A review of initiatives to reduce energy-related CO_2 emissions from the city of Oxford: past, present and future

Dr Rajat Gupta
Department of Architecture
School of the Built Environment
Oxford Brookes University
United Kingdom
rgupta@brookes.ac.uk

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Abstract
This paper reviews three key initiatives undertaken in the historical city of Oxford to bring about reductions in energy-related CO_2 emissions on a city-wide scale. The author has been part of all the three initiatives. In 2002, a collaborative partnership between academia, industry and city council started the Oxford Solar Initiative (OSI) which uses a community-based approach to help households and organisations in Oxford, financially and technically, to install solar energy systems and energy efficiency measures in buildings. So far OSI has facilitated the installation of 80 active solar systems, over 450 energy efficiency measures and 3,000 low energy bulbs.

The scientific basis of OSI is a GIS-based DECoRuM model which estimates and maps baseline energy use and CO_2 emissions on a house-by house level, identifies 'pollution' hotspots, predicts the potential for reductions in CO_2 emissions and monitors reductions achieved as a result of deploying energy efficiency measures and renewable energy systems. The application of DECoRuM model to a case study in Oxford shows that CO_2 emission reductions above 60 % are possible, at a cost of between £ 6 to £ 77 per tonne of CO_2 emissions saved, depending upon the package of measures used, and the scenario of capital costs (low or high) employed.

The OSI and DECoRuM projects have led to the development of an action-oriented Oxford Climate Change Action Plan (OCCAP) which constructs an accurate CO_2 emissions inventory for Oxford city for a baseline year, establishes CO_2 reduction targets and proposes action for each of the energy-related sectors to meet those targets. The OCCAP will be implemented by Oxford City Council and provides a useful example for other cities in their endeavour for emission reductions.

Introduction
Climate change, caused by the release of greenhouse gases (mainly carbon dioxide) into the atmosphere, has been recognised as one of the greatest threats of the 21^{st} century. Cities account for three-quarters of the total global energy demand and produce almost 80 % of these carbon dioxide (CO_2) emissions driving climate change (Droege, 2002). Moreover half of the global population lives in cities and this proportion is increasing; almost three-quarters of the human population is expected to become city dwellers by around 2050. In addition, with growing concern over the long-term availability and security of fossil fuel supplies (DTI, 2005b), the need to reduce energy use and CO_2 emissions from cities has never been greater. In fact cities have great potential to make a difference since they form the very framework for development: local government, planning structures and the powerful civic organizations, that are so important in many cultural contexts. That is why there is a growing recognition of the role that local authorities can play in efforts to mitigate the worst impacts of climate change. Studies by Shackley et al. on the importance of area-based carbon emission reduction in the UK find that:

Actions at the local to regional scale are needed to deliver extensive carbon emission reductions, but to date most strategic thinking has focussed on national mechanisms. There is great untapped potential for bottom-up-led carbon reduction. (Shackley et al., 2002, p. 9)

Such area-based carbon emission reductions will require concerted action by all sectors of the community. In fact most of the measures required to reduce CO_2 emissions will be implemented at the city level, working with City Councils since they have the ability to make communities more energy efficient by using their influence over the community and existing statutory powers, e.g. land use and planning decisions, infrastructure investment and municipal service delivery etc (McEvoy et al., 1998). In recognition of this, challenging and credible targets for CO_2 emission reduction have been set by some local authorities in the UK. Results of a survey undertaken in 2002 of targets established by UK local authorities, shows that only 34 % of UK local authorities had set an emissions reduction target for their own emissions, and only 25 % had set a target for the local community emissions (Fleming et al., 2002). The most common CO_2 reduction target was 20 %. However some authorities are now considering more ambitious CO_2 reduction targets, e.g. Newcastle-upon-Tyne and Plymouth are proposing a net zero carbon target, and the City of Leicester has set a target of 50 % reduction in CO_2 emissions based on the 1990 level by the year 2025.

As a city, Oxford (located in the south-east of United Kingdom) has had a strong commitment to energy efficiency and renewable energy technologies. For example, Oxford City Council has been procuring green electricity for many years, and owns a fleet of low emission electric and LPG-fuelled vehicles. Most recently Oxford has been one of 24 local authorities to become part of the UK Councils for Climate Protection (CCP) Pilot Programme. Oxford is also home to numerous environmental organisations - academic, non-governmental and commercial. Many of these have an international reputation for their work on greenhouse gas accounting and/or climate change. These include the Oxford Institute for Sustainable Development at Oxford Brookes University, Environmental Change Institute at University of Oxford, Oxford Ecohouse, Best Foot Forward and UK Climate Impacts Programme. Furthermore, in April 2006, Oxford played host to the 2nd International Solar Cities Conference (see: www.solarcities.org.uk).

Within such a context, this paper reviews three key initiatives undertaken in the historical city of Oxford to bring about reductions in energy-related CO_2 emissions on a city-wide scale. These include: the Oxford Solar Initiative which was started in 2002 to help households and organisations in Oxford, financially and technically, to install solar energy systems and energy efficiency measures in buildings; the on-going further development of a GIS-based DECoRuM model to count, cost and reduce domestic CO_2 emissions on an urban scale; and the Oxford Climate Change Action Plan which has been recently completed and underpins future work on carbon emission reductions from the city of Oxford.

Oxford Solar Initiative

The use of renewable energy and micro-power systems is already on the rise today but the current speed of change is still too slow to meet the global goals for CO_2 emissions reduction. In recognition of this need to move rapidly towards a renewable energy future, in 2002, a group of local Oxford Councillors, council employees, consultants and academicians from Oxford Brookes University (including the author) put together a team to promote Oxford as a leading Solar City in the UK; the Oxford Solar Initiative (OSI) project (Roaf et al., 2002; Roaf et al., 2004; Roaf et al., 2005b). Technically a 'Solar City' is a city that aims at reducing the level of greenhouse gas emissions through a holistic strategy for the introduction of RES (Renewable Energy Systems) and RUE (Rational Use of Energy) to a climate-stable level in the year 2050 (Droege, 2002). In line with this, the overall aim of OSI is to significantly increase the rate of CO_2 emissions reduction in Oxford city, by targeting additional marketing and support to consumers, primarily householders, to remove barriers and increase the rate of take-up for energy efficiency measures and solar energy installations. To achieve this aim, the initiative contains clear goals, which are:

Goal One: 10 % of all houses in Oxford to have solar systems by the year 2010.

Goal Two: To implement a capacity building programme to the local government for the provision of information, training, and other services oriented to CO_2 mitigation strategies.

Goal Three: To establish strategic alliances, and participation, of the local government, households, business organisations, energy supply companies and community organisations to fulfil Oxford's CO_2 reduction targets.

Goal Four: To initiate and implement a solar campaign to support local CO_2 reduction initiatives at every level within the Oxford community from primary school children to business leaders.

To meet these goals, OSI focusses on three key areas as follows (Figure 1):

- CO_2 reduction focused urban planning strategies

In part due to restrictions imposed by clients, construction, design, architecture and development firms can, but rarely do, have a major influence over the embedded carbon in new developments. Local authorities, through planning strategies, could reverse this situation.

- Targets, baseline studies and scenario development

Ambitious long-term targets for carbon reduction are valuable, but are often best seen as 'aspirational' given that the target formulators rarely have the agency to deliver them. Milestones can be used to monitor and manage the achievement of long-term targets over shorter time scales. The development of tools to evaluate and assess individual initiatives needs to be done with scientific rigour.

- Urban energy technologies, industry and business development

This group of actions included job creation, attracting green industry, creating a new 'green' economic sector, promoting entrepreneurship in the green sector, efficiency improvements that reduce expenses and improve profits.

The Oxford Solar Initiative recognised that its success depended upon a collaborative community-based approach among all involved parties. Therefore the main role of the Oxford City Council in the initiative was to be a catalyst in the

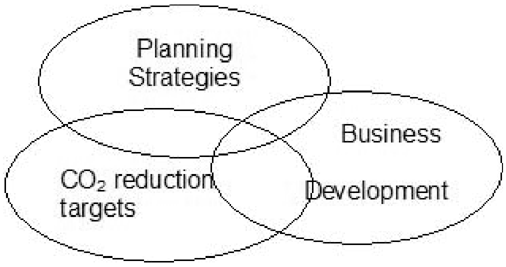


Figure 1. Three Areas of focus of Oxford Solar Initiative

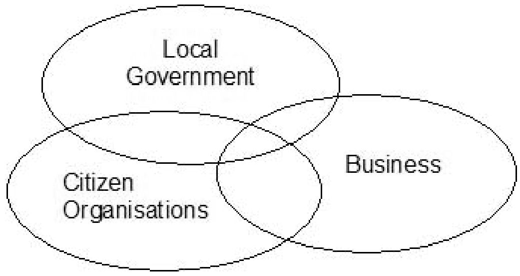


Figure 2. Actors involved in Oxford Solar Initiative

Table 1. Results from the questionnaire survey. (Source: Roaf et al., 2003)

External wall construction	
Cavity wall / Not insulated	4.0 %
Cavity wall / Insulated	3.0 %
Solid brick/stone (mainly pre war)	67.4 %
Don't know	8.9 %
Other	16.8 %

Loft insulation	
25 mm (1")	2.0 %
50 mm (2")	11.9 %
75 mm (3")	10.9 %
100 mm (4")	15.8 %
150 mm (6")	5.9 %
200 mm (8")	2.0 %
None	4.0 %
Don't know	47.5 %

Draught proofing	
All	12.9 %
Most	11.9 %
None	25.7 %
Some	49.5 %

Hot water cylinder insulation	
Jacket	34.7 %
Rigid foam	36.6 %
None	28.7 %

Low energy lighting	
All	1.0 %
Half	2.0 %
Most	9.9 %
Some	66.3 %
None	20.8 %

Secondary/double glazing	
All	25.7 %
Half	3.0 %
Most	11.9 %
Some	40.6 %
None	18.8 %

Type of heating	
Condensing boiler	9.9 %
Standard boiler	65.4 %
Standard combi	14.9 %
Other	9.9 %

If standard boiler or combi, year installed	
Before 1980	37.0 %
1980-1990	29.6 %
1990-2000	21.0 %
After 2000	12.4 %

Consider applying energy efficiency	
Agree	26.7 %
Agree strongly	64.4 %
Don't know	8.9 %

Consider using solar energy	
No	2.0 %
Yes	64.4 %
Don't know	33.7 %

From yes, price to pay for solar hot water	
£ 1000	37.0 %
£ 1500	26.2 %
£ 2000	9.2 %
£ 3000	3.1 %
Don't know	24.6 %

From yes, price to pay for solar PV	
£ 1500	44.6 %
£ 2500	18.5 %
£ 5000	6.2 %
Don't know	30.8 %

creation of a local *Oxford Team* (Figure 2), which was expected to draw together the relevant stakeholders, who would in turn develop a co-ordinated approach to energy efficiency and renewable energy solutions.

The OSI project ran in two phases: the feasibility stage and the implementation phase, both of which were financially supported by the UK's Energy Saving Trust (EST). The following sub-sections detail these two stages:

FEASIBILITY STUDY

As part of the feasibility study, a survey was conducted to investigate customer attitudes towards installation of solar photovoltaic (PV), solar hot water (SHW) and/or passive solar features in combination with energy efficiency measures on houses in North Oxford; this also provided evidence for the likely success of the proposed implementation phase. 600 questionnaires were distributed to households in north Oxford and 100 returns were received[1]. The results of the survey are shown in Table 1.

Figure 3. GIS map of North Oxford showing location of survey areas based on number of responses.

It appeared from the survey that a large percentage of the respondents (68 %) have solid brick/stone walls without insulation. 26 % do not have any draught proofing on their doors and windows while 50 % have some draught proofing. Only 2 % of the respondents have 200 mm thick loft insulation while 29 % have no hot water cylinder insulation. The results showed that there is a considerable scope for improvement in terms of fabric insulation. And since only 10 % of the respondents had condensing boilers, there was potential for improving heating systems also. Importantly, 91 % of the respondents agreed that they would consider applying energy efficiency measures. 65 % of them also agree to consider using solar energy. And among these, 41 % agree to pay £ 1000 - £ 1500 for solar hot water systems and £ 1500 - £ 2500 for solar PV systems (Roaf et al., 2003). A GIS (Geographical Information System) map of the local area of North Oxford was developed to identify location of survey areas and to map the information gathered in the residents' surveys. This is shown in Figure 3.

Key findings from the feasibility study

The survey demonstrated that there was a high demand for energy efficiency measures and solar advice; properties were typically in poor condition and therefore offered a high potential for improvement. A large proportion of boilers were ready for replacement and could be replaced with gas condensing boilers. Solar hot water systems emerged to be a popular choice and people are willing to install them, if they perceive them to be reasonably-priced. Furthermore the survey confirmed that there was an excellent opportunity to pursue the implementation phase of the project, and that it made sense to prioritise energy efficiency measures before solar hot water systems and consider photovoltaics as a final (and not inexpensive) add-on in the 'Low Carbon Homes package', because whilst solar measures work well to stimulate interest, householders are more likely to take-up energy efficiency measures. Hence the implementation stage focussed on installing energy efficiency measures with solar installations being used as a marketing tool.

IMPLEMENTATION PHASE OF OSI

This phase focussed on the residents of north Oxford in the Summertown and Wolvercote wards, since residents in these wards were shown by the feasibility study (Figure 3) to be both receptive to the aims of project and challenging of the detail in respect of practicalities and cost-effectiveness. If successful, it was anticipated that the initiative would be marketed throughout the Oxford city towards the end of the implementation project as part of a roll-out programme, and the information on the method of approach would be made available to other towns and cities wishing to pursue a similar approach. The full range of energy efficiency measures were promoted including, loft insulation, cavity insulation, draft stripping, double glazing, improved heating controls, condensing boilers. Special attention was paid to practical methods of solid wall insulation which is a major issue for the predominately terraced housing in the area. Traditional approaches to marketing energy efficiency measures frequently meet with a disappointing response whereas, by contrast, solar measures stimulate considerable initial interest and even enthusiasm. Unfortunately the high cost of SHW and PV installations frequently discourages progress to implementation. However, by jointly marketing energy efficiency measures alongside solar installations the former are clearly shown to be highly cost-effective and the likelihood of take-up can be significantly increased.

The implementation plan for the Oxford Solar Initiative was carried out along the following strategy (Roaf et al., 2005b):

Oxford Solar partnership: Strategic alliances were established with the participation of Oxford Brookes University, elected Oxford Council, the local Authority and leading UK consultants specialised on RUE and SET.

OSI public events: The OSI team held a number public open events to create awarness, one with stalls set up one Saturday on a busy city thoroughfare, while the second was a very successful Solar Fair in Oxford Town Hall where over 400 members of the public visited and saw a wide range of displays of solar hot water systems. People were encouraged to even try making their own solar systems and discuss their own homes and plans for the installation of energy efficiency measures and solar technologies. A seminar for architects and builders was also organised in the Town Hall.

Oxford Solar Scenarios: OSI project also included scenario development using bottom-up models that can provide input into planning and strategy development and influence research and urban development policy. This involves producing a range of varied high-end and low-end scenarios to evaluate the optimum routes for the introduction of solar systems and RUE in Oxford. it forms the basis for the DECoRuM model discussed in the following section.

Pilot Projects: As part of OSI, two pilot projects under development are:

- A Street or small area of houses equipped with PV with single point of connection to grid, sized to qualify for ROC (Renewable Obligation Certificate).
- Solar suburb

A package of basic energy efficiency, solar hot water and solar PV systems has been developed and tied up with two different economic models: selling energy to the grid through as a single energy producer (by using the Renewable Obligation Contribution – the ROC facility), or installing individual systems by using a local CO_2 programme funding (by using National funds from EST, etc). The public reaction towards these two different implementing options is to be tested.

Dedicated Website: A dedicated website for OSI (see: www.oxfordsolar.org.uk) has been set up to provide:

- Advice on energy efficiency and renewable energy solutions for the home
- Technical assistance with selecting EE and RE products and providers
- Information on financing opportunities – grants, subsidies and discounts
- Support with accessing and applying for grants and subsidies

As a result of these activities, so far OSI has facilitated the installation of 80 active solar systems, over 450 energy efficiency measures and 3,000 low energy light bulbs (CFLs). A solar map has been developed which shows the houses where these measures have been installed (see: www.oxfordsolar.org.uk/links/OSI_map.pdf). However most importantly, OSI has established strategic alliances, and participation, of the local government, households, business organisations, energy supply companies and community organisations to fulfil Oxford's CO_2 reduction targets in the future.

Development and demonstration of DECoRuM model

The scientific basis of OSI is a GIS-based DECoRuM™, a GIS-based domestic energy, carbon-counting and carbon-reduction model, which has been developed, demonstrated and validated by the author using Oxford as a case study (Gupta, 2005b; Gupta, 2006a). Recently, DECoRuM model has also received the Royal Institute of British Architects' President's medal for outstanding research 2006. DECoRuM model estimates and maps baseline energy use and CO_2 emissions on a house-by house level, identifies 'pollution' hotspots, predicts the potential for reductions in CO_2 emissions and monitors reductions achieved as a result of deploying energy efficiency measures and renewable energy systems on an urban scale. Also, it has an additional unique feature of assessing the cost-benefits of various CO_2 reduction measures and putting a financial cost to CO_2 emission reduction (£ /tonne of CO_2 saved).

DEVELOPING DECORUM

The physically-based annual version of Building Research Establishment's domestic energy model, BREDEM-12, combined with the government-approved Standard Assessment Procedure (SAP) 2001 home energy rating methodology, are the underlying energy models in DECoRuM, which calculate annual energy use, fuel costs and CO_2 emissions resulting from space heating, water heating, cooking, lights and appliances, as well as a SAP energy rating (scale of 1 to 120), which is based on calculated annual energy cost for space and water heating for a dwelling (Anderson et al., 2002; BRE, 2001). The net annual cost (NAC) method is chosen to assess the cost-effectiveness of deploying individual CO_2 reduction measures. Microsoft Excel dynamically linked to the Geographical Information System (GIS) software, MapInfo, are the operating platforms for DECoRuM. The GIS software is the user interface.

Estimating baseline energy use and CO_2 emissions

Although, BREDEM-12 is a reputable, validated model, which performs calculations rapidly and at a level of detail appropriate to city planners, the quantity of input data (95 parameters) it requires, is not easy to obtain in practice, owing to the high cost of detailed on-site surveys. This poses problems for energy modelling on an urban scale. In DECoRuM, to overcome the problem of data collection, data reduction techniques have been developed to enable most of the dwelling-related data required by the underlying energy models to be supplied from traceable sources. Data reduction techniques classify the 95 input data parameters required by BREDEM-12 (linked to SAP model) into 4 categories, according to the source of data. Category 5 includes data to be collected for estimating the solar potential of dwellings (Gupta, 2006a). The categories along with the number of dependent parameters are listed in Table 2.

The data for categories 1, 2 and 3 are derived from a range of secondary sources including traceable national statistics, UK Building Regulations, BRE reports, English House Condition Survey (EHCS) 2001, and locally relevant Home Energy Survey Forms, while data for categories 4 and 5 are obtained from

Table 2. List of categories used for data reduction in DECoRuM

No.	Category used for data reduction	Number of parameters	Percentage of parameters
1.	Data common to all dwellings	50	52.7 %
2.	Data derived from built form	5	5.3 %
3.	Data derived from age	18	19.0 %
4.	Data to be collected for individual dwellings	22	23.0 %
	TOTAL (BREDEM-12 calculation)	95	100 %
5.	Data collected for estimating the solar potential	4	

primary sources, which include a GIS urban map and walk-by survey. As a result of the data reduction techniques, only *one-fifth* of the data items required for a BREDEM-12 calculation need to be collected for individual dwellings in a case study, and only *one-tenth* are to be collected by a walk-by survey. Results of energy use, CO_2 emissions, fuel costs and SAP energy ratings can be displayed in the form of thematic maps in MapInfo GIS, with an individual dwelling displayed as the basic unit of resolution. This helps to pinpoint *hot spots* of energy use and CO_2 emissions.

DECoRuM CO_2 reduction and cost-benefit model

A wide range of literature was reviewed and the following measures were identified for reducing domestic CO_2 emissions on the demand and supply side of energy. For these measures to be incorporated in DECoRuM, the baseline energy model is used to filter suitable dwellings for every CO_2 reduction measure by use of appropriate criteria. Subsequently, for the 'passed' dwellings, the measure is incorporated in their baseline energy models using appropriate procedures to quantify the energy savings and reductions in CO_2 emissions that occur on an individual dwelling level, and also aggregated to an urban scale. This approach developed in DECoRuM is presented in Figure 4.

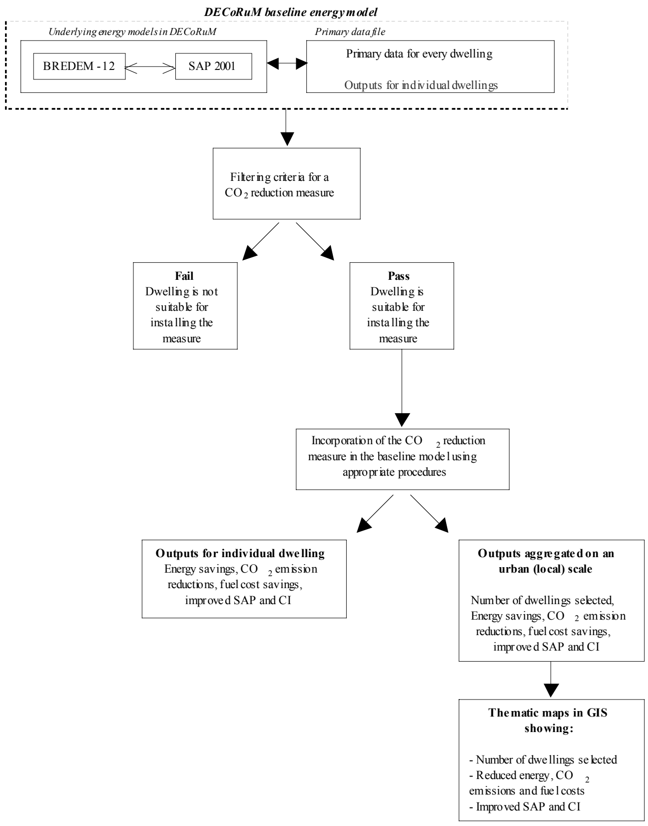


Figure 4. Approach for assessing CO_2 reductions in DECoRuM

Depending upon the measure, the filtering criteria and procedures are derived from field trials, laboratory experiments, theoretical calculations, or from a realistic mixture of these (EST, 2001; EST, 2002; HEEBPp, 2003; Shorrock et al., 2001). For instance, in case of solar hot water systems, dwellings with roof orientation lying between ±45° of south (Northern Hemisphere), roof inclination lying between 0° and 60° and roof area >3.9 m² are selected. When insulation-related energy efficiency measures are run in DECoRuM, the procedure is to change the appropriate U-values and ventilation rate; a more detailed calculation is performed to quantify the potential for solar hot water yield of the selected dwellings (BRE, 2004, p. 46). The results are displayed in GIS in the form of thematic maps.

The net annual cost (NAC) methodology is incorporated in DECoRuM as the cost-benefit model to assess the cost-effectiveness of individual CO_2 reduction measures. The cost-effectiveness is assessed for high and low capital costs, with the expectation that in most circumstances, the real Figure would lie somewhere between them. This cost-benefit model requires standard input parameters relating to typical capital costs per dwelling for installing a measure, lifetime of the measure, the cost and CO_2 emission factor of the fuel displaced, as well as case-study-specific parameters. One of the key results of using the DECoRuM cost-benefit model is that the *net annual cost per tonne of CO_2 emissions saved* can be derived, and used to assess the cost-effectiveness of that measure. A measure is taken to be cost-effective if the NAC is negative; the larger its absolute value, the more cost-effective that measure is. The DECoRuM cost-benefit model also gives the *cost for reducing a tonne of lifetime CO_2 emissions* by using one or a combination of measures.

DEMONSTRATION OF DECORUM MODEL: APPLICATION TO A CASE STUDY IN OXFORD

DECoRuM model was applied to a case study in Oxford covering approximately 318 dwellings, to demonstrate and validate its capabilities (Gupta, 2005a). The case study dwellings contained all the built forms and age-bands present in UK housing, although in different proportions from those of the national stock. Data for individual dwellings was derived from GIS

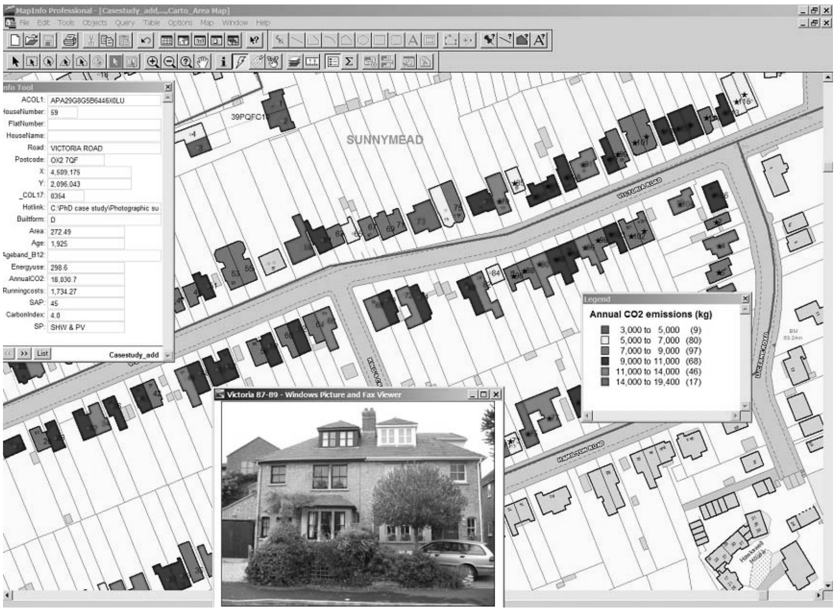


Figure 5. Representation of annual CO_2 emissions in the form of GIS thematic maps using DECoRuM for dwellings in north Oxford. The dwelling footprints in red and pink indicate the hotpots of energy use.

urban map, local authority records and walk-by surveys. The DECoRuM model calculated the baseline energy consumption and associated CO_2 emissions for every dwelling in the case study area (318 dwellings) and aggregated them together to give a total baseline energy consumption Figure of 49,699 GJ/year and total CO_2 emissions of 3,026 tonnes/year. A thematic map is created in MapInfo GIS, showing the estimate of baseline total annual CO_2 emissions from every dwelling (Figure 5). Also, in the GIS map, through *hot links,* digital images of street-facing façades of dwellings can be presented to get an idea of their construction.

As expected, space heating consumed the most energy (61 %), producing 55 % of the total CO_2 emissions, and was responsible for 44 % of the total running costs. The breakdown of baseline results according to the different built forms showed that mid-terraced dwellings in the case study had the highest average SAP rating at 47.9 (and a Carbon Index of 3.6) and the lowest average fuel cost of £ 657/year, while bungalows (open from all 4 sides) had the lowest SAP rating of 36.3 and the lowest CI of 2.7.

When the baseline figures of the case study were broken down by age group, as expected, dwellings built between 1996 to 2002 had the highest average SAP rating, 90.3, highest CI, 7.3, and the lowest running costs of £ 676/year. On the other hand, pre-1930 dwellings have the lowest average SAP rating and CI. Furthermore, SAP ratings increased, as the dwellings got more recent (Figure 6).

These results were extensively validated by comparisons with national and city-level statistics, as well as with case-study-specific databases. This instilled confidence in the predictions from DECoRuM, and built the case for extrapolation of findings from the case study to the national level. Each CO_2 reduction measure embedded in DECoRuM was then applied individually in the case study, using appropriate filtering criteria to select the most suitable dwellings. The corresponding savings in total annual energy use, total annual CO_2 emissions, fuel costs, and improvement in SAP ratings and CI were calculated.

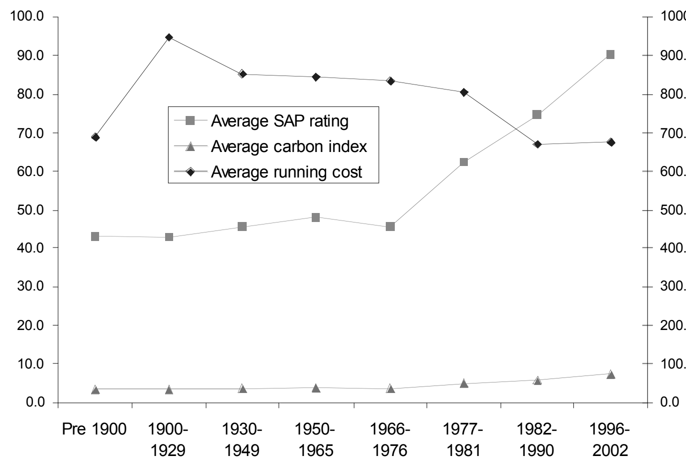


Figure 6. Distribution of SAP rating, Carbon Index and annual running cost by age band in the Oxford case study dwellings

Results indicated that external solid wall insulation saved the most energy, CO_2 emissions and fuel costs in the case study dwellings. The cost-benefits of applying these measures were evaluated at 2001 fuel prices, and it was shown that measures which were the most cost-effective did not necessarily save the most CO_2 emissions. Energy-efficient appliances, for instance, have considerable savings in expenditure only when installed collectively. However, hot water cylinder insulation, replacement with condensing boilers, roof insulation and cavity wall insulation appeared to be cost-effective in any circumstance (low capital cost and high capital cost scenario), and this justifies the wide promotion they have received over the years. While domestic micro-CHP units appeared to be cost-effective in any circumstance, ground source heat pumps (GSHP) systems emerged as cost-effective only when government grants were included. SHW and solar PV systems were not cost-effective at current prices. Although the simple payback period for a 1-kWp solar PV system reduced to 30 years from 95 years if government grants were included and if it was assumed that domestic PV systems qualified for selling Renewable Obligation Certificates (ROCs) to energy suppliers.

The overall potential for reducing CO_2 emissions from the case study dwellings was then predicted. Five alternative packages were developed, using a combination of energy efficiency measures, low carbon technologies, solar energy systems and green tariff electricity. The analyses showed that reductions in excess of 60 % were possible from the case study dwellings at a cost of between £ 6/tonne of CO_2 - £ 77/tonne of CO_2 emissions saved. This cost depended upon the package of measures used, and the scenario of capital costs (low or high) employed. These figures compared favourably with the UK's estimated social cost of CO_2 emissions (£ 19/tCO_2). Cost-effective savings of 2,044 tonnes of CO_2 emissions per year were estimated for the case study dwellings. This is equivalent to 67.5 % reductions of CO_2 emissions over baseline if green tariff electricity is included and 57 % if it is not. This indicated a total expenditure of between £ 0.4 million and £ 1 million as currently necessary to install all the cost-effective CO_2 emission reduction measures in all the case study dwellings.

The Oxford DECoRuM model has been used in the OSI project to undertake targeted marketing to increase the uptake of the energy efficiency measures and solar energy installations. The model could be further used by the City Council in Oxford to develop and review the energy efficiency strategy and targets for improvement. In particular, the cost-benefit analysis of the measures and financial cost of CO_2 emission reduction is likely to be useful in supporting funding applications, or to make the case for re-allocating internal resources.

DECoRuM model is presently funded as a 'proof of concept' to be further developed as a toolkit for carbon emission reduction planning for use by UK local authorities to report, monitor and improve the energy efficiency of both public and private housing, as required by the Home Energy Conservation Act. It is expected that a robust GIS-based toolkit would be available to UK local authorities, energy advisers, building surveyors and real estate professionals to assist them in counting, costing and reducing domestic carbon emissions. For further information on DECoRuM, please visit www.decorum-model.org.uk.

Oxford Climate change Action Plan

The OSI and DECoRuM projects have led to the development of an action-oriented Oxford Climate Change Action Plan (OCCAP) by the author (commissioned by the Oxford City Council). Although Oxford has had a strong commitment to energy efficiency and renewable energy technologies, yet, no complete CO_2 emissions assessment of the city has been undertaken. The OCCAP therefore constructs an accurate CO_2 emissions inventory for the city of Oxford for a baseline year, establishes CO_2 emissions reduction targets and proposes action and measures for each of the energy-related sectors to meet those targets, and suggests ways of monitoring and verifying the reductions achieved (Gupta, 2005c; Gupta, 2006b).

ASSESSING BASELINE CO_2 EMISSIONS IN OXFORD CITY

The most important part of any climate change action plan is to have an accurate CO_2 assessment for a baseline year. This not only enables one to identify the main energy-using sectors and set reduction targets, but it also provides a benchmark to measure the effectiveness of actions and programmes adopted, and monitor the progress towards targets. The OCCAP constructs a disaggregated CO_2 emissions inventory for Oxford city by assessing the CO_2 emissions generated *directly*, in the jurisdiction of Oxford (such as a home heating system powered by natural gas, or a car or truck powered by petrol or diesel), and *indirectly* in case of generation of electricity that is used within Oxford city. There is no attempt made to detail the embodied energy of goods consumed or energy use undertaken by residents outside Oxford, for instance air travel or waterborne transport or emissions related to food. A combination of both top-down methods (national datasets) and bottom-up approaches (the use of localised datasets) are selected to calculate the major sources and levels of CO_2 emissions (by sector) in Oxford. While the top-down datasets provide an overall picture of the sectoral CO_2 emissions in Oxford, local datasets provide disaggregated figures for taking action.

Top-down approaches (national datasets)

The top-down datasets included are those published by various UK government departments: National Atmospheric Emissions Inventory (NAEI), Department of Trade and Industry (DTI) (DTI, 2004; DTI, 2005a) and Department of Environment, Food and Rural Affairs (DEFRA) (DEFRA, 2005). NAEI inventory differs fundamentally from DTI and DEFRA in its approach to collecting data, by focusing on the source of emissions (point, line or area source), whilst both DTI and DEFRA focus on the consumption of energy. DTI Energy Statistics, on the other hand, focus on gas and electricity consumption, and road transport fuels. According to DEFRA, CO_2 emissions from Oxford in 2003 are estimated to be 987,853 tCO_2, with domestic energy use and road transport responsible for almost half the total CO_2 emissions (Figure 7).

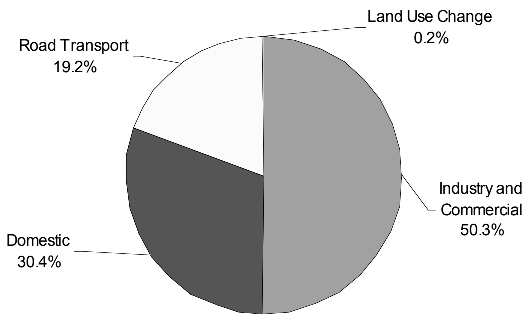
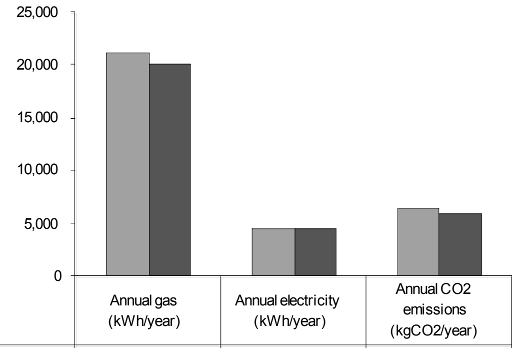


Figure 7. Percentage breakdown of CO_2 emissions by sector in Oxford in 2003.

The sectoral emissions in Oxford are indicative of the trends observed regionally and nationally, especially the domestic sector which in 2003 was responsible for around 30 % of the total emissions at all levels. In fact the average annual gas consumption per household in Oxford was calculated as 21,150 kWh in 2003, almost 5 % more than the average consumption of gas per household across Great Britain, while the average electricity consumption per household in Oxford was 1 % less than the GB average in 2003 (Figure 8). This results in higher overall annual CO_2 emissions from an Oxford dwelling (6,478 kgCO_2)



	Annual gas (kWh/year)	Annual electricity (kWh/year)	Annual CO2 emissions (kgCO2/year)
Oxford dwelling-average	21,150	4,554	6,478
GB typical dwelling	20,111	4,600	6,000

Figure 8. Comparison of annual average gas, electricity consumption and related CO_2 emissions of an Oxford dwelling with GB typical.

as compared to the GB typical of 6,000 $kgCO_2$, clearly offering potential for reductions.

Furthermore, it is realised that the average annual gas and electricity consumption (per square metre) of, and CO_2 emissions from, the commercial and industrial sector in Oxford in 2003 were almost 20 % more than corresponding figures for Great Britain. Obviously this sector provides another opportunity for taking action to reduce CO_2 emissions. Nevertheless the per capita annual CO_2 emissions of an Oxford resident (at 6.9 tCO_2 (DEFRA statistics) are much lower than that of the Southeast of England (8.8 tCO_2) and UK (9.5 tCO_2) averages. However in a global context they appear very high, almost three times the sustainable level of 2.5 tCO_2 per person (see Figure 9).

Bottom-up approaches (local datasets)

Although the national datasets construct an overall inventory of CO_2 emissions from Oxford city by sector, these do not identify which particular areas within a sector could be targeted for future action and improvement. Such information is generally provided by bottom-up local datasets. For the domestic sector in Oxford, various organisations have quantified its energy consumption and CO_2 emissions for different years. While the Oxford House Condition Survey carried out in 1995 estimates the average SAP (energy rating) of Oxford dwellings to be 43, Elmhurst energy surveys in 2001 calculate it as 44, while DECoRuM studies conducted in 2003 assess the average SAP as 45 for North Oxford dwellings (Gupta, 2005b). Most recently, the private house condition survey undertaken in 2004 estimates the average SAP as 54. It is realised that DECoRuM is the only GIS-based domestic energy and emissions model deployed in North Oxford which displays results on an individual dwelling level, pinpoints pollution hotspots, and predicts the potential for emissions reduction. Its capabilities could be extended to evaluate energy consumption in, and CO_2 emission reductions from, the entire Oxford housing stock, and the cost of a range of measures to reduce both.

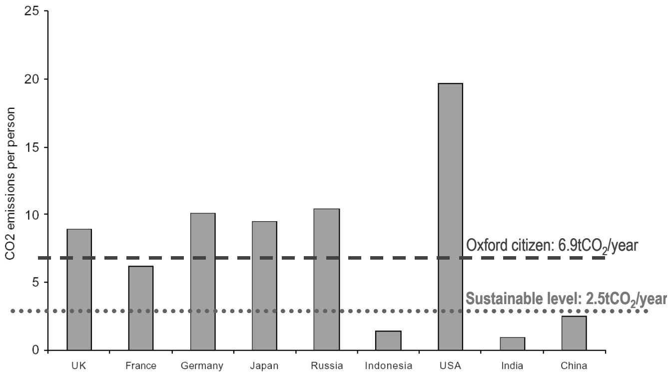


Figure 9. Comparison of per capita annual CO_2 emission figures of an Oxford citizen with international figures.

For the non-domestic sector, the only local dataset available is the regular monitoring of energy use and CO_2 emissions for only 16 high-energy consuming council-buildings. These 16 monitored buildings are responsible for only 1 % (4,463 tCO_2/year) of the Oxford's total industrial and commercial CO_2 emissions, so it is important to extend the collection of bottom-up energy data to include more non-domestic buildings. Even performance of these 16 buildings could considerably be improved as most of them compare poorly with both UK typical and good practice standards.

SETTING CITYWIDE CO_2 REDUCTION TARGETS

The CO_2 emissions inventory of Oxford has revealed that there is much scope for reducing CO_2 emissions from the various energy-related sectors in Oxford. The next step is to establish targets for Oxford to reduce CO_2 emissions in the medium to long term, and propose action to achieve these targets in each of the energy-related sectors. Worldwide many cities as part of ICLEI (www.iclei.org), International Solar Cities Initiative (www.solarcities.co.kr) and the European Solar Cities Initiative (www.eu-solarcities.org/) have set targets for reducing future CO_2 emissions at levels consistent with stabilising levels of atmospheric CO_2. The UK target under the Kyoto Protocol is a 12.5 % reduction based on 1990 levels. However, the UK has also set its own domestic target of a 20 % reduction in CO_2 emissions on 1990 levels by 2010. In addition, the UK government has stated in the Energy White Paper published in 2003 to cut emissions of CO_2 by 60 % by around 2050 (DTI, 2003). To help achieve this, the Government has set a target of producing 10 % of UK electricity from renewable sources by 2010. In line with such national goals (both legal and aspirational) and the pressing need to stabilise atmospheric concentration of CO_2 emissions, the overall aim for OCCAP should be to ultimately achieve CO_2 emission reductions in Oxford above 60 % by 2050 over the 2005 baseline emissions. This long term target should be accompanied with the following intermediate goals (objectives) of CO_2 reduction (over 2005 baseline emissions) in the near to medium term:

- 15 % reduction in CO_2 emissions by 2010
- 20 % reduction in CO_2 emissions by 2015
- 30 % reduction in CO_2 emissions by 2020
- 40 % reduction in CO_2 emissions by 2030

Such emission reduction targets will no doubt require concerted action by all sectors of the community in Oxford city, which is described in the following section.

IDENTIFYING ACTIONS TO ACHIEVE TARGETS

It is clear that no one individual, group or institution can effect the changes necessary to meet the challenging target of above 60 % reductions in CO_2 emissions from Oxford city by 2050. Instead a partnership approach is required across the city, with all energy-related sectors fully engaged in taking action. It is therefore important to identify the key strategies (which have the greatest impact) that Oxford City Council could adopt in its effort to bring citywide CO_2 emission reductions. These include:

- Raising awareness and understanding of the impact of lifestyle on climate change
- Mapping CO_2 emissions in Oxford using GIS-based modelling
- Encouraging energy conservation and local generation of energy.
- Setting and achieving targets for domestic energy efficiency.

To improve domestic energy efficiency in Oxford by 10 % by 2010 and 20 % by 2020 on 2005 levels. This would in turn help in also alleviating fuel poverty by 2010 in vulnerable households.

- Energy audits and surveys of non-domestic buildings;

As a result of energy auditing, aim to reduce CO_2 emissions from all council-owned non-domestic buildings by at least 25 % on 2005 levels by 2010.

- Improving energy efficiency standards of new developments

To ensure that by 2010 all new residential developments in Oxford are built to the best practice standard, which could be introduced for approximately capital costs 6 % above the datum for traditional masonry build, and 8 % for timber frame constructions (EEBPH, 2005).

- Increasing the uptake of low carbon systems;

10 % of all houses in Oxford (in 2005) to have solar systems (solar hot water or solar PV) by the year 2010 and 25 % of all houses to have solar systems by 2020. All new residential and non-residential developments (>1000 m^2) in Oxford to supply 10 % of expected electricity consumption by on-site renewable energy systems.

- Minimising transport impact of new developments

New developments should be located close to local travel destinations (such as the city centre) or where there is good access to public transport. It should be ensured that facilities in new developments are included to support the use of low/zero carbon-fuelled vehicles.

- Transforming Oxford into a Solar (sustainable) City.

FURTHER WORK

Although this Climate Change Action Plan operates on a long-term perspective, it also includes targets and actions to be achieved in both the short and the medium term. The action plan therefore is a flexible document reviewable on an annual basis. Therefore it is essential that an in-house Climate Change Team within the Oxford City Council be set up with the responsibility of delivering the OCCAP. Whilst climate change later this century will be determined by the emissions we allow now, climate change we expect in the next 30-40 years will be due to our past greenhouse gas emissions (Roaf et al., 2005a). Further work needs to be done to develop a climate change adaptation strategy for Oxford city bearing in mind that adaptation measures that lead to increasing greenhouse gas (CO_2) emissions be avoided.

Conclusions: Future work for Oxford city

All the three initiatives discussed above have led to the reduction of energy-related CO_2 emissions from Oxford city, by involving and empowering the people (OSI project) to install carbon reduction measures in their homes, by providing a robust scientific model to measure, benchmark and verify the reductions in emissions achieved through the DECoRuM model, and finally, by developing a strategic action plan to assess and reduce energy-related emissions from all sectors in the future. In particular, the actions identified in the OCCAP are being currently implemented by the Oxford City Council. Two new posts for Climate change officers have also been created in the Oxford City Council to take forward the recommendations suggested in the OCCAP. Gupta (2006) has been appointed to do post-occupancy evaluations (energy, environmental and occupant satisfaction) of 35 City Council-owned non-domestic buildings. The next step is to monitor and verify the reductions in CO_2 emissions achieved as a result of those actions. A GIS-based CO_2 model extended to the whole city of Oxford, would enable the city council to track progress and assess the emission reductions achieved. Therefore, work on building the GIS CO_2 model (especially for the domestic sector) should be commissioned as soon as possible.

Undoubtedly, these experiences from Oxford provide a useful example for other cities in their endeavour for emission reductions. But importantly all the three initiatives also make the case for all of us to do our bit as urban city dwellers, since the delivery of emissions reductions would require a partnership approach across a city, with all sectors including individuals fully engaged in taking forward an agreed action plan.

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(Endnotes)

[1] This very high response rate is even more impressive considering that respondents had to provide their own envelope and stamp in order to return the questionnaire and in addition the 3 week survey period straddled the Christmas break.