



Low Carbon Cities: an Overview of Scenario-based Studies

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1.0 Introduction

A recent article in New Scientist (Barley, 2010: 32) suggested that '*there are many reasons to expect that cities might actually reduce each individual's carbon footprint, all of which hinge around the fact that cities concentrate people closer together rather than spreading them thinly across the landscape*'. This is not to suggest that cities are 'green utopias': they do generate large amounts of carbon emissions and deplete resources, but not only are there complexities over how we measure these emissions, cities can be part of the solution to these same issues because they offer access to capital; economies of scale and the opportunity to rapidly deploy technologies in retrofit programmes.

As Weisz and Steinberger (2010) suggest, the 2008 World Energy Outlook chapter devoted to cities (IEA, 2008) was a milestone in recognising the potential impact of cities both positively and negatively. Indeed there are an increasing number of studies which have attempted to model the impact of energy use and carbon emissions in cities (see Dhakal, 2010 for a comprehensive overview). Much of this work has been carried out against the backdrop of the 'Low Carbon Development' (LCD) agenda which seeks to move countries and cities towards a more sustainable future (Skea and Nishioka, 2008). Some of these studies include scenario-based analysis but there has been very little academic literature which compares and contrasts the techniques used in these studies. The aim of this short paper is therefore to examine these studies in more detail in the context of the development of the LCD agenda.

2.0 Low Carbon Development

A low carbon development plan (LCDP) offers one way in which climate change responses and sustainable development ambitions can be linked, and in this context a LCDP should be viewed as part of but not synonymous with sustainable development (King, 2009). A variety of definitions of LCDP (or low carbon economy (LCE) or low carbon society (LCS) that would result from this plan) have been developed. Skea and Nishioka (2008), for example, suggest that a low carbon society should:

- Take actions that are compatible with the principles of sustainable development ensuring that the development needs of all groups within society are met;
- Make an equitable contribution towards reducing global carbon emissions;
- Demonstrate a high level of energy efficiency and use low-carbon energy sources and production technologies;
- Adopt patterns of consumption and behaviour that are consistent with low levels of greenhouse gas emissions.

Whilst these are generic in application there are different implications for different countries at different stages of development. For example, for developed nations this involves making deep cuts by the middle of this century, whereas developing countries will need to achieve a level of cuts that is compatible with wider development goals. Other definitions include (King, 2009):

- A development path that simultaneously restrains energy demand growth, drives new production towards low carbon sources, and provides sufficient, secure energy

supply for global economic growth (Renewable Energy and Energy Efficiency Partnership, 2007)

- Sustainable growth which helps reduce GHG emissions and environmental pollution (Cho, 2008).

One of the first national government references to a low carbon economy was the UK's 2003 White paper on Energy (Secretary of State for Trade and Industry, 2003). Here a LCE was seen as a development path where 'higher resource productivity, producing more with fewer natural resources and less pollution, will contribute to higher living standards and a better quality of life', which underpinned the subsequent commitment to reduce carbon emissions by 60% by 2050. Other countries such as Japan have also adopted similar plans (Fujino, 2008, Strachan et al, 2008). In these and other LCDP/LCE/LCS ambitions, energy is strongly centre stage with commitments to (King, 2009):

- Reduce energy demand
- Move away from carbon-intensive fossil fuels
- Continuing to meet the development needs of all within society
- Ensuring energy security and
- Adopting appropriate technologies and policies.

Urban and Mulugetta (2009) and Urban and Sumner (2010) offer a helpful conceptualisation of low carbon development, which can be mapped by axes that represent changes in production and growth. As Figure 1 shows there are four broad categories of LCD, which are also outlined in Table 1.

Figure 1 Types of low carbon development (LCD) (Mulugetta and Urban, 2010)

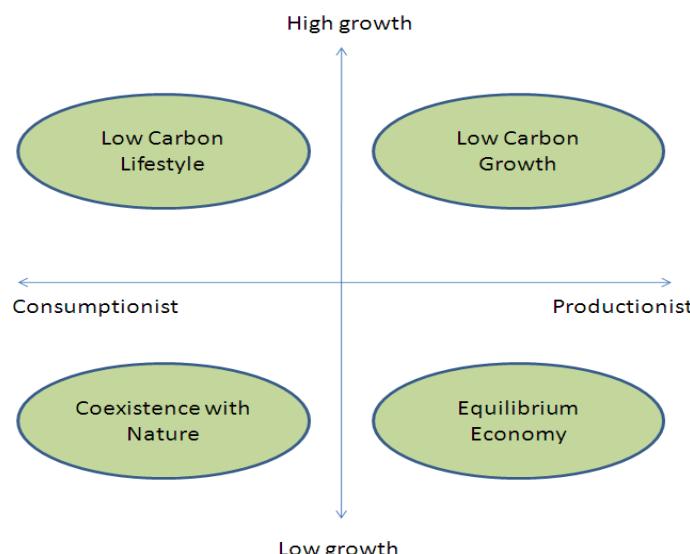


Table 1 Types of LCD (Urban and Mulugetta (2009) and Urban and Sumner (2010))

Types of Low Carbon Development	Focus and approach
Low Carbon Growth ('Green Economy'): Focuses on the production side of an economy and on how goods and services can be produced with lower emissions. It aims at decoupling	Focus mainly on mitigation, though adaptation also plays a role. Approach: Technological change, sectoral change

economic growth from carbon emissions (e.g. halving emissions, but doubling GDP).	
Low Carbon Lifestyle ('Green lifestyles'): Focuses on the consumption side of a growing economy and on the consumer's ability to reduce emissions by consuming climate-friendly products. It implies lifestyle changes and behavioural changes and also leads to a decoupling of carbon emissions (e.g. halving emissions, but doubling GDP).	Focus equally on mitigation and adaptation. Approach: Behavioural changes, sectoral change, technological change
Equilibrium economy: Focuses on the production side of an economy and aims at development rather than growth. No decoupling is necessary as growth is neutral (e.g. halving emissions, but keeping GDP stable).	Focus mainly on mitigation, though adaptation also plays a role. Approach: Technological change, sectoral change
Coexistence with nature: Focuses on the consumption side of an economy and aims at development rather than growth. No decoupling is necessary as growth is neutral (e.g. halving emissions, but keeping GDP stable).	Focus equally on mitigation and adaptation. Approach: Behavioural change, sectoral change, technological change

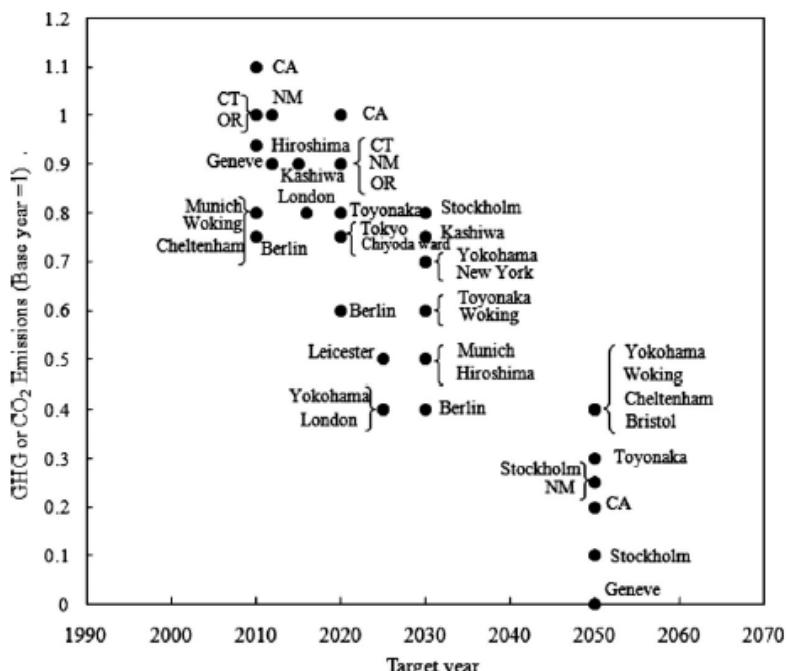
The first two types of LCD (lifestyle and growth) assume that economic growth is compatible with significant carbon reductions, whereas the co-existence and economy paths do not. The growth and equilibrium economy approaches put an emphasis on reducing carbon production through technological change whilst the lifestyle and co-existence approaches focus on reducing demand through lifestyle and behavioural choices.

3.0 Low Carbon Cities

As Skea and Nishioka (2008) point out, whilst LCD is a long-term goal, there are practical steps that can be taken today. A number of 'experiments' have therefore been conducted at city scale in the LCD arena (see Deacon, 2007). Hodson and Marvin (2010) see the emergence of low and zero carbon cities as a response to resource constraints and energy security by decision-makers to reconfigure cities, set within the broader context of low carbon visions for the future. As governance and management systems become more sophisticated, new urban metrics will be required (Kennedy et al, 2009). These include measures of urban competitiveness; gross metropolitan product; greenhouse gas emissions; material flows and vulnerability to climate change.

A large number of municipalities around the world have set low carbon goals for 2020 and beyond (Gomi et al, 2010) (Figure 2). Li et al (2010) list some of these examples ranging from Bangkok and Berkeley through to Wellington and Worcester (UK). Also more than 500 of the International Coalition for Local Environmental Initiatives (ICLEI) have established greenhouse gas emissions baselines (Kennedy et al, 2009). Eighteen EU urban areas have used Greenhouse Gas Regional Inventory Protocol GRIP) (also in Scotland and Sacramento, CA). The majority of these studies use techniques based on the IPCC guidelines but there are differences in methodology.

Figure 2 Low carbon targets from local governments around the world (Gomi et al, 2010)



In China for example the WWF's 'Low Carbon City Initiative' (LCCI) 'aims to explore low carbon development models' by supporting research and implementation, exploring new finance and investment opportunities and improving public awareness. Initial pilots are based in Shanghai and Baoding. Sceptics have argued (Jianquiang, 2010) that China's low carbon cities are in reality 'high carbon' but nonetheless this represents an example of how national and city level interest are being mobilised and deployed to tackle climate change and related issues.

A similar experiment has also been conducted in the UK with the Low Carbon Cities programme¹ supported by the Carbon Trust which is focused on Bristol, Leeds and Manchester and which is closely linked with the Core Cities programme. Under the new scheme, the Carbon Trust and the Energy Saving Trust will work with Leeds, Bristol and Manchester to develop individual city-wide action plans to achieve low carbon economies which are both prosperous and sustainable. New measures and initiatives will be introduced and could include renewable energy and tri-generation (creating power, heat and cooling from a single source) along with energy saving measures such as insulation and promoting cycling to work. Key public service bodies, businesses and community leaders in each of the cities will contribute to the strategy and its implementation.

Globally there have been a number of studies which have focused on LCD, and in particular carbon emissions. These have often been conducted on the premise that cities create between 60-80% of carbon emissions globally and nationally (see for example, studies cited by Dhakal, 2010). However, in many cases, as Satterthwaite (2010) points out, some studies may assume that all industries and power stations are in cities, or they may be confusing

¹ See <http://www.lowcarboncities.co.uk/cms/>

cities with ‘urban centres’ (which may well be smaller than cities). In his view, the real figure is closer to 60%, although a recent IEA study (2008) put the figure at 71% (with equivalent energy demand at 67%) in 2006. It is also true that (i) cities (with one or two exceptions) produce lower per capita emissions than the countries in which they are located; and (ii) 20% of the world’s population living in high income countries accounts for nearly half of global carbon emissions (Dodman, 2008). This suggests that high consumption lifestyles in the world’s wealthiest nations are an important issue to address.

3.0 Examples: UK and International

The following section includes a short overview of recent, relevant scenario-based studies relating to low carbon cities.

3.1 London (London Energy Partnership)

3.1.1 Background

London is characterised by complex urban energy governance structures (Keirstead and Schulz, 2010). For example, besides the Greater London Authority, national and international agencies set many of the general priorities and market conditions in London and the 32 boroughs address a range of smaller scale issues. In the context of the GLA there are for example three major documents: the energy strategy; climate change action plan and spatial development strategy. Key initiatives include Energy Action Areas, the London Energy and GHG Emissions Inventory and a target of 375MW of renewable electricity capacity installed by 2020.

3.1.2 Scenarios

In 2006 the London Energy Partnership (2006) commissioned SEA/RENU to develop a stretch target (or visionary ambitious target) for carbon savings to 2026 and then to produce four scenarios to meet the target. A fifth ‘hybrid’ target was added subsequently. The five scenarios were developed to meet a 60% reduction on 2000-based emissions by 2050 and contain the same mix of technologies to achieve the target but with different proportions. These are (Table 2):

- Large scale CHP led
- Micro-CHP led
- Renewables led
- Insulation and Efficiency led
- Hybrid which is a combination of all of the above scenarios.

The hybrid scenario was ultimately preferred, based around the most effective in terms of NPV (large scale CHP) but also including elements of the other three scenarios.

Table 2 Summary of results from the London Carbon Scenarios (from London Energy Partnership, 2006)

Scenarios	Description	Heat (GWh/y)	Power (GWh/y)	CO ₂ Savings (ktpa)	Capital Cost (£m)	NPV (£m)
Scenario 1	Large CHP	30,296	23,587	10,442	8,392	1,192
Scenario 2	Building &	58,478	22,799	10,285	7,455	-531

	micro CHP					
Scenario 3	Renewables	21,852	13,380	10,414	14,591	-4,237
Scenario 4	Insulation and Energy Efficiency	38,177	14,526	10,362	10,797	-1,429
Scenario 5	Hybrid	29,843	18,184	10,344	8,427	678

Scenario 5, the preferred scenario adopted a range of measures shown in Table 3.

Table 3 Summary of measures adopted in Scenario 5 (London Energy Partnership, 2006)

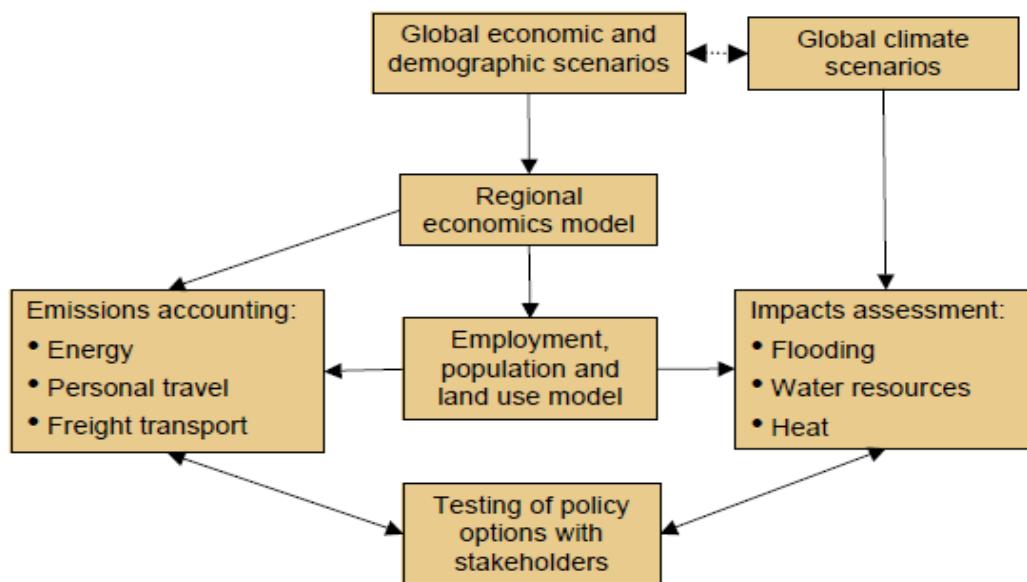
Technology		Installed Capacity by 2026	Comments
Biomass CHP	MW _e	500	It has been estimated that 200MW _e of biomass CHP are required to comply with the Mayor's Energy Strategy.
Large Gas CCGT CHP	MW _e	1,500	Lower than scenario 1, but some capacity has been included within the biomass CHP technologies.
Gas CHP – building	MW _e	500	1,000 MW _e assumed for this scenario, UK potential estimated to be 12GW _e by 2020 by CHPA.
PV – domestic	MW _p	100	Some uptake of domestic PV has been assumed.
PV- large	MW _p	100	Similar as above.
Wind - large	MW _e	50	Mayor's Energy Strategy proposes no less than 6MW _e .
Wind - domestic	MW _e	50	Mayor's Energy Strategy proposes no less than 0.5MW _e . A large uptake of domestic wind has been assumed here.
Solar thermal	Dwellings	100,000	Mayor's Energy Strategy proposes no less than 75,000 domestic systems. It has been estimated that there are more than 1.5 million houses in London.
Biomass boilers - large	MW _{th}	250	There are no real targets for biomass boilers.
Biomass boilers - domestic	Dwellings	25,000	As above, but in this case they would be applicable to houses with space for fuel storage.
GSHP	Dwellings	5,000	This is not considered to be a very cost effective retrofit measure and it would applicable only to new houses.
Micro-CHP stirling	MW _e	100	Defra proposes 0.5GWe and EST 3.2GWe by 2020 for the UK. CHPA estimates 1.5GWe by 2020.
Micro-CHP fuel cell	MW _e	50	As above.
Cavity wall insulation	Dwellings	1,000,000	It has been estimated to be more than 1 million homes with unfilled cavity wall in London.
Loft insulation	Dwellings	1,500,000	It has been estimated to be more than 2

			million homes with low levels of loft insulation in London.
Double glazing	Dwellings	800,000	It has been estimated that more than 800,000 homes have single glazing in London.
Solid wall insulation	Dwellings	1,000,000	It has been estimated to be more than 1 million homes with solid walls in London.
Heat from Power Stations	MW _{th}	250	It has been estimated that there are some 250MWth that could be potentially used from existing power stations in London (SELCHP & Barking). In this scenario only 100MWth are included.

3.2 London (Tyndall Centre Study)

Work by the Tyndall Centre (Dawson et al, 2009) has developed an integrated assessment framework for cities which attempts to link climate impacts, adaptation and mitigation strategies in the same quantified framework. The framework set in the city context within the global context of climate and economy, and this provides the boundary conditions for city scale analysis in London. The boundary conditions in the model drive scenarios of regional economy and land use change (Figure 3).

Figure 3 Overview of Integrated Assessment methodology for carbon emissions and climate impacts analysis at a city scale (Dawson et al, 2009)



3.3 Manchester

3.3.1 Background

In 2009 Greater Manchester was designated one of two city pathfinder regions, and subsequently as the UK's first Low Carbon Economic Area for the Built Environment. The intention behind this was to help enable an acceleration of low carbon activities and to help underpin improved productivity. The mini-Stern review for Manchester (Deloitte, 2008) had

already identified £20bn of additional business from putting a low carbon plan in place. The vision promoted by AGMA was therefore that by 2015 Greater Manchester has established itself as a world leader in the transformation to a low carbon economy. In particular it is expected that by 2015 the LCEA could (AGMA, 2010):

- Deliver up to £650m additional Gross Value Add (GVA).
- Support 34,800 jobs in total (including 18,000 in the supply chain) and contribute approximately £1.4 billion GVA in the built environment in total; the increased jobs would result in the workless getting into work and provide skills progression for those already working in the sector or related sectors.
- Save 6 million tonnes CO₂ from 2010 to 2015.
- Benefit the North West and UK through developing and sharing best practice, as well as economic spill-over benefits.
- Benefit other European areas through developing and sharing best practice, as well as economic spill-over benefits.

3.3.2 Initial Scenarios

Four worked scenarios were developed to highlight how large-scale retrofit programmes in Greater Manchester could help deliver the key benefits outlined above. The scenarios were:

- Residential retrofit
- Non-residential retrofit (commercial multi-let offices)
- Public sector retrofit
- New Build and supply (landfill gas generation)

A summary of the scenarios is given in Table 4. As such they represent project descriptions rather than scenarios which identify particular trajectories.

Table 4 AGMA Worked Scenarios (AGMA, 2010)

Scenario	Description
Residential retrofit	This scenario aims 'to deliver basic energy efficiency measures to homes at scale across Greater Manchester, with 75% of all remaining homes with under-insulated lofts or un-insulated cavities to be treated by 2013.' In terms of residential retrofit installing insulation in 280,000 homes over a five year period would save Greater Manchester residents nearly £23m in energy bills during that period alone. The scenario presented only focuses on the low cost cavity wall and loft insulation interventions. In this scenario it is assumed that the cost per property of insulating amounts to just over £600. The total amount of funding required to install insulation across the 280,000 properties is therefore just over £170m.
Non-residential retrofit (commercial multi-let offices)	This hypothetical scenario, set out in <i>Figure 6</i> , assumes a 100,000 sq ft multi-let office building in the regional centre, which is owned by a pooled investment fund (the landlord) and is 85% let to 9 tenants on standard fully repairing and insuring leases. Tenants comprise two public agencies, three professional services firms, a public limited company selling products to the public sector and a high-street bank. Additionally, there are two food retail units on the ground floor. Lease expiries range from eighteen months to six

	years. The property was built in the mid 1980s.
Public sector retrofit	The public sector occupies real estate across the region, which, generally speaking, would benefit from retrofit to reduce the carbon footprint, energy spend and increase occupational comfort. Local authorities are invariably participants in the Carbon Reduction Commitment, and reducing the carbon footprint of their real estate can be a major driver in reducing their exposure under the scheme. However, the availability of capital budget is likely to be limited. In this scenario it is assumed that a £4m retrofit programme across a number of publicly owned and occupied buildings is expected to yield energy savings of 20-25%. If it is assumed that the £4m investment yields energy savings of £750k per annum, and the savings are shared between the service provider and local authority on a 75:25% ratio, with a contract term of 15 years.
New Build and supply (landfill gas generation)	The vision and 5 year outcome is that from 2019 all new developments will be zero carbon. Where possible the scenario will accelerate this process and bring forward investments in energy infrastructure ahead of new developments. In achieving this acceleration one of the projects identified by WP3 is the Pilsworth Landfill Gas Generation Heat Off-take ('PHeat') project.

3.3.2 Sustainable Energy Action Plan (SEAP) Scenarios

Manchester is my Planet has built on this initial work by AGMA to work with Arup and other partners to develop a Sustainable Energy Action Plan (SEAP) for Manchester. This will inform and shape energy priorities at city-regional level.² Part of the SEAP development process involved a wide range of partners in visioning future energy scenarios using Carbon Captured's GRIP Scenario Tool (see below). The SEAP development work has been made possible with participation in the trans-national PEPESEC. In addition Manchester: Knowledge Capital has contributed to the establishment of a new Energy Group that is working to advance low-carbon actions at city-regional level. The SEAP recommends new CO2 reduction targets for Greater Manchester of 34% by 2020 and 90% by 2050.

In developing the SEAP two scenarios were explored—DEFRA market transformation (assuming 16% renewables by 2020) and the low carbon transition plan, assuming 40% of electricity is low carbon by 2020 (ARUP, 2010).

The Greater Manchester Environment Commission (GMEC) was also formed in May 2009 to co-ordinate the delivery of strategic environmental plans and projects, including the SEAP (Manchester Knowledge Capital, 2010). Future energy scenarios were produced using GRIP methodology to bring about the CO2 reduction targets identified above.

3.4 Other UK examples: region and city region

3.4.1 West Midlands Housing³

² See <http://manchesterismyplanet.com/sustainable-energy-action-planning>

³ For other regional examples in the UK see the 'Sustainable Consumption and Production Network' (<http://www.scenet.org.uk/>)

This study was based on Resources and Energy Analysis Programme (REAP) methodology underpinned by Material Flows Analysis and National Environmental Accounts and National Footprint Accounts (SEI, 2007). REAP-based methods can incorporate the following change variables within a ‘built environment’ component:

- Demolition rates
- Demolition mix by housing type
- Number of new houses (building rates) in total and according to housing type
- Retrofit rate
- Electricity mix
- Effectiveness of building regulations
- Population projections

The report formed part of the technical advice to inform Phase 2 of the revision process for the Regional Spatial Strategy. Using housing growth projections four scenarios were produced and evaluated:

1. Introduction of Ecohomes (100% by 2015).
2. All new builds will have 25% of renewable on-site energy by 2015.
3. A “combined moderate” scenario including:
 - All new builds have 25% on-site renewables by 2015
 - By 2015, all new builds will be “Ecohomes excellent”
 - The demolition rate will be increased to 400% by 2026
 - Energy consumption through retrofit measures has been reduced to 58% by 2026
 - Better enforced building regulations achieve a 3% reduction in energy consumption in new build houses per year.
4. “Combined aspirational” scenario: As in number 3 but with an EU renewable target of 25% renewable energy by 2015 and 30% by 2026.

Scenarios 3 and 4 were found to have the most significant impact on carbon emissions, but all of the scenarios would fail to achieve the carbon emissions required without ‘additional planning strategies’.

3.4.2 Greenhouse Gas Regional Inventory Project (GRIP)

Further development of methodologies has also led to the Tyndall centre’s Greenhouse Gas Regional Inventory Project (GRIP) (Carney and Shackley, 2009) and work on global cities by Kennedy et al (2009). The GRIP methodology, which is strongly focused on a stakeholder-led scenario building exercise, incorporates all supply and demand categories and is based around a three stage process:

- Set up a regional greenhouse gas inventory (or several) (IPCC sectors of energy industry, waste and agriculture).

- Develop 'Energy Scenarios'.
- Use the scenario outputs to inform plans.

GRIP has also been used in an English regional context and in Scotland, as well as internationally, and was the basis for the EU, CO2 20/50 project based at Metrex⁴ (GRIP, 2006; GRIP, 2009; CURE, 2009). For example, in the North West region project (GRIP, 2006) 40 interviews were conducted with representatives from academia, industry, policy-making, local government, NGOs and pressure groups. The purpose was to determine how stakeholders perceived the then target of 60% reduction by 2050. An array of reductions ranging from 38%-90% was produced and then four scenarios were generated. An interactive workshop then divided the stakeholders into groups and asked to backcast from 2050 to 2020 to determine what needed to be done by then to achieve the relevant end point. The four scenarios presented are shown in Table 5. GRIP methodology is based around a colour coding methodology which uses green for most certain data (level 1); orange for intermediate data (level 2) and red for lower quality data (level 3).

Table 5 GRIP Scenarios in North West Region (reductions for 2050) (GRIP, 2006)

Scenario	Description
40% reduction: "4x4"bye'	Associated with a low economic growth coupled with a predominantly unchanged level of energy demand. The economy of the North West region retains the same basic composition as that of today, while improvements in energy efficiency slightly outstrip economic growth. A small switch in fuel choices has occurred on both the demand and supply side.
50% reduction: 'Hanging out the washing'	This scenario, 'Hanging Out the Washing', is characterised by a low level of economic growth, with all sectors experiencing a net decrease in energy demand. The economy is based upon the commercial and service industries.
60% scenario: 'Greening business is usual'	This sees a future with a 60% reduction in GHG emissions, characterised by a region with an economy that has tripled in size. This phenomenal growth has been achieved in combination with a reduction in energy demand of about 20%, delivered through massive increases in efficiency, in a region that continues to be led by its service sector.
70% scenario: 'Upwardly mobile'	A combination of high level economic growth in conjunction with innovative and widespread use of new energy efficiency techniques. Although the economy has blossomed, it remains relatively unchanged in terms of its mix across the service and manufacturing sectors when compared to the year 2000.

3.4.3 UWE Carbon Management at the City scale: Exploring Carbon Futures for the Bristol Region

This PhD CASE research⁵ (Bailey, 2009; 2010) seeks to fill a knowledge gap at city scale, by undertaking a comprehensive assessment of emissions from the Bristol city region.

⁴ See <http://www.eurometrex.org/>

⁵ Taken from <http://www.uwe.ac.uk/aqm/rose.html>.
See also: http://www.iuappa2010.com/presentations/3A/a183_2.pdf

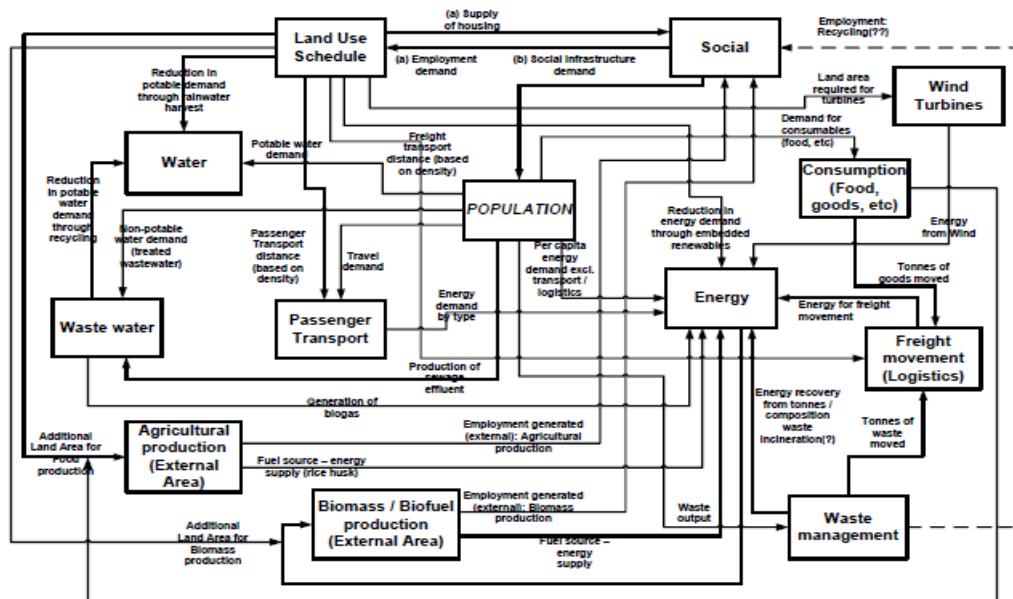
Forecasts of possible pathways for carbon emissions will be produced, based upon local development frameworks and related plans and policies, using high, low and ‘business as usual’ carbon assumptions. This will be complemented by backcasting: the identification of carbon reductions in sectors that will be required to achieve a series of alternative 2050 low-carbon ‘Bristols’. These low carbon scenarios will be generated using a quasi-Delphi technique, involving local experts. Options to close the gaps between the forecast and backcast pathways will be identified, with the outcome being the generation of a robust and practical CO₂ pathway, from the present emission state to a future low carbon scenario in 2050. This will better inform regional and local policy and decision making, and seek to close the gap between ‘what needs to be done’ and ‘what is being done’.

3.5 Other examples

3.5.1 Arup: Integrated Resource Management (IRM) Tool and Foresight/SlimCity Cards

Arup have developed a tool which it is claimed, enables a more balanced approach to sustainable urban design to be achieved. The IRM tool (Figure 4) is closely based on the concept of urban metabolism (Page et al, 2008; Roberts, 2004) and besides land use change the tool enables transport, energy, waste and water to be modelled in a linked and coherent way. The IRM model processes inputs and then outputs quantitative values linked to a comprehensive list of key performance indicators (e.g. energy consumption or total GHG emissions), which are defined within a framework set to appraise the sustainability of the whole design. The tool enables ‘what if’ scenarios to be tested.

Figure 4 IRM Tool (Page et al, 2008)



Arup (in parallel) with the World Economic Forum have also identified key issues affecting cities over the next 5 years (WEF/ARUP, 2009). The ‘knowledge cards’ produced are designed to highlight global best-practice and policy across urban mobility, smart energy and sustainable buildings. The cards offer practical solutions to many of the problems facing cities in both the developed and developing world, supporting them towards building a more resilient future. In compiling the cards, Arup’s researchers selected content on the basis that any Mayor could ask the question ‘Could we do this in our city?’ The cards were informed by

global workshops with SlimCity members, desk research, interviews with Forum members, and global research with 50 cities around the world conducted by ICLEI, the international association of local governments.

Arup have also identified key drivers for change in their FORESIGHT team across the energy, waste and water sectors but also for climate change, demographics, urbanisation and planning (ARUP, 2009).

3.5.2 International

Bhatt et al (2010) provide a very helpful description of methods for city level energy analysis and Dhakal (2010) provides a comprehensive review of urban carbon mitigation research. As Dhakal (2010) notes, comparisons of over 50 cities globally point out that differences in emissions occur because of urban economic structures (manufacturing and services balance), local climate and geography, state of economic development, fuel mix, transport and other factors. Often large cities in developing nations also emit higher per capita amounts than the developed world (Dhakal, 2009).

A useful summary of carbon emission calculators and their suitability at different scales is shown in Table 6. City-based studies have used a variety of methods to account for emissions and there is often inconsistency in regard to gases measured, emissions sources covered sectoral definitions and the type of IPCC methodology employed, and there are arguments that a carbon footprint – based methodology may more accurately represent embodied energy consumed in goods and services sourced from outside cities (Dhakal, 2010). Recent research has attempted to create a more consistent global methodology (Kennedy et al, 2010).

Table 6 Different GHG calculators and their appropriability at different scales (from Carney and Shackley, 2009)⁶

Model	Scale/Application	Other references
National air emissions inventory	UK	All six 'Kyoto' greenhouse gases
DREAM	City/urban region	High resolution data required
EEP	City/urban region	High resolution data required
Greenhouse gas protocol	Company	Detailed company data needed
Leicester model	City	
REWARD	English regions	'Mass-balance' approach
Various	Individual	Life style emission calculations
REEIO	English regions	Economic allocation
REAP	Sub-national	End-user including embodied energy

⁶ MARKAL is now also used extensively. MARKAL is a bottom-up technology model of the energy system initially developed by the International Energy Agency (IEA). As a bottom-up model it consists of a menu of energy technologies characterising the production, transmission and use of energy, with associated information on the costs of these technologies (see <http://www.energycommunity.org/default.asp?action=71>)

However, Weisz and Steinberger (2010) suggest that there are a number of research challenges with tackling research issues at city level:

- Lack of data: frequently harmonised datasets are available only at national level.
- Definitions: The terms 'city' and 'urban area' are often treated synonymously but no international definitions of these terms exist.
- Openness of cities: cities operate in their hinterlands and access resources, goods and services from this area which has a global dimension. This poses problems in measuring material and energy flows.
- Dematerialisation versus securing access: a focus on decreasing resource use overlooks a key fact for many people, that is, how to access energy and material resources. Energy poverty predominates in high income countries and many former communist states.
- Relevance of the urban scale: which components of the material and energy system are specific to urban scales, as opposed to rural and national scales?

A range of further international carbon emissions studies are provided in Table 7⁷. It is clear from these studies that they adopt 'business as usual' and 'basic policy' scenarios; they use a range of techniques for modelling impact and generally focus on five main sectors:

- Commercial;
- Industrial;
- Government;
- Residential; and,
- Transport.

The studies also raise a number of important methodological issues, which include questions over the assumptions of activity levels, including socio-economic indicators such as population, industrial output and transport demand. It is also clear that the majority of the studies fail to focus on governance systems and exclusively focus on carbon emissions.

4.0 Conclusions

Cities are part of the problem and the solution to carbon emissions and environmental issues. There are a range of methodologies which have been developed for assessing carbon emissions from cities. These methods raise a number of research challenges:

- What is the definition of a city and should the measurement of carbon emissions be production or consumption-based (i.e. end user)?
- To what extent should city based models attempt to include coterminous climate change impacts?

⁷ See also the 'Urban and Regional Carbon Management' website at : www.gcp-urcm.org

Similarly, the scenario-based models discussed here often just simply include a baseline with ‘business as usual’ and ‘policy’ as variants. Governance structures and civic society are underplayed in many scenarios so there is weak ‘co-evolutionary’ element. This raises additional questions for city-scale scenarios:

- How can city-based models best incorporate scenarios which incorporate governance structures?
- How can disruptive technologies be best included in scenario-based analysis? (for example, carbon sequestration).

Finally the GRIP approach to scenario-building, which did attempt to consider policy/governance structures at city level, used ‘backcasting’ from a future vision in 2050 to help shape outcomes for 2020. Delphi-based techniques and interviews with workshops have also been used successfully to underpin this work.

Table 7 International examples of scenario-based, city-level carbon emissions studies

City	Country	Scenarios	Technique	Description	Sectors	Reference
Jilin	China	'Business as usual' 'Policy' 'Low carbon' to 2030	IPAC-AIM (Integrated Policy Model for China)	Based upon an energy technology model which focuses on scenarios and policy interventions set against three main sectors.	Industry Buildings Transport	Chatham House, 2010 ¹
Shanghai	China	'Business As Usual' 'Basic Policy' to 2020	Future transitions/scenarios analysed Energy demand modelled Energy demand distributed to fuel types Primary Energy demand calculated Emissions calculated	Scenarios underpinned by model which includes economic growth, population growth, the structure of the economy and the energy structure.	Primary Secondary Tertiary Households	Li et al, 2010
Bangkok	Thailand	'Business As Usual' 'Intervention' (based on sixteen policies ranging across the five sectors) to 2025	Long Range Energy Alternatives Planning (LEAP) for energy demand and supply analysis and data for energy planning	Multi-criteria Decision making Approach (weighting of criteria which include resource use, environmental loading, financial and economic factors, and socio-political factors)	Commercial Industrial Government Residential Transport	Phdungsilp, 2010
Kyoto	Japan	"2030FX (fix)" (i.e. BAU) "2030CM (countermeasures)" to 2030	Backcasting techniques and builds on Shimada et al and Gomi et al, 2007.	Based on a low carbon target of 50% reduction in CO2 by 2030 compared with 1990	Household Commercial Industrial Transport	Gomi et al, 2010
Shiga Prefecture	Japan	"Business As Usual (2030)" "Cases with measures (2030)"	Three policy based scenarios for CM: 30% ('moderate'), 40% ('hi-tech') and 50% ('eco-	Scenarios to reduce carbon emissions by 30-50% from 1990 level by 2050 while	Industrial Residential Commercial Passengers	Shimada et al, 2007 Gomi et al, 2007

¹ See also: http://www.chathamhouse.org.uk/research/eedp/current_projects/china_lc/

References

- AGMA (2010) *Greater Manchester's Low Carbon Economic Area for the Built Environment Joint Delivery Plan*. Association of Greater Manchester Authorities.
- ARUP (2009) *Drivers for Change* (accessed November 2010 from: <http://www.driversofchange.com/>)
- ARUP/WEF (2009) Slim City Knowledge Cards (accessed November 2010 from: <http://www.arup.com/Publications/SlimCity.aspx>)
- ARUP (2010) *Sustainable Energy Action Plan*. Manchester is My Planet
- Bailey, R (2009) 'Carbon Management at the City Scale: Opportunities and Challenges'. *FET Student Conference*, June. Bristol.
- Bailey, R. (2010) 'City-Scale Carbon Management: An Innovative Methodology for Imagining a Low Carbon Future', *15th IUAPPA World Clean Air Conference*, Vancouver.
- Barley, S. (2010) 'Escape to the city', *New Scientist*, 6 November, 32-34
- Bhatt, V., Friley, P., and Lee, J. (2010) 'Integrated energy and environmental systems analysis methodology for achieving low carbon cities', *Journal of Renewable and Sustainable Energy*, 2.
- Carney, S., and Shackley, S. (2009) 'The greenhouse gas regional inventory project (GRIP): designing and employing a regional greenhouse gas measurement tool for stakeholder use', *Energy Policy*, 37: 4293-4302
- Chatham House (2010) *Low Carbon Development Roadmap for Jilin City*. Chatham House, London.
- Cho, Y. (2008) *Low Carbon Development and Growth Strategies for Emerging Economies and Developing Countries*, Korea University.
- CURE (2009) *Greenhouse Gas Emissions Inventories for 18 European Regions*. METREX.
- Dawson, R et al (2009) *A Blueprint for the Integrated Assessment of Climate Change in Cities*. Tyndall centre for Climate Change Research. Working Paper 129.
- Deacon, A. (2007) 'The low carbon society: making it happen', in DEFRA (2007) *Achieving a Sustainable Low Carbon Society*, DEFRA.
- Deloitte (2008) 'Mini-Stern' for Manchester.
- Dhakal, S. (2009) 'Urban energy use and carbon emissions from cities in China and policy implications', *Energy Policy*, 37, 4208-4219.
- Dhakal, S. (2010) 'GHG emissions from urbanization and opportunities for urban carbon mitigation', *Current Opinion in Environmental Sustainability*, 2: 277-283

Dodman, D. (2009) 'Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories', *Environment and Urbanization*, 21 (1), 185-201

Fujino, J. (2008) 'Aligning Low-Carbon Society and Sustainable Development'. *International Meeting on Mid-Long-Term Strategy for Climate Change*, £0 June, Tokyo.

Gomi, K., Shimada, K., Matsuoka, Y., and Naito, M. (2007) 'Scenario study for a regional low-carbon society', *Sustainability Science*, 2: 121-131

Gomi, K., Shimada, K., and Matsuoka, Y. (2010) 'A low carbon scenario creation method for a local-scale economy and its application in Kyoto city', *Energy Policy*, 38, 4783-4796.

GRIP (2006) Focus North West

GRIP (2009) *InterMetrex Project Extension*.

Hodson, M., and Marvin, S. (2010) *World Cities and Climate Change: Producing Ecological Security*. McGraw Hill.

IEA (2008) 'Energy Use in Cities' in International Energy Authority (IEA), *World Energy Outlook*.

Jiangqiang, L. (2010) 'China's Low Carbon Cities: from Sham to Reality', *China Dialogue* (downloaded November 2010 from : <http://www.chinadialogue.net/article/show/single/en/3916-From-sham-to-reality>)

Keirstead, J., and Schulz, N. (2010) 'London and beyond: taking a closer look at urban energy policy', *Energy Policy*, 38: 4870-4879.

Kennedy, C., Ramaswani, A., Carney, S., and Dhakal, S. (2009) Greenhouse Gas Baselines for Global Cities and Metropolitan Regions'. *Proceedings of the 5th Urban Research Symposium*, Marseille, France, June 28-30.

Kennedy, C., Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., Havranek, M., Pataki, D., Phdungsliip, A., Ramaswami, A., Mendez, G. (2010) 'Methodology for inventorying greenhouse gas emissions from global cities', *Energy Policy*, 38, 4828-4837.

King, P (2009) *Low Carbon Development Path in Asia-Pacific*. Institute for Global Environmental Studies.

Knowledge Capital Ltd. (2010) *Developing Future Energy Scenarios for Greater Manchester*. Knowledge Capital Ltd.

Li , L., Chen, C., Xie, S., Huang, C., Cheng, C., Wang, H., Wang, Y., Huang, H., Lu, J., and Dhakal, S. (2010) 'Energy demand and carbon emissions under different development scenarios for Shanghai, China', *Energy Policy*, 38:4797-4807.

London Energy Partnership (2006) *London Carbon Scenarios to 2026*.

Mulugetta, Y., and Urban, F. (2010) 'Deliberating on low carbon development', *Energy Policy*, 38, 7546-7549

Page, J., Grange, N., and Kirkpatrick, N. (2008) 'The Integrated Resource Management (IRM) Model- A Guidance Tool for Sustainable Urban Design', *PLEA 2008, 25th Conference on Passive and Low Energy Architecture*, Dublin, 22-24 October.

Phdungsilp, A. (2010) 'Integrated energy and carbon modelling with a decision support system: Policy scenarios for low-carbon city development in Bangkok', *Energy Policy*, 38, 4808-4817

Renewable Energy and Energy Efficiency Partnership (2007) *Climate and Energy Security: Towards a Low Carbon Society*. Report on the Wilton Park Conference.

Roberts, C. (2010) 'Spatially-linked Integrated Resource Management (IRM): A tool to inform sustainable city planning'. *New Partners for Smart Growth 2010*, Seattle VA, February.

Satterthwaite, D. (2010) 'The contribution of cities to global warming and their potential contributions to solutions', *Environment and Urbanization*, ASIA: 1(1) 1-12.

Secretary of State for Trade and Industry (2003) *Energy White Paper: Our Energy Future-Creating a Low Carbon Economy*. Ministry of Trade and Industry.

Shimad, K., Tanaka, Y., Gomi, K., and Matsuoka, Y. (2007) 'Developing a long-term local society design methodology towards a low-carbon economy: An application to Shiga Prefecture in Japan', *Energy Policy*, 35, 4688-4703.

Skea, J., and Nishioka, S. (2008) 'Policies and practices for a low carbon society', *Climate Policy*, 8, s5-s16.

Stockholm Environment Institute (SEI) (2007) *Carbon Dioxide Emissions of West Midlands Housing: A Scenario Analysis*.

Strachan, N., T. Foxon, J. Fujino (2008) 'Low-Carbon Society (LCS) Modelling'. *Climate Policy*, 8 (2008): S3-S4.

Urban, F. and Sumner, A. (2009) *After 2015: Pro-Poor Low Carbon Development*, IDS in Focus Policy Briefings 9.4, Brighton: IDS

Weisz, H., and Steinberger, J.K. (2010) 'Reducing energy and material flows in cities', *Current Opinion in Environmental Sustainability*, 2: 185-192.