministry of the Environment and Water Resources, says that “almost every study of energy efficiency concludes there is a huge potential for savings.”

The obvious question is why people have not taken those steps which yield such returns on investment. The reasons for this are complex. First, it is important to realise that most of these investment choices are in the hands of individuals or companies, not cities or even national governments. The proportion of the technological changes which are ultimately controlled by consumers through their purchasing decisions – whether people or businesses in London – is about 75%.

Whatever the cumulative savings, individuals and companies as a group might not be acting

Past emissions, targets, and identified abatement potential – London



* Compared to 1990 emissions

irrationally. Behavioural theory suggests that, where total spending on a good, such as energy or water, does not form a large percentage of total outlay, people and firms are less likely to be affected by price issues. If fuel bills took up as much of a Londoner's monthly budget as mortgage payments, insulation would already be much more widespread. Moreover, even if people otherwise might choose to make the savings, they might not know about them. Mr Sng's experience of consumers in Singapore is similar to that of many others: "Nobody thinks that a light bulb that costs $5 saves you money. You don't think you spend that much [on] energy over time." The efforts of Singapore, Toronto, and London all have in common information provision, which is leading to greater uptake.

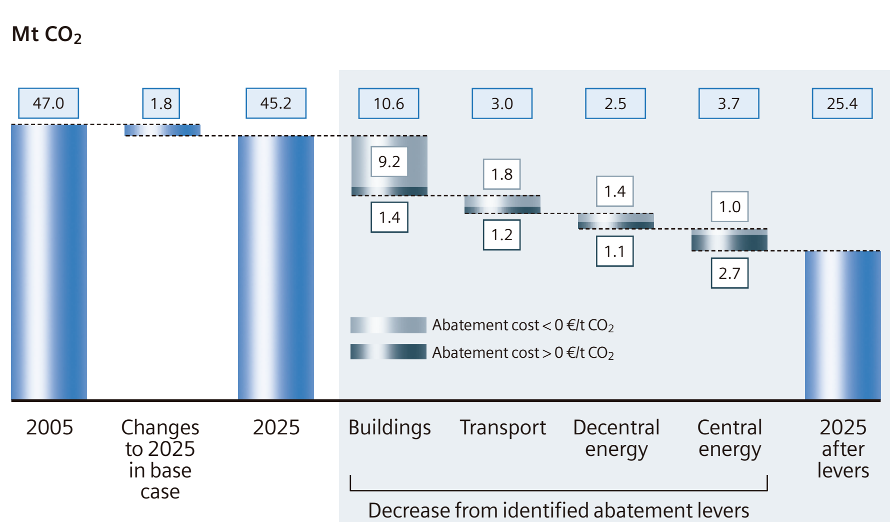
A bigger, structural problem, however, is the occasional wedges between those who pay for the environmentally positive changes and those who benefit financially. For example, landlords are typically responsible for spending on structural improvements such as insulation, but the immediate benefit accrues to tenants, who are usually responsible for utility bills. "[This landlord-tenant issue is] a problem area, not just for us but for energy efficiency of course," says Jeremy Leggett, Founder and Executive Chairman of Solarcentury. And the problem is universal. According to Ms MacDonald, for example, the proportion of renters in Toronto is 50%, even higher than London. Another issue is that many energy efficiency improvements don't obviously add to the appeal – and thus value – of a house, in the way that a renovated kitchen might, for example. Water charging, and even composting, are two other examples of this sort of disconnect discussed in detail later in this report.

Finally, even with a range of help, encouragement, and self-interest, some people ultimately choose not to make such investments. There are many possible reasons why not, ranging from concerns about the hassle involved to simple inertia. As Ms MacDonald says, "Why they don't, who knows? Why don't people do things that are good for their health?"

So where does this leave policy? The London government has direct control over the introduction of only just above 3% of the technological levers outlined in this study. It obviously needs to do what it can directly through its own actions, but it also must use the full range of tools it has to influence other stakeholders – especially ordinary Londoners. This will involve all the hard and soft powers at its disposal, from regulation and taxes to free information on bulletin boards and active campaigning as well as cooperation and interaction with other cities, in order to encourage those who can reduce the city's environmental footprint to do so.

There are some encouraging signs that this is starting to take root. "There is evidence pretty much everywhere I go that individuals are becoming more concerned and more motivated to change their approach," says Peter Head, Director and Leader of Global Planning Business at Arup, a design and consulting firm. "The greatest success seems to be the education of young people who influence the behaviour of their parents. The most effective programmes are those that are carried out through schools."

Summary of greenhouse gas abatement – London



Key findings

- **If adopted, the measures outlined in this chapter would account for more than half of London's overall emissions reduction potential, cutting emissions by 10.6 Mt, or nearly one-third, by 2025.**
- **Almost 90% of this carbon abatement potential is based on technological levers that will pay back their initial investment through energy savings.**
- **Insulation offers the single greatest CO_2 reduction potential, of 4.5 Mt per year by 2025. This would require a total investment of €10.4bn, but would pay back through reduced energy bills.**
- **Installing energy-efficient lighting in homes is the single most cost-effective measure identified for buildings, cutting 0.4 Mt of emissions while providing savings of €270 per tonne of CO_2 abated.**
- **Beyond these, businesses and homeowners have a wide array of carbon-cutting options at their disposal, ranging from more efficient appliances to optimised building automation.**

Buildings

London's sustainability profile. The total energy used within London's buildings – encompassing residential, commercial, public and industrial – accounts for 34.9 Mt of CO_2 every year—or nearly three-quarters of London's total carbon emissions. This represents 4.7 t per person, or 100 kg of CO_2 for every square metre of building space. Compared to New York, within both its homes and its offices, London has a higher carbon intensity and uses more energy per square metre.

Heating and cooling alone accounts for 16.8 Mt of CO_2 — about half of the total carbon emissions from London's buildings. This equals 48 kg of CO_2 per square metre, which is higher than the value for New York (38 kg CO_2/m^2). However, a more accurate comparison would require consideration of the differences in temperature between the two cities. On the heating front, London's performance then looks even worse. Relative to New York, the city actually has fewer cold days that require heating. This points to the poor insulation of the city's older buildings. By contrast, New York does worse with cooling. Relative to London, it has far more hot days that require cooling. Accordingly, its cooling-related emissions are nearly double those for London. This result arises from a more widespread use of residential air conditioning in New York. Overall, however, cooling accounts for a much smaller fraction of the overall energy bill than heating.

Heating and cooling aside, a large proportion of London's building-related emissions is accounted for by electrical appliances within residential buildings and lighting in commercial buildings. Overall, lighting accounts for 16% of the total emissions originating from London's buildings.

Identified reduction potential. According to the projections calculated for this report,

buildings-related CO_2 emissions are actually likely to decrease slightly by 2025. This is despite an expected annual increase in total building floor space of 0.5%, resulting from population growth and economic development, which is likely to increase annual CO_2 emissions by 3.8 Mt. Planned changes that reduce the carbon intensity of the UK's national electricity grid will indirectly reduce the greenhouse emissions attributable to London by approximately 1.5 Mt of CO_2. In addition, emissions will decline due to the ongoing adoption of more energy-efficient appliances, as people replace old or obsolete items, or as new homes are built with a higher standard of insulation due to stricter building standards.

Even though the projections indicate a slight decline in overall emissions, a range of further options exist to deliver much more substantial reductions. Compared with the baseline scenario, which shows buildings-related emissions reaching 33.2 Mt of CO_2 by 2025, the technological levers outlined in this report could deliver an annual reduction of nearly one-third (10.6 Mt) to reach 22.6 Mt by 2025.

For the majority of the building-related technological levers outlined in this report, the resulting energy savings more than cover the upfront investment required. These options range from energy-efficient lighting and appliances to various sorts of insulation, condensing boilers, optimised buildings controls and heat recovery in automated buildings. In fact, almost 90% of the carbon abatement potential identified for residential and commercial buildings is based on technological levers that will pay back over the relevant time period.

Within residential buildings, improved insulation in particular, in all its various forms, could abate 4.1 Mt of CO_2 per year by 2025. Almost every type of insulation pays back the required investment, barring double-glazed windows, which would come at an additional cost. Similarly, low-energy lighting and more efficient appliances in homes can contribute a combined CO_2 reduction of 1.4 Mt, all while more than paying back the original investment.

Commercial, public sector and industrial buildings also have self-funding technological levers available. These mainly relate to more energy-efficient lighting and appliances, as well as building automation systems that control ventilation, cooling and lighting. In total, these levers provide a carbon abatement potential of 2.6 Mt of CO_2 per year by 2025. For example, just optimising automated controls within commercial and public buildings – making sure

Buildings – Composition of CO_2 emissions in London

Mt CO_2 (2005)

	Residential	Commercial/public	Industrial	Share of total
Heating	9.3	5.5	0.8	45%
Hot water/catering	3.6	2.5	0.7	20%
Lighting	0.9	3.6	1.1	16%
Appliances/IT	3.2	0.6	0.1	11%
Cooling	0.2	0.8	0.2	3%
Other	0	1.6	0.2	5%
Total	17.2	14.6	3.1	**34.9 Mt total emissions**

Source: GLA, BERR, McKinsey & Company

that systems are set up optimally and continuously adapted to the buildings' use – could reduce carbon emissions by 0.7 Mt and produce significant savings. This encompasses a range of steps, such as ensuring that heating or cooling turn off at night and over weekends, adjusting climate control systems in accordance with a room's use or taking outside temperatures into account. In addition, insulation is also a good investment for these sectors, particularly for offices and schools, with a carbon reduction potential of 0.4 Mt.

Relative to the number of levers that do pay back, only a handful seem uneconomic on the merits of their carbon abatement alone, such as double glazing. For new residential buildings, improving the energy efficiency per square metre by another 40% on top of existing standards would deliver reasonable carbon abatement, but would also come at an additional overall cost for the abatement. Improving energy efficiency in commercial air conditioning units is also generally costly—and provides a relatively negligible impact in terms of potential for carbon abatement.

Implementation barriers. Even though implementation of most of these technological levers should be a "no-brainer" for businesses and individuals, take up is not always as easily achieved as it might seem.

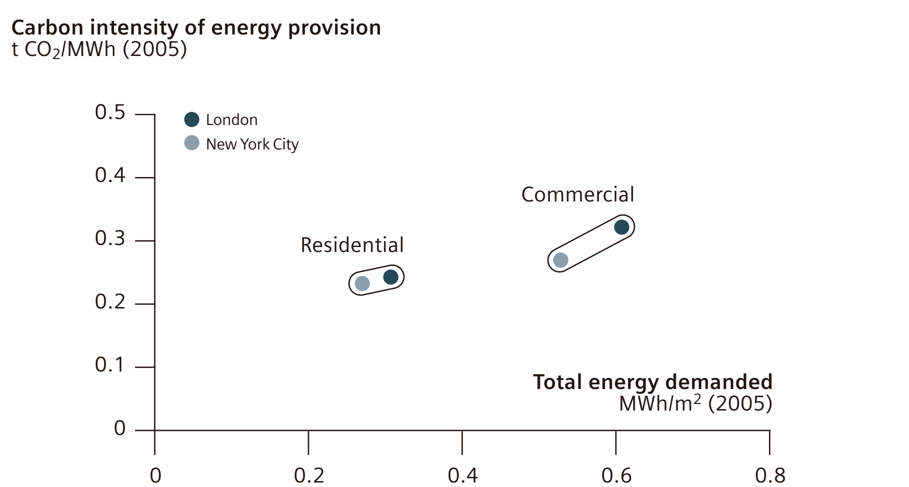
Some of the barriers are financial. High upfront costs can put off governments, businesses and consumers alike, especially if they mistakenly feel that the investment might not pay off as planned. Moreover, the direct cost of these measures does not necessarily reflect the inconvenience associated with them. Cavity wall insulation, for example, which is an extremely effective means of reducing energy use, is relatively inexpensive, and can be installed quickly. But if a home has tiled walls, for example, installing the insulation would require the removal and reinstallation of all tiles so that holes can be made into the underlying wall.

An even larger problem is about who gets the benefit from such efforts. In London, about 42% of households did not own their accommodation in 2006. For these properties, landlords are typically responsible for spending on structural improvements, such as insulation, but the immediate benefit accrues to tenants, who usually are responsible for utility bills. Of course, when it comes to selling a home, features such as better insulation and efficient heating systems can help bolster a sale. Nevertheless, the full value of the investment will not be as great for a landlord as for a homeowner.

Another problem is simple inertia. For many individuals, finding the time and motivation to undertake what can often be a time-consuming job, even when they know it is worthwhile, often proves too hard. This problem is often exacerbated by a lack of clear information about energy efficiency and possible solutions. Consumers that are confused about the best approach and possible rewards will be unwilling to take any action. For businesses especially, information comes at a cost in terms of time and money. And for many companies, even though energy prices have gone up significantly, this still only represents a small part of their overall costs.

So how can these barriers be overcome? Addressing financial barriers sometimes requires creativity rather than simple cash. If a city is to provide leadership on greenhouse gas emissions, it obviously cannot ignore its own buildings. All too often, however, local

Buildings – Comparison of emission drivers

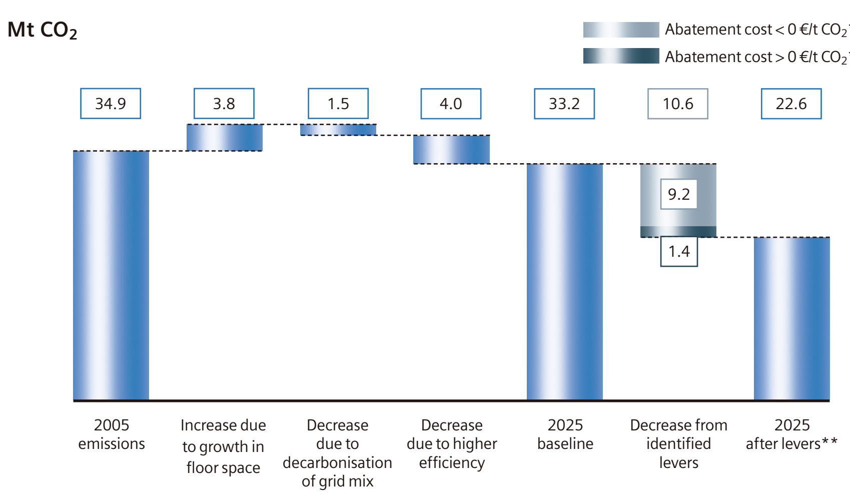


governments may lack the funds necessary for any upfront investment, as they may face restrictions on borrowing levels, regardless of the expected payback from improved energy efficiency.

One solution is to treat the potential savings as a saleable asset. For example, the City of Berlin, in 1996, instituted its "Energy Saving Partnership Berlin", which outsourced its energy management to private partners. The city received a guaranteed 25% saving on its annual energy costs, while the partners provided financing and expertise to improve the energy efficiency of city properties. Over 6% of these savings are delivered directly to the city budget, while the rest is used to finance the modernisation and optimisation of these buildings. In return, the partners receive any savings achieved over and above the amount guaranteed to the city, while the city retains ownership of any newly installed equipment. Once the twelve-year contract period is complete, all energy savings achieved will directly benefit the city.

Such arrangements are not restricted to governments. Certain businesses also face upfront investment barriers, and use such performance contracting, or third party financing. The typical arrangement is for the technology or energy provider to bear the upfront investment costs, which the business then pays back over a period

Buildings – Projection of emissions and identified abatement potential for London



* Decision maker perspective
** Before further improvements in energy supply

Source: © Copyright 2008 McKinsey & Company

Case study: Green New York

With soaring towers crowded onto a small island, Manhattan is one of the world's most spectacular city centres. Yet as political and business leaders contemplate the sustainability of the city, the buildings that make Manhattan and its surroundings so visually appealing also account for a large proportion of the city's carbon emissions. And while new construction projects present an opportunity to introduce cutting-edge green technologies, existing buildings dominate the urban landscape.

When it comes to new buildings, New York has numerous examples that illustrate what can be done to create more sustainable structures. One of the most prominent, due for completion this year, is the 51-storey Bank of America Tower at One Bryant Park, which will be home to four trading floors and 4,000 of the bank's employees. Work on making the structure a green building began even before the architectural designs were considered. Consultants were brought in to calculate exactly how the building should be positioned and constructed to allow for the maximum infusion of sunlight during the winter and to minimise use of air-conditioning in the summer months. The result is a structure that tapers towards the top. Floors with 10-foot ceilings and floor to ceiling window glass with an extremely high insulation factor minimise energy use while making the most of natural light. Meanwhile, 70% of the building's energy requirements will be generated by the building's 5.1-MW combined heat and power, or cogeneration, system.

"The system, essentially a small power plant, will utilise clean-burning natural gas as well as capturing and re-using heat from electricity production," explains Mark Nicholls, corporate workplace executive at Bank of America. "Whereas typical power generation is 27% efficient, due to energy losses in combustion and transmission, the cogeneration system will achieve 77% efficiency." Other energy-efficiency technologies deployed in the building include a thermal storage system at cellar level, which produces ice in the evening to reduce peak daytime demand loads on the city's power grid.

However, owners of existing buildings have rather different concerns: retrofitting older buildings with new air-conditioning and heating systems is somewhat more challenging. Still, small measures can make a difference, argues Sally Wilson, head of environmental strategy and brokerage services at CB Richard Ellis, which is promoting a variety of energy-efficiency programmes to owners and tenants of the 1.9bn square feet of building space it manages worldwide. "It's a case of making smart decisions about what you're putting in and planning on a long-term basis," she says. "So rather than buying the cheapest lighting, buy better lamps. It is more of an investment but has a higher performance, reducing energy usage – and there's a payback for that."

These sorts of measures were what Elliot Zuckerman focused on when he was trying to secure environmental certification for the New York Mercantile Exchange, an 11-year-old building in downtown Manhattan. And much of the work lay in examining every detail of how the building operated and changing equipment where possible. "It's everything from the motors that operate the fans to the air-conditioning units, to exhaust and heating systems and all the infrastructure that goes with it," explains Mr Zuckerman, who was director of building operations at the exchange before establishing Earth Management Systems, the consultancy of which he is now chief executive.

Performance contracting is also seen as having the potential to accelerate the adoption of green technologies and infrastructure when it comes to existing buildings, helping building owners cover the upfront investment of retrofitting their facility. Energy service contractors guarantee that a certain level of energy savings will be generated as a result of installing energy-efficient equipment. These savings are shared between the building owner and the energy service contractor, which takes on the performance risk. This sort of mechanism is part of the Energy Efficiency Building Retrofit Programme, a US$5bn finance package launched in May 2007 by the Clinton Foundation. The scheme will support performance contracts managed by energy-service companies in cities around the world.

But while cost savings can be a driver, so can legislation. New York's approach is that of the carrot and stick. The city is introducing financial incentives for sustainability measures in buildings that will gradually decline over a period of several years, after which retrofitting will become mandatory. The city already requires new buildings and substantial alterations to be designed to meet the US Green Building Council's LEED (Leadership in Energy and Environmental Design) certification. Moreover, financial incentives are available from both city and state authorities. Under New York State law, tax credits are available for owners and tenants of buildings and spaces that meet certain "green" standards. PlaNYC, a sustainability programme for New York City launched by its Mayor, Michael Bloomberg, in 2007, lays out incentives designed to encourage green building construction and retrofitting.

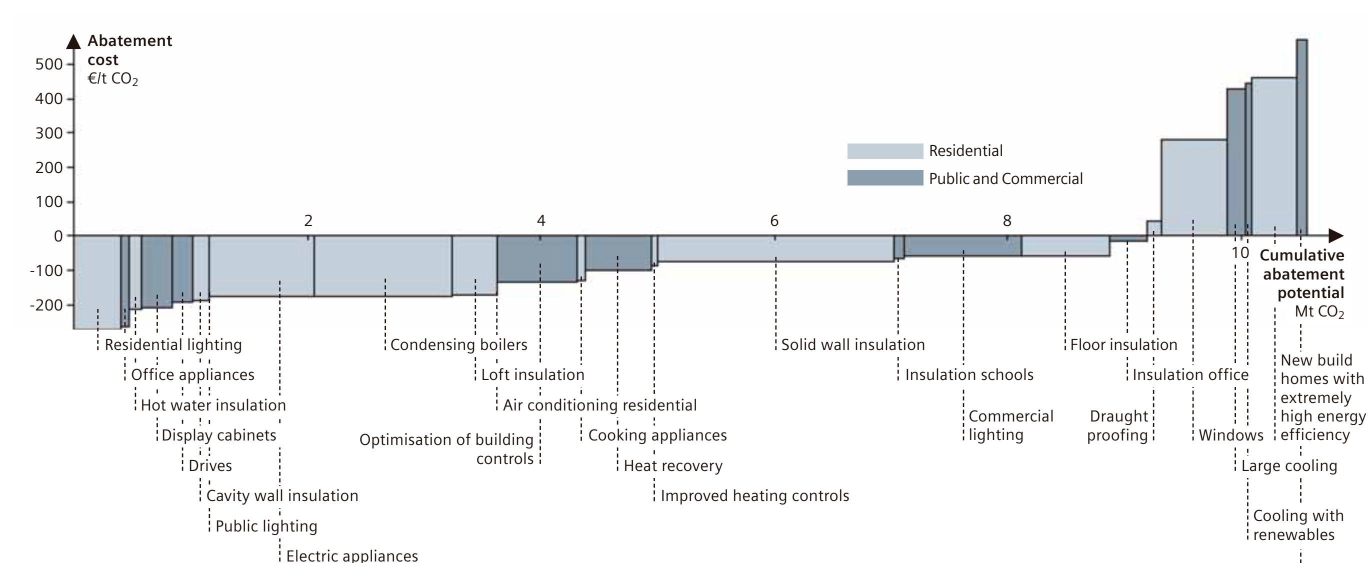
One such proposal covers green roofs, which literally involves the creation of a layer of soil and foliage on top of a building, helping reduce urban heat, while also absorbing CO_2 and reducing heating and cooling costs by providing additional insulation. "Cities are typically a degree or two warmer than rural environments and that's because as cities they retain heat from the lighting and heating of buildings," notes Paul Toyne, Head of Sustainability at Bovis Lend Lease, a project management and construction company. "One of the ways we have to adapt to challenges of global warming is to reduce the ability of cities to be heat sponges absorbing energy and radiation from the sun – and having green roof helps. A green roof is organic, and plants capture energy of the sun." In New York, the PlaNYC proposal seeks to make building owners eligible for a property tax abatement to help offset 35% of the installation costs of these roofs on new or existing buildings.

of time from the energy savings delivered, usually seven to ten years. However, this is generally only available for public and larger commercial properties, rather than individual homes.

Beyond large-scale financing, many cities already use taxes, incentives and building regulations to reduce the energy requirements of buildings. Some are starting to do so more creatively. In Toronto, for example, those seeking funds for home micro-renewable generation from the city's energy fund will first need to have taken a range of basic energy-efficiency measures on their properties. Experts also stress the importance of ensuring a balance of both incentives and penalties to motivate individuals and businesses. People are more likely to move where there are carrots as well as sticks. However, even simple regulations can do a lot. In Berkeley, California, the Residential Energy Conservation Ordinance requires all households to meet certain minimum efficiency standards whenever they are renovated, sold, or transferred. The city credits the ordinance with a reduction in energy use of 13% from already comparatively low per person requirements.

The above implementation barriers suggest two other fruitful areas of action. One is attempting to address the gap between the investor and the individuals who benefit. Among other things, the Better Building Partnership, which launched in late 2007 in London, gives public recognition and awards to members – who include all of the city's leading commercial landlords – who improve energy efficiency, especially as part of routine refurbishment. The other avenue for action is reducing the cost of information. Singapore provides building energy audits for businesses as part of

Buildings – Greenhouse gas abatement cost curve for London (2025, decision maker perspective)



a government programme. This usually provides significant savings, even for companies that think they are quite efficient. At a residential level, London's Green Homes Concierge Service goes even further. For a fee of £200, it will do an energy audit of a person's home, advise on contractors for any required work, project manage those alterations, and sort out the grant and planning permission. The overall aim is to remove all the hassle from the consumer.

The Dutch are trying to take this approach one step further with their "Meer met minder" (More with Less) programme. This recently-announced initiative involves government, energy, housing, construction and related industries and aims to reduce energy use in 2.4 million homes by 30% over the next twelve years—at no net cost to the consumer. The scheme focuses on existing buildings, with the greatest potential for efficiency gains. Specific programmes will target different groups, including homeowners, landlords, tenants and business users. The scheme provides information on the benefits of energy efficiency, individualised audits of structures and project management help to carry these out. It also provides qualification and guarantee programmes for contractors and helps consumers find appropriate financing. The government also expects to provide subsidies for the resultant measures.

The programme is still in its infancy, with several dozen pilot projects taking place in 2008. If successful, however, the scheme will eliminate demand for 100 Petajoules of energy by 2020—enough to meet the needs of all the homes in Amsterdam, Rotterdam, The Hague, Utrecht, Eindhoven, Breda, Tilburg, Almere and Groningen.

On the horizon: building automation, next generation LEDs and OLEDs

It comes as little surprise that buildings are responsible for such a high level of CO_2 emissions. "Until very recently, buildings have been notoriously inefficient," says Jason Pontin, Editor of the *MIT Technology Review*. Embedded solar generation in the construction of new homes and offices, as well as sensors to allow the development of truly smart buildings, can both help, he says. Paul Camuti, President and CEO of Siemens Corporate Research, Princeton, USA, outlines three main steps towards such facilities. One is simply the set of technologies that exist today that could be applied to solve individual problems, such as better lighting or insulation. The next step is integration: linking individual technologies to create a joined up system, connecting occupancy sensors with lighting controls, for example, or using weather forecasts for predictive building management. The final step is integrating new materials into the building structure itself, such as passive solar or micro-wind. Mr Camuti believes that once the efficiency of solar energy generation is sufficiently increased, it will become standard practice to integrate it within the roofs or facades of buildings.

Looking ahead at technologies for buildings, lighting is one of the big issues, argues Kevin Bullis, *MIT Technology Review's* Nanotechnology and Material Sciences Editor. New light sources, such as light emitting diodes (LEDs), currently last up to 50 times longer than traditional bulbs, and provide far superior light output per input of energy—and this efficiency has increased five-fold in the last six years. LEDs available today already use 80% less electricity than conventional light bulbs. LEDs typically provide a power of up to one watt, which makes them excellent for small displays, where they are valued for being small, compact and robust. Applying them to room lighting, however, requires a larger number of LEDs used together, thus raising costs, complexity and heat output. Despite these challenges, LEDs are starting to enter the general lighting market.

Beyond LEDs, organic LEDs (OLEDs) are also likely to have an impact. Unlike LEDs, OLEDs can be used to light up entire surfaces. They can be made in different shapes and sizes and applied to glass panels or flexible surfaces, thereby opening up completely new application possibilities. For example, they could be used as guidance elements in public walkways, subway stations and for emergency exits, or as illuminated wallpaper and ceilings at home. The challenge will be to develop production techniques for wide-area OLED light sources of acceptable quality, reliability and homogeneity. If such low-cost mass production methods can be achieved, both LEDs and OLEDs might change the nature of lighting in cities.

04

Key findings

- **The measures outlined in this chapter could help cut London's transport emissions by about one-quarter, from 12.1 Mt of CO_2 in 2005 to 9 Mt in 2025.**
- **Better fuel efficiency in cars is the single most important means of reducing carbon emissions from transport, and most measures pay back. By contrast, hybrid cars do hold some abatement potential, but at a high cost.**
- **Increased use of biofuels could cut emissions by 0.5 Mt—assuming only biofuels with a positive CO_2 balance are used. This would, however, come at a high cost.**
- **London could save 0.3 Mt of CO_2 by 2025 by switching to hybrid buses and optimising road traffic management. The returns on both, in the form of savings on fuel, would outweigh the costs.**
- **Public transport is far and away the most effective approach to transport from an environmental perspective. However, any major shift would require behavioural change and an expansion of capacity.**

Transport

London's sustainability profile. Annual carbon emissions from transport in London are 12.1 Mt, or just more than one-quarter (26%) of London's total. This amounts to about 1.6 tonnes of emissions for every resident in the city. This is a little less than New York, which has a per capita figure of 1.8 tonnes. About 90% of London's transport emissions originate from two primary sources: passenger travel and road freight, while airports and the planes arriving and departing from them account for the balance.

Passenger travel: Cars and taxis, buses, the Underground and overland trains, trams and motorbikes collectively account for 68% of the city's transport emissions. In 2005, collective emissions from these forms of transport accounted for 8.2 Mt of CO_2, equalling 128g of emissions per passenger kilometre. This is markedly lower than New York's figure of 185g. In fact, New York has no category of passenger transport that has a higher average efficiency than London. On the other hand, Londoners travel more, a result of the city's lower density.

Cars, especially taxis (both black cabs and minicabs), are by far London's most carbon intensive type of transportation, emitting 151g and 192g of CO_2 per passenger kilometre respectively. Yet, emissions of these vehicles in New York are far higher (238g and 322g respectively). This is mainly due to differences in fuel efficiency and a slightly higher number of passengers per vehicle in London.

London's public transport is far more carbon-efficient than its cars, producing just 52g of CO_2 per passenger kilometre for the Underground and 119g for buses. However, public transport only accounts for one-third of all travel when measured by passenger km. New York's proportion is slightly higher, but also with slightly higher carbon emissions (58g of CO_2 per passenger kilometre for the subway and 138g for buses).

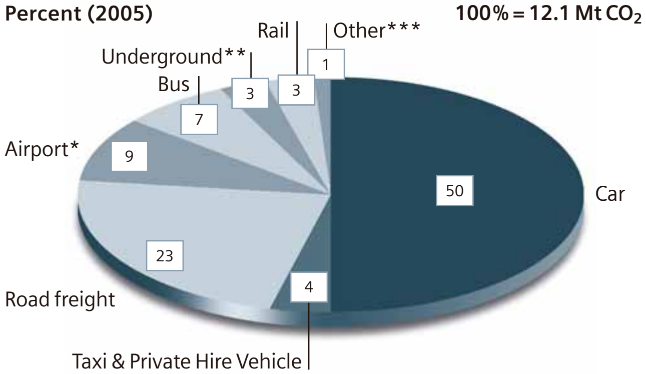
Road freight: This accounts for 23% of London's transport emissions. Most of this comes from light commercial vehicles, as heavier vehicles can't easily negotiate London's roads.

Identified reduction potential. London is forecast to have 20% more jobs by 2025, even though population growth will only be about 11%. The gap will be filled by additional commuters. These trends would normally lead to higher carbon emissions from transport over time. However, as old vehicles wear out, Londoners will naturally replace these with new ones. Given the existing fuel efficiency of new vehicles, this should counterbalance the carbon effects of increased commuting, keeping transport emissions roughly the same.

Overall, technological levers could permit the reduction of 3.0 Mt of CO_2 emissions per year by 2025. More than half (60%) of this reduction could be achieved through investments in technologies that would pay back the required total incremental investment of about €3.5bn over the investment horizon (e.g., the holding period of a vehicle). The remaining technology levers, which ultimately do not pay back, also require a higher incremental investment (of over €9bn).

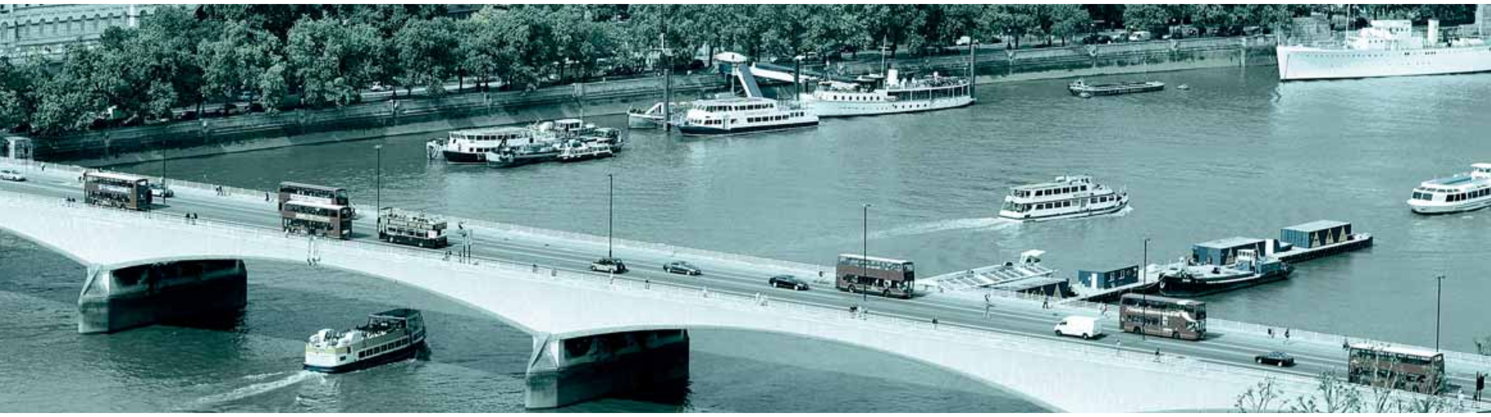
When discussion turns to cars, hybrid vehicles are regularly touted as a technological saviour. Around 350,000 were sold in the US alone last year, making up roughly 2% of that country's car market. The good news is that they do reduce carbon emissions. The bad news is that because of the high upfront investment currently required, they are an extremely expen-

Transport – Composition of CO_2 emissions in London



* Including take-off and landing (Heathrow and London City Airport only)
** Including light rail
*** Including two-wheel vehicles, tram and London river services

Source: GLA; BERR; McKinsey & Company



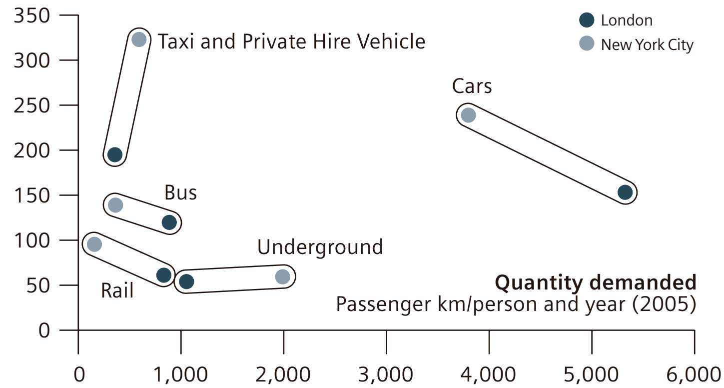
sive way of reducing carbon emissions, compared with fuel-efficiency improvements within petrol or diesel cars. For London specifically, hybrid cars have an abatement potential of 0.3 Mt. However, the cost would be high: €1,700 per tonne of CO_2 abated.

By contrast, straightforward fuel-efficiency improvements for vehicles – better engines, start-stop technology, advanced aerodynamics, lighter materials, lower rolling-resistance tyres and so on – have a much greater carbon abatement potential. Better yet, they come at a lower cost. Implementing all of the levers for cars that are economical would cut emissions by 1.2 Mt of CO_2 per year, and require an additional investment of around €2.4bn. If manufacturers installed all of the technologies outlined in this chapter, this would improve petrol-engine cars by 35% and diesel cars by 25%. Of course, this requires action on the part of the manufacturer, but consumer demand can clearly drive this—and any increase in the ticket price of the car would be outweighed by the reduced fuel bills for the average driver. The economics become even more obvious in an environment of record oil prices. (Note that this report assumes that people will drive the same-sized cars as they do today. Any shift towards smaller vehicles would imply an additional reduction potential.)

When the debate turns to transport, another popular idea is that of biofuels—although the topic has become a source of controversy lately. The adoption of biofuels in London's vehicles holds a relatively high abatement potential of 0.5 Mt per year, assuming that the 5% share of biofuels currently expected for the city is raised to 15%. But this comes at a high price and with some caveats. To begin with, the utility of biofuels is the subject of strong debate: only those derived from the sustainable farming of certain crops, such as sugar cane, have a real abatement potential. Fuel from other crops, such as corn, currently has a limited effect – if any at all – because only some parts of the plant can be used for fuel production. In addition, when biofuels are grown on land that was made available by cutting down rainforest, for example, they have a net negative impact on emissions. The calculation of this lever assumes that London's vehicle fuel will come from plants with a beneficial carbon balance. However, this comes at a high price: around €140 per tonne abated.

Passenger transport – Comparison of emission drivers

Carbon intensity of mode of transport
g CO_2/passenger km (2005)

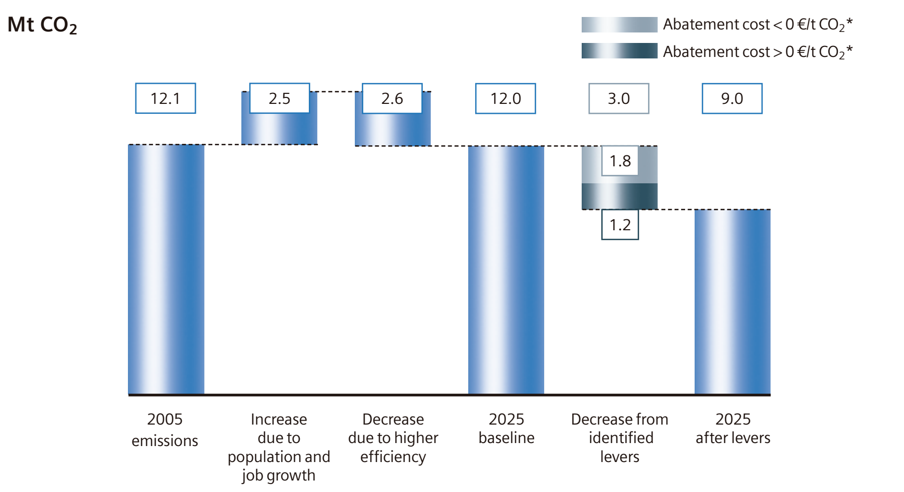


From private to public transport. Public transport, already much less carbon intensive than private cars, can also reap gains from more energy-efficiency technology. It is also an area where cities are able to directly influence the decisions being made.

Take hybrid buses, which use about 30% less fuel than a standard diesel bus. Unlike hybrid cars, these are a money-saver. The technology holds an abatement potential of 0.2 Mt for London. Other cities have already led the way on this. After helping to develop the technology, the New York's MTA now has a fleet of hundreds of hybrid buses, with 40% better fuel efficiency than the MTA's conventional buses, which saves about 19,000 litres of diesel for each bus every year. The nature of urban bus traffic, with very frequent stops and starts as well as high mileages driven in the course of a year, helps explain why this technology pays back, while often hybrid passenger cars do not. This technology is also available now, unlike the hydrogen buses that are seeing limited trials in some cities, including London.

Rail is also open to technological improvements. New trains recently purchased for the Oslo subway system use 30% less energy than their predecessors, largely because their electric drive systems switch to generator mode while braking, much like hybrid cars. The carriage bodies are made entirely from aluminium, making them much lighter and therefore less demanding of energy. To top it all off, 95% of materials used in the carriages can be recycled when they are replaced. However, accelerating London's investment cycle and substituting the city's underground trains with more efficient ones earlier than planned would only yield a small abatement potential at comparatively high costs.

Transport – Projection of emissions and identified abatement potential for London



* Decision maker perspective

Source: © Copyright 2008 McKinsey & Company

Beyond vehicle improvements, optimising London's Underground and rail traffic management could increase network capacity by up to 5% and promote more energy-efficient acceleration and braking of trains. The consequent energy savings would cut costs and reduce carbon emissions by a further 0.1 Mt of CO_2. Similarly, London could look at innovative road traffic management systems that can further reduce congestion. Based on the existing infrastructure, this could reduce annual carbon emissions by around 0.1 Mt. However, as traffic flows improve, more people might start switching back to cars, thus making other traffic reduction measures necessary (see case study).

Beyond the technological levers, an obvious means of cutting emissions is for Londoners to shift away from driving cars. Even if all of the technological levers for cars outlined in this chapter were implemented, a 5% shift from private cars would still remove around 0.2 Mt of carbon from annual emissions, but would also require a 10% growth in public transport. However, since such a shift also involves behavioural change, this study has excluded this potential from its overall abatement potential for transport.

London, unusually for large cities, has already been experiencing such a modal shift from automobiles to bicycles, walking, or public transport – 4% over 10 years – principally due to investments in public transit such as rail and buses. For such a positive change to continue, however, greater than planned investment will be necessary. London's rail and Underground networks are already operating at full capacity in peak hours. This study calculates that current expansion projects will only accommodate the rising demand from employment and population growth.

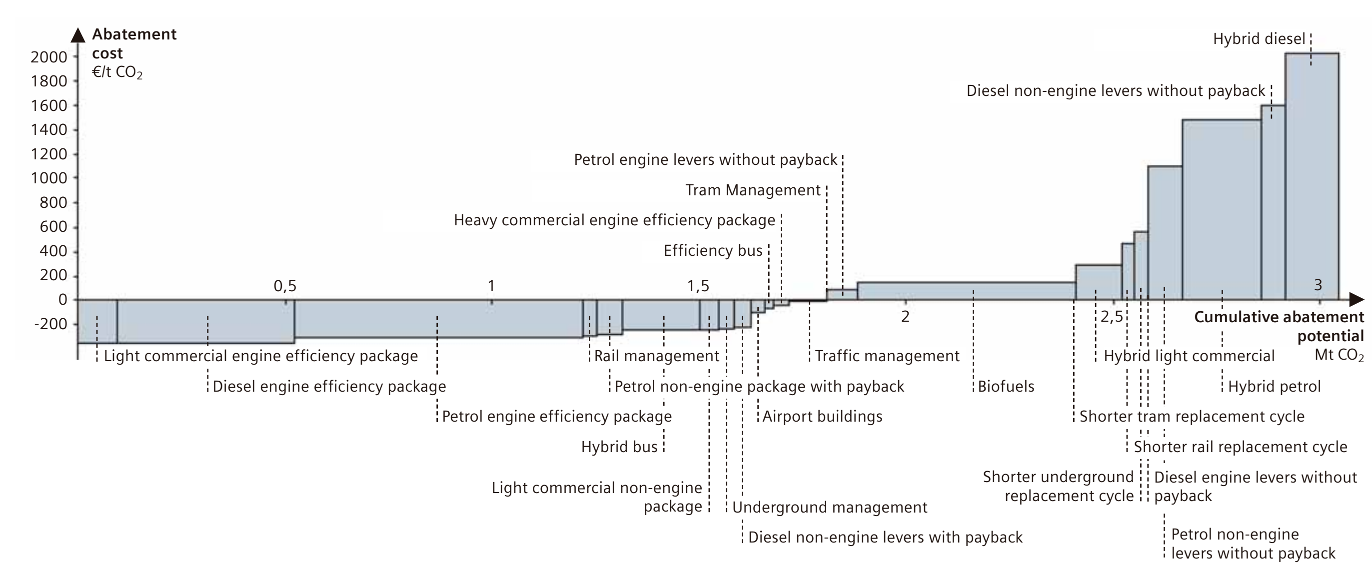
Therefore, more capacity will be required to permit an ongoing shift away from cars to public transport. Relative to London, New York has performed well here, in part by providing a denser network of subway stops and more trains. Other cities are trying alternative approaches. Paris has implemented a high-profile scheme to provide cheap bicycles (free for the first 30 minutes of use) across the city, known as Velibs, which has proven popular with local citizens.

Toronto is also increasing the availability of bicycle paths, while expanding its public transit coverage into the less well served areas. Singapore is planning to almost double its rail density, which is bolstered by the city's congestion pricing scheme for vehicles. The overarching strategy is to make greener travel – whether foot, cycle or public transport – more convenient. This usually includes a range of approaches, rather than a single silver bullet. Some are straightforward, such as providing dedicated parking for so-called Park and Ride schemes. Others address more complex issues of personal safety.

Although each individual step may be small, bringing them together can have impressive effects. Vancouver's Downtown Travel Plan, for example, consisted of 83 specific initiatives, many as minor as wider pedestrian crossing zones at specific busy intersections or the creation of cycle lanes on ten major roads. As a whole, the Plan and its various predecessors have contributed to an important modal shift. Between 1992 and 2004, the number of people coming to the city in cars – whether as drivers or passengers – has dropped from 62% to 39%, while those on foot or bicycle has doubled from 15% to 30%.

There can be other benefits too from efforts to expand the transport network. Improved transport links to a neighbourhood can improve its popularity and help to regenerate the area, which in turn can help boost property prices.

Transport – Greenhouse gas abatement cost curve for London (2025, decision maker perspective)



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Implementation barriers. The most striking barrier in the transport sector is just how little, from a technology perspective, a city can directly influence. London is already considering some of these levers: it hopes, for example, to only order diesel-electric hybrid buses from 2012 onwards. It can also consider others, such as further optimisation of its rail and road traffic systems. However, the levers involving cars and trucks – which account for a much greater proportion of emissions – are under the control of consumers and manufacturers.

Still, although the direct influence is limited, it does exist. For example, London's one-time plans for differentiating the congestion charge based on carbon emissions might have discouraged the use of energy-inefficient vehicles, and potentially even their purchase in the first place (this measure is not considered in this study, as it is not specifically a technology lever).

Measures taken at other regulatory levels, however, are pushing in the desired direction and therefore support efforts at a city level:

➔ The British government's introduction of

Case study: London's congestion charge

London was not the first city with a congestion charge. Singapore's scheme, for example, goes back to the 1970s. The concern there, as in London, was clogged streets. However, Daryl Sng, Deputy Director (Climate Change) in the Ministry of the Environment and Water Resources, notes that "with transport there is a nice confluence between trying to reduce congestion and trying to reduce emissions."

Indeed, when proposed, London's congestion charge sought to tackle congestion itself rather than emissions. From February 2003, with a few exceptions, any vehicle coming within a specified part of central London between 7am and 6pm on weekdays had to pay a fee of £5. Since then, the area of the scheme has expanded and the charge gone up to £8, but the idea remains the same. Although uncertainty about the likely results accompanied its introduction, the scheme has been widely hailed as a success. On the environmental side, the numbers are positive. The mayor's office estimates that the charge is responsible for 60,000 fewer car trips into the city per day, out of a total or approximately 375,000. About 50%-60% of this decline is picked up by public transport and 15%-25% by cycling or walking. Nitrous oxide emissions are down by 13%, while CO_2 output is down by 16%. Most of this was achieved very quickly after the introduction of the scheme. Also, all profits are used to improve public transport.

That said, the scheme has not permanently eliminated congestion. Currently, electric cars, those running on alternative fuels and hybrid engine cars are given a 100% discount from the charge. Indeed, the mere announcement of a proposed larger charge (of £25) for more polluting vehicles led to an increase in the purchase of hybrid and other vehicles exempt from the charge—and a net increase in the number of cars on the road. This, in conjunction with Thames Water's extensive blockage of streets while working to reduce water leakage, has ironically served to increase congestion.

Congestion levy aside, almost all of the Greater London area has become a low emission zone (LEZ). From February 2008, trucks over 12 tonnes that fail to meet certain emission standards have had to pay £200 to enter the LEZ. This levy is slowly being expanded to other vehicles.

vehicle licence tax rates that are differentiated on the basis of carbon emissions in 2004 has already increased the number of lower-emission, diesel cars on the roads.

→ Legislation currently before the European Parliament will mandate the automotive industry to achieve average emissions from cars of 130g of CO_2 per km by 2012. Such a level would reduce the average output from traffic in London.

→ The UK has mandated that 5% of transport fuel be biofuel by 2010, and the EU has mandated that a further reduction of 10g of CO_2/km beyond the 130g noted above also take place through the use of biofuels by 2012.

For their part, car manufacturers are not unwilling to change. Such regulation creates a level playing field and thereby reduces the risk to sales posed by including costly carbon-reducing technology in vehicles. This will help the market move faster. The widespread introduction of airbags, for example, came in the wake of American regulation in the mid-1980s rather than in response to consumer demand.

On the horizon: hybrid development and advanced biofuels

Carmakers know that carbon is a pressing issue. Hybrids have been around for some years. Conversion kits to let motorists charge their batteries from home electrical supplies are already available, and next year the first such plug-in hybrids will appear on the market. Of course, the carbon impact depends on the grid mix of the electricity used. However, *MIT Technology Review's* Jason Pontin notes that these sorts of changes are just the beginning: "Under pressure from CO_2 regulations, auto makers are casting about for a lot of new technologies. You are going to start seeing that every vehicle is going to be part hybrid."

The implications go far beyond a switch towards greater use of electricity, which is potentially just as carbon intensive. Current technology would allow batteries to receive a charge allowing for about 55km of travel, the average distance an American drives in a day. In effect, people could sufficiently charge their vehicles overnight for most of their travel needs at a price far less than that of conventional petrol. Moreover, the increased electricity demand, because it would mostly take place during off peak hours, could improve the efficiency of power plants and the electricity network. Professor Andrew Frank, Director of the Hybrid Electric Vehicle Research Centre at the University of California at Davis, calculates that even if every car in the US were a hybrid, three quarters could be charging simultaneously without requiring the construction of another power plant. Finally, the batteries in the vehicles could act as a collective store of the unpredictable amount of energy arising from micro solar and wind energy projects and feed back the electricity stored into the grid in times of lower supply.

Siemens' Mr Camuti adds that hybrids may merely be a transitional technology. "The alternative to all of this is hydrogen. Hydrogen makes a lot of sense, although there is a lot of technology development that needs to go on. If you project out ten years, it's not clear if all-electric or hydrogen-based vehicles will be prevalent."

An even bigger difference than hybrids could also come from biofuels. Although some of the current ethanol-based offerings are on balance harmful for the environment, *MIT Technology Review*'s Kevin Bullis points out that "having a hydrocarbon fuel made from renewable resources could have a faster impact than hybrids because it would not require a huge shift in infrastructure". Accordingly, Silicon Valley has joined in the chase for better energy. Some particularly interesting developments are coming out of biopharmaceutical companies. LS9, for example, has re-engineered bacteria to produce a completely sulphur-free crude hydrocarbon that could be processed in ordinary oil refineries. This process would be based on a renewable feedstock, although the company has not yet revealed exactly what crops these would be. Amyris Biotechnologies is attempting to go one step further. It aims to modifying its bacteria to churn out a ready-to-use biofuel. The problem, notes Mr Pontin, is cost. Such fuels must compete against petrol not only at current world prices, but also if those drop substantially too. "Biofuels need to cost significantly less than any likely future cost of petrol – say, $16 to $20 a barrel."

05

Key findings

- **If adopted, the technology levers outlined in this chapter, which aim to reduce the carbon intensity of London’s electricity supply, could cut 6.2 Mt of CO_2 from London’s emissions—reducing the city’s overall emissions by 13% by 2025.**

- **At a local level, combined heat and power (CHP) plants that capture and use the otherwise wasted heat produced during power generation could cut 2.1 Mt of CO_2 emissions in London annually by 2025.**

- **Changes in the national grid mix, in particular from a shift from coal to gas, would provide a 3.7 Mt reduction from the CO_2 emissions attributable to London. However, the city has limited influence here.**

- **Technologies for renewable power generation at both a local and national level provide a total abatement potential of 1.2 Mt for London, but currently come at a higher abatement cost in comparison to the alternatives. Nevertheless, various regulatory efforts aimed at the proliferation of such technologies will ensure that they play an increasing role in London's energy supply.**

Energy supply

London's sustainability profile. Londoners are not particularly wasteful of electricity compared to other cities. The average resident uses 5.3 MWh annually, which is noticeably lower than usage in New York, Tokyo or Paris, all of which consume more than 6 MWh per person.

However, the carbon emissions related to London's electricity use are directly driven by the carbon intensity of the UK's grid mix. Almost three-quarters of electricity comes from fossil fuels – 37% natural gas, 34% coal, 1% oil – with nuclear power providing most of the rest (20%). Renewables account for around 5% of the total. Overall, the UK's use of fossil fuels is higher than in other countries. As a result, among the cities reviewed for this study, London's electricity has the highest carbon intensity—0.47 tonnes of CO_2 per MWh. This surpasses that of New York and Tokyo by nearly 10% and is far higher than that of Paris, as nuclear power plays a much greater role in France.

Identified reduction potential. It is often stressed that the megawatt avoided – the so-called "negawatt" – is by far the cleanest and cheapest way to secure low-carbon electricity supply, given that many options for making power generation less carbon-intensive are expensive. Demand reduction must therefore be a key component of any sustainable electricity supply strategy.

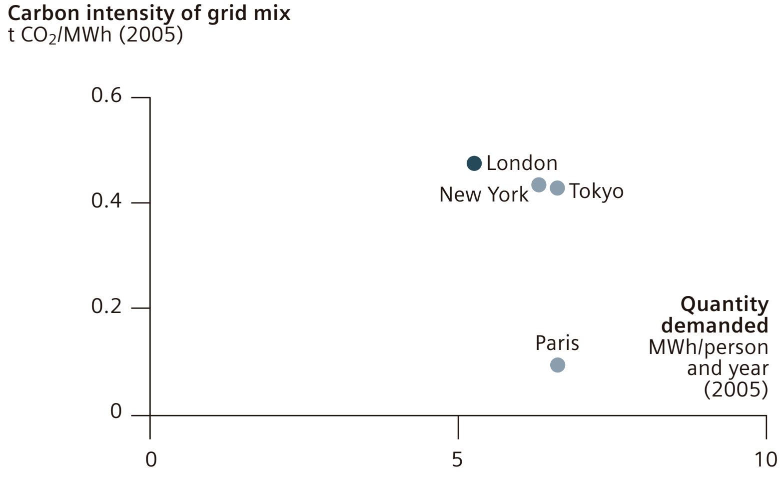
The technological levers discussed in the chapters on buildings and transport, if fully implemented, would roughly meet the UK's 30% reduction target. In addition, this chapter deals with the technology options that can make London's electricity supply less carbon-intensive, initially covering those levers that the city can influence directly at a local level, before considering what could be achieved at a national level.

Put together, the technology levers outlined

in this chapter offer a total abatement potential of 6.2 Mt of CO_2—2.5 Mt from decentralised power generation and 3.7 Mt from the national mix of power generation technologies. To ensure that these gains are not over-estimated – for example, by double counting potential gains on both the supply and demand side – this study assumes that all the technologies in the previous sections (buildings and transport) are being adopted, thus reducing London's overall demand for power by about 30%. If, however, less is achieved on the demand side, the carbon abatement potential from the levers described in this chapter would actually be larger.

Decentralised power generation for London. At a city-level, London has a range of options available for introducing less carbon-intensive technologies for power generation, ranging from micro wind turbines and photovoltaic cells to combined heat and power (CHP) plants. These would not be mere sideshows to the national grid: the London Climate Change Action Plan wants to shift 25% of London's electricity supply off the grid and expects 30% of the necessary abatement it has targeted by 2025 to come from city-level power generation —so-called decentralised power generation. The most high profile of these technologies are, of course, wind and solar. A number of projects for decentralised power generation from renewables have already been developed within London—two wind turbines in Dagenham, for example, which provide all the power for Ford's clean engine facility in the area. In addition to the already existing and planned projects, the incremental carbon abatement potential for decentralised power generation from wind and solar in London is split evenly across both technologies. However, the overall carbon abatement potential of these technologies is relatively limited: a total of 0.4 Mt. Naturally, the potential for these technologies varies

Electricity – Comparison of emission drivers



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largely according to climate: southern Spain, for example, is twice as productive for solar as southern England. As a consequence, the cost is high in London when compared to alternative means of power generation, especially for solar. Generating an additional 380 GWh of power per year from photovoltaic cells within London would require an investment of almost €2.2bn—leading to costs of over €1,000 per tonne of CO_2 abated. By contrast, the installation of micro wind turbines would require an investment of about €600m above the baseline, resulting in abatement cost of €50 per tonne of CO_2.

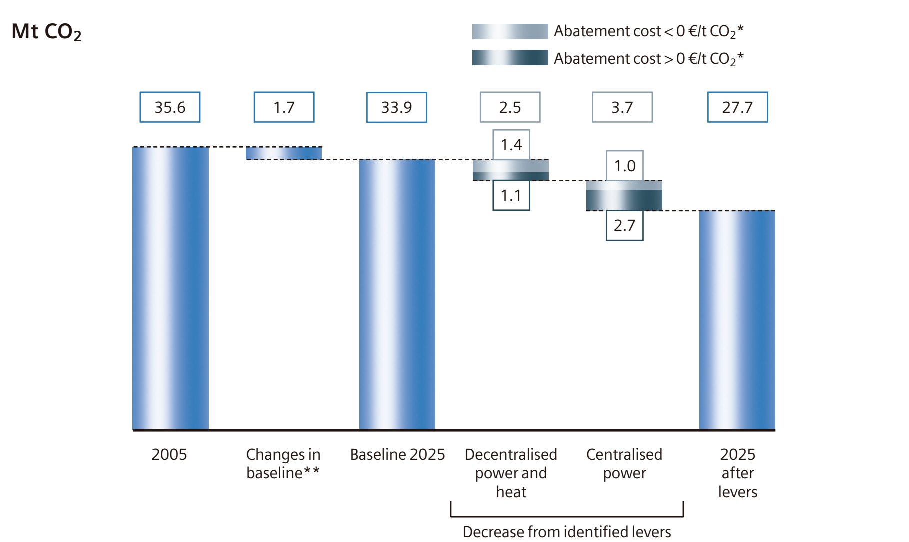
Despite these issues, the popularity of renewable energies remains high. In part, this is due to the spread of the so-called Merton Rule, which requires a percentage of the energy in new developments in much of London to come from renewable sources. In addition, the fact that solar panels and wind turbines play a visible, symbolic role in efforts against climate change out of proportion to their current contribution seems to be another reason for their popularity.

By contrast, the introduction of CHP in its various forms – gas-engine, biomass, waste to energy and so on – offers a far greater abatement potential: 2.1 Mt of CO_2 annually by 2025. Delivering this reduction would require an incremental investment of about €4bn beyond related spending already planned for London. This includes all necessary infrastructure, such as pipes to conduct heat. Of these various CHP options, gas-engine holds the greatest potential for London's existing building stock. This is primarily because the gas-based system works best in areas with mixed residential and commercial use, which are most prevalent in London. For new large-scale developments where an effective heat grid can be put in place, combined-cycle gas turbine CHP schemes prove more cost-effective than the gas-engine equivalent. Alternatives such as building-based CHP work best for a single large user, such as a hospital or university.

However, the economics of CHP as a source of heat and power depend on the particular fuel being used and the size of the operation. Gas-powered and larger biomass facilities would both pay back their investment while delivering two-thirds of CHP's total abatement potential (1.4 Mt of CO_2). By contrast, other CHP possibilities are pricier, at an average of about €40 per tonne abated.

The benefits of CHP, however, depend heavily on it being deployed in the right context. First, the technology requires a particular usage pattern. As the name itself suggests, CHP works best in situations where there is a simultaneous demand for heat and power—in effect the waste heat from power generation, whatever the fuel, ceases to be waste because the heat is actually a desired outcome. On a neighbourhood scale, in order to provide a consistent, high demand for heat, CHP's consumers should be a mix of residential, commercial and industrial users. If correctly combined, the varying demands of these groups would ideally provide

Energy supply – Projection of emissions and identified abatement potential for London



* Decision maker perspective; ** Constant technology adaption

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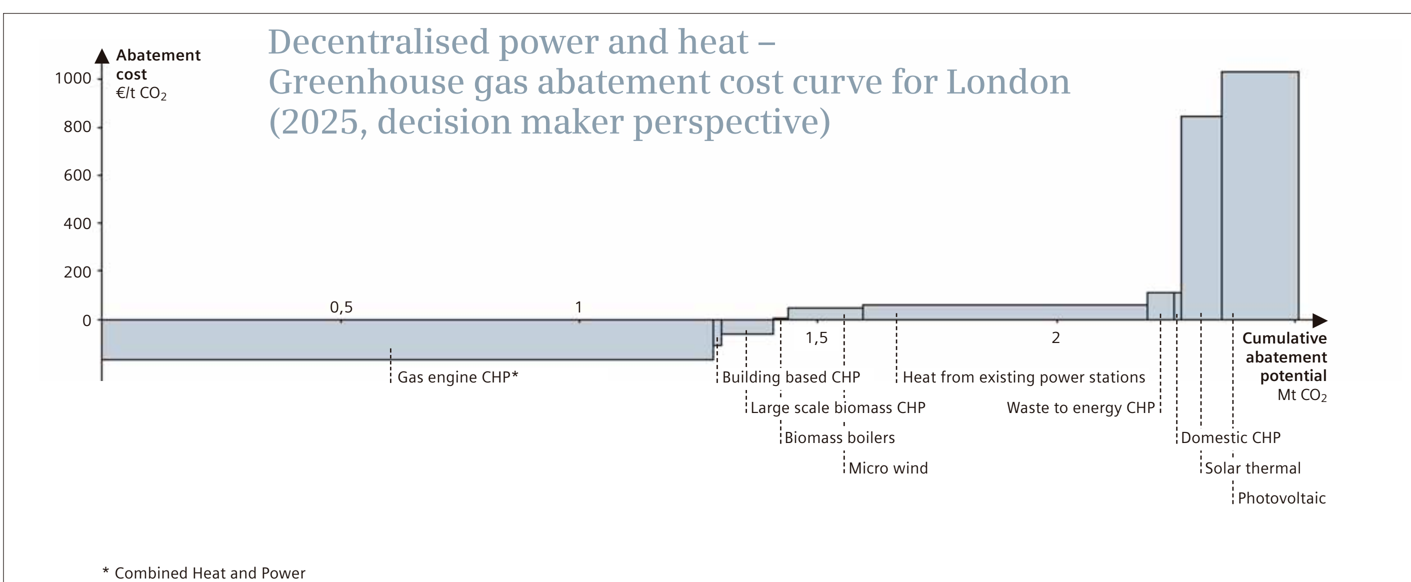
a relatively steady demand throughout a good share of the day. The lack of energy-intensive industry in London, however, while reducing overall emissions, also reduces the scope for CHP by taking one possible element out of the user mix. Nevertheless, opportunities exist.

Second, to be more economically attractive, the CHP plant could sell excess electricity to the national grid if a good price was offered. Take Co-Op City, for example, a large residential complex in New York's borough of the Bronx, which is investing in a combined cycle gas turbine CHP plant. This will not only provide electricity, heat, hot water and air conditioning for the complex's 60,000 residents, but will also have some 20 MW of surplus capacity to sell back to the city, which will help the facility pay for itself within three to five years. However, within Britain, the feed-in tariffs for power generation from CHPs are currently relatively low when compared with other countries, such as Germany, that explicitly incentivise CHP investments through attractive tariff rates.

Third, the carbon benefit of CHP depends on the grid mix of the electricity that it replaces. For example, gas-engine CHP, the most effective and financially attractive form for London's existing buildings, only reduces CO_2 emissions in situations where the grid provides electricity at a carbon intensity greater than 0.22 tonnes of carbon per MWh. This makes it suitable for London, as the carbon intensity of the grid is expected to remain markedly higher than that for the foreseeable future. However, it would not provide carbon benefits in cities with less carbon-intensive electricity, such as Paris, where a comparable gas-fired CHP installation would actually increase overall carbon emissions.

The UK's national grid mix. As outlined above, the national grid presents an even greater opportunity for carbon abatement. The UK's grid mix is already set to move away from coal to gas, while introducing a higher proportion of renewable energies. This will improve the carbon intensity of the UK's grid to 0.43 tonnes of CO_2/MWh by 2025 from 0.47 tonnes, cutting the carbon emissions attributable to London by an expected 1.7 Mt of CO_2 by 2025. If all the technology levers outlined in the cost curve were implemented, they would collectively improve the UK national grid's carbon intensity to 0.33 tonnes of CO_2 per MWh—a total reduction in emissions of 3.7 Mt for London.



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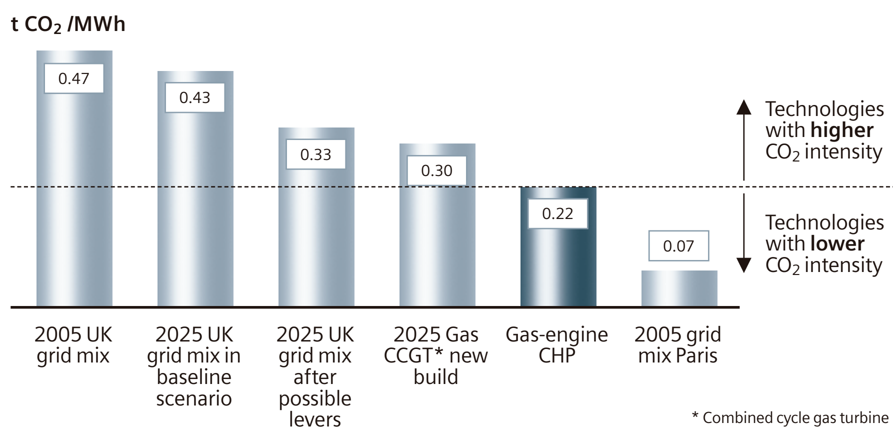
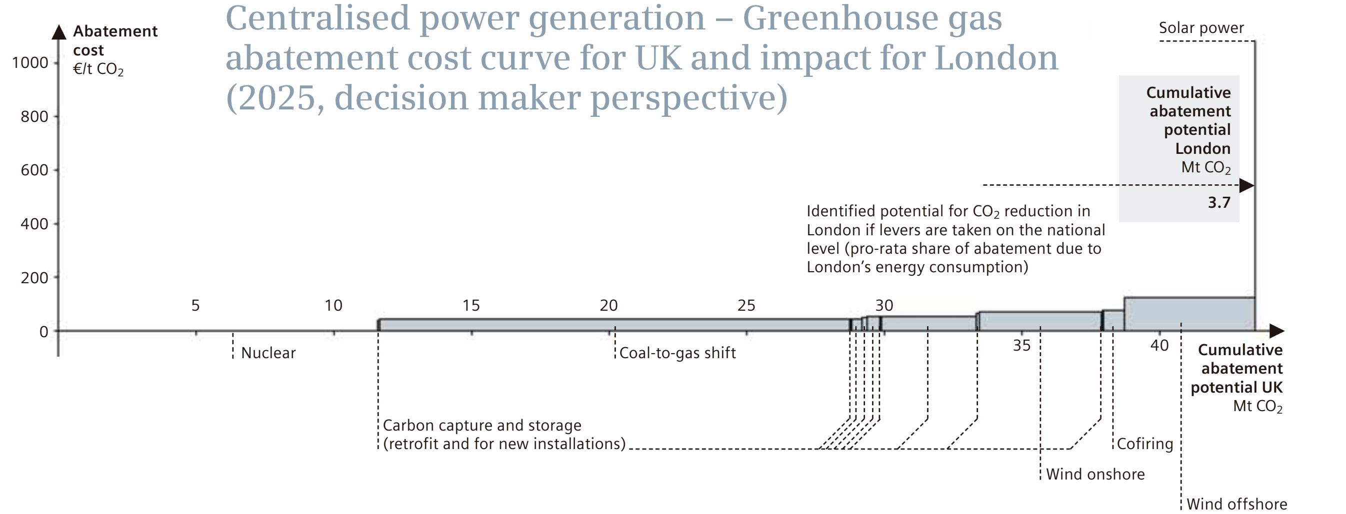
Maximising the use of gas instead of coal at a national level could provide a carbon abatement potential of 1.5 Mt per year for London—a larger impact than any other technology lever in power generation. This implies that 56% of the UK's power production would then come from gas-fired power plants in 2025, whereas just 2% would come from coal-fired plants. Currently, the UK sources 37% of its power from gas-fired power plants and 34% from coal-fired ones.

An additional reduction in London's carbon emissions could be achieved if new nuclear capacity was added at a national level. Assuming an addition of 1GW of nuclear capacity per year, starting from 2019, the carbon abatement potential for London would be 1 Mt of CO_2. However, the decision to build new nuclear

Comparison of CHP with grid mix



Centralised power generation – Greenhouse gas abatement cost curve for UK and impact for London (2025, decision maker perspective)



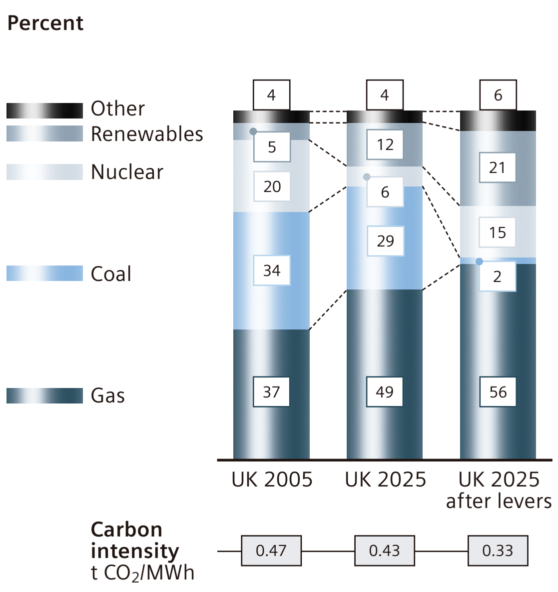
power plants is clearly beyond London's sphere of influence, given that nuclear power generation remains a controversial technology, with significant public and political concerns regarding its safety and sustainability.

A further move towards renewable power generation at a national level could provide an additional 0.8 Mt of carbon abatement for London, albeit at a relatively high cost when compared with alternatives. Of the available options, onshore and offshore wind provide the largest overall abatement potential. Of these, onshore wind makes the most sense from a cost perspective, at €70 per tonne of CO_2 abated. By comparison, offshore wind would cost €130 per tonne abated, while solar power costs more than €1000 per tonne. Despite the costs, many renewable power installations are still likely to happen, especially in wind power, given the push for an increasing share of renewable power generation by the national government and the EU. If the UK's Renewables Obligation scheme was extended, as is currently being discussed, wind parks would be significantly more profitable than shown in this report. Also, the performance of wind turbines has significantly increased in recent years and is likely to improve further.

Finally, installation of carbon capture and storage (CCS) facilities in both new and existing coal and gas power plants, as well as biomass plants on the national level, could add another 0.4 Mt of carbon abatement for London. The report assumes that CCS technology becomes viable from 2020, with a slow ramp-up period towards 2025.

The cost of most technology levers that can improve the carbon intensity of power generation on the UK level are comparatively high, driven both by assumptions on fuel price developments and by the early technological development stage of some technologies, in particular renewable power generation and CCS.

Electricity – Projection of UK grid mix



Source: GLA; BERR; McKinsey & Company

Implementation barriers. Potential for carbon abatement in power generation exists at both local and national levels. So do the impediments. The barriers for decentralised power generation revolve mostly around money. Without additional incentives, technologies like solar and micro wind turbines – with high upfront costs – are much less popular in London and the UK than elsewhere. For example, generous feed-in tariffs in Germany have resulted in significant adoption of solar power. Even for biomass-fired CHP, uncertainty over the possible supply of fuel means it is necessary to use a high discounting rate in calculations, making investments much less appealing. Integrating CHP plants with waste flows in the city is one possible approach to "secure" fuel supply. For example, Sweden's Hammarby Sjöstad is a residential development that captures all local waste through a system of underground tubes and then burns this in a CHP plant to provide power and heat to the local area. In London, property developer Quintain is hoping to emulate this scheme with a mixed use development it is building around the New Wembley stadium.

The policy implications are clear. Cities can

either be satisfied with the carbon reductions being brought about by other stakeholders, or must engage in creative market interventions to accelerate them. Of course, city leaders have to remain conscious of the fact that abatement costs associated with power generation are typically higher than those associated with better energy efficiency. Nevertheless, there are a range of interventions that can work at a city level. These include: using subsidies, taxes and regulation to tip the economic balance, such as the already widespread adoption of the Merton Rule; encouraging schemes or subsidies which ensure that investors in decentralised power generation are able to make a viable rate of return on their investments, such as supportive feed-in tariffs; paying the cost of distribution infrastructure for some solutions, such as a heat grid for CHP; and investing in a large number of local energy generation projects. Although this final point would entail the loss of certain efficiencies in large-scale power generation, local power generation to match local usage patterns could cut waste. Accordingly, the London

Case study: Controlling Munich's energy supply

Most cities hold limited ability to influence the make-up and sustainability of the energy that is provided to their residents. Decisions such as those are driven primarily by national regulations—and by customer demand. Some cities, however, are different. Take Munich, for example.
The city has a 100% stake in its municipal utility firm, Stadtwerke München (SWM), which is the country's largest. And although environmental considerations are written into SWM's articles of association, the City Council, led by Mayor Christian Ude, has stipulated that at least 20% of the electricity consumed in Munich by 2020 must be sourced from renewable energies.

Munich has already done much of the work needed to achieve this target. SWM is currently expanding its use of geothermal energy to generate heat and, where possible, electricity. This comes on top of a range of renewable generation projects – including hydroelectric, wind and solar power installations, as well as geothermal and biogas – which now deliver 17% of the city's total energy supply.

However, this all begs the question of whether Munich's utility ownership structure guarantees a "greener" energy supply, but at a higher overall cost to its residents. Not so, argues Mr Ude. Instead, the utility's customers benefit from Germany's Renewable Energy Sources Act, which mandates that the cost of generating electricity from renewable sources must be distributed nationally, so the additional cost is shared by every German electricity consumer. On top of this, there is a general consensus that the city's energy offerings must be as economical as they are customer-friendly. "The SWM must be able to maintain itself with its products in today's competitive environment," says Mr Ude.

In practical terms, Munich has balanced these considerations by embracing combined heat and power (CHP) to a large extent. SWM has built a new combined cycle CHP plant, which has helped to take the city's share of CHP-derived power to over 80%. This makes Munich one of Europe's front-runners in CHP usage—and part of a wider city-led effort to expand the use of CHP, says Mr Ude. "Most of the world's CHP plants have been built by municipal utilities." Finally, other energy gains are made on the demand side of the equation. "A large number of cities have established energy management programmes for their real estate and contributed to further savings through support and information programmes," notes Mr Ude.

Despite Munich's performance, there are limitations for any city when it comes to urban sustainability. Mayors cannot force residents to change and they hold no influence at all on bigger energy companies. "Even the national government has problems here," says Mr Ude. Likewise, for those cities where the utility firms have been partly privatised, the ability of cities to influence their decisions will be limited, as those companies will focus primarily on profitability. While cities can do a lot to bring about real sustainability changes in energy supply, they also require the right basic conditions and support of regional and national government.

Climate Change Action Plan hopes to shift a quarter of generation by 2025 to such local sources, and the city's London Energy Partnership is considering ways to draw in the necessary investment.

For changes in the electricity supply on a national level, London's options are limited. It could petition the national government to provide stricter carbon policies. Alternatively, it could influence the national grid mix by bulk-buying green energy on behalf of its residents. However, this only provides genuine abatement as long as suppliers actually meet this demand by deploying additional renewable energy generation. Finally, it could choose to invest in a large-scale, low-carbon energy project to feed into the national grid. The ambitious London Array project seeks to establish over 300 offshore wind turbines within the Thames Estuary, providing renewable energy to the national grid. However, the recent exit of one of the project's partners due to concerns about costs highlights the challenges associated with such schemes.

On the horizon: far offshore wind and smart electricity grids

One means of renewable power generation currently being investigated is far offshore wind. Rather than standing on fixed platforms, these turbines would float in the sea where winds are stronger and more consistent. The US National Renewable Energy Laboratory calculates that the potential at 50 nautical miles offshore is the equivalent to America's entire electricity generating capacity. *MIT Technology Review*'s Kevin Bullis says that the distances envisaged "are a lot closer to cities than the wind farms in the Midwest, and the quality of the wind makes them economically attractive." Some people even talk about adding wave energy, generated from the turbines moving about.

Beyond these ideas, other gains might come from optimising power generation in combination with the distribution networks: so-called smart grids, which promise to improve the coordination between power generation, power distribution and power demand while saving money and cutting emissions. Rather than a hierarchical system of large-scale power generation with one-directional distribution to many users, interconnected arrangements could involve many smaller generators supplying many users through a common network. Siemens' Mr Camuti notes that this is a two-edged issue. On the one hand, interconnected systems can overcome the inability of individual large power plants to quickly adjust to changes in usage: "If you can distribute the generation, and link it closer to the distributed loads, then you can optimise how you use and generate the power on a local basis. That is where you are going to gain." On the other hand, he notes that on the generation side, especially after improvements in recent years, larger power plants have "inherent benefits in terms of the conversion efficiencies. The scale effect of central generation is still hard to beat. What you pick up though smaller generation is the ability to link loads to the supply."

This type of structure will require the development of flexible billing rates as a means of influencing energy consumption and thus making it easier to control power movements in the grid. Electricity will need to be cheap during times of surplus generation and more expensive when supplies are stretched.

Although some of this technology is available today, new control strategies and technologies are currently at a pilot stage. Mr Camuti adds that green technologies from other areas might help. A large number of plug-in hybrid car batteries could, for example, act as a reservoir to store power at times of low demand and potentially even a source of power at peak demand times, should their owners so choose. The first city-wide smart grid project has just been announced for Boulder, Colorado. Lessons learned there may have a huge impact on how cities make and use power in future.

Financing city sustainability

Financing greater energy efficiency is a challenge in its own right. Cities are home to a complex network of stakeholders, from landlords and tenants to commuters and students, healthcare providers and local authorities. Many of these parties may have conflicting commercial interests and priorities. However, given the scale of the transformation needed to cut the carbon emissions of the buildings, industries and transport systems in cities, partnerships between the public and private sector will play an increasingly important role, with government using everything from new taxes to tax abatements, subsidies and sub-contracts to prompt action from the private sector.

"In cities you'll see more activities going from public sector to private sector, even if they need some additional public sector activities such as sovereign guarantees, financing or legislation," says Andreas von Clausbruch, Head of Cooperation with International Financing Institutions at Siemens Financial Services. Private sector financial institutions also have an important role to play – and for banks, insurers and others, climate change is a business opportunity as well as an environmental challenge. Banks are increasingly offering carbon trading and credit products designed to help both consumers and industries reduce emissions. Moreover, banks have a natural role in climate-related investments. They have traditionally financed schools, roads and hospitals, so they can also finance everything from flood defence systems to renewable energy equipment.

One example is the Environmental Infrastructure Fund recently launched by HSBC. The fund is targeting total commitments of €500m, including a commitment of up to €165m from HSBC. It will invest in environmental infrastructure targeting the renewable energy, waste and water sectors. Like schools, roads or railways, the assets offer infrastructure investors the benefits of long term stable cash flows. "Historically, we've been financing social infrastructure," says Jon Williams, Head of Group Sustainable Development at HSBC. "It's entirely logical for the same skill set to be applied to environmental infrastructure."

When it comes to financial products for consumers, the mortgage is an obvious vehicle through which to provide incentives for investing in sustainability—by financing various measures for higher energy efficiency. So-called energy efficient mortgages make it easier for borrowers to qualify for loans to purchase homes with energy-efficiency improvements. Additional funds can be made available to people who want to install solar panelling or insulation in their homes in the expectation that the house will be worth more as a result. In the US, as part of its green mortgage programme, Bank of America is offering homebuyers either a reduced interest rate or a US$1,000 refund if they buy a newly constructed home that meets the country's Energy Star rating.

Similar incentives can be brought to bear for manufacturers and other companies. In Hong Kong, as concerns mount about the pollution generated by factories in southern China, HSBC has introduced a Green Equipment Financing programme, which provides a lower interest rate for companies investing in equipment with a lower environmental impact and lower energy consumption.

"If you help a company reduce its operating costs and its exposure to potential future regulation, then you are probably creating a better credit risk," says Mr Williams. "You can't measure that in year one, year two or year three, so you invest in a lower interest rate to create a market. And that's beginning to transform the sort of equipment financing we do." Bank of America has a specific loan programme to help small and midsize trucking firms finance new fuel efficiency technologies.

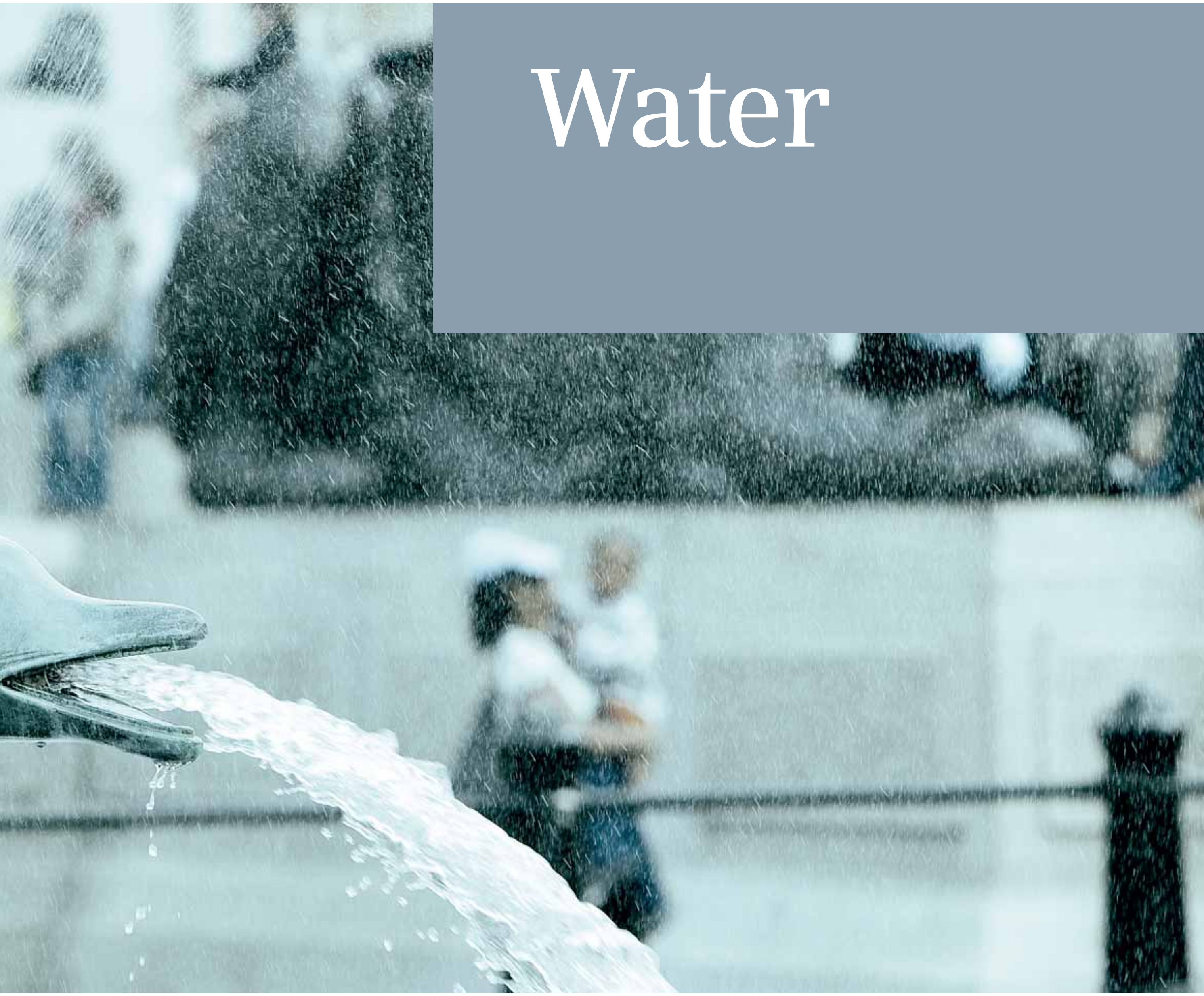
Whether it is public or private sector behind the investment, what makes climate-related financing models compelling is the potential costs savings that accrue from installing energy-efficient infrastructure. In Budapest, for example, a private partner is equipping all the city's traffic lights with light-emitting diodes, which use up to 80% less power than conventional lamps and only need replacing every 10 years. Here, despite high initial investment, a financing model was set up that meant the city authorities incurred no additional charges since these are distributed over monthly instalments that are lower than the savings produced by the reduced power consumption and maintenance costs.

06

Key findings

- **The technology levers outlined in this chapter could cut the water production required for London by just over 20% by 2025, to 541 million cubic metres from 681 million today, despite a growing population.**
- **Demand reduction is even more important in light of London's current high leakage rate of 33%—for each litre saved at the tap, 1.5 fewer litres need to be supplied.**
- **The purchase of more efficient appliances, along with other simple measures, such as aerated taps and dual flush toilets, could slash demand by more than 60 million cubic metres per year, more than 13%, and save money.**
- **The key implementation barrier for this and other water-saving measures is that relatively few households are metered, so consumers have no financial incentive to reduce demand.**
- **Although this report does not seek to address supply side options, there will be no alternative in the long run but for London to address its water leakage.**

Water



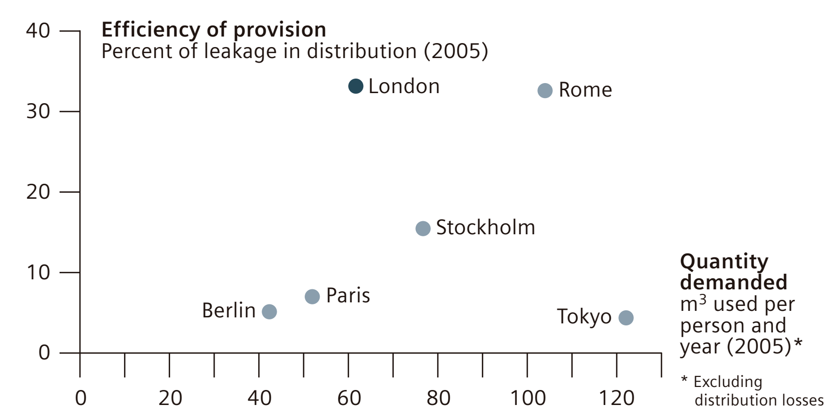
London's sustainability profile. Water consumption in London is relatively low compared to other major cities. At 61 cubic metres per person per year, it is markedly lower than Rome, Stockholm, and Tokyo, although Londoners consume more than residents within Paris and Berlin.

However, overall water production per person is another story. This is much higher, due to the extremely high leakage rates in London's water infrastructure (33%) compared to all other cities but Rome. The city loses approximately 680,000 cubic metres of water every day through leakage. About one third of the city's water mains are more than 150 years old, dating back to the Victorian era. The overall impact of this is that the entire water production for each Londoner reaches 91 cubic metres per year, which is more than double that of Berlin (45), much higher than Paris (56) and about the same as Stockholm. This is despite the latter's significantly greater consumption.

Because this study focuses on London, it does not address a number of other water-related issues, such as access for the population, water quality, and the efficiency and quality of the sewage system. Although they are not pressing issues in London, they are certainly relevant in other cities, in particular those in less developed countries.

Identified reduction potential. London's water requirements are expected to remain roughly flat until 2025, despite an expected increase in population of 11% that will demand an extra 77 million cubic metres of water. In part, this will be countered by a reduction in demand brought about by more than doubling the proportion of households who have their water use metered—from 22% in 2005 to about 55% in 2025. This should lead to a 4% drop in consumption (about 29 million cubic metres per year). Furthermore, ongoing efforts to combat leakage in the supply and distribution system should also reduce total production by 6%

Water – Comparison of drivers



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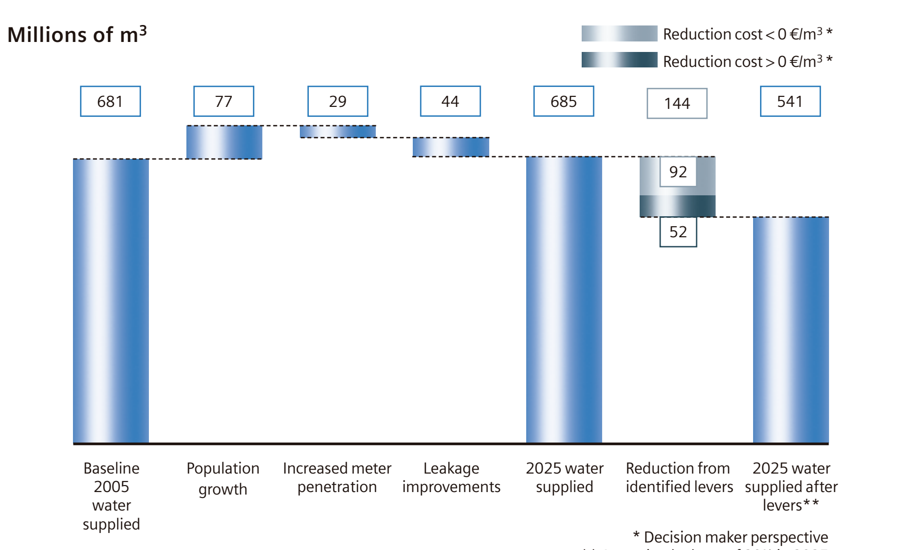
Water – Projection of water production and identified reduction potential for London



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by 2025 (about 44 million cubic metres per year), if they continue to yield reductions at the current rate. Together, these two measures nearly cancel out the likely increase from population growth.

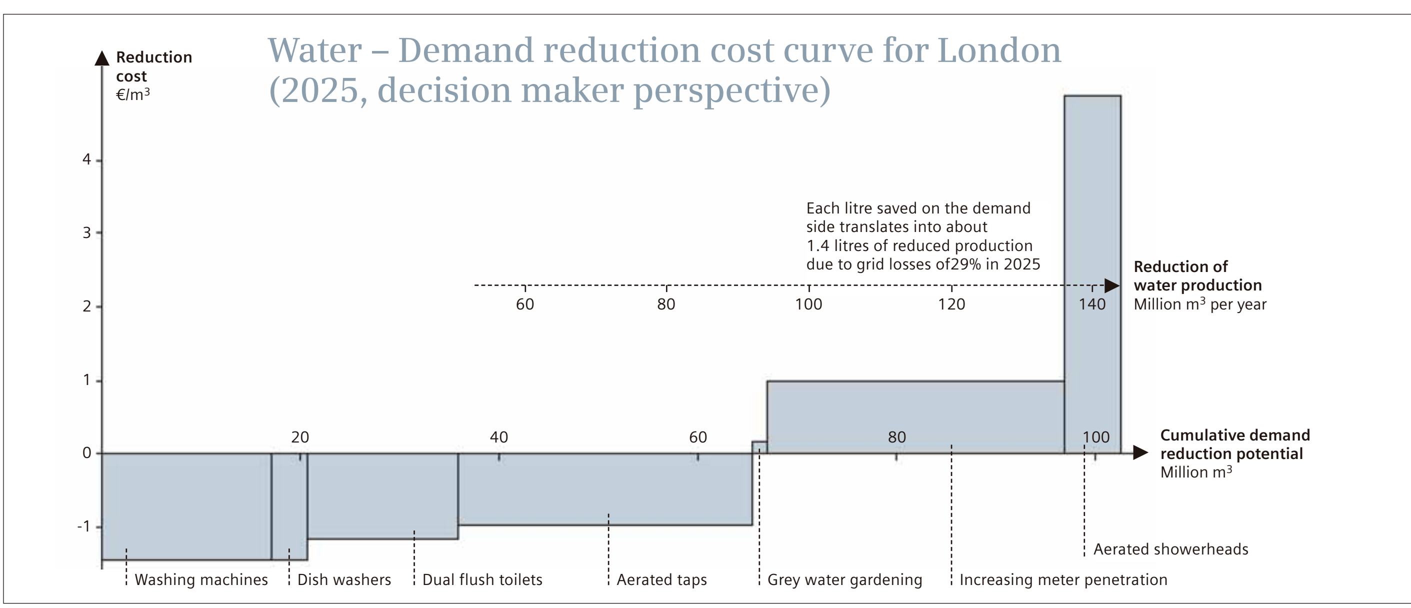
Of course, London can do far better than just standing still. Technology levers, many money-saving, could reduce total annual tap side demand for the city by 100 million cubic metres, or 21%. The increased adoption of devices that use water better – more efficient dish washers and washing machines, dual flushes for toilets, and aerated taps – would together save more than 60 million cubic

metres per year in households and an even higher amount on the supply side. Overall, this would account for more than 13% of 2025 consumption—and for every one of these technologies the savings would outweigh the costs.

A more widespread implementation of water meters than currently planned could save an additional 30 million cubic metres per year, or more than 6% of today's consumption. This assumes that the water meters induce water-conscious behaviour that results in savings beyond the installation of the devices already mentioned. This is a reasonable assumption given the average 12% drop in water use their installation brings today when such appliances are not widespread. This does not come for free, however, but would involve some cost for installing the meter. This study assumes that this cost has to be borne by the consumer.

Interestingly, while aerated taps effectively pay for themselves through reduced water use, aerated showerheads do not, primarily because the flow of water through a showerhead tends to not be as much as through household taps, thereby reducing the scope for savings. That said, if a household were to install all of the measures outlined in the cost curve, starting with the ones that pay back and ending off with the ones that don't, the net effect would still be a cost saving—and a significant reduction in water consumption.

Although levers for London's water supply were not evaluated, possible steps could include further network upgrading and pipe replacement. This is expensive though: Thames Water, for example, estimates that it is currently spending half a million pounds per day on its repair programmes. Many of these do not reduce the leakage rate but only serve to maintain the status quo, given that new leaks continually emerge. Despite the costs, the company is



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going ahead with an upgrade of London's water network. There may actually be no alternative in the long run. Although the Victorians were excellent engineers, about one-third of London's water mains date back to that era, and this infrastructure can clearly not last forever. Another concern that needs to be addressed is the available supply of water—despite all of its rain, London's demand threatens to outstrip its supply. Part of London's solution is a desalination plant to supply water during times of drought. However, this approach is controversial, given that the process is hugely energy-intensive and thus could contribute to greater CO_2 emissions. Thames Water proposes to power the plant with biodiesel, as a partial response to this concern.

Another possible option would be a pressure management system within the distribution network. São Paolo in Brazil uses such a system to not only help identify large leaks quickly, but also to make more accurate water consumption forecasts, integrating other data such as outside temperature. This allows the water compa-

Case study:
NEWater – Singapore's recycling success

Singapore has very little fresh water of its own. More than a century ago, it started collecting rainfall into catchment reservoirs, which now provide about half of the city's needs. Most of the rest comes from neighbouring Malaysia, but political tensions affect the long-term price and certainty of that supply. The city has therefore been looking for alternatives, including damming the Singapore River and building desalination plants. The most innovative solution in a city famous for its technology, however, has been to recycle waste water.

Starting with a test facility in 1999, three NEWater plants now return 92,000 cubic metres of water a day into the city's water system. Most of this goes to industrial use. The Public Utilities Board, which controls water issues, also made a conscious decision to mix it into the city's drinking water, where it currently makes up 1% of daily consumption. This will rise to 2.5% by 2011.

The city's water cleansing process contains four steps. First the water undergoes conventional waste water treatment. Then micro-filtration takes out any suspended solids, large particles and bacteria. Third, reverse osmosis, a process already used in desalination, takes out any metals, nitrates, chlorides and other salts, as well as viruses, by sending the water through a semi-permeable membrane. The already very pure product is then treated with ultraviolet radiation to kill off any organisms that might have survived the earlier filters. The result is water that meets the highest international water quality standards. Energy use for the entire process is less than that for desalination.

However, the real innovation for Singapore is not the technology but applying it to turn waste water into drinking water. Daryl Sng from the city's Ministry of the Environment and Water Resources notes that "people instinctively have an aversion to recycled water. It is not necessarily rational, but it is an important issue and you have to work to increase acceptability. It is about showing people that drinking such water is the same as drinking any other water." Singapore has worked hard in that regard, in particular with leaders drinking NEWater at public events, including state dinners. "The introduction of the water into the reservoir system has been a big part of the process. Now the public doesn't think much about it," says Mr Sng.

He adds that for now "of course people will only accept the recycling of water when it is clear there is a situation which will necessitate its use. In Singapore it was cross border tension, in Australia it was drought." As the world pays more attention to its limited freshwater resources, however, more cities may need to look to Singapore's example.

ny to lower pressure at times of lighter usage, thereby reducing energy use and water leaks.

Implementation barriers. The key barrier to implementation of technological levers that could reduce demand is that many of the people who need to make and pay for the decision – those consumers without water meters, who form the majority of the populace – would lose out financially. Only the 22% of London households that are currently metered actually pay for the volume of water used. Everyone else is charged a set annual fee, based on anything from the value of the house to the size of the pipe that supplies it from the mains. Nearly 8 in 10 residents therefore have no idea how much water they are using.

Worse still, any improvements to their water systems that reduce usage – such as the installation of a dual flush mechanism in a toilet – would be an economic cost to them but the benefit would accrue solely to the water company. This leads to some surprising results: some British water companies will send out a plumber to replace washers on dripping faucets in households at no charge simply in order to reduce the water use. Indeed, long-term consumer care of water infrastructure is a pressing issue.

Thames Water estimates that nearly a quarter of current daily leakage from the water system comes from customer-owned pipes on their properties, rather than from its main supply pipes. Conservation is easier for people to take seriously when they have to pay for what they are using.

On the horizon: carbon nanotube desalination, differentiating water usage

Siemens' Mr Camuti notes that "water is probably the least discussed issue in urban development that presents the most immediate challenge. People just kind of assume that water is available." Nevertheless, a shortage of supply can quickly lead to significant problems. Water desalination is one response. The big problem is how much energy the process takes. *MIT Technology Review's* Jason Pontin explains that "the way water has been reclaimed historically only makes sense where water is more expensive than oil." This means it works for the Saudis, but is otherwise extremely expensive. The Spanish have for many years been trying to make reverse osmosis technology as inexpensive as possible, but the energy required to push a constant flow through the required membrane is costly.

Now, *MIT Technology Review's* Kevin Bullis believes that "carbon nanotubes are promising as a way of filtering water." New membranes being developed at the Lawrence Livermore National Laboratories have carbon atoms rolled so tightly into a tube that just 7 water molecules fit through its diameter. Through an as yet unexplained facet of carbon nanotube physics, the smaller the hole – and therefore the better the filter – the faster the water goes through. These rates are significantly better than for existing filters and therefore require much less pressure – and energy – for desalination. An early estimate puts the potential cost savings at 75%. If this technology is scalable, today's economic and environmental concerns surrounding urban water supply could be completely transformed.

Mr Camuti adds that at least part of the solution may lie not in water treatment but in its collection and use. Buildings, for example, can be designed to capture and use rainfall, thus reducing their total water demand. "When you look at water recycling and water use in urban environments, there's a lot of impact from landscaping. Through more environmentally conscious design, you pick up a lot of natural impact." Moreover, differentiating types of water use can be very cost effective. For example, rather than being a single one-price-fits-all product, varying water standards and prices might emerge for water used for drinking, as opposed to gardening. Indeed, Mr Camuti believes that whatever the progress in filtration, "it may be unavoidable in the future in cities to separate potable from [minimally treated] grey water."

07

Key findings

- **London produces a total of 18.1 Mt of waste every year, from construction, industry, commercial activity and citizens.**
- **Although the municipal waste created per person in London is not unusually large in comparison to other cities, London's recycling rate is just 17%, with about two-thirds (64%) going to landfill.**
- **Rising landfill taxes mean that different treatment technologies for municipal waste that are ecologically more sustainable are also becoming economically attractive.**
- **The recycling of general waste (e.g. metal, glass, plastic) combined with anaerobic digestion for organic waste (such as food) seems to be the most attractive option of these.**
- **The key barrier to implementation for waste treatment facilities is the long and uncertain planning period, compounded by the "NIMBY" (not-in-my-backyard) phenomenon.**

Waste

London's sustainability profile. London produces 18.1 Mt of waste every year. Of this, 7.2 Mt is accounted for by construction and demolition, 6.6 Mt by commercial and industrial activity and 4.3 Mt by municipal waste—the garbage collected by local authorities from residents. In per capita terms, at just under 600 kg of municipal waste per person, the city is producing less than Rome and New York, but about 50% more than Berlin and Stockholm, both cities noted for their attention to waste issues.

The problem is most acute with municipal waste. Nearly two-thirds of municipal waste goes to landfill, while just 17% is recycled, a figure well below that of several other leading cities. By contrast, a relatively high 85% of construction waste is recycled, and for commercial waste a combination of recycling, incineration and other technologies leaves 40% for landfill. Other types of refuse, such as toxic industrial waste, have not been addressed in this report due to their low prevalence in London.

Identified reduction potential. This report's approach in analysing CO_2 emissions and water usage – developing cost curves for technological levers – cannot be applied usefully to waste treatment, where the key technological question is not how to reduce the amount but what to do with it. Cutting the actual amount of waste is ultimately a behavioural issue. By contrast, the different strategies considered here could, potentially, be employed to treat all of London's municipal, and most of its commercial, waste.

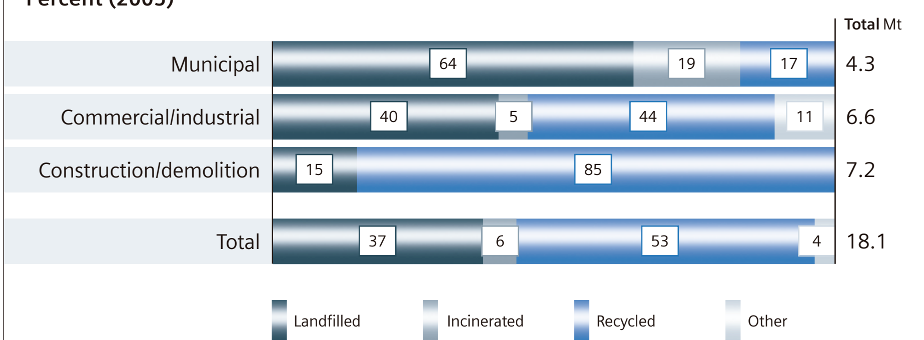
Regarding the future development of waste production, this study makes several assumptions. One is that people's behaviour in producing waste will not change, so overall municipal waste production will rise in line with population growth, at about 0.5% per year. Another is

that construction and demolition waste will increase at a similar rate, based on the expansion of building activity, while commercial and industrial waste will grow faster, at a rate of approximately 0.9% per year, as job growth outpaces population growth. A final assumption is regarding costs. The average gate fee for landfill today is €30 per tonne of waste. An additional fee is the national government's landfill tax. This stood at about €27 per tonne in 2005, is currently at about €47, but is expected to rise to €70 in 2010.

"Reduce, reuse, recycle" has been a mantra of the environmental movement for decades. Thus, if waste cannot be avoided or put to other use, the most sustainable option to treat waste is the diversion of useful commodities into recycling programmes. What constitutes a valuable raw material and what is, in fact, just garbage depends on a variety of factors, including the recovery technology, the cost of obtaining the good from other sources, and the cost of its safe disposal if not reused. Obviously some materials, such as metal, paper and plastic, have long met the test. In fact, the net cost of disposal arising from this process of sorting and recycling comes in at a very low €2-€8 per tonne, depending on materials recovered and the revenue that can be generated from selling

Waste – Composition and treatment methods in London

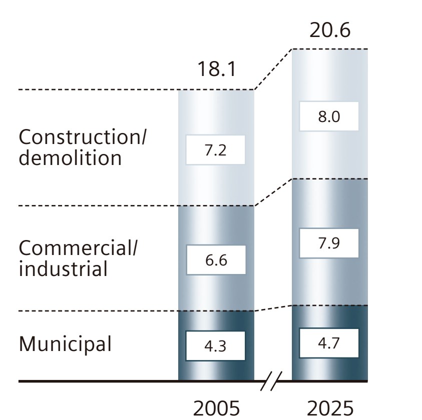
Percent (2005)



Source: GLA

Waste – Projection of London waste production

Mt



Source: GLA, McKinsey & Company

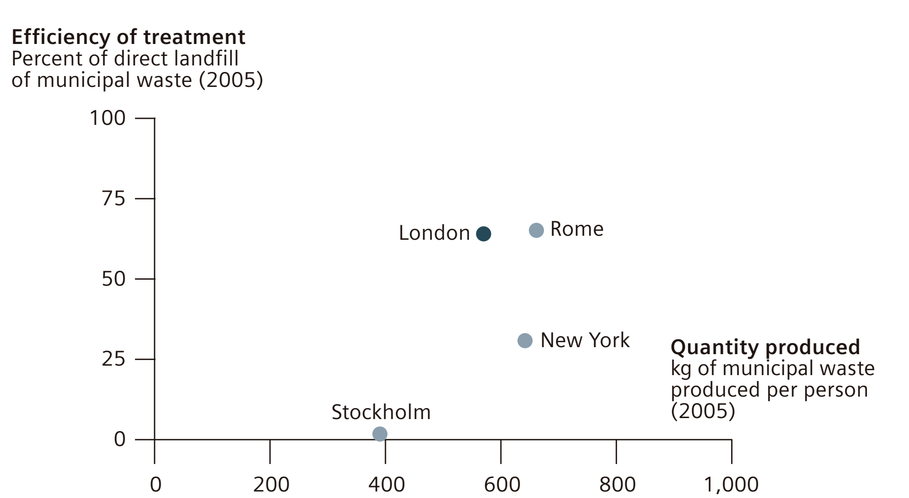
these materials to offset the expense of the operation. London has made some progress recently, especially in recycling. The overall rate of household waste dealt with in this way has almost doubled in the last six years, and the boroughs with the highest rate now reach 40%. Merton Council, for example, currently recycles 26% of its waste and expects to increase this to 60% by 2011-12. Taking things a step further, the London Development Agency is establishing a sustainable business park in Dagenham in the hope of using some of the material now being recovered in increasing quantities (see case study). Clearly, a certain proportion of waste will need to go to landfill – currently costing nearly €80 per tonne, a figure set to increase by 2010 to €100 because of the higher landfill tax – or some form of treatment. Various options exist, each with its own advantages and drawbacks. The options outlined below assume that municipal waste is first sorted and recycled, the non-recycled material then subjected to the treatment methodologies, and finally only the remaining residual sent to landfill.

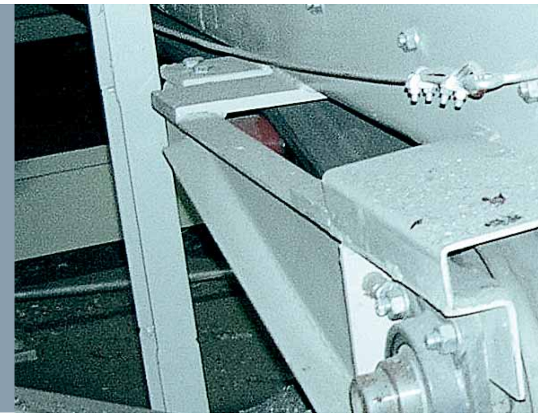
→ **Anaerobic digestion:** This relatively clean technology involves the use of microorganisms to break down organic material in waste, reducing its volume and mass. The process results in a very flexible biofuel – syngas – as well as a residue, or digestate. Some or all of this, depending on the composition of the initial waste, can be a useful fertilizer. This approach costs around €37 per tonne of waste treated and leaves behind just 10% of the original treated waste for landfill, making it the most promising technology for treating London's garbage. However, this is only true if the resulting digestate is put to use. If it is sent to landfill instead, the economics look much worse. This is an important consideration in Britain, because compost needs to be certified not only to be sold but even to be given away free.

→ **In-vessel composting:** This is another technique for using microorganisms to break down organic waste, this time directly into compost. It differs from ordinary composting in that it is done within a closed container (vessel), thus enabling the process to be done at an industrial scale under greater control. Although more expensive than anaerobic digestion at €53 per tonne, it also leaves behind slightly less waste for landfill. Even more than anaerobic digestion, however, it has the certification problem for the produced compost, which could result in more material going to landfill, and hence much higher costs.

→ **Anaerobic digestion coupled with production of refuse-derived fuel:** This approach presses combustible waste into pellets that can fuel electricity plants, CHP or industrial installations. This combination is comparable in price to anaerobic digestion, costing about €42 per tonne treated, but leaves behind a bit less waste for landfill. There are, however, three

Waste – Comparison of drivers



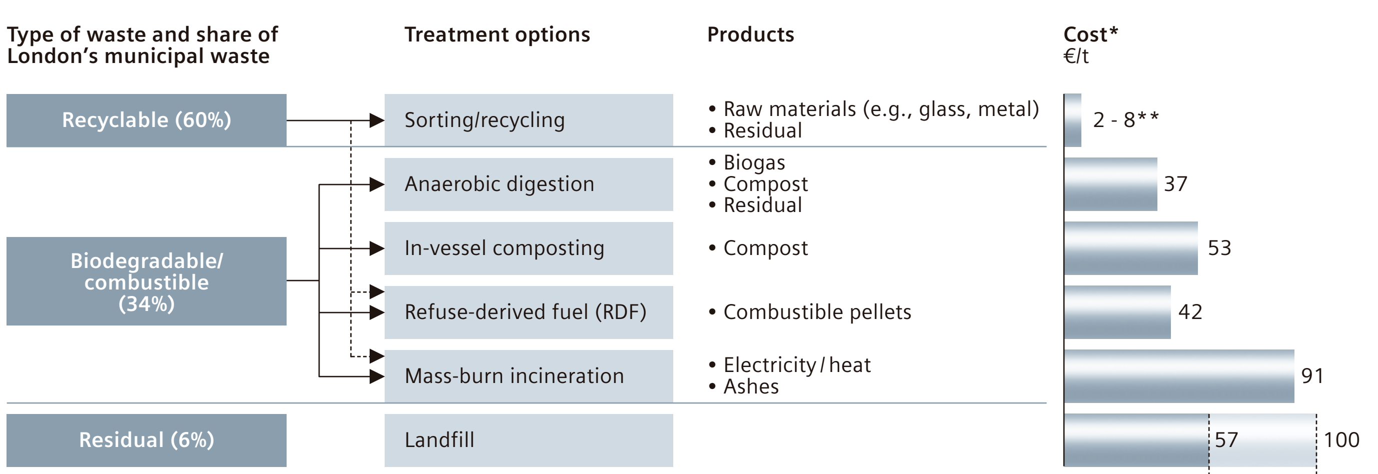


problems with this approach. First, paper and plastic cannot be recycled in the prior stage because they are needed to increase the calorific value of the pellets to actually make them combustible. The second issue is political: while modern filter technologies can remove a significant share of the potentially toxic substances contained in the pellets, its use is likely to prompt popular concern, making it less marketable.

The third is the lack of a market: the absence of energy-intensive industry in London makes it harder to find customers for the fuel within a distance that does not significantly worsen the economic and ecological balance of this approach—due to the associated transport costs and emissions. Furthermore, specifically building CHP plants in London that are powered by refuse-derived fuel will likely run into the same popular resistance as incineration plants (see below).

→ **Mass-burn incineration:** Burning the sorted and recycled waste under controlled conditions, and using this heat to generate power, costs about €91 per tonne of waste treated and leaves behind 20% of the volume for landfill. In other words, this is currently

Waste – Illustration of waste treatment options and costs for London



* Including revenues generated (e.g., sale of recyclables, biogas) and landfill tax, decision maker perspective ** Depending on materials recovered

Source: GLA, McKinsey & Company

Case study: Waste as an asset

In the 1960s and 1970s, the city of St. Catharines in Ontario, Canada, had a quirky social institution. Once a year, the city sanitation department would collect more than the usual amount of waste from each household, in order to help with the annual rite of spring cleaning. The day before collection, substantial mounds of bags, furnishings and other unwanted items in various states of disrepair lined the streets. That evening, often on foot, sometimes in cars or trucks, a surprising number of residents would unselfconsciously go about literally poking into their neighbours' piles of garbage, returning sometimes hours later laden with previously unappreciated treasure. This annual event (locals did not as a rule rummage through their neighbours' refuse on any other day of the year) requires a mental shift to treat waste as an asset rather than as garbage. But cities around the world are finding this a change well worth making.

In Sydney, Australia, a public-private partnership between two municipal governments and Global Renewables, a waste technology company, has introduced an integrated mechanical-biological treatment for solid waste. The process, dubbed "The urban resource – reduction, recovery, and recycling", sorts the waste stream to remove toxic elements (such as batteries), recover a maximum amount of recyclable material, obtain waste water and generate biogas so that the facility is self-sufficient. It also creates 30,000 tonnes per year of high-quality, organic compost which sells at €12-€20 per tonne. Overall, the facility annually processes 175,000 tonnes of solid waste, saves 210,000 tonnes of CO_2 emissions, and generates revenue of over €7m. The system has proved so successful that it is now being used in Britain's largest waste-related Private Finance Initiative to date, in Lancashire. The company also hopes to roll it out in a number of developed and developing Asia-Pacific countries in the near future.

London is also seeking to use its waste more effectively. Shanks East London, a private company, has a target of recycling 33% of the East London Waste Authority's household rubbish by 2016. It has built two mechanical and biological materials recycling facilities in the area that automatically extract recyclable materials before turning the rest into solid fuel. More ambitious still is the London Development Agency's plans for a Sustainable Industrial Park at Dagenham Docks, which will develop the first plastic recycling plant in Britain. This will not only expand recycling, but also serve a market for its output: a variety of small businesses within the business park will use the recycled plastic as an input. The hope is to use this as a model for other combinations of recycling facilities and industry at the park, including glass, electronic components and end of life vehicles, so that the park can become a home for "small and medium companies that specialize in taking recycled materials and making stuff out of it."

Although technology helps, even the poorest cities can benefit from better waste treatment. In Dhaka, Bangladesh, the city can afford to collect less than half of its garbage. In the early 1990s an entrepreneurial pair – Iftekhar Enayetullah, an urban planner, and Maqsood Sinha, a civil engineer – realized that 80% of this waste is organic and thus capable of being made into compost. This serves a pressing need in the country where topsoil erosion encouraged overuse of chemical fertilizer. When the partners could not win city officials over to the idea, they founded Waste Concern, an NGO, to trial it themselves. A pilot project in the impoverished Mirpur section of the city's inner core – which involved collecting the waste for a nominal fee from each household and then treating it – had striking results. Done using simple composting technology, the site was operated at its full capacity of 3 tonnes of garbage per day, generating a net margin of 29%. The surrounding area was also cleaner, with less incidence of disease, while the fertilizer increased crop yields by over 50% compared to the standard chemical used in the country. It has also convinced officials of its merits, so Waste Concern has been rolled out in over a dozen Bangladeshi cities, as well as in Vietnam and Sri Lanka.

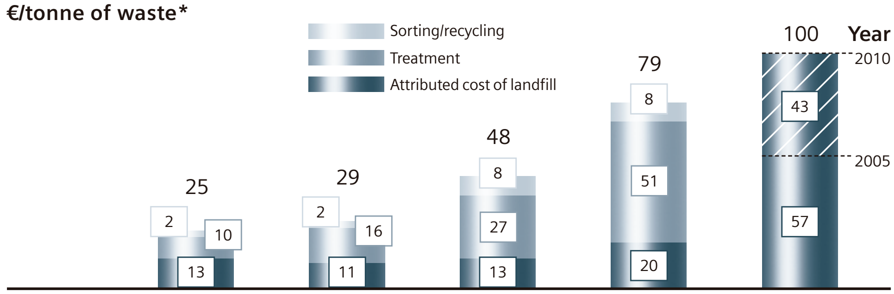
more costly than landfill, although it will become competitive once the cost for landfill reaches €100 in 2010. As with refuse-derived fuel, paper and plastics need to remain in the treated waste in order for it to have a sufficiently high calorific value.

Another problem with incineration is political. While, as with refuse-derived fuel, modern filtering can protect the environment around the facility, popular opposition almost always arises, making the planning process lengthy and highly unpredictable. On the other hand, if all of London's municipal waste were dealt with in this way, it would provide 2,000 GWh of electricity, or about 5% of London's demand in 2005.

Overall, the best combination of cost and environmental results seems to be to first recycle whatever possibly can be, then to treat the remaining waste by anaerobic digestion, before finally sending to landfill any digestate that cannot be used elsewhere. However, this evaluation relies on certain assumptions for London's situation: different regulations, different markets for the output (biogas, fuel pellets, compost, electric power derived from incineration) and different costs for land,

Waste – Comparison of waste treatment scenarios for London

€/tonne of waste*



Scenario	Anaerobic digestion	In-vessel composting	Anaerobic digestion + RDF**	Mass-burn incineration	Landfill
Landfill avoided Percent	77	80	77	66	–
Key points	• Clean technology • Flexible output	• Reliable technology • Certificate and customers for compost required	• Customers required for RDF • Risk of toxic emissions	• Experience at scale • Risk of toxic emissions • Public opposition	• Not sustainable • Reduction politically mandated

* Decision maker perspective
** Refuse-derived fuel

Source: © Copyright 2008 McKinsey & Company

labour and landfill costs, can certainly lead to other conclusions.

Implementation barriers. Some of the barriers to the adoption of different waste treatment strategies are common to other sustainability issues. Increased education about recycling, simplifying the process and providing a coherent, holistic approach to the issue of waste are all vital. This sphere, however, has two significant additional features which influence any strategy.

First of all, governance is spread more widely: London's 32 boroughs and the waste management companies they employ have authority in this field. This makes coordination across the city difficult. Some councils recognise this and have established partnerships. The boroughs of Merton, Croydon, Kingston and Sutton, for example, which all face similar challenges locally, have established the South London Waste Partnership (SLWP).

The goal of the partnership is to generate economies of scale by combining each borough's efforts to reduce the amount of waste to landfill by one-quarter by 2010, 50% by 2013 and ultimately 65% by 2020. The SLWP aims to issue a joint contract for the treatment of waste and the management of all four boroughs' household reuse and recycling centres, as well as the transport of residual waste to a landfill site and management of the site itself.

Whatever the relative benefits of highly devolved waste governance, another issue that would affect anyone trying to deal with waste is the strong public aversion to any technologies other than recycling and landfill. This resistance can play havoc with the planning process, making the long-term management of waste highly problematic, regardless of who is in charge.

On the horizon: gasification of waste, better consumer packaging

One possible technology for waste disposal on the horizon is gasification. It involves heating waste to obtain biogas and a residual char which can be used in road construction. At €102 per tonne, the technology is currently expensive, but not significantly more than the cost of landfill in Britain by 2010. The process also leaves just 5% for landfill. *MIT Technology Review*'s Kevin Bullis says "various forms of gasification really do look promising. A number of companies are trying to get this going, but they are up against a pretty entrenched system, which is more a political problem that a technological one." Siemens' Mr Camuti says it is feasible to do waste to energy conversion today. "Biogas is a proven technology that needs to be scaled. There is not really a reason why you couldn't." If this could be done at a reasonable price, gasification might well provide highly efficient waste treatment and carbon emission reduction in the years ahead.

Focusing too much on waste treatment, however, is putting the cart before the horse. Mr Camuti believes that "what we need here is systems thinking", such as building better sorting mechanisms into the garbage collection process. At an even earlier stage, there is much to consider about where much of this waste comes from. "You have to backtrack into how the waste is generated. This is more a consumer product or capital goods design issue." For example, improved packaging could raise the percentage of waste that is recyclable, thus helping to decrease the total amount sent to landfill. Regulation to drive technology in this area might do as much to help as innovation in waste treatment.

08

As this report shows, the struggle for sustainability is very much an urban one: people and environmental stress are increasingly centred in cities. Technology can be a potent weapon in this fight. Take climate change: in London's case, existing technological levers alone – without any behavioural change – could deliver the emission cuts that are necessary for it to meet its share of most of the relevant national and international targets. Only the city's own Climate Change Action Plan goals of a 60% reduction by 2025 go beyond what technology can deliver, but the 44% cut that is possible still goes a long way towards meeting these. Although much more uncertain, innovations currently on the drawing board could deliver far more. To make this picture even rosier, most of the carbon reductions would actually save money. It should be easy. It is not.

Urban life – governance, economic activity, and its myriad other aspects – is one of humanity's most complex creations. Changing how we do things as central to our existence as obtaining our energy and water, or disposing of our waste, is, nevertheless, far too complicated to be brought about by the mere existence of clean solutions put together in a laboratory. It requires understanding and working on the dynamics of the system to let people make the choices that are necessary. For the moment, however, there are too many barriers blocking this from happening. In the words of the famous Italian writer Giuseppe Lampedusa, "If we want everything to remain the same, everything will have to change."

As this report makes clear, many different stakeholders are involved in making sustainability-related decisions. Success will require cooperation, rather than dictation from any one of these. Certain things can take place at the national and municipal government levels, but the most powerful actors in all of this are con-

Conclusion

sumers, who can through their purchasing decisions bring about 70% of all possible CO_2 abatement. Absolutely crucial to lowering emissions, therefore, will be removing the barriers to them doing so. Key steps will include:

➔ Informing citizens about possibilities of influencing sustainability and the economic benefits associated with them. Many people may not know how much money insulation can save, for example.

➔ Bringing together actors – such as financing institutions, insulation installers, and energy companies – that can make the implementation of technologies more convenient for consumers.

➔ Putting in place policies and schemes that promote ecologically and environmentally attractive choices over their alternatives. This can range from local building or waste disposal standards to specific financing schemes for decentral or renewable power generation.

➔ Finally, removing, or at least addressing, the wedges between those making the necessary investment in sustainability and those benefiting. At an extreme, this can even involve turning the potential for savings in energy costs into an unrealised asset and renting it out to an enterprising energy company to exploit.

This study is only a beginning. It has sought to shed light on the problems of sustainability by focusing on one city, and London's challenges, strategies, and even its eccentricities have revealed much of use. Although a world city, however, London is not the world. Understanding the sum of urban challenges will require looking at other cities, and the method developed here can be applied broadly, as we hope it will. After all, the fight for sustainability will inevitably need to go on city by city, and detailed data will help lift the fog of ignorance which makes effective strategy so difficult. The end result is too important to leave to guesswork.

List of levers

Levers	Explanation	Abatement potential Mt CO_2 in 2025	Abatement costs €/t CO_2	Required investment €m	Abatement/ investment ratio kg CO_2/€
BUILDINGS – RESIDENTIAL					
Air conditioning	Efficiency increase in new residential air conditioning units	< 0.1	-160	< 100	6.8
Cavity wall insulation	Cavity wall insulation in residential buildings	0.1	-190	< 100	1.8
Condensing boilers	Replacement of boilers in existing residential housing stock with condensing boilers	1.2	-170	500	2.4
Cooking appliances	Efficiency increase in new residential cooking appliances	< 0.1	-130	< 100	1.5
Draught proofing	Draught proofing in residential buildings	0.1	40	300	0.5
Electric appliances	Increased penetration of best available technology in residential appliances (e.g., energy efficient white goods); Reduction of stand by losses in residential appliances (e.g., audio and video equipment, PCs)	0.9	-180	500	1.8
Floor insulation	Floor insulation in residential buildings	0.8	-60	1,800	0.4
Hot water insulation	Hot water insulation in residential buildings	0.1	-210	< 100	8.1
Improved heating controls	Improved heating controls in residential buildings (e.g., more accurate thermostats)	< 0.1	-90	< 100	0.9
Lighting	Increased penetration of compact fluorescent lighting in residential buildings	0.4	-270	< 100	7.2
Loft insulation	Loft insulation in residential buildings	0.4	-170	300	1.4
New build homes*	New residential buildings with energy efficiency of 40% above the expected improvements in new buildings	0.4	460	5,200	0.1
Solid wall insulation	Solid wall insulation in residential buildings	2.0	-70	4,200	0.5
Windows	Improved insulation through double-glazing in residential buildings	0.5	280	3,200	0.2
BUILDINGS – COMMERCIAL/PUBLIC					
Cooling with renewables	Solar water cooling and solar air cooling systems in commercial buildings	< 0.1	450	700	0.1
Display cabinets	Increased penetration of best available technology in retailers' refrigerated display cabinets (e.g., beverage coolers, ice-cream freezers, open cabinets, vending machines)	0.3	-210	200	1.1
Drives	Use of more efficient variable speed drives in commercial buildings (e.g., in ventilation systems)	0,2	-190	100	1.5
Heat recovery	Replacement of inefficient ventilation systems with heat recovery systems in commercial buildings	0.6	-100	300	1.6
Insulation office	Improved insulation of office buildings	0.3	-20	500	0.7
Insulation schools	Improved insulation in schools/education buildings	< 0.1	-70	100	0.5
Large cooling	Efficiency increase in large commercial air conditioning units (>12 kW)	0.2	430	500	0.3
Lighting	Switch from less to more efficient fluorescent lamps in commercial buildings; improved lighting controls in commercial buildings	1.0	-60	700	1.4
Office appliances	Efficiency increases in office appliances (e.g., reduction of stand-by losses for PCs, telephones, photocopiers)	< 0.1	-270	–	n/a

* New build homes with extremely high energy efficiency

		Abatement potential	Abatement costs	Required investment	Abatement/ investment ratio
Levers	Explanation	Mt CO_2 in 2025	€/t CO_2	€m	kg CO_2/€
BUILDINGS – COMMERCIAL/PUBLIC					
Optimisation of building controls	Optimisation of controls in commercial and public buildings for energy efficiency	0.7	-130	–	n/a
Public lighting	Replacement of mercury vapour lamps with high pressure sodium lamps for public lighting	< 0.1	-180	100	0.0
Small cooling	Efficiency increase in small commercial air conditioning units (<12 kW)	< 0.1	570	800	0.1
TRANSPORT					
Airport buildings	Combination of levers for lighting, appliances, heating/cooling and drives in airports	< 0.1	-110	< 100	1.0
Biofuels	Increasing the share of biofuels in the fuel mix with ethanol from sugar cane or second-generation biofuels from 5% in the baseline to 15%	0.5	140	–	n/a
Diesel engine efficiency package	A group of engine levers for passenger diesel cars which pay back the investment (electrification of auxiliary components, energy management, downsizing, reduced friction losses, thermo management, torque-oriented boost)	0.4	-360	500	0.8
Diesel engine levers without payback	Start-stop function for passenger diesel cars	< 0.1	770	< 100	0.0
Diesel non-engine levers with payback	Low rolling resistance tyres and weight reduction for diesel cars	< 0.1	-220	< 100	0.5
Diesel non-engine levers without payback	A group of non-engine levers for diesel passenger cars which do not pay back the investment (advanced automatic transmission, dual-clutch, improved aerodynamic efficiency, piloted gearbox)	< 0.1	1,600	1,000	0.1
Efficiency bus	Levers improving the engine efficiency as well as the aerodynamics for buses	< 0.1	-70	< 100	0.4
Heavy commercial engine efficiency package	Levers improving the engine efficiency as well as the aerodynamics for heavy commercial vehicles	< 0.1	-40	< 100	0.7
Hybrid bus	Full-hybrid engine for buses	0.2	-240	500	0.4
Hybrid diesel	Mild-, full-hybrid engine and start-stop function with regenerative braking for diesel passenger cars	0.1	2,030	2,300	0.1
Hybrid light commercial	Mild-, full-hybrid and start-stop with regenerative braking for petrol light commercial vehicles	0.1	290	600	0.2
Hybrid petrol	Mild-, full-hybrid and start-stop with regenerative braking for petrol passenger cars	0.2	1,480	2,900	0.1
Light commercial engine efficiency package	A group of engine levers for light commercial vehicles (electrification of auxiliary components, energy management, downsizing, reduced friction losses, start-stop function, thermo management, torque-oriented boost)	< 0.1	-360	< 100	1.3
Light commercial non-engine levers	A group of non-engine levers for light commercial vehicles (dual-clutch, improved aerodynamic efficiency, low rolling resistance tyres, weight reduction, piloted gearbox)	< 0.1	-240	< 100	0.6

		Abatement potential	Abatement costs	Required investment	Abatement/ investment ratio
Levers	**Explanation**	Mt CO_2 in 2025	€/t CO_2	€m	kg CO_2/€
TRANSPORT					
Petrol engine efficiency package	A group of engine levers for petrol passenger cars which pay back the investment (direct injection, electrification of auxiliary components, energy management, downsizing, reduced friction losses, thermo management, variable valve timing)	0.7	-300	1,600	0.4
Petrol engine levers without payback	Start-stop function and variable valve control for petrol passenger cars	< 0.1	90	400	0.2
Petrol non-engine levers with payback	Low rolling resistance tyres, weight reduction and optimised transmission for petrol cars	< 0.1	-290	200	0.4
Petrol non-engine levers without payback	A group of non-engine levers for petrol passenger cars which do not pay back the investment (advanced automatic transmission, dual-clutch, improved aerodynamic efficiency, piloted gearbox)	< 0.1	1,100	1,200	0.1
Rail management	Optimisation of capacity utilisation and more energy-efficient acceleration and braking of the trains	< 0.1	-300	< 100	0.8
Shorter rail replacement cycle	Replacing older trains with newer, more efficient trains after 25 instead of 30 years	< 0.1	460	400	0.1
Shorter tram replacement cycle	Replacing older trains with newer, more efficient trains after 25 instead of 30 years	< 0.1	150	< 100	0.2
Shorter underground replacement cycle	Replacing older trains with newer, more efficient trains after 25 instead of 30 years	< 0.1	560	400	0.1
Traffic management	Optimisation of traffic flow leading to less congestion and less braking/acceleration activity through IT system (based on existing traffic management infrastructure)	< 0.1	-10	< 100	4.4
Tram management	Optimisation of capacity utilisation and more energy-efficient acceleration and braking of the trains	< 0.1	50	< 100	0.2
Underground management	Optimisation of capacity utilisation and more energy-efficient acceleration and braking of the trains	< 0.1	-240	< 100	0.9
DECENTRAL ENERGY					
Biomass boilers	Penetration of biomass boilers to around 1% in new residential and commercial developments	< 0.1	10	< 100	2.4
Building based CHP (Combined Heat and Power)	Dedicated gas engine CHP systems on site for building complexes such as hospitals, university campuses (0-5 MWe each)	< 0.1	-110	< 100	0.5
Domestic CHP	Small CHP units (Stirling engines) instead of domestic boilers in less than 1% of homes (~1 kWe)	< 0.1	110	< 100	0.2
Gas engine CHP	Gas engine CHP in high density housing areas with mixed commercial use (0.5-10 MWe)	1.3	-170	2,900	0.4
Heat from existing power stations	Capture of heat produced by existing centralised power stations (e.g., Barking)	0.6	60	800	0.7
Large scale biomass CHP	Single biomass plant (~10MWe)	0.1	-60	< 100	1.4
Micro wind	New building developments will satisfy 20% of their electricity demand through decentral renewables (share of micro wind)	0.2	50	600	0.3

Levers	Explanation	Abatement potential* Mt CO_2 in 2025	Abatement costs €/t CO_2	Required investment** €m	Abatement/ investment ratio kg CO_2/€
DECENTRAL ENERGY					
Photovoltaic	New building developments will satisfy 20% of their electricity demand through decentral renewables (share of photovoltaic)	0.2	1,030	2,200	0.1
Solar thermal	Solar thermal heating for 10-15% of new builds and existing stock	< 0.1	850	700	0.1
Waste to energy CHP	Existing CHP in South East London is supplied with waste for fuel	< 0.1	110	100	0.5
CENTRAL ENERGY					
CCS	Carbon capture and storage for existing and new power plants (gas, coal, biomass), with and without enhanced oil recovery; viable from 2020 with slow ramp-up phase	0.4	50	< 100	6.7
Coal-to-gas shift	Planned coal new builds shift to gas; utilisation of gas plants maximised at expense of existing coal utilisation	1.5	40	–	n/a
Co-firing	Co-firing with biomass in existing power stations	< 0.1	70	< 100	8.5
Nuclear	New nuclear power plants with start date of 2019 with a maximum capacity added of 1GW per year	1.0	-10	400	2.4
Solar power	Centralised electricity production with solar power	< 0.1	1,080	< 100	0.1
Wind offshore	Incremental penetration of offshore wind at 10% above the baseline UK government renewables target	0.4	130	500	0.9
Wind onshore	Incremental penetration of onshore wind at 10% above the baseline UK government renewables target	0.4	70	400	1.0

* For Central Energy: pro-rata share for London of abatement achievable on a national level (based on electricity consumption)
** For Central Energy: pro-rata share for London of required investment on a national level (based on electricity consumption)

Levers	Explanation	Reduction potential Million m^3 of water in 2025	Reduction costs €/m^3	Required investment €m	Reduction/ investment ratio litres/€
WATER					
Aerated showerheads	Increased penetration of aerated showerheads to reduce rate of water required for equivalent shower experience	5.5	4.9	170	33
Aerated taps	Fitting of aerating modifications to domestic taps to reduce rate of water required for flowing water uses (i.e., a running tap rather than filling a container/sink)	29.6	-1.0	60	537
Dish washers	Increased penetration of best available technology for best water efficiency in dish washers	3.4	-1.5	–	n/a
Dual flush toilets	Increased penetration of dual flush systems in domestic toilets	15.2	-1.2	40	409
Grey water gardening	Use of grey water for gardening with siphon/hose	1.4	0.2	10	130
Increasing meter penetration	Increased penetration of water meters to all households	30.0	0.9	510	59
Washing machines	Increased penetration of best available technology for best water efficiency in washing machines	17.2	-1.5	–	n/a

Data sheet

Variable	2005	2025	Units	Source
GENERAL				
Population	7.5	8.3	Million inhabitants	Office of National Statistics
Number of jobs	4.6	5.5	Million jobs	Greater London Authority (GLA)
Gross Value Added (GVA) of London	266	n/a	€bn	GLA
GREENHOUSE GASES				
Total emissions	47.0	45.2*	Mt CO_2	
Buildings	34.9°	33.2*	Mt CO_2	GLA, McKinsey & Company
Industry	-°	-°	Mt CO_2	GLA, McKinsey & Company
Transport	12.1	12.0*	Mt CO_2	GLA, McKinsey & Company
BUILDINGS				
Emissions total	34.9	33.2*	Mt CO_2	GLA, McKinsey & Company
Commercial/public	14.6	13.0*	Mt CO_2	GLA, McKinsey & Company
Industrial	3.1	2.7*	Mt CO_2	GLA, McKinsey & Company
Residential	17.2	17.5*	Mt CO_2	GLA, McKinsey & Company
Floor space total	348	385	Million m^2	GLA, McKinsey & Company
Commercial/public	84	98	Million m^2	GLA, McKinsey & Company
Industrial	26	21	Million m^2	GLA, McKinsey & Company
Residential	238	266	Million m^2	GLA, McKinsey & Company
Heating degree days	2,327	2,327	degree days	
Cooling degree days	265	265	degree days	
TRANSPORT				
Emissions total	12.1	12.0*	Mt CO_2	GLA, UK Department of Business, Enterprise & Regulatory Reform (BERR), McKinsey & Company
Airports	1.1	1.4*	Mt CO_2	GLA, McKinsey & Company
Buses	0.8	0.6*	Mt CO_2	BERR, McKinsey & Company
Cars	6.0	5.9*	Mt CO_2	BERR, McKinsey & Company
Rail	0.4	0.3*	Mt CO_2	GLA, McKinsey & Company
Road freight	2,7	2.8*	Mt CO_2	BERR, McKinsey & Company

Variable	2005	2025	Units	Source
TRANSPORT				
Taxis/PHVs	0.5	0.5*	Mt CO_2	McKinsey & Company
Tram	<0.1	<0.1*	Mt CO_2	GLA, McKinsey & Company
Two-wheel vehicle	0.1	0.1*	Mt CO_2	BERR, McKinsey & Company
Underground/light rail	0.4	0.4*	Mt CO_2	GLA, McKinsey & Company
CO_2 emissions per passenger km	128	104*	g CO_2/passenger km	
Buses	119	77*	g CO_2/passenger km	GLA, McKinsey & Company
Car	151	127*	g CO_2/passenger km	GLA, McKinsey & Company
Rail	60	41*	g CO_2/passenger km	GLA, McKinsey & Company
Taxi/PHV	192	166*	g CO_2/passenger km	GLA, McKinsey & Company
Tram	49	41*	g CO_2/passenger km	GLA, McKinsey & Company
Two-wheel vehicles	129	105*	g CO_2/passenger km	GLA, McKinsey & Company
Underground/light rail	52	44*	g CO_2/passenger km	GLA, McKinsey & Company
CO_2 emissions from airport per weight load unit	12,601	12,520*	g CO_2/weight load unit km	GLA, McKinsey & Company
CO_2 emissions per freight vehicle km	548	431*	g CO_2/km	GLA, McKinsey & Company
Total passenger kms	64,477	74,652	Million passenger km	GLA, McKinsey & Company
Buses	6,714	7,774	Million passenger km	GLA, McKinsey & Company
Car	40,000	46,313	Million passenger km	GLA, McKinsey & Company
Rail	6,370	7,375	Million passenger km	GLA, McKinsey & Company

Variable	2005	2025	Units	Source
TRANSPORT				
Taxi/PHV	2,608	3,020	Million passenger km	GLA, McKinsey & Company
Tram	116	134	Million passenger km	GLA, McKinsey & Company
Two-wheel vehicles	823	953	Million passenger km	GLA, McKinsey & Company
Underground/light rail	7,846	9,084	Million passenger km	GLA, McKinsey & Company
ENERGY SUPPLY				
Carbon intensity of generation				
Coal	0.95	0.90*	t CO_2/MWh	BERR, McKinsey & Company
Gas	0.39	0.36*	t CO_2/MWh	BERR, McKinsey & Company
Nuclear	–	–	t CO_2/MWh	BERR, McKinsey & Company
Oil	0.76	0.76	t CO_2/MWh	BERR, McKinsey & Company
Renewables	–	–	t CO_2/MWh	BERR, McKinsey & Company
Other	–	–	t CO_2/MWh	BERR, McKinsey & Company
Overall	0.47	0.43*	t CO_2/MWh	BERR, McKinsey & Company
ELECTRICITY GENERATED				
Total	368	415*	TWh	BERR, McKinsey & Company
Coal	125	119*	TWh	BERR, McKinsey & Company
Gas	135	202*	TWh	BERR, McKinsey & Company
Nuclear	75	25*	TWh	BERR, McKinsey & Company
Oil	2	1*	TWh	BERR, McKinsey & Company
Renewables	17	48*	TWh	BERR, McKinsey & Company
Other	14	19*	TWh	BERR, McKinsey & Company
SHARE OF GENERATION				
Coal	34%	29%*		BERR, McKinsey & Company
Gas	37%	49%*		BERR, McKinsey & Company
Nuclear	20%	6%*		BERR, McKinsey & Company
Oil	1%	<1%*		BERR, McKinsey & Company
Renewables	5%	12%*		BERR, McKinsey & Company
Other	3%	4%*		BERR, McKinsey & Company

Variable	2005	2025	Units	Source
WATER				
Water produced	681	685*	Million m^3	Water Services Regulation Authority (Ofwat), McKinsey & Company
Water consumed	451	486*	Million m^3	Ofwat, McKinsey & Company
WASTE				
Commercial/industrial	6.6	7.9*	Mt	GLA
Construction/demolition	7.2	8.0*	Mt	GLA
Municipal	4.3	4.7*	Mt	GLA
AIR				
NOx	67,042	n/a	t	GLA
PM10	3,076	n/a	t	GLA
SOx	1,460	n/a	t	GLA
ENERGY PRICES				
Oil	59	60	US$/barrel	International Energy Agency (IEA)
Gas	35	41	€/MWh	McKinsey & Company
ELECTRICITY				
Commercial	102	132	€/MWh	BERR, McKinsey & Company
Retail/consumer	119	141	€/MWh	BERR, McKinsey & Company
DISCOUNT RATES FOR DECISION MAKERS				
Consumers				
Secured on home	6%			Bank of England, McKinsey & Company
Unsecured	10%			Bank of England, McKinsey & Company
Businesses	9%			McKinsey & Company
Public sector	4%			McKinsey & Company
EXCHANGE RATES				
Exchange rate USD/EUR	0.80	0.65	US$/€	Global Insight
Exchange rate GBP/EUR	0.68	n/a	£/€	Global Insight

° Industry emissions mainly stem from industrial buildings, so they are subsumed in the "buildings" section in the text
* Baseline figures before any technology implementation

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