Carbon emission reduction model: a new GIS-based approach

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Benefits and applications of DECoRuM.
Background to the study

Debate on the cause of climate change is over
CO₂ emissions by sector in UK, USA and India

**UK**
- Agriculture: 1%
- Transport: 26%
- Industrial processes: 22%
- Commercial and public buildings: 13%
- Industrial buildings: 5%
- Domestic buildings: 26%

**USA**
- Industrial: 36%
- Residential: 23%
- Transportation: 3%
- Commercial: 7%
- Agriculture: 21%
- Domestic buildings: 17%

**India**
- Transportation: 3%
- Residential: 23%
- Commercial: 7%
- Industrial: 30%

UK CO₂ emissions by sector, 2002
USA CO₂ emissions by sector, 2005
Electricity use by sector, 2005

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CO₂ emissions from building energy use

**Direct** (on-site): Emissions from fuels combustion (space heating)

**Off-site**: Emissions from public electricity use and district heat consumption.

Globally, the building sector is responsible for 42% of electricity consumption more than any other sector.
US residential CO2 emissions

- Space Heating: 26%
- Cooling: 5%
- Other: 4%
- Refrigeration: 7%
- Electronics: 8%
- Lighting: 12%
- Water Heating: 12%
- Adjust to SEDS: 6%

US commercial CO2 emissions

- Space Cooling: 25%
- Lighting: 13%
- Other: 8%
- Refrigeration: 4%
- Computers: 3%
- Cooking: 2%
- Wet Clean: 6%
- Electronics: 6%
- Space Heating: 13%

Residential sector consumed 37% of all electricity produced in US

About 80% of all CO2 attributed to the commercial sector comes from electricity consumption.

Most of the focus has been on new-build...

- **UK**
  - Building A Greener Future: Towards Zero Carbon Development
  - Code for Sustainable Homes
  - Technical Guide

- **USA**
  - 2030 - Carbon Neutral: (no fossil fuel energy to operate)

- **India**
How do you set boundaries for carbon counting?

LIFE CYCLE ENERGY USE, NEW HOUSE

- Embodied energy
- Elec. for lighting and appliances
- Gas for heating and cooking

NOTE: For a 160m² detached house built to Part L of the 2002 Building Regulations and assuming that energy use for space heating matches the design predictions. Calculated over a lifecycle of 100 years.
Key principles: energy efficiency and carbon intensity

Reduce the demand for energy (heating, cooling, lighting or ventilation).

Provide the reduced demand through low carbon and zero carbon technologies

Decarbonising the electricity supply,

Feedback on actual energy used in buildings through smart metering.

Regular post-occupancy evaluation studies of refurbished projects to provide evidence-based lessons for the building community and users.

EU Directive of Building Energy Performance (EPBD)

- Introducing energy performance certificates (EPCs) when buildings are let, sold, built or refurbished.
- Requiring public buildings to display energy certificates (DECs); and
- Requiring inspections for air conditioning systems.
Following consultation in 2007, the Government has issued a national indicator set (198) against which local councils will begin to report their performance from April 2008.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NI 185</td>
<td>Percentage CO₂ reduction from LA operations</td>
</tr>
<tr>
<td>NI 186</td>
<td>Per capita CO₂ emissions in the LA area</td>
</tr>
<tr>
<td>NI 187</td>
<td>Tackling fuel poverty - % of people receiving income based benefits living in homes with a low energy efficiency rating</td>
</tr>
<tr>
<td>NI 188</td>
<td>Planning to Adapt to Climate Change</td>
</tr>
</tbody>
</table>

It is within this context that our research is undertaken...
Carbon emission reduction planning approach for cities

5-step approach:

• Assessing baseline (existing) CO₂ emissions from all energy-related sectors in cities.
• Establishing ambitious (and realistic) citywide CO₂ emission reduction targets.
• Identifying robust actions to achieve those targets.
• Developing incentives and programmes for implementing the actions.
• Monitoring and verifying the reductions achieved as a result: sharing experiences.
**DECoRuM: a next generation domestic energy model**

Capability to estimate baseline CO₂ emissions from individual dwellings using a locally-relevant approach, and well-established methodologies to ensure credibility.

Aggregates these to an urban scale – street, district or city level.

This enables it to evaluate the potential for domestic CO₂ emission reductions from a whole range of measures on both the demand and supply sides of energy.

An additional and unique feature of assessing the cost-benefits of individual CO₂ reduction measures and putting a financial cost to CO₂ emission reduction.

A mapping tool for representing domestic CO₂ emissions and reductions.

DECoRuM provides local authorities and energy advisers with a tool to address the barrier of counting and reducing emissions locally.

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### Core methodologies used in DECoRuM

<table>
<thead>
<tr>
<th>Methodology used</th>
<th>Details of methodology</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building Research Establishment Domestic Energy Model (BREDEM) 12</strong></td>
<td>Industry standard to calculate energy use for different dwelling types in UK. Estimates annual energy requirement for space heating, water heating, lights &amp; appliances and cooking. Requires 95 input parameters</td>
<td>Annual energy use (GJ/year) Annual CO₂ emissions (kg/year) Running costs (£/year)</td>
</tr>
<tr>
<td><strong>Standard Assessment Procedure (SAP) 2005</strong></td>
<td>Government’s recommended system for home energy rating based on energy costs for space and water heating.</td>
<td>SAP rating (scale of 1-100)</td>
</tr>
<tr>
<td><strong>Net annual cost method</strong></td>
<td>Used by BRE to assess cost-effectiveness of energy efficiency measures.</td>
<td>Net annual cost/tonne of CO₂ saved</td>
</tr>
</tbody>
</table>

Underlying physically-based energy models: BREDEM – 12 linked to SAP 2005.

Cost-benefit analysis approach.
## Outputs from DECoRuM

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Expressed as</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy use</strong></td>
<td></td>
</tr>
<tr>
<td>Total annual energy use</td>
<td>kWh/year</td>
</tr>
<tr>
<td>Annual energy use by end use</td>
<td>kWh/yr</td>
</tr>
<tr>
<td><strong>CO₂ emissions</strong></td>
<td></td>
</tr>
<tr>
<td>Total annual CO₂ emissions</td>
<td>kgCO₂/year</td>
</tr>
<tr>
<td>Annual CO₂ emissions by end use</td>
<td>kgCO₂/m²/year</td>
</tr>
<tr>
<td><strong>Fuel costs</strong></td>
<td></td>
</tr>
<tr>
<td>Total annual running (fuel) costs</td>
<td>£/year</td>
</tr>
<tr>
<td>Annual running (fuel) costs by end use</td>
<td>£/year</td>
</tr>
<tr>
<td><strong>Energy rating</strong></td>
<td>SAP rating</td>
</tr>
<tr>
<td></td>
<td>Scale of 1 to 100</td>
</tr>
</tbody>
</table>

DECoRuM: estimating baseline energy and CO₂ emissions
DECoRuM baseline energy model estimates energy consumption and CO₂ emissions of individual dwellings as the basic component for calculation, and then aggregates these to an urban scale.

**Framework for baseline predictions**

Data Reduction in DECoRuM

- Data common for all dwellings: 53%
- Data derived from age: 19%
- Data derived from built form: 5%
- Data to be collected for individual dwellings: 23%
- Data to be collected by walk-by survey: 10 parameters (16% of total)
DECoRuM: predicting CO₂ emission reductions and cost-benefits

### DECoRuM: 30 CO₂ reduction strategies

<table>
<thead>
<tr>
<th>Strategies for CO₂ reduction</th>
<th>End-uses of energy in a typical UK dwelling</th>
<th>Appliances</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEMAND SIDE OF ENERGY</strong></td>
<td>Space heating</td>
<td>Water heating</td>
</tr>
<tr>
<td>Energy efficient measures:</td>
<td>60%</td>
<td>24%</td>
</tr>
<tr>
<td>Roof insulation</td>
<td>Energy saving</td>
<td>Solid wall insulation</td>
</tr>
<tr>
<td>Solid wall insulation: external</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Low-e double glazing</td>
<td>Draught stripping</td>
<td>Draught lobby</td>
</tr>
<tr>
<td><strong>SUPPLY SIDE OF ENERGY</strong></td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Low carbon technologies:</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Micro CHP</td>
<td>Geothermal energy</td>
<td>District heat networks</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>Solar hot water systems</td>
<td>Solar PV</td>
</tr>
<tr>
<td>Wind turbines</td>
<td>Wind energy</td>
<td>Nuclear energy</td>
</tr>
<tr>
<td>Fuel switching</td>
<td>Diesel</td>
<td>Diesel</td>
</tr>
</tbody>
</table>
Primary data for every dwelling
Outputs for individual dwellings

- Filtering criteria for a CO2 reduction measure
- Dwelling is not suitable for installing the measure
- Fail

- Dwelling is suitable for installing the measure
- Pass

- Incorporation of the CO2 reduction measure in the baseline model using appropriate procedures
- Outputs for individual dwelling
  - Energy savings, CO2 emission reductions, fuel cost savings, improved SAP and CI

- Outputs aggregated on an urban (local) scale
  - Number of dwellings selected
  - Reduced energy and CO2

Thematic maps in GIS showing:

DECoRuM: cost-benefit methodology

<table>
<thead>
<tr>
<th>Use</th>
<th>Outputs (Low capital cost high capital cost scenarios)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To assess the cost-effectiveness of deploying various CO2 reduction measures.</td>
<td>Net annual cost is divided by the annual CO2 saving to give the net annual cost per tonne of CO2 saved</td>
</tr>
<tr>
<td>To determine the capital cost of reducing a tonne of CO2, using a single or a combination of measures on an urban scale.</td>
<td>Cost for reducing a tonne of lifetime CO2 emissions</td>
</tr>
<tr>
<td>To be widely used and understood.</td>
<td>Simple payback period</td>
</tr>
</tbody>
</table>
Application of DECoRuM to a case study in Oxford

Oxford case study: DECoRuM baseline energy & CO$_2$ model
Thematic map showing estimate of total annual energy consumption in the case study dwellings

Thematic map showing SAP ratings for dwellings in the case study
Thematic map of dwellings in the case study showing annual fuel costs

Results from DECoRuM baseline model: by built form and age groups

<table>
<thead>
<tr>
<th>Built form</th>
<th>Number of dwellings</th>
<th>Annual energy use (GJ)</th>
<th>Annual CO\textsubscript{2} (tonnes CO\textsubscript{2} year\textsuperscript{-1})</th>
<th>Running costs (£s/year)</th>
<th>SAP</th>
<th>Carbon Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached</td>
<td>56</td>
<td>10095.2</td>
<td>669.1</td>
<td>1074.2</td>
<td>43.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Semi-Detached</td>
<td>175</td>
<td>27774.6</td>
<td>1698.5</td>
<td>919.2</td>
<td>46.4</td>
<td>3.5</td>
</tr>
<tr>
<td>End-Terrace</td>
<td>21</td>
<td>3955.6</td>
<td>1330.2</td>
<td>618.6</td>
<td>38.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Mid-Terrace</td>
<td>51</td>
<td>5958.8</td>
<td>359.2</td>
<td>656.9</td>
<td>47.9</td>
<td>3.6</td>
</tr>
<tr>
<td>FLAT</td>
<td>10</td>
<td>1583.6</td>
<td>95.3</td>
<td>897.2</td>
<td>41.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Bungalow</td>
<td>3</td>
<td>514.2</td>
<td>31.2</td>
<td>961.7</td>
<td>36.3</td>
<td>2.7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>318</td>
<td>48,699.1 GJ</td>
<td>3,086.31</td>
<td>£892.1</td>
<td>45.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Breakdown of energy use, CO\textsubscript{2} emissions, running costs, SAP rating and carbon index as per built forms of dwellings in the case study.
DECoRuM CO₂ reduction model: estimating solar potential

87% of the dwellings in the case study were suitable for installing either a SHW or a PV system or both.

<table>
<thead>
<tr>
<th>Dwellings with potential for</th>
<th>Number of dwellings</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 m² flat plate SHW (available roof area: 4.0 m² - 9.9 m²)</td>
<td>38</td>
<td>11.9%</td>
</tr>
<tr>
<td>PV (available roof area: 10.0 m² - 13.9 m²)</td>
<td>46</td>
<td>14.5%</td>
</tr>
<tr>
<td>SHW &amp; PV (available roof area: &gt;13.9 m²)</td>
<td>192</td>
<td>60.4%</td>
</tr>
<tr>
<td>None</td>
<td>42</td>
<td>13.2%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>318</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Potential for CO₂ emission reductions above 60%

SHW and solar PV systems, individually installed cost £335 and £644/tonne of CO₂ saved in a low capital cost scenario. When applied in combination in package 3, the cost drops to £44/tonne CO₂ saved.

Emissions trading scheme: £15/tonne CO₂
Carbon capture and storage: £30-60/tonne CO₂

Shadow price of carbon in 2008: £26/tonne CO₂
DECoRuM: Benefits

- Individual dwelling is represented as the base level of resolution but results can be displayed up to a street, district and city level.

- Pollution hotspots can be spatially located and targeted for improvement.

- Assessment requires no access to the property.

- A robust data filtering process provides accurate and reliable results.

- Cost-benefits analysis enables cost comparison of different measures.

- Helps to estimate the potential for citywide application of solar energy systems.

- A useful visual aid when encouraging householders to install energy efficiency measures.
Applications: Local Authorities and DECoRuM

Provides a GIS-based toolkit to enable LAs to develop a carbon footprinting capability to:

- Assess and map the current carbon emissions of their housing stock.
- Benchmark baseline emissions against typical and good-practice standards.
- Identify ‘hotspots’ of pollution.
- Establish carbon emission reduction targets.
- Evaluate strategies and technologies to achieve those targets in terms of carbon reduction and cost-benefits.
- Verify and monitor the reductions achieved.
- Help to develop guidelines (solar legislation, solar rights, and building energy standards) to restrict the housing stock’s carbon emissions to good practice benchmarks.

RIBA President’s medal for outstanding research 2006

www.decorum-model.org.uk/