The Little Book of ENERGY and the city

AbuBakr Bahaj, Luke Blunden, Leonidas Bourikas,
Milena Büchs, Patrick James, Yue Wu and the entire
Liveable Cities Team

Editors of the Little Books series:

Dr Christopher T. Boyko and Dr Claire Coulton,
ImaginationLancaster, Lancaster University

With design by Roger Whitham, Rachael Hill and Michael Stead,
ImaginationLancaster, Lancaster University

ISSN 1747-0544

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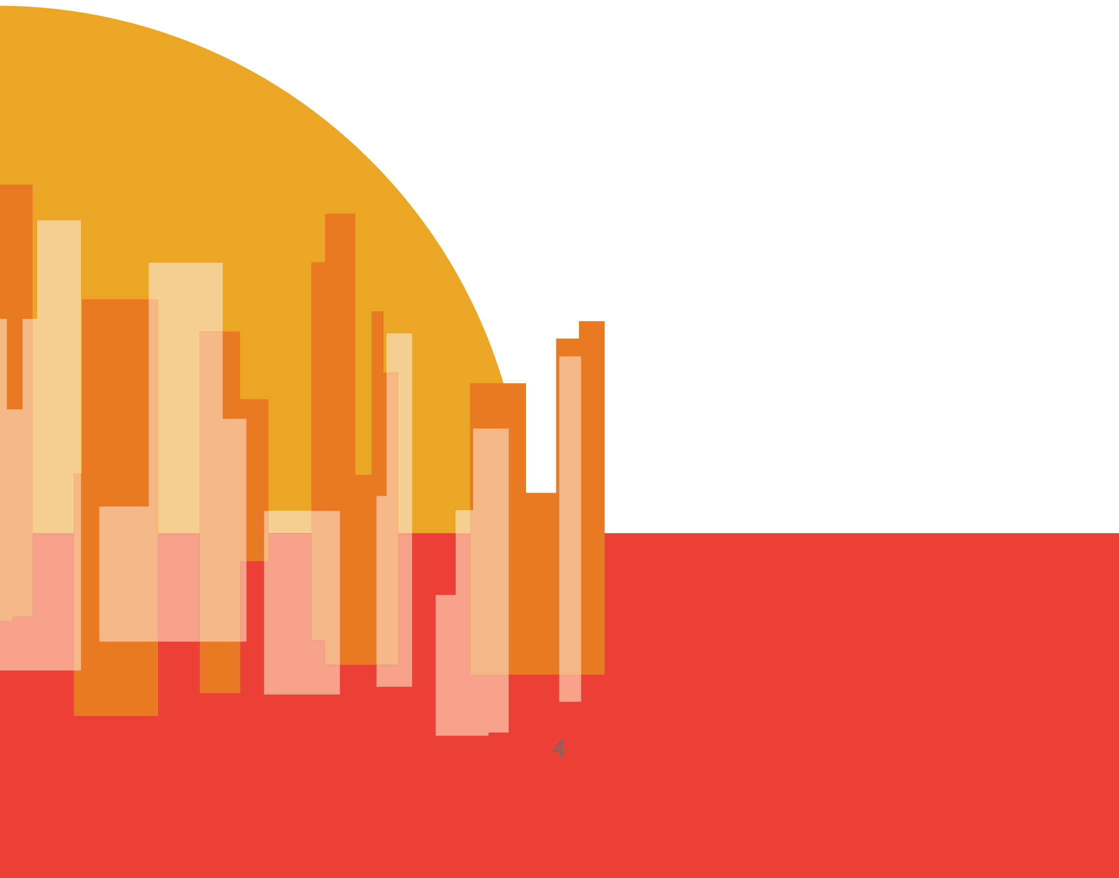
Acknowledgements

This work is part of the research theme on Energy and Cities conducted by the Sustainable Energy Research Group (SERG) and the Energy and Climate Change Division (www.energy.soton.ac.uk) within the Faculty of Engineering and the Environment at the University of Southampton. Funding for this book and the work it describes is through the UK's Engineering and Physical Science Research Council (EPSRC), grant EP/J017698/1 entitled Transforming the Engineering of Cities to Deliver Societal and Planetary Wellbeing. The authors are grateful for the commitment, participation and support of the residents of Southampton and Portsmouth in conducted field studies. Special thanks also to the Southampton City Council and the Portsmouth City Council teams for their insights and close collaboration to support this work. Lastly, we would like to thank the many researchers, including PhD students, who are part of the programme for their contribution to debates and the outcomes of this work.

Contents

What this little book tells you

This 'Little Book' is a whistle-stop tour of 'Energy and the City'. The book identifies ways to help cities achieve energy and carbon emissions savings through interventions in the urban environment that are not too drastic or expensive. The uses of energy in the city are complex and multifaceted, so we won't be able to cover everything here. In this little book we make a start, using the City of Southampton as a case study. We detail some of the work we carried out for the Liveable Cities programme including city-wide studies of the refurbishment of buildings, using buildings as power generators, and aspects of residents' choices in the context of energy. We also discuss how options under these three themes can contribute to the reduction of CO_2 emissions in Southampton and UK cities.



1. Introduction

More people live in cities than ever before due to economic opportunities (cities represent 80% of global Gross Domestic Product) including employment, better services and amenities (UN-Habitat, 2016). Energy is essential for a city to function at all levels, especially if it is to contribute to the national and global economy. Switching to sustainable energy resources and reducing energy consumption are both urgently required as cities consume the majority of energy resources and generate the majority of carbon dioxide emissions. Low carbon technologies for electricity generation, efficient transportation of people and goods, smart distribution of energy and reductions in energy wasted along the way, are all key challenges. However, there is no 'silver bullet' for energy in cities – switching to renewable sources; managing demand; encouraging people to change their behaviour and improving the built environment will not, on their own, meet the carbon emissions reductions that will be needed.

2. Energy and carbon emissions

The Climate Change Act of 2008 made the UK the first country in the world to have a legally-binding emissions reduction target. This act stipulated that we must reduce CO_2 emissions by 80% by 2050 from the level it was in 1990. The new 80% reduction target was set to be achieved in stages and the responsibility for making sure this happened belonged to the Climate Change Committee (CCC). This committee presents periodic carbon budgets to the UK Government to be fulfilled by a specific time (Figure 1).

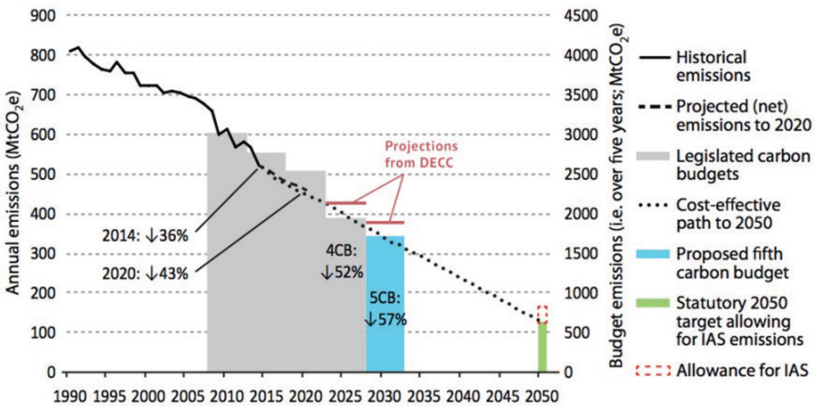


Figure 1. CCC's carbon budgets & cost-effective path to the emission reduction target (Committee on Climate Change, 2015)

The Climate Change Act came about due to many global and UK discussions on the urgent need to reduce emissions. In Figure 2, you can see a brief timeline of some the major events involved in the development of UK carbon policy and the level of CO_2 emissions of the UK during this period.

As can be seen from Figures 1 and 2, although CO_2 emissions have decreased considerably since 1990, there is a long way to go to achieve the 2050 target. This means that more ways to reduce emissions are going to be needed.

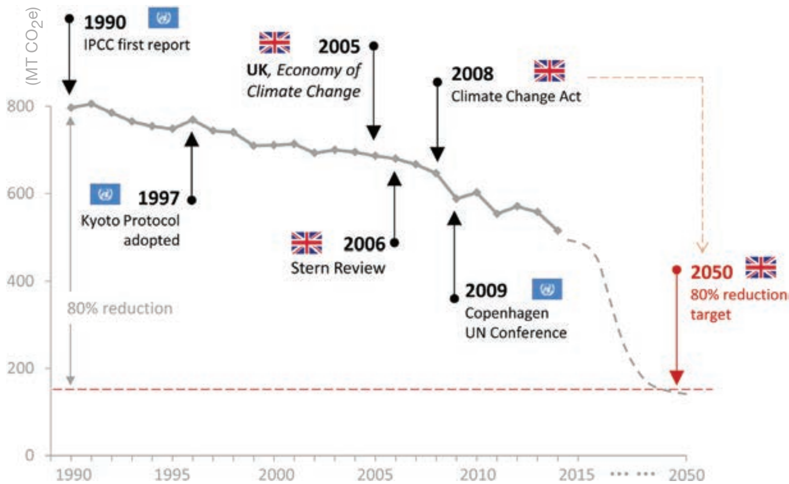


Figure 2. Changes of GHG emissions in the UK from 1990 to 2014 and timeline of the development of emission-related policies (DECC, 2016).

Figure 3 shows the fuel supply and main energy consumption sectors in the UK in 2014. Over 50% of the primary energy consumed was directly from fossil fuels, including 348 terrawatt hours (TWh) of coal (equivalent to 16% of total UK consumption) and 754 TWh of crude oil (35%). Although the proportion of renewable energy supplies has increased significantly in recent years, and is higher than in most countries in the world, it is still the lowest among all types of major energy sources.

Figure 3 also shows that 30% of energy consumed in the UK is wasted during the conversion of primary energy into electricity, of which around 5% is lost in transmission and distribution. This loss of energy can only be reduced by being more efficient: first, in how we generate electricity, and second, by moving towards distributed and renewable power generation that is situated closer to where there is demand (i.e. cities).

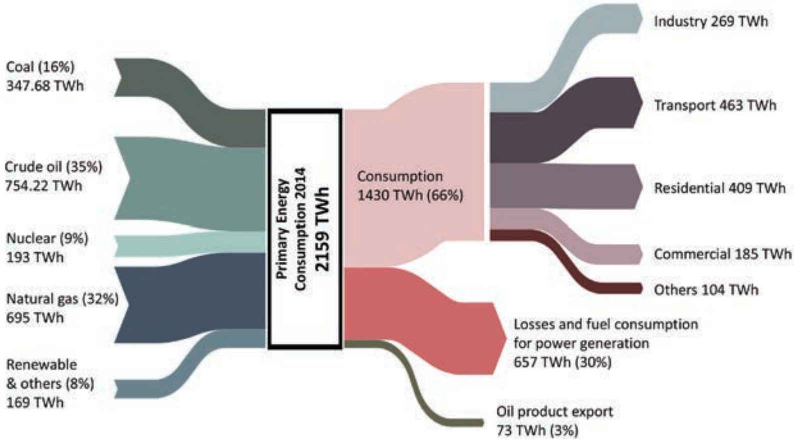


Figure 3. Fuel supply and energy consumption of the UK in 2014 [IEA statistics].

3. Energy and the city

As mentioned earlier, cities need and use a great deal of energy; to power and heat buildings, in industry, for transporting people and goods, and for other services, like healthcare, education and utilities. Urban areas in the UK consume around 56% of energy supply (see Figure 4). Of this energy consumption, transport is responsible for 40% of the total (Figure 5) (Department for Business Energy & Industrial Strategy, 2017b). In *The Little Book of Mobilities in the City*, (2017), our Liveable Cities colleague, Katerina Psarikidou quotes John Urry who argues: “Cities are places of intense, overlapping and energy-dependent movements of people, information and objects”. Therefore, we believe it is important for cities to address these issues in a coherent way. It is now critical that we reduce as much as possible the energy intensity – that is, units of energy per unit of GDP – and the carbon intensity of our power supply.

Local authorities have set city-level targets in an effort to reduce carbon. These include:

- London with a target of 60% by 2025;
- Birmingham 60% by 2026;
- Southampton 34% by 2020 and 80% by 2050;
- Liverpool 35% by 2024.

In order to deliver these targets, there will need to be a radical transformation of energy infrastructure from the current situation where a few large fossil-fuel power stations supply energy through a hierarchical network in a strictly downward direction, to a future where a huge number of small generators (including households and businesses) generate, use, store and supply low carbon electricity, combined with high efficiency in energy end-use. We are assuming here (as does the UK government) that transport fuel consumption will be transferred to transport electricity consumption as road transport is electrified. However, at this stage, we do

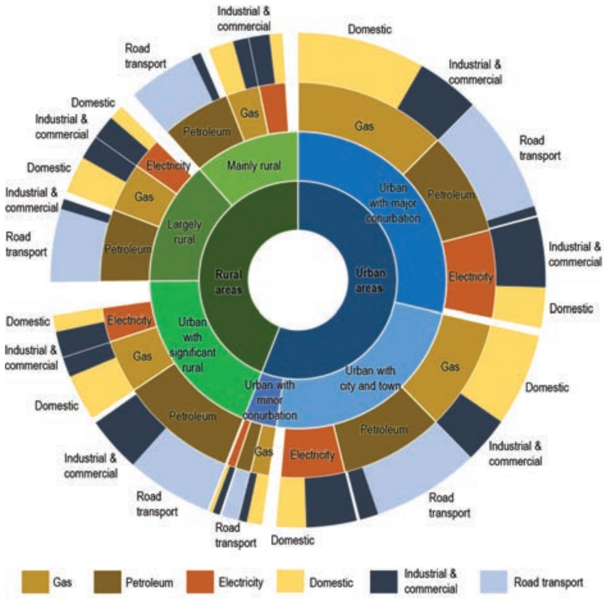


Figure 4. Comparison between urban and rural energy consumption in the UK. Data from 2015 [DBEIS 2017].

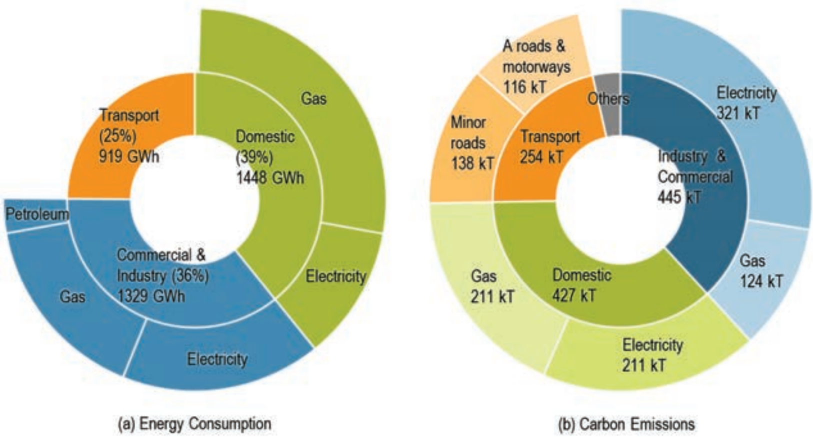


Figure 5. Energy consumption and carbon emissions from the primary sectors in the UK. Data for 2015 [DBEIS 2017].

not know how this will affect people's wellbeing and health; furthermore, the cost of delivering these solutions is an open question since little is currently known about these relationships.

An example here might be walking or cycling for shorter distance journeys instead of using cars. Doing this would reduce energy emissions and could also be beneficial to our health and wellbeing. On the other hand, a negative example might be if we had less energy available for heating our houses. If room temperatures fell below what was healthy and comfortable, this could have a negative impact on our health and wellbeing. We acknowledge that there is a great deal of research being conducted on energy reductions and behaviour; however, it is still difficult to truly evaluate the effectiveness of these interventions. Furthermore, evidence from research also shows that it can be challenging for these interventions to be effective over time.

Our research looked at how a large intervention on the fabric of buildings in Southampton could contribute to a reduction in energy consumption and a reduction in emissions. In the following sections, we provide a brief background of the City of Southampton, an outline of the methods we used, our analysis and the outcomes of the research.

4.City of Southampton

4.1 Background

Southampton is located on the South-east coast of England (50.9°N 1.4°W) and it is the largest city in the county of Hampshire (Figure 6). The area of Southampton has been inhabited since prehistory. Recognising the importance of the location, the Romans laid the first foundations in the settlement of Clausentum, at the site of modern Bitterne Manor, as early as 43AD (Rance, 1986; Kilby, 1997). Most of the current historical landmarks such as the Bargate, Town walls, Wool House, Tudor House and St. Michael's church were built between the 12th to 15th centuries. Under the reign of King Charles I, the town expanded beyond the walls and, in the 18th century, Southampton became a famous spa resort (Kilby 1997). From the 19th century onward, Southampton grew to become one of the most important ports in the United Kingdom (Kilby 1997).

The city shows a clear radial urban growth pattern over time, as the major residential areas have expanded significantly from the Bargate, which is still the city centre, to the outskirts of the city, such as Woolston and Hedge End, as shown in Figure 7.

From an urban planning perspective, the city spans 51.8 km^2 (Southampton City Council, 2017), with about 11 km^2 of greenspace, or about 20% of the total area (Ordnance Survey, 2014). The population is approximately 250,000 people (Office for National Statistics, 2016) resulting in an average density of 3,400 persons per km^2. By way of comparison, Shanghai in China has a density of 6,200 persons/km^2 and Los Angeles, USA 2,400 persons/km^2 (Wendell Cox Consultancy, 2014). The population is expected to grow by 5% by 2022.

The major employers are the National Health Service (NHS), the education sector and ABP Southampton Port. In addition, the city has about 40,000 students from the two Universities

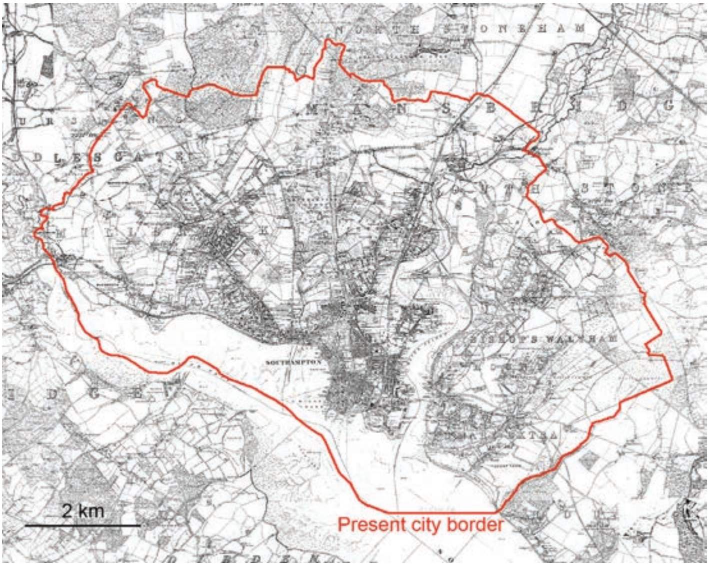


Figure 6. Historical map of Southampton (1870s) and the present city border (red polygon) (Ordnance Survey & Landmark Information Group, 2011).

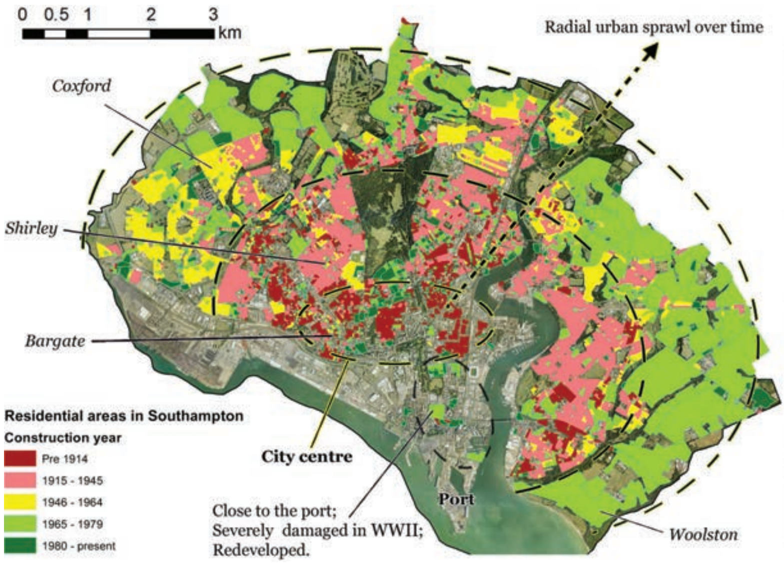


Figure 7. Progress of urban expansion in the development of Southampton.

4.2 Opportunities for carbon reductions in Southampton

We began our research by looking at the energy flows in Southampton; Figure 8 shows the energy flows into Southampton in 2015 (Department for Business Energy & Industrial Strategy, 2017a). As can be seen from the figure, 70% of the energy was used in the domestic and non-domestic sectors, predominantly for energy demand within buildings. This mainly consists of heating buildings in winter, providing domestic hot water, and electricity use. Electricity (on the left side of the diagram) refers to electricity imported from the National Grid. The diagram in Figure 8 also indicates where action needs to be taken in order to improve energy efficiency and hence emission reductions in Southampton and other cities. Buildings offer a major route to reducing emissions through (a) making them more efficient through refurbishment and (b) making them clean power generators themselves. By this, we mean that we need to identify areas on these buildings where power generation technologies, such as solar photovoltaic (PV) systems, can be used.

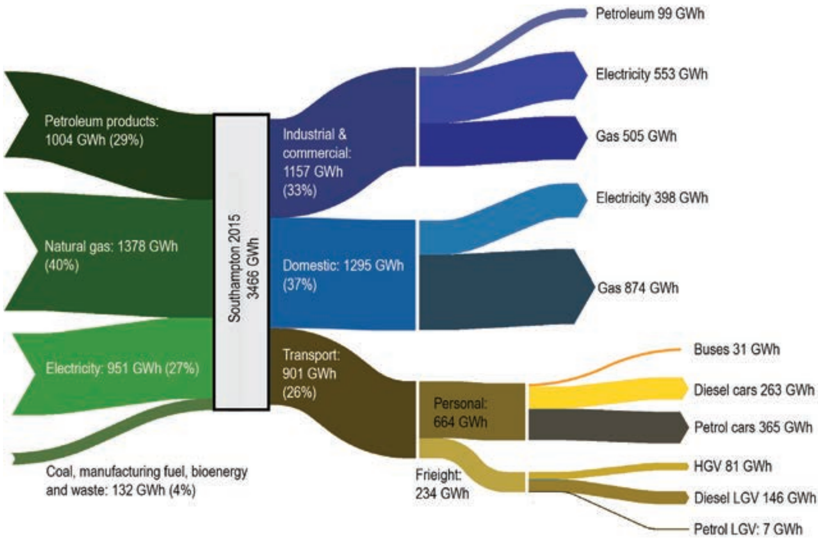


Figure 8. Energy flow in Southampton, UK in 2015. Electricity refers to electricity imported from national grid (Department for Business Energy & Industrial Strategy, 2017a).

5. Pathways to emission reductions

5.1 Energy saving potential from building refurbishment

In the second phase of the research, we pinpointed all the domestic and non-domestic buildings in Southampton. This gave us the location and the characteristics of all 31,000 domestic buildings as well as the 7,000 non-domestic buildings. These buildings have a total footprint area of 7.4 km^2, covering 15% of the land within the city boundary.

Domestic buildings in Southampton, including blocks of flats, occupy a ground area of about 159 m^2 on average, which is, as would be expected, significantly smaller than the average size of non-domestic buildings in the city, which occupy on average 949 m^2. In comparison with national average, domestic buildings in Southampton are smaller and the population density is higher. Consequently, there is less rooftop area per capita in Southampton than in the UK as a whole. This means that we would expect lower numbers of solar panels able to be installed per capita in Southampton when compared to the UK average, other things being equal (the amount of sunshine for example).[1]

There are significant variations in energy demand across the city, as shown in Figure 9. Our analysis shows that households in Shirley and Bassett currently consume the most energy (including electricity and natural gas), whilst households in Bargate

1 Please see Section 5.2 for detailed discussion of rooftop PV development in Southampton.

and south Woolston have the lowest energy demand. This is caused mainly by the combination of three factors – (i) size of dwelling, (ii) energy efficiency, and (iii) the behaviour of residents. A change of any of these factors will affect the final energy demand and hence emissions.

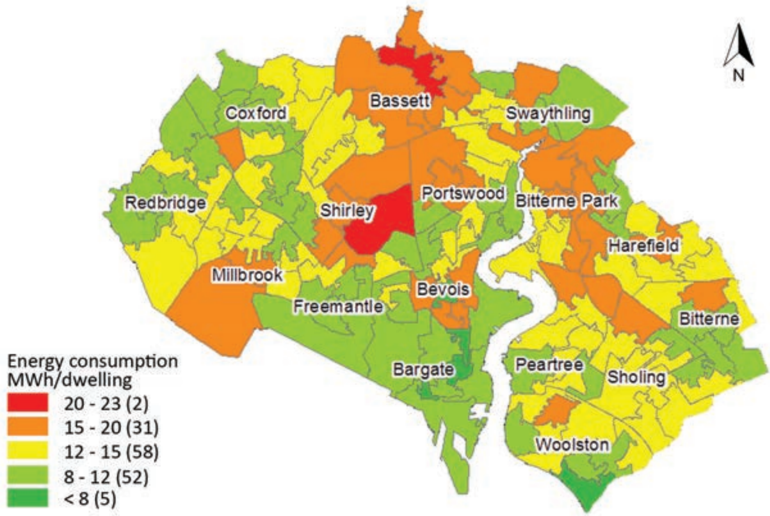


Figure 9. Average energy consumption per household in different areas of Southampton in 2014.

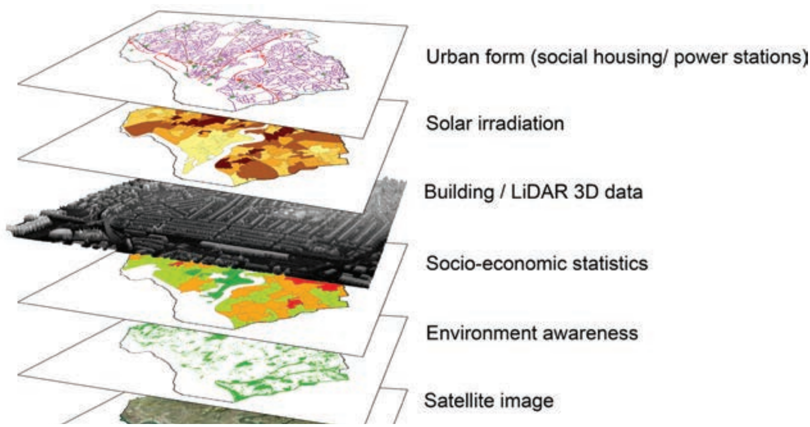


Figure 10. Approaches used by GIS model to analyse multidisciplinary factors.

In our study of the City of Southampton, we have developed a modelling approach based on building physics within a GIS platform so that we can analyse the energy performance of 100,000 dwellings in the city. The model incorporates datasets from a wide range of disciplines, such as building form, urban layout, and citizens' socio-economic statistics, into an analysis platform, and each of the datasets is presented as layers so their correlations can be analysed, as shown in Figure 10.

National surveys show that the energy efficiency of domestic buildings varies significantly. For example, Figure 11 shows the percentage of dwellings that have been fitted with various energy efficiency measures, such as double-glazed windows, cavity wall insulation, or condensing boilers. The figure shows that the coverage of different measures varies significantly, and more detailed information would be needed for an analysis at the city-scale to understand the energy performance of each individual dwelling.

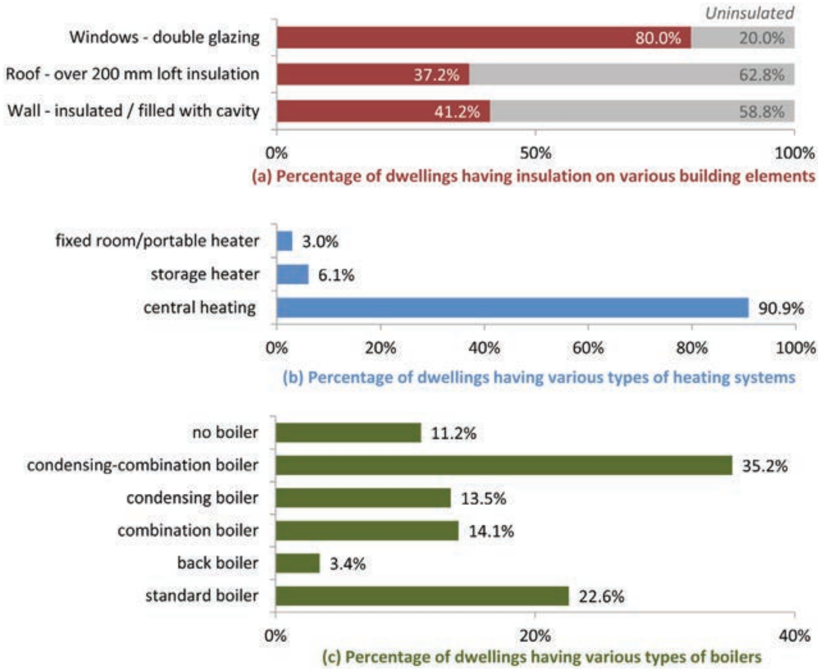


Figure 11. Energy efficiency measures in dwellings in the UK. (Department for Communities and Local Government, 2013)

The analysis we conducted also used Energy Performance Certificates (EPCs) to obtain the characteristics of the energy system of individual dwellings. The EPC scheme was established in the UK in 2007 to promote improvements in building energy efficiency and to evaluate and label the energy performance of buildings (UK Government, 2007). It requires domestic properties to have an EPC when constructed, sold or let (Department for Communities and Local Government, 2014). Each certificate presents the overall energy efficiency of an individual dwelling and gives it a rating (from G to A+) to indicate the energy efficiency. In addition, EPCs also show efficiency ratings of building elements (more of which below) and provide recommendations for improving building energy performance. These recommendations also include an economic assessment so that building owners are aware of how much energy and money they could save.

5.1.1 Robust data on energy performance of individual buildings to support analysis

In order to get the best possible picture of how buildings in Southampton are performing on an individual basis, in 2013 we obtained all the EPCs available for the city, 47000 EPC in Southampton accounting for over 40% of the housing stock. The coverage of the EPCs dataset varies significantly for different areas in the City as shown in Figure 12. Certain areas such as the city centre (Bargate) and Bevois have much higher data coverage than other areas, whereas in many areas that are away from the city centre, the data coverage is less than 40%. To date, only around 50% of the building stock in the UK have participated in the EPC scheme. This incompleteness of data reflects a nationwide challenge to make appropriate energy saving assessments for individual buildings across the whole city. To overcome this, we developed a computer model to systematically identify similarity between buildings and automatically cluster dwellings into groups based on their characteristics such as geographic proximity, building age, and form in terms of size, height and shape. The model which, is validated using existing EPC data, is now able to assign an EPC to buildings that have no certificate, expanding the data to cover the entire city.

The average EPC rating of building elements in Southampton including their energy systems is shown in Figure 13. The results show that floor insulation is the least efficient element in building energy systems in Southampton, with a rating of "very

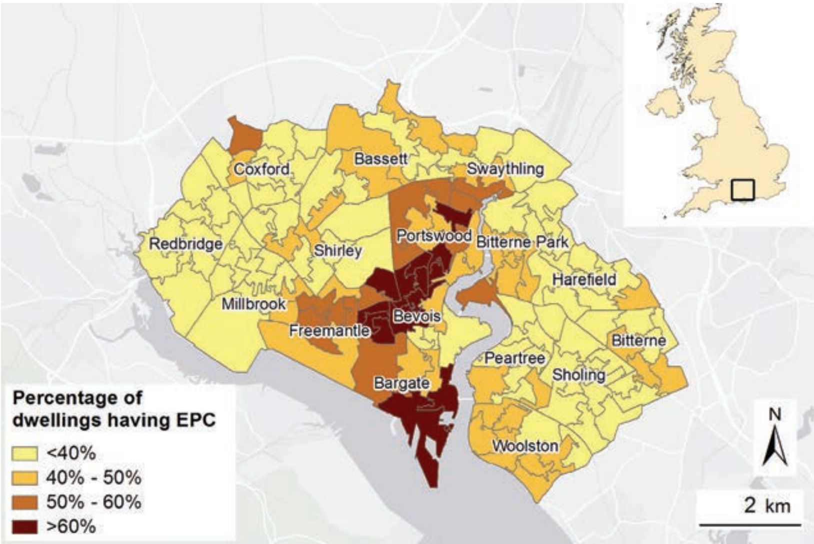


Figure 12. Coverage of existing EPC data in Southampton.

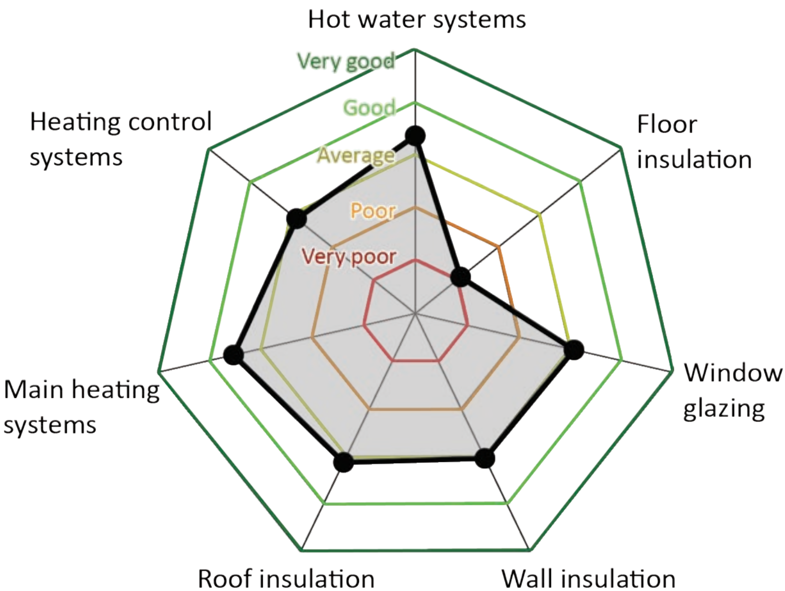


Figure 13. Average energy performance of energy systems in Southampton dwellings.

insulation (or, to be slightly more accurate, we only have evidence that a small proportion of dwellings in Southampton have underfloor insulation). Thus, it is clear that floor insulation could be improved in Southampton buildings; but this could be both costly and disruptive.

In addition, the ratings for windows, walls and roofs are at the same level, "average" (Figure 13). This level typically equates to double-glazed windows, partially insulated cavity walls, and approximately 100 mm of loft insulation. At this level, building elements are assumed to have a high efficiency but still possess potential to be further upgraded. For example, double-glazed windows can be replaced with triple-glazed ones; cavity walls can be fully filled or clad with external wall insulation; and loft insulation can be increased to over 270 mm. Loft and wall insulation (cavity fill) have very short payback times and are easy to apply. Other measures such as glazing upgrades are often applied for other reasons such as to reduce noise, improve security or to add value to a property.

Building heating systems (including both space heating and water heating) are the best rated sectors in Southampton, but despite this, their ratings are between "average" and "good". Therefore, it is still possible that many dwellings will benefit from improved heating. But it is important to note that a large number of dwellings in Southampton are flats, and they may be required to use electrical heating due to safety regulations. These dwellings are therefore not included in the consideration of replacement heating systems. Replacing electrical heating with an entirely new 'wet' central heating system is very expensive and disruptive. On the other hand, replacing and old inefficient gas boiler with a new highly efficient one is a very effective option in cost and carbon terms, providing the initial capital investment can be made. In summary, heating systems are currently the most efficient element within building energy systems in Southampton (Figure 13), and the rate of upgrades being carried out is estimated to be slower than that for building fabric elements such as wall insulation.

In order to know how well the city did in terms of energy saving and hence emission reductions, the data for all the buildings were aggregated and assessed under six different scenarios, considering various level of room temperature settings (ranging from 17 to 22°C as average room temperature). The analysis indicates that the City of Southampton has the potential to reduce energy consumption by 295 gigawatt hours (GWh) per year (25%) under the central scenario, with the range from 184 GWh per year to 369 GWh per year.

Southampton City Council has committed to reducing CO_2 emissions by 80% from the 2010 level before 2050. Therefore Figure 14 shows the potential of emission saving is compared with the 2010 baseline (1157 thousand tonnes). Under the central scenario, the overall emission saving potential is 82,000 tonnes per year, which is equivalent to 7% of the baseline emissions. By comparison, the UK per capita carbon footprint is 6.5 tonnes. The upper bound of the emission saving potential is 103,000 tonnes per year, equivalent to a relative saving of 9%, and the lower bound is 51,000 tonnes per year, equivalent to a relative saving of 4%. Full details of this analysis can be found in Wu (2017).

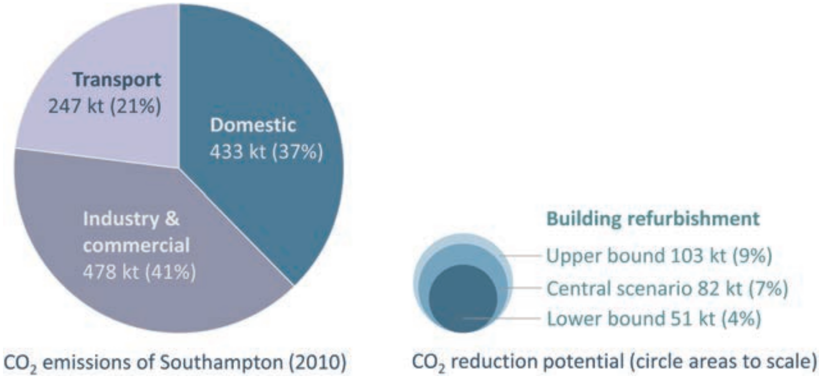


Figure 14. Baseline CO_2 emissions of Southampton in 2010 and the potential of emission saving from building refurbishment. Size of circles are to scale.

The CO_2 saving potential of Southampton, even under the upper bound, is considerably lower than the target proposed by the council. This means to achieve the council's target of reducing CO_2 emissions by 80%, other measures will need to be implemented.

5.2 Power generation from rooftop solar systems

With the exception of combined heat and power (CHP) – which is a technology that uses waste heat from an electricity generation process to provide useful heat for buildings – it is rare for cities to use large-scale, renewable energy power plants within the city boundaries. This is due to the limited availability of land, and its cost, as well as the visual impact of such power systems. However, there are appropriate building surfaces, such as roofs in cities that could be used to help produce power from modular systems, like solar photovoltaic (PV) technologies. For cities to meet their energy demand, all available opportunities will need to be explored to allow some degree of energy supply within their boundaries. The most practical approach for cities is to install large numbers of photovoltaic (PV) modules taking advantage of the unused roof surface of buildings. However, because buildings have very different densities and shapes, it can be challenging to achieve very high rates of installation across urban areas.

To achieve this, we used Light Detection and Ranging (LiDAR) data to obtain the height of buildings at fine resolution. The LiDAR data illustrates the geometry of objects including residential buildings, trees, and structures (Figure 15).

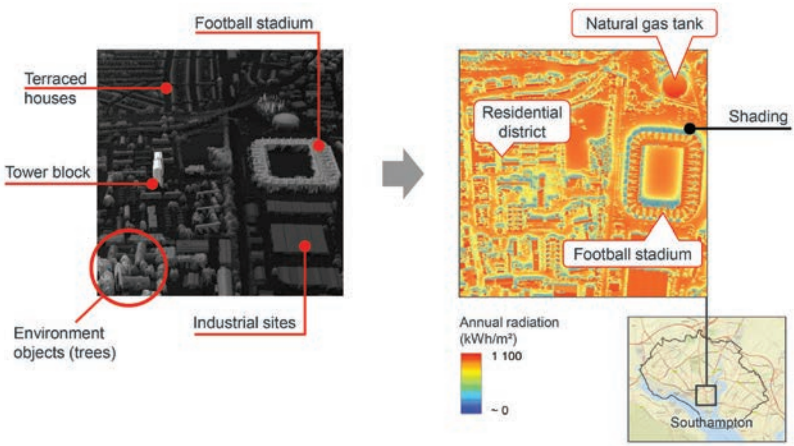


Figure 15. LiDAR (left) and in-plane solar radiation (right) results of an example area in Southampton.

Due to the variability in available roof areas of buildings upon which to install solar PV, systems have to be designed and sized appropriately. A range of system sizes were considered in our case studies to address this variability. Our results indicate that, overall, if all appropriate building roofs in Southampton are used, a capacity to generate over 250 MW of electrical power is possible, on a sunny day. Such a capacity can contribute around 25% of the city's annual electricity needs, even accounting for variations in sunshine over the year.

As part of an initiative together with a local MP and Southampton City Council to create a step increase in the deployment of solar PV in Southampton, we conducted two case studies, which are described next.

Case study 1

A first phase, which would involve installing solar PV on the roofs of all properties that belong to Southampton City Council, as shown in Figure 16. Areas where PV installations can be undertaken are clustered and highlighted (red indicates the highest density and yellow indicates the lowest). The estimated capacity for these building is 12 MWp.[2] The generated power could be used not only to supply residents living in social housing, but potentially also other city residents.

It is important to point out that where large, community PV projects are considered, there is also a need to assess the limitations of infrastructure, especially the capacities of electrical substations within the surrounding areas to withstand large fluctuations in power when the sun goes behind a cloud, for example. Figure 16 also incorporates the location of all sub-stations within Southampton and illustrates their capacity by

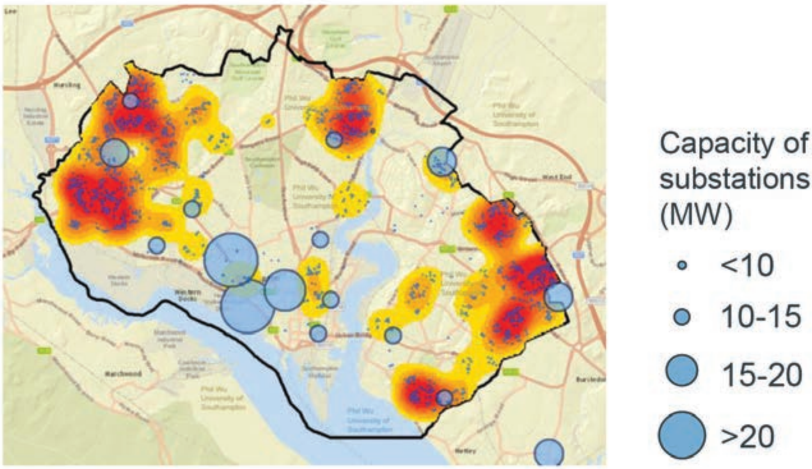


Figure 16. Suitable Southampton City Council buildings for rooftop PV deployment as estimated by model and capacity of power sub-stations in the city.

[2] The ‘p’ in MWp indicates ‘peak’, or the the power output on a sunny day

the size of each circle. This helps the Southampton City Council to better select areas for future renewable energy investments.

Case study 2

This second phase considers an assessment of the roofs that are able to house large system sizes in the city. From our calculations, we found over 6160 buildings. These systems, if used, could provide a power generation capacity of 84 MWp with an estimated annual electricity generation potential of 74 GWh, providing a carbon (CO_2) saving of 36 KT (Table 1).

Table 1. Solar energy potential from suitably selected roofs in Southampton City (see text).

	Roof type	Number	Mean annual yield kWh/kWp	Capacity MWp	Annual Generation GWh	CO_2 saving KT
Domestic	Sloping	4888	836	29	25	12
	Flat	124	889	0.8	0.7	0.4
Non-domestic	Sloping	1000	869	49	44	21
	Flat	148	886	5	4	2
Total		6160	844	84	74	36

6. Conclusions

Our results show that cities will not be able to meet all their energy demands by doing what they are currently doing. If they are to meet future demand, they will need to draw on renewable energy from outside the city boundaries and work collaboratively with the surrounding regions. Nevertheless, we also need to identify ways to help cities achieve energy and carbon emissions savings through appropriate interventions within the urban environment.

Energy use in the city is complex and multifaceted, requiring more attention than that gained through a limited research programme such as this. However, in order to achieve UK climate change targets we need to make a start on understanding where contributions can be made. Hence, this work only considers buildings and how these can be made more efficient and the opportunities for them to self-generate electrical power. From this work, we conclude that:

- The measures considered here – including refurbishments of building and buildings as electrical power generators at city-scale resulted in carbon reductions especially from city buildings.
- Annual electricity generation from buildings within the city could displace a substantial part of current electricity demand in cities. In order to benefit from photovoltaics - direct conversion of sunlight to electricity - cities will need to start supporting energy storage in order to extend the availability of local generated supply. This is important in terms of future diversification of energy sources enabling cities to be ready for future technologies such as smart grids and time of use tariffs. Issues of infrastructure needs, ICT and distributed energy networks will need to be addressed in a city context.
- Additionally, local electrical power generation from buildings could be implemented to support the decarbonisation of transport through the charging of electric vehicles and replacing fossil fuel driven vehicles. It is likely the installed capacity of systems on buildings will impact future national electricity capacity needs, which will require a whole system study.
- Other emission reductions can be gained through decarbonisation of transportation systems which are not considered here. In addition to electrical

vehicles mentioned above, this should include park and ride schemes and rapid transit rail systems where carbon abatement associated with these solutions are among the highest in cutting emissions in the cities. This area will required further study at it has implications to air quality and health in the cities.

- A combination of short and long term policy and funding regimes will be needed to initiate and support the findings depicted in this work.
- Apparent progress of UK cities toward achievement of their emission targets can be misleading as the emission reductions are mainly the result of the steady replacement of carbon intensive electricity generation technologies (coal and oil) with gas and renewables, the majority of which is taking place outside of UK cities. The measures considered in this work, by contrast, lie within the power of cities to effect change within their own area of influence.

Resources

This resources page provides a summary of the tools developed during the Liveable Cities project. The suite of tools developed by the University of Southampton team are currently in the form of scripts which require software, like ArcGIS, to run. For further details and updates, please see **energyandcities.org**. A brief summary of the tools is given below:

- **A building height estimation tool** (ArcPy code), which is able to estimate the height and number of floors of individual buildings at scale using freely available LIDAR data. It bridges a current gap in building data availability, providing essential information for building energy simulations.

- **A building energy efficiency tool** (ArcPy code), which estimates the overall energy efficiency of a building and the performance of various components included in the building's energy system. It uses freely available EPC data, but also requires cadastral maps/data that are available for public bodies and researchers.

- **A solar resource assessment tool** (ArcPy code), which is able to automatically identify suitable roof-top areas within a city for the use of solar photovoltaics (PV) systems. The results indicate the potential for electricity generation by using all suitable roofs for developing renewable energy systems.

- **Energy Performance Certificate parser** (Bash script). EPC bulk data is often missing, or incorrectly states, key parameters which are present in the original digital version of the Energy Performance Certificate. This parser attempts to read the Energy Performance Certificate, recording as many details as possible. It can handle scanned as well as text-based pdfs.

- **A flexible web platform**, which is used for displaying energy and environmental data. The platform can use a combination of custom php, wordpress and highcharts code in order to display household variables in a user-friendly format. The code could be re-used by any web sites that need to display building energy and environmental parameters.

- **A methodology for assessing the development of urban micro-climates**, which introduces a simplified urban representation, the "urban unit model", for use in micro-climatic simulations to produce building simulation weather data files for locations within a city. The methodology is used to adapt air temperature from a TMY file to calculate the heating and cooling loads of buildings for the duration of a year.

Other studies conducted by the Southampton team include

Technology development: A bespoke home environment monitoring kit for home energy studies developed using off-the-shelf open hardware components. The kit measures carbon dioxide, temperature, humidity and electric current down to 10 second resolution. It buffers the data locally and uploads to the cloud via a 3G connection when a signal is available.

Study of energy efficiency in tower blocks: International Way (Southampton), Wilmcote House (Portsmouth), Tipton and Edgbaston Towers (Portsmouth) – pre- and post-retrofit thermal comfort studies in social housing tower blocks.

Distributed generation: CHP & district energy schemes, Portsmouth – monitoring delivered heat and electrical power to assess and improve the performance of the schemes.

Large scale energy interventions: Boiler replacement study, Portsmouth – investigating 'comfort take' in social housing.

Thermal stress in buildings: Overheating in social and institutional housing – how occupant profiles affect perceived thermal comfort.

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