Civil Engineering for Sustainability and Resilience International Conference, **CESARE '14**
Amman, Jordan, 24-27 April 2014

A TALE OF TWO CITIES: A STUDY OF THE ENERGY SYSTEMS IN BIRMINGHAM, AN INDUSTRIALISED UK CITY, AND MASDAR CITY, A DEVELOPING CITY IN THE MIDDLE EAST

Susan E. Lee [1], Peter Braithwaite[1], Steve Severance[2], Joanne M. Leach [1] and Chris D.F. Rogers[1]

[1]School of Civil Engineering, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

e-mail:s.e.lee@bham.ac.uk; web page: http://www.liveablecities.org.uk

[2]Abu Dhabi Future Energy Company Building, Airport Road, Masdar City, Khalifa City A
54115 UAE
e-mail: sseverance@masdar.ae

Keywords: *Liveable Cities, Sustainability, Resilience, Robustness, Solar PV, Wind Power*

ABSTRACT

Energy is a vital resource in modern life. With increasingly limited availability of existing energy resources there is a raised awareness that energy needs to be used more efficiently, and generated in line with thinking on sustainability. This is essential if we wish to maintain our current way of life without compromising our well-being or the carrying capacity of the planet.

The Liveable Cities Programme, established in 2012, aims to assess how cities perform, with a view to developing the radical engineering necessary to deliver resource secure, low carbon cities which prioritise the well-being of their inhabitants. To do this, it is essential that lessons are learnt from the development of cities globally.

Birmingham is a well-established post-industrial city that has evolved over the last fourteen hundred years. It was one of the fastest growing cities in 19th century England[1]. Masdar, founded in 2008, is a dynamic new city being built in a desert environment. Its aim is to be the most sustainable city in the world and offers an exciting opportunity to provide unique insights into the application of different innovative technologies within an urban environment.

This paper demonstrates the differences and similarities between these two very different cities. It highlights the opportunities and mutual benefits that each city will gain from the experiences of the other. This work shows how a greater understanding of common issues can lead to more sustainable, resilient and robust cities, able to face the challenges of the next 50 years.

1 INTRODUCTION

Energy is a vital component in modern-day life and is responsible for the survival (food production, heating, cooling, water and transport) and day-to-day activities (mobilities, lighting, machinery, equipment, communications, and entertainment) of billions of people across the globe. Unfortunately, the current global resources supplying this energy demand are on the decline and, according to BP[2], we will have consumed all known global oil reserves by around 2066. At the same time, there is an unprecedented demand on such resources from the developing countries of the world[2]. Notwithstanding the contributions of shale gas and tight oil, the common concern of rising costs of energy and a greater awareness of the need for sustainability has spurred many nations into action to address their dwindling resource supply. In the developed world, in particular, there has been increasing interest in renewable energy. The UK's Climate Change Act (2008) states that: "It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline"[3]. The European Union has endorsed this objective arising from the Kyoto Protocol, which came into force in early 2005[4]. In the UK this legislation has also fed through to the local level with many UK councils, including Birmingham City Council, developing their own carbon plan[5]. Renewable energy plays a major part of the Government's plans for decarbonising the UK National electricity grid and for a reduction in the use of fossil fuels in the UK'S energy supply[6] .

In recent years there has been an increasing global interest in sustainable energy and several countries such as Denmark[7], Germany[8] and Sweden[9] have incorporated initiatives into their own future development plans. Another country, perhaps surprisingly given its dependence on and access to oil and gas, showing a lead in the development of sustainable energy is the United Arab Emirates. There has been phenomenal growth in this region over the last 10 years, a surge of development combined with generous government funding. Since the economic collapse of 2007 expansion has occurred at a slower pace. Some projects have been reduced in scale or stopped, but despite this, ambitious plans are still being achieved.

The Engineering and Physical Sciences- (EPSRC-) funded Liveable Cities Programme[10], established in 2012, aims to address issues of resource security as part of its sustainability remit. Its objectives are to develop a methodology to analyse how cities perform and how the flows into and out of the city, as well as internal flows, interact in the provision of goods and services for its citizens. The focus is on existing cities and how they can develop in the future. The Programme's vision is to achieve low carbon cities which are resource secure and to prioritise well-being for those who live, work and visit cities. To realise these ambitions it is vital to understand the current resource flows, of which energy is a strongly influencing component, in order to develop future strategies that can maximise resource security and efficiency of use.

In order to understand the feasibility of radical movements towards sustainability in cities, it is useful to study developments both in existing and new cities. Such studies can provide data to assess successes and identify areas where further work is required to utilise resources with maximum efficiency and obtain resources responsibly.

The aim of this paper is to explore energy supply and use in two very different cities – Birmingham, UK and Masdar City, United Arab Emirates (UAE) – with very different histories, climates and cultures and to show how developments in both can lead to a common understanding about the most efficient use of energy. The two cities are introduced followed by descriptions of their energy supply and usage. The paper concludes with a discussion about the applicability of the different renewable energy sources for each city and how this understanding will help Masdar and Birmingham to be more resilient, robust and sustainable over the next 50 years and beyond.

2 BIRMINGHAM

2.1 Birmingham, its History and its Economy

Birmingham (52°28′59″N 1°53′37″W) is the UK's second largest city after London. It is a post-industrial city with a population of just over a million[11]. Birmingham Metropolitan District covers an area of 268 km^2 with a density of 4,012 people/km[11] and employs 467,300 people[12]. Birmingham is Europe's youngest city, with 22.8% of its population under 16[13], and is ethnically diverse with people from a non-UK background accounting for 42% of the city's population[14]. Situated in the English Midlands, Birmingham is 300 m above sea level, has no major river (it is served by two minor rivers, Rivers Cole and Rea), has an extensive canal network[15], has more than 3,200 hectares of park and open spaces [16] and has 2536 km of roads [17]. It is built on fertile soil and, benefitting from a ready supply of local coal, iron, limestone and water, became a centre for iron and steel making, during the industrial revolution, hence the name "Black Country"[18].

Established around the early 7th century[19], Birmingham prospered with the development of many industries linked to metal work. During the 18th century, as part of the Midlands Enlightenment[20], it was at the forefront of worldwide developments in science and technology and grew into a major manufacturing and engineering city – in 1791 it was acknowledged to be "the first manufacturing town in the world"[21]. During the 20th Century it became renowned for car manufacturing, its Longbridge car plant opening in 1905 and by the 1960s becoming the largest in the world, employing around 250,000 workers[22]. However during the 1970s and 1980s, Birmingham's manufacturing base declined such that today its economy is led by the service sector, the latest available data (2008) showing that this sector accounted for 86% of Birmingham's employment (416,700 people)[23]. The city is the largest UK centre for employment in public administration, education and health (156,000 people)[24], and the third-largest centre for employment in banking, finance and insurance outside London[25]. Interestingly, in 2011, it was ranked as a "beta minus" world city, along with Abu Dhabi, by the Globalization and World Cities Research Network[26],[27] – an important world city instrumental in linking its region or state into the world economy[26].

2.2 Birmingham Energy Strategy

One of the Birmingham's visions "…is to create a leading green city for a better life and make Birmingham more prosperous, healthier, fairer, resource-efficient and better for business. In doing this we will enhance the quality of life and well-being for all of our citizens"[16]. Accordingly, Birmingham City Council has ambitious targets to reduce the amount of carbon produced by the city, adopting a bolder interim target (60% reduction from 1990 levels by 2027) alongside the UK Government's legally-binding targets (50% by 2027, 80% by 2050) in response to climate change initiatives[3]. To achieve this the city is relying on both national reductions in CO_2 emissions brought about by decarbonising the UK's National Grid, through the use of wind power and other renewable forms of energy, as well as the local initiatives[5] discussed hereafter. At the same time financial restrictions imposed by the National Government mean that local councils like Birmingham are seeking to reduce costs, in part via energy efficiency measures.

The UK produces and imports around 296 Mtoe (million tonnes of oil equivalent) of energy annually, consumes 148 Mtoe, experiences transmission/distribution losses of 66 Mtoe (22%, mostly from coal and gas fired power stations) and exports around 28%. UK energy consumption is divided between the three main sectors – domestic (29%), industry (17%) and transport (36%) – with other final consumers including services (commerce and the public sector) and agriculture accounting for 13%, and 5% being used for other purposes"[28].

Birmingham has the highest domestic building CO_2 emissions in the UK[5], and amongst the highest from transport (second to Leeds)[5]. Its emissions per capita, at 5 tonnes, are, however, below the UK average and in-line with emissions from other core cities[5]. This is partly due to its large population and partly due to the fact that rural areas use more energy per capita because of greater energy use at home and for transportation. Elsewhere emissions for many Local Authorities are strongly affected by industrial activities, which lead to higher overall emissions in Wales and Yorkshire and Humberside[29]. Birmingham energy consumption (Figure 1) for the domestic and industry sectors follows a similar pattern to the national figures, but the transport sector as a proportion is less prominent. This is perhaps surprising given Birmingham's history as a city of car manufacturing and road building, but as the housing sector is so large, the domestic energy consumption is correspondingly greater. Household heating dominates the domestic consumption of gas[30], while private cars[31] are the major user of petroleum fuel (including diesel).

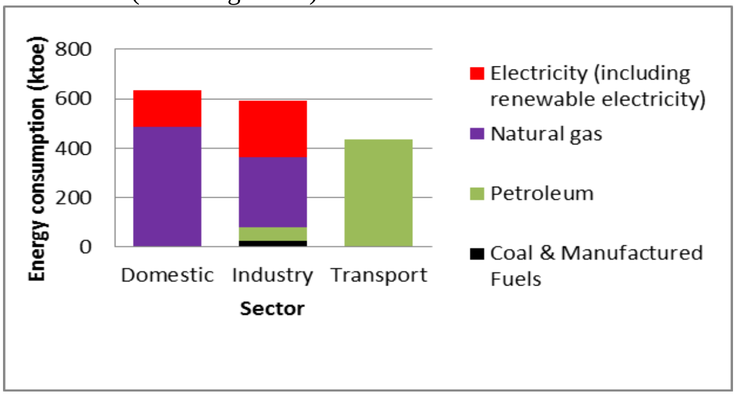

Figure 1. Birmingham Energy Consumption (ktoe) in 2011 by sector and fuel[32]

The contribution of all renewables to UK electricity generation is relatively low (11.3% in 2012), although this is 1.9% higher than the previous year and has now reached 41.3 TWh[33]. Capacity also grew by a quarter (to 15.5 GW) between 2011 and 2012. The use of renewable energy is continuing to develop both in the domestic and industrial markets. There is increasing use of wind power with both offshore (18%) and onshore (29%) wind farms contributing a total of 47% of UK's renewable electricity [30], while the use of bioenergy is also increasing. However, it should be noted that for landfill gas, sewage sludge, municipal solid waste and other bioenergy sources a substantial proportion (75%) of the energy content of the input is lost in the process of conversion to electricity[34] – e.g. in 2012, 1704 ktoe of landfill gas produced only 14ktoe which was consumed as energy[34]. Several local 'energy efficiency' initiatives have been adopted by Birmingham, including addressing heat loss from housing, making use of excess heat around the city and burning waste. For example, in 2010, the Tyseley Energy-from-Waste Plant, a large incineration plant built in 1996 for Veolia[35], burnt 366,414 tonnes of household waste and produced 166,230 MW of electricity, while a District Heating scheme supplies energy (6.8 MW_e with 32.2 MW_{th}) to several public buildings in the city centre including the new Library of Birmingham[36]. There are plans to extend the district heating network to include other private and public city centre buildings. Birmingham has very little solar renewable energy, limited to localised solar PVs on domestic housing and on some company roofs. Thus in spite of Birmingham's ambitions, the contribution of renewable energy is currently small, e.g. for 2011 the West Midlands as a whole produced around 869 GWh from renewable energy sources with 10.6 GWh from solar panels[37]. Exemplars of good practice include Birmingham Airport's installation of 200 solar panels on the roof of its terminal building generating 40 MWh and saving approximately 22 tonnes of carbon dioxide each year[38], and Severn Trent Water, exploring the production of methane gas from sewage while alongside their current use of wind turbines and solar panels.

In 2012, the Birmingham Energy Savers (BES) [36] scheme was introduced by Birmingham City Council in partnership with a private energy company. Its aim is to retrofit 29,000 domestic properties and 163 non-domestic buildings in the first three years of operation and to help 26,000 people out of fuel poverty. In addition, BES plans to develop a collective energy project to enable people to lower their bills through collaboration. To date, BES has carried out 750 assessments, scheduled a further 330, and retrofitted seven tower blocks (providing gas-powered ecopods, a low carbon heating system, and external wall insulation), 100 houses, two schools, five community centres, a church and a business centre. The scheme has saved 20,000 tonnes of CO_2.

3 MASDAR CITY

3.1 Masdar City, its History and Development

Masdar City (24°25′45″N 54°37′6″E) is a large-scale mixed use real estate development which lies 17km south-east of the centre of Abu Dhabi, the capital of Abu Dhabi Emirate in the United Arab Emirates. Abu Dhabi had an estimated population of 968,000 in 2012[39] and a population density of 130 people/km^2 in the city region[40], though with 39 people/km^2 for the Emirate as a whole. The city of Abu Dhabi is located on a low-lying island and surrounded by desert (70% of Abu Dhabi Emirate's land area is desert)[41].

The Emirate's economy is heavily dependent on the production and selling of oil and natural gas, with petroleum royalties and tax income accounting for nearly 90% of Abu Dhabi Government revenues[41].The country as a whole is a high user of natural gas, which is used in its power stations to generate electricity (47 TWh in 2012[42]) for the domestic market and the desalination of water. In addition, the UAE has embarked on a nuclear programme with two nuclear power stations underway and two more planned. These are due to be completed by 2020 with a combined electric capacity of 5.6 GWe[43].

Against this backdrop, Masdar City has been established to develop sustainable energy and to act as a showcase for new technologies. The government of Abu Dhabi has a target of 7% of renewable energy capacity by 2020[44]. It has committed $15 billion to the project, along with more than $1.7 billion of equity in renewable energy projects worth more than $6.4 billion in Abu Dhabi and around the globe, including the London Array and solar projects in Spain. At its heart is the Masdar Institute, an education establishment with 337 students and the global headquarters building for the Siemens electrical company[44].

Masdar City was established in 2006[45] through the Mubadala Development Company owned by the Abu Dhabi Government with a view to building "the world's most sustainable city" of 40,000 people with 50,000 commuters[45] covering 6 km^2 and spawning economic development and diversification in the Emirate. It was due to be completed in 2016, but with the global economic downturn this led to a revised completion date of 2025[45]. The city is designed to encourage walking, with the nearest public transport link being within a maximum walking distance of 350m. Residents and commercial tenants can drive their car to their apartment and walk or use public transportation for all their needs within Masdar City. Additionally, Masdar City will be linked to Abu Dhabi's upcoming clean public transportation options of the LRT and Metro. Masdar's buildings are only permitted to be up to five stories high, and built on narrow streets, with rooftops covered with solar panels and street-level "solar canopies" providing shade. The shaded walkways and narrow streets aim to create a pleasant walking environment in Abu Dhabi's extreme climate. The City will consist of 10 neighbourhoods constructed one at a time and building on previous experiences. The city is to be constructed in seven phases and is to be surrounded by a wall to protect it from the desert winds, and from the nearby Abu Dhabi airport.

The first six buildings of the Masdar Institute of Science and Technology campus have been built. They include three residential buildings, two laboratory buildings and a Knowledge Centre – a total of 35,000m^2 of gross floor area. Students live in on-campus housing within Masdar City and are served by retail, services and food and beverage outlets as well as a monthly market[45]. Construction of the second phase of Masdar Institute is now complete, more than doubling the size of the Institute to approximately 80,000 m^2 with new student residences, apartments, laboratories, a sports hall, and an Olympic-sized swimming pool[46]. The 10,000m^2 Courtyard Building, the first commercial building in the city, is also finished with companies like GE, Mitsubishi Heavy Industries, Schnieder Electric and more than 50 small and medium-sized enterprises (SMEs) taking office space. In addition, the 23,100m^2 Siemens Middle East Headquarters Building will soon be occupied by 1500 employees. These represent projects that will triple the size of the city, from 35,000m^2 to approximately 110,000m^2. Once the new Masdar HQ building and the building for the International Renewable Energy Agency (IRENA) are built as well as upcoming residential projects, the city population will increase. Masdar City has a current population of 1000, consisting mostly of students [46].

Masdar, the energy company, was set up to establish a new sustainable energy industry in Abu Dhabi with the goal of using the city as a case study that can be employed at other locations. There have been challenges to the city project since its initiation, with modification of some of the original plans due to reduced funding caused by the world-wide economic disruption of 2008. Plans for pod-based rapid transport cars had to be modified to a more modest system while not every building will now have rooftop solar panels[46]. Nevertheless, there are still plans for the use of electric, battery-powered cars[46]. Electric buses currently serve the residential areas.

3.2 Masdar Energy Strategy

The distribution of energy use in the UAE is shown in Figure 2. Renewable solar energy is included in the electricity data. Natural gas dominates the Industry sector, which includes the water and electricity companies which are run together (i.e. there is no separate water company). This industry uses a considerable amount of electricity in the desalination of water. In 2012, the amount of available desalinated water in the Abu Dhabi Emirate totalled 1085 x 10^6m^3, of which 1059 x 10^6m^3 were consumed. Wastewater amounted to around 276 x 10^6m^3, of which 96% was treated and 139 x 10^6m^3 was re-used to irrigate agriculture[42]. The main user of electricity (derived from natural gas-fed thermal generation) is the Domestic sector together with "Other Final Consumers", which include the commercial and public services sectors (Figure 3). The Abu Dhabi region, which contains Masdar, uses 62% of the Emirate's electricity[42]. The Domestic and Service sectors account for 84% of the total electricity consumption in the Emirate.

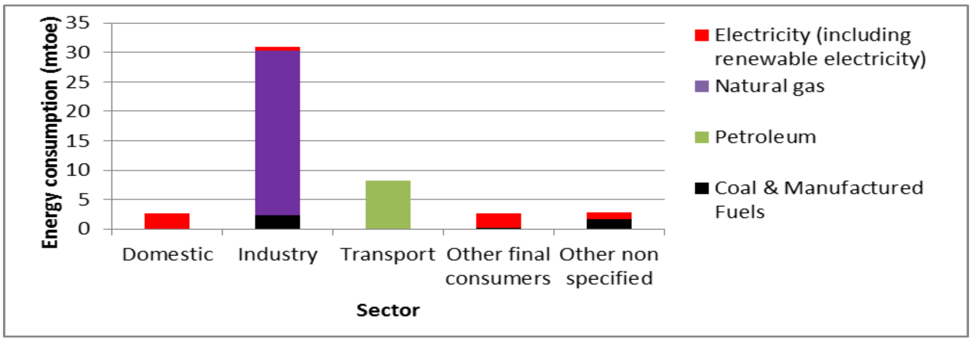

Figure 2 United Arab Emirates Energy Consumption (Mtoe) 2010 by sector and fuel [47]

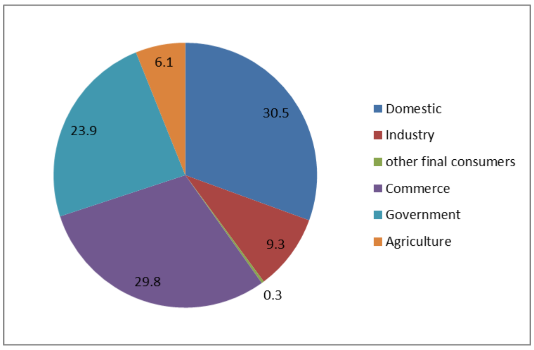

Figure 3 Abu Dhabi Emirate's Electricity use by sector (percentages) [40]

When initially conceived, Masdar aimed to be a zero carbon city, although this ambitious target was replaced in the face of anticipated difficulties in achieving this goal. With the ultimate goal in mind, the city's buildings and infrastructure is being planned and designed with energy-efficiency as the primary criterion.

The city is powered from a number of sources both internal to the city as well as from outside its boundaries. The SHAMS 1[48], a stand-alone 2.5 km^2, 100 MW Concentrated Solar Power (CSP) plant, has been built approximately 100 km from Masdar with an estimated cost of $600 million. The largest in the world, this plant generates electricity from the sun's heat rather than sunlight, as used by solar photovoltaic technology. In addition, Masdar City is supplied by another 0.2km^2 10MW solar photovoltaic plant within the city, which provides 3-4 MW (6-7 MW is sent back to the national grid of Abu Dhabi). There is a 1 MW photovoltaic panel on the roof of the Masdar Institute of Science and Technology and the solar panels on Masdar headquarters generate 3 MW[49]. Other initiatives include a solar cooling project, which is expected to work as a 170 kW chiller, and a geo-thermal cooling project, which has involved digging two 2.5 km deep wells[44]. A 45m tower in Masdar is also used as a cooler by directing hot air up and out of its surrounding area. A 100 kW thermal power plant is being established that will convert solar energy into thermal energy through a set of reflective mirrors. Power usage in Masdar City is monitored through the Building Management systems and shown through a series of video screens in the buildings demonstrating usage. The city currently uses 13 Personal Rapid Transport (PRT) carts, which run from the parking area at the city's outer edge to the Masdar Institute.

4 LESSONS IN ENERGY PRODUCTION AND USE FOR BIRMINGHAM AND MASDAR CITY

Both the UK and the UAE have a history of reliance on the oil economy, but with global trends of changes in climate and rising energy costs there is a greater interest in alternative sources of energy. Birmingham and Masdar benefit from this increased interest and concomitant efforts to develop and implement renewable energy. Birmingham has the advantage of having established processes and infrastructures into which new technologies can be integrated with minimal disruption to the city's residents, workers and visitors, while Masdar benefits from the lack of such processes and infrastructures, allowing for more radical interventions.

The ability of a country or a city to finance renewable energy technologies directly influences their development and implementation. Renewables are expensive when compared with the current (direct economic) cost of oil and natural gas (primary sources of energy in the UK and UAE) and thus market-led economics overlooks them. In the UK, the renewable energy market is gaining strength helped in part by policy and governance initiatives such as feed-in tariffs for solar PV panels and planning law exemptions for some wind farm developments. However, there are severe budgetary restraints both at the National and Local Government level, which limits the ambitions of many councils to advance this renewable energy agenda. In Masdar City, finance, essential for the concept initially to be realised, has been far less of a concern, being funded from oil revenues, although financial limitations emerged with the 2007 economic downturn. Masdar has, however, demonstrated that to be relevant it is vital to be cost conscious and that economic sustainability is a key component of environmental sustainability. Unlocking finance to support renewable energy is crucial if a city is to reduce its carbon emissions, though for projects as ambitious as Masdar's, the costs are substantial and beyond the reach of most countries, let alone cities.

Birmingham can learn much from Masdar's experiences with new technologies, particularly with regard to solar panel research and returns on investment. Although the UK climate is not as sunny as the UAE's, it is useful to establish different panels' performance and energy efficiencies. The use of the wind tower in Masdar City for cooling at the street-level is also of interest, particularly as the global climate warms and energy demand for air conditioning rises. Wind towers could possibly be used to combat the 'heat island' effect in our cities alongside building shading and the creation of wind tunnels, which are proving effective and should be considered for new developments through building layout strategies.

Alternative, low energy cooling strategies will need to be used in cities of the future. Masdar's buildings also provide a useful demonstration of improved building efficiency both in water and power consumption. Other areas of particular relevance to Birmingham include Masdar's work on smart grids, meters and appliances, as well as studies into an urban systems management platform across the whole city, green transportation, day lighting systems, and a sustainable supply chain. Masdar's power grid operators have access to comprehensive data on how energy is being used at any given time from each property and can directly control high rates of consumption to balance supply with demand. In addition, people's 'user behaviour' response to different incentives and stimuli regarding power, water and waste services will be especially useful as the UK moves towards a less oil-driven economy. It should be noted that Masdar has the benefit of installing smart grids prior to building occupancy, and thus the consumer knows what to expect, whereas in existing cities, energy fittings need to be modified to convert to a smart grid.

Masdar is a young city and has much to learn from an established city such as Birmingham that has seen many transitions over centuries, amongst which are the pitfalls of an over-reliance on one industry. It is important that Masdar develops a solid economic base and develops its focus on research and development to fund further growth. Moreover to achieve long-term success Masdar must be resilient to changes in the global economy (e.g. decreasing revenue from the sale of oil and natural gas, on which it has relied) and an increasingly arid climate.

As Masdar matures, its population will grow. It will move from 'creating something from nothing' to 'changing what already exists'. In other words, it will create a legacy of which it will have to take increasing cognisance as it further develops. It will become ever more important to consider the well-being of its citizens, e.g. ensure there are adequate parks and naturally vegetated areas for people to relax in, as well as including them in decision making about the city's future development. Processes and infrastructures will increasingly benefit from integration to increase security of supply as well as efficiencies. For example, the current research effort into hydrogen fuel cells for cars[50] could prove applicable in Masdar as existing desalination plants could be used to extract hydrogen. Other operational schemes used by Birmingham City Council, such as the reuse of waste, energy from waste and district heating (the same principles apply to district cooling), could also be relevant to Masdar, as well as methane gas extraction from sewage works and research on biofuels and cryogenic energy storage. New technologies, processes and the linkages between them must be carefully considered to prevent 'lock in'. This is a combination not only of the choices made (e.g. to prioritise solar power), but also of the sequencing of those choices (e.g. roof pitches must be set to maximise the effectiveness of roof-mounted solar panels, as must the orientation of building, otherwise the benefits of the panels will be reduced)[51]. This takes foresight and directed action.

5 DISCUSSION

Two very different cities have been compared. Masdar, in terms of size, is not currently a city but has aspirations to develop into one. Whether this succeeds or not is dependent upon its attractiveness for inward migration as well as a place to live, work and play and its ability to generate its own revenue for future growth.

Both Masdar and Birmingham have aspirations to be low carbon. Masdar has had a good start given its size and building restrictions, which only allow low-rise energy efficient buildings and the introduction of smart metering to provide comprehensive performance data. Data from such buildings can inform operational practicalities, including behavioural changes, and the potential savings to be made. More energy efficient buildings could be constructed in the UK given the political will and finance. Furthermore, with the aridity of the UAE climate, it is instructive to see how this climatic challenge is addressed. Masdar can learn from the mistakes of Birmingham such as domination of the car in the 1960-70s, and, though this lesson appears to have been accounted for in their focus on public transport and battery powered vehicles, it must be recognised that whatever approach is adopted will have the potential to 'lock in' physical infrastructures – today's decisions are tomorrow's legacy. They can also potentially benefit from new technologies emerging in the UK (e.g. hydrogen cars).

It is encouraging that both cities have the same bold aims to be as sustainable and resource secure as possible, and that they are both intent to provide demonstrations of how this might be achieved. In the end the responsibilities will lie with the cities of the world to learn from each other. This will lead to a greater understanding of what is required, and what can be appropriately applied, in terms of technology, investment and expected 'user behaviours', to be sustainable. This will be particularly important as the global climate changes and cities need to ensure that they are resilient, robust and sustainable in the face of, perhaps radical, change to survive.

ACKNOWLEDGEMENTS

The authors wish to thank the UK Engineering and Physical Sciences Research Council (EPSRC) for their support under grant number EP/J017698/1

REFERENCES

[1] Popp, A. and Wilson, J. F. (2009) "The emergence and development of industrial districts in industrialising England," in *Handbook of Industrial Districts*, Becattini, G., Bellandi, M., De Propris, L., Eds., Edward Elgar Publishing, UK.

[2] BP. (2013, 12.12.13). *Statistical review of world energy 2013. June 2013*. Available: http://tinyurl.com/ozfea2d

[3] UK Government. (2008, 12.12.13). *Climate Change Act*. Available: http://tinyurl.com/boxgy2y

[4] United Nations Framework Convention on Climate Change (UNFCCC). (1997, 27.11.13). *Kyoto_Protocol*. Available: http://unfccc.int/kyoto_protocol/items/2830.php

[5] Birmingham City Council (BCC). (2013, 12.12.13). *Birmingham Carbon Plan Analysis. An illustrative look at future emissions in Birmingham*. Available: http://www.birmingham.gov.uk/sustainability

[6] UK Government.(2013, 27.11.13). *UK Renewable Energy Roadmap*. Available: http://tinyurl.com/mpxjgyh

[7] Danish Government. (2013, 12.12.13). *Energy Statement*. Available: http://tinyurl.com/qf5jn9j

[8] German Federal Government. (2013, 12.12.13). *Perspectives for Germany. Our Strategy for Sustainable Development*. Available: http://tinyurl.com/otkw4hm

[9] Swedish Institute. (2013, 12.12.13). *Energy Use in Sweden*. Available: http://tinyurl.com/ndeklz7

[10] Liveable Cities. (2013, 27.11.13). *Liveable Cities: Transforming the Engineering of Cities for Global and Societal Wellbeing.* Available: www.liveablecities.org.uk

[11] Office for National Statistics (ONS). (2012, accessed 30.9.13). *Population Estimates for England and Wales, Mid-2011 (2011 Census-based)*. Available: http://tinyurl.com/9afw4vx

[12] ONS. (2013, 11.10.13). *nomis - official labour market statistics. Labour Market Profile. Birmingham. Employment and unemployment*. Available: http://tinyurl.com/pkbrm83

[13] ONS. (2013, 14.10.13). *Regional Profiles - Population and Migration - West Midlands, March 2013*. Available: http://tinyurl.com/pu7xsbf

[14] ONS. (2012, 11.10.13). *2011 Census: Key Statistics for local authorities in England and Wales. Ethnic group, local authorities in England and Wales.* Available: http://tw.gs/RbSecX

[15] Shill, R. (2013), *Birmingham Canals*, The History Press Ltd, UK.

[16] Birmingham City Council (BCC). (2013). *Birmingham's Green Commission. Building a green city.* Available: http://www.birmingham.gov.uk/greencommission

[17] BCC. (2013). *Birmingham Council Business Plan and Budget 2013*," Available: http://tinyurl.com/ptnjgu6

[18] Natural England. (2013, 21.11.13). *West Midlands (City of Wolverhampton, Walsall, Dudley, Sandwell, Birmingham, Solihull and Coventry Districts)*. Available: http://tw.gs/RbSe0v

[19] Gelling, M. (1956), "Some notes on the place-names of Birmingham and the surrounding district", *Transactions & Proceedings, Birmingham Archaeological Society* vol. 72, pp. 14–17.

[20] Jones, P. M. (2009), *Industrial Enlightenment: Science, technology and culture in Birmingham and the West Midlands, 1760–1820*, Manchester University Press.

[21] Hopkins, E. (1989), *Birmingham: The First Manufacturing Town in the World, 1760–1840.* Weidenfeld & Nicolson, London,

[22] Sharratt, B. (2000), *Men and Motors of the Austin: The inside story of a century of car making at Longbridge*, Haynes Publishing, Sparkford.

[23] ONS. (2008, 18.11.13). *Labour Market Profile Birmingham: Employee Jobs 2008*. Available: http://www.nomisweb.co.uk/reports/lmp/la/2038431965/report.aspx#tabjobs

[24] ONS. (2008, 18.11.13). *Birmingham – Employee Jobs – Area Comparison – Public administration, education and health employee jobs (Great Britain).* Available: http:// tinyurl.com /q8c2vjz

[25] ONS. (2008, 18th November 2013.). *Birmingham – Employee Jobs – Area Comparison – Banking, finance and insurance employee jobs (Great Britain)*. Available: http://tinyurl.com/qd2e6h6

[26] Globalization and World Cities Research Network. (2011). *The World According to GaWC 2010.* . Available: http://www.lboro.ac.uk/gawc/world2010t.html

[27] Beaverstock, J. V. , Smith, R. G. and Taylor, P. J. (1999), "A Roster of World Cities", *Cities*, vol. 16, pp. 445-458.

[28] Department of Energy and Climate Change (DECC). (2013, 27.11.13). *UK Energy Flow Chart 2012*. Available: https://www.gov.uk/government/publications/energy-flow-chart-2012

[29] DECC. (2013, 14.10.13). *2011 carbon dioxide emissions for Local Authority and regional level: Statistical release*. Available: http://tinyurl.com/bz57fqp

[30] DECC. (2012, 27.11.13). *United Kingdom housing energy fact file*. Available: http://tinyurl.com/ntbk7qx

[31] DECC. (2013, 14.10.13). *Sub-national road transport fuel consumption 2005 - 2011*. Available: http://tinyurl.com/q9h5ejq

[32] DECC. (2013, 11.10.13). *Total final energy consumption at sub-national level*. Available: http://tinyurl.com/mfovp69

[33] DECC. (2013, 27.11.13). *Chapter 6 Renewable sources of energy*. Available: http://tinyurl.com/ox78cgh

[34] DECC. (2013, 27.11.13). *Renewable Energy Statistics Data Sources and Methodologies*. Available: http://tinyurl.com/od46vqc

[35] Veolia Environmental Services. (2013, 14.10.13). *Energy Recovery*. Available: http://tinyurl.com/nnwvv26

[36] DECC. (2013, 14.10.13). *District Heating - Birmingham*. Available: http://tinyurl.com/o5jdf26

[37] DECC. Digest of UK energy statistics' (DUKES). (2012, 14.10.13). *Generation of electricity from renewable sources, 2011*. Available: http://tinyurl.com/n4k7n8

[38] Birmingham Airport. (2013, 28.11.13). *Birmingham Airport submission*. Available: http:// tinyurl.com/ qbu4re4

[39] Population.net. (2012, 22.11.13). *United Arab Emirates: Urban areas (Population 2012)*. Available: http://tinyurl.com/ospdnle

[40] Statistics Centre − Abu Dhabi (SCAD). (2013, 22.11.13). *Statistical Yearbook of Abu Dhabi 2013 - Population size*. Available: http://www.scad.ae/SCADDocuments/population%20siza%2020113.pdf

[41] Masdar City. (2013, 22.11.13). *Living in Abu Dhabi*. Available: http://tinyurl.com/pnudmmd

[42] SCAD. (2013, 26.11.13). *Statistical Yearbook of Abu Dhabi 2013*. Available: http://tinyurl.com/nlghzwl

[43] World-nuclear.org. (2013, 26.11.13). *United-Arab-Emirates*. Available: http://tinyurl.com/pm2obyv

[44] Masdar. A Mubadala Company. (2013, 26.11.13). *Masdar Factsheet. Fast Facts*. Available: http://www.londonarray.com/wp-content/uploads/Masdar-Factsheet.pdf

[45] Masdar City. (2013, 15.11.13). *Masdar City. Frequently asked questions.* Available: http://tinyurl.com/pcpfubu

[46] Masdar City. (2013, 15.11.13). *Masdar City role model for a sustainable future* Available: http://9mp.com/HqIbp

[47] International Energy Agency (IEA). (2012, 29.11.13). *Energy Statistics of non-OECD Countries*. Available: http://tinyurl.com/nz8xfaa

[48] Masdar City. (2013, 22.11.13). *Shams 1*. Available: http://www.masdar.ae/en/#energy/detail/shams-1

[49] Gulfnews.com. (2011, 26.11.13). *Masdar-city-saves-more-power-than-it-consumes*. Available: http://gulfnews.com/business/general/masdar-city-saves-more-power-than-it-consumes-1.747986

[50] University of Birmingham. (2013, 28.11.13). *Hydrogen*. Available: http://tinyurl.com/6uvlpfc

[51] Lombardi, D.R., Caserio, M. Donovan, R., Hale, J., Hunt, D.V.L., Weingaertner, C., Barber, A., Bryson, J.R., Coles, R., Gaterell, M., Jankovic, L., Jefferson, I., Sadler, J. and Rogers C.D.F. (2011), "Elucidating Sustainability Sequencing Tensions and Tradeoffs in Development Decision-making," Environmental Planning B , Vol. 38, pp. 1105 – 1121.