A quiet revolution: Mapping energy use in low carbon communities

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ABSTRACT

Recent Government funding in the UK has enabled 22 low carbon community organisations to work with the private and academic sector to understand and reduce energy consumption in domestic and non-domestic buildings. This has helped communities prepare for policy mechanisms such as the national Green Deal programme which aims to improve existing housing and non-domestic buildings by offering up-front loans to be repaid by energy savings. This paper presents the role and application of a unique carbon mapping approach, which has enabled five of these low carbon communities to rapidly assess on a house-by-house level, the potential for improving the energy efficiency of their housing stock. DECoRuM, an award-winning GIS-based carbon counting model is used to measure, model, map and manage energy use and CO_2 emission reductions from approximately 1,300 houses across five communities, displaying estimates of energy use and carbon emissions before and after community action. Incremental packages of energy saving measures and low carbon technologies are assessed for their impact on CO_2 emissions to reveal further potential for large-scale refurbishment in the local area. Eligibility for the Green Deal is tested to show that on average 72 per cent of homes over all communities are suitable for finance. Through community events, results are visualised and fed back to the householders using colour-coded spatial maps along with thermal imaging. Findings from this study are relevant for policy-making and practitioners engaged in area-based carbon reductions.

INTRODUCTION

The UK is committed to reducing greenhouse gas (GHG) emissions by 80% from 1990 levels. In response to this commitment, the national Green Deal programme has been proposed to offer energy efficiency improvements to homeowners and businesses at little or no upfront cost with payment recouped through customers' energy bills (DECC, 2012a). The Energy Company Obligation (ECO), proposed to work alongside the Green Deal, will similarly support those experiencing fuel poverty and in hard to treat homes. In addition to the Green Deal, recent Government funding in the UK has enabled 22 low carbon community organisations to work with the private and academic sector to understand and reduce the amount of energy that is used in homes and buildings. One such programme, the Low Carbon Communities Challenge (LCCC), focussed on stimulating energy improvements of homes through capital funding of physical interventions to homes and buildings, behaviour change campaigns and low carbon living activities. The theoretical savings from the 8,206 installed measures and technologies for the entire programme is 3,062 tonnes of CO_2/yr (DECC, 2012b).

The Department of Energy and Climate Change (DECC) (2012b) provide an overall qualitative review of the LCCC impact. Gupta *et al.* (2014) applied a measurement, monitoring and evaluation (MME) approach to 88 households across six LCCC communities. Their findings show mixed results in

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terms of energy use across the households depending on a number of factors including the physical and technical interventions, and occupant behaviours and lifestyle. The detailed evaluations also uncovered unintended consequences associated with energy behaviours, such as increased use of washing machines and other such appliances due to 'free electricity' from low/ zero carbon technologies.

Geographical information systems (GIS) provide a platform for presenting findings in an aggregated form which can be visually effective in communicating results to householders and community groups. A number of GIS based studies focus on energy use estimations using a top-down approach. These include using remotely sensed anthropogenic heat to serve as a proxy to derive the spatial pattern of energy use (Zhou et al., 2012) or combining location, demographic and end-use data to enable energy consumption to be calculated and mapped (Pereira and Assis, 2013). In contrast to the above, the present study combines a bottom-up building characteristic data collection approach to estimate energy use and carbon emissions of approximately 1,300 dwellings over five communities, Community A, B, C, and D (anonymised as per communities' request) in England and Wales, combined with a top-down approach to analysis and geographical visualisation. This is demonstrated through the application of urban energy modelling using DECoRuM© (Domestic Energy, Carbon counting and carbon Reduction Model), to rapidly model, map, and measure energy use and carbon emissions on a house-by-house level. The following method calculates the carbon reduction impact of the LCCC and the impact of further carbon reduction measures for the five communities. The work presented in this paper is part of the Evaluating Low Carbon Communities (EVALOC) project which seeks to assess, explain and communicate the changes in energy use due to community activities within selected case study projects under DECC's LCCC initiative.

METHODOLOGY

The following steps are taken to map and assess the energy consumption, carbon emissions, and retrofit potential for the selected communities:

1. Data collection (e.g. home details, local climate data, etc.), modelling and mapping in GIS
2. Assessment of results, e.g., carbon emissions, before the LCCC and after the LCCC
3. Selected carbon reduction / Green Deal packages are applied to the neighbourhood and the results are calculated and mapped

The communities

Table 1 lists the five communities and some further details.

Community	Number of Households	Dominant Built Form
A	311	1930-49 semi-detached
B	242	1966-76 terraced
C	274	Pre-1900s terraced
D	184	Pre-1900s terraced
E	275	Pre-1930s terraced

DECoRuM model

DECoRuM is a GIS-based toolkit for carbon emissions reduction planning with the capability to estimate energy-related CO_2 emissions and effectiveness of mitigation strategies in existing UK dwellings, aggregating the results to a street, district and city level. The aggregated method of calculation and map-based presentation allows the results to be scaled-up for larger application and assessment. The background calculations of DECoRuM are performed by BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009 (Standard Assessment Procedure) both of which are dynamically linked to create the model. BREDEM is a methodology for calculation of the energy use of dwellings based on characteristics; it is suitable for stock modelling. It shares some features with the SAP methodology, but allows users to adjust inputs which are fixed in SAP (BRE, 2014). SAP, based on BREDEM is the Government approved method for the assessment of the energy and environmental performance of dwellings. Though not as robust as dynamic thermal simulation, the strength of DECoRuM is in the ability to rapidly process results for many dwellings and present them on an urban scale. The tool is useful for communicating energy related concepts and identifying potential areas for concern and further investigation, including simulation, house assessment and monitoring.

Some limitations include:

- Time required for data collection and entry; home questionnaires are helpful in reducing this initial effort.
- Behaviour related assessment is limited: occupancy times, heating schedules, window opening schedules, etc. are not available. Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.
- The model does not calculate where specifically a homeowner should insulate walls and whether internal or external insulation is ideal (insulation is simply either solid wall or cavity).

Data collection and modelling. In the DECoRuM model, CO_2 emissions are the result of heat loss calculations from fabric and ventilation, estimated energy use from heating, domestic hot water and electricity use as calculated using BREDEM-12. To inform the model, actual house characteristics are gathered from historic and current maps, on-site assessment, home occupant questionnaires, Energy Performance Certificates (EPCs), and literature describing home characteristics based on age and typology. As examples: occupancy, unless known, is calculated from floor area using the BREDEM-12 method; street-facing windows and frames are directly observed but all other unseen windows are assumed to be the same; wall construction and U-values (unless known, e.g. reported in EPCs) are based on the age of the home where construction methods are well documented (e.g. BREDEM reference tables). Verification is performed by calibrating the aggregated results to DECC's *lower level super output area* (LSOA) energy consumption data for England and Wales. LSOAs are zones made up of an average of 1500 residents or 400 households with relative social homogeneity, for which there are gas and electricity consumption figures reported (DECC, 2014a). Use of LSOA data for a similar purpose can be found in Booth and Choudhary (2011) and Williams *et al*. (2013).

Mapping the results. The results for each household are displayed on a map using GIS software; in this instance MapInfo. GIS allows any variable to be mapped for visual communication, e.g. kWh/ year, CO_2 emissions/m^2/year, homes in need of cavity wall insulation, PV suitability, etc. Previously, DECoRuM maps have been used by the Grassroots Leads Energy Efficiency community group in Highfield, Bicester to provide residents with energy consumption information and to suggest energy efficiency improvement measures (Gupta and Cherian, 2013), and to present climate change impact and adaptation effectiveness to communities in the SNACC project (Suburban Neighbourhood Adaptation for a Changing Climate (Williams, *et al.*, 2013).

Carbon reduction measures. Previous research by the authors and others has demonstrated the development of mitigation measures and packages, which were found to be effective for similar home typologies (Gupta and Gregg, 2012; DECC, 2014b). This and other research (simulation and building performance evaluation) have demonstrated the effectiveness of specific mitigation measures for CO_2 reduction in homes. These include reduced U-values on building elements, high efficiency boilers, insulating hot water cylinder and pipes, and increased level of heating control. When creating packages, focus on a fabric based package is done to emphasise the importance of implementing fabric first (low tech demand reduction) measures and also due to its (generally) lower capital cost.

MAPPING LOW CARBON COMMUNITIES

Each of the 22 communities, as a part of the LCCC, received grants ranging from £250k - £970k to pay for physical interventions to homes and buildings (90%) and behaviour change activities (10%) (DECC, 2012b). **Table 2** lists the physical measures purchased for households against those which were mapped in DECoRuM. Community scale measures or non-domestic measures, e.g. wind turbines (Communities A and B), PV on community centres and schools (Communities D and E), are not listed because the contribution of these measures are not calculated in the household (demand side) energy consumption modelling of DECoRuM; in addition, LSOA, used to validate DECoRuM, only provides consumption values. With regard to household measures, not all households in the communities received physical measures and not all households that did receive measures are mapped. The impact of behaviour change will likely indirectly come out of the aggregated figure as the aggregated figure is validated by the LSOA, however, the MME method used in Gupta and Barnfield (2013) is essential for measuring the impact of behaviour change activities in detail.

Table 2. Physical Measures Applied to Households in Each Community (DECC, 2012b)

Community	LCCC measures (total households)	Measures (mapped)
A	(0)	PV (9), solar thermal (2) ASHP (2)
B	Cavity wall insulation (125), loft insulation (223), PV (12), solar thermal (6), ASHP (4)	Cavity wall insulation (10), loft insulation (28), PV (3), solar thermal (1)
C	PV (11), solar thermal (4), wood pellet boiler, ASHP (3)	PV (6), solar thermal (4), ASHP (3)
D	PV (53)	PV (53)
E	PV (8)	PV (4), solar thermal (1)

Communities before LCCC action

Occupant questionnaires (requesting specifically when measures were installed), EPCs (pre-2010) and LCCC household details were especially helpful in modelling the communities before LCCC implementation. Though occupant questionnaires or EPCs were not available for each household, these tools served to inform the model with regard to what measures did not exist in many households before the LCCC. Since measures were purchased and installed anywhere from 2010 – 2012, the maps of Pre-LCCC implementation are referred to as *Pre-2010*.

Communities after LCCC action

In the same way, the same tools were used to assess what measures are in place after LCCC implementation. These maps are referred to as *2012*. **Figure 1** shows the Pre-2010 and 2012 results from Community E. *After* the interventions made by LCCC programme in Community E, there is a mean annual CO_2 reduction of 536 $kgCO_2$/yr/household or 12 per cent in the mapped area in 2012. These results can be attributed to LCCC involvement, but not entirely, as not all mapped households were involved in the LCCC.

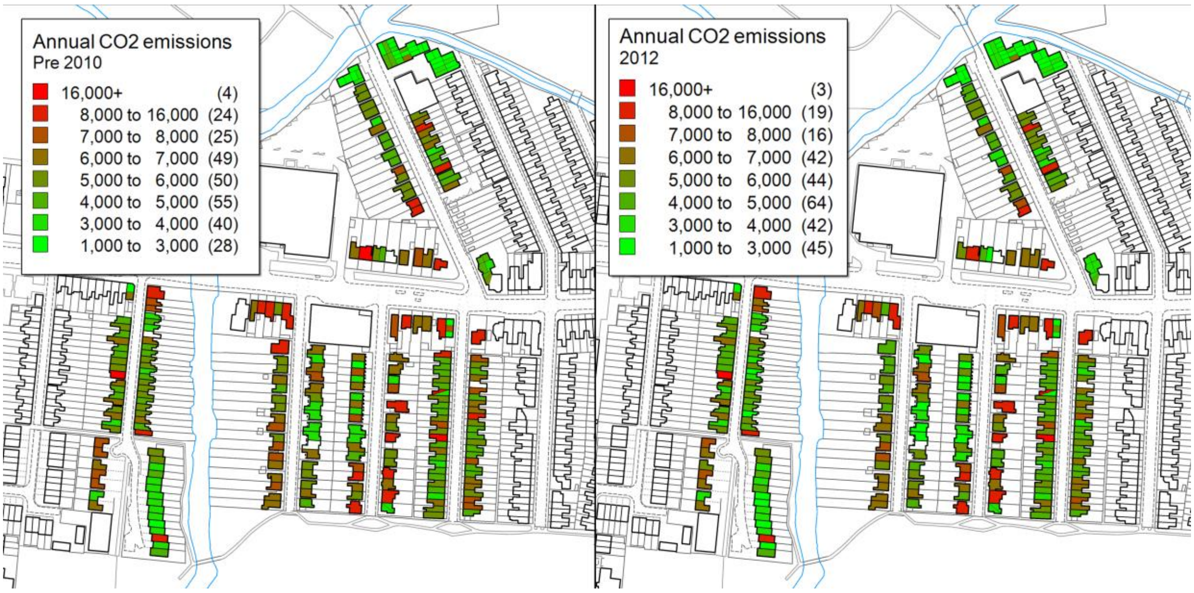

Figure 1 Pre-2010 and 2012 maps of annual CO_2 emissions for Community E.

Table 3 lists the communities and the results from the mapping for these two periods. Aside from other differing factors, Communities A and C are not served by the National Gas Network and are notably higher in annual emissions due to a majority of occupants utilising oil or electricity for heat.

Table 3. Mean annual domestic CO_2 emissions ($kgCO_2$/year) before and after LCCC programme

Community	Pre-2010	2012	2012 City Mean
A	5,969	5,286	Not available
B	4,564	4,046	4,179
C	9,298	7,111	Not available
D	5,753	4,889	4,895
E	4,574	4,038	4,454

Carbon reduction measures and packages

The model filters suitable dwellings for each retrofit measure based on the current (2012) condition of the dwelling, e.g. solid walled homes receive solid wall insulation and insulated cavity walls received no further insulation. Potential energy and carbon reductions are then calculated by the model for each household and then aggregated to realise community level impact. To meet the Government's carbon reduction target, most UK homes will require a package of measures (DECC, 2014b); therefore, the following typical retrofit measures were tested individually and also incrementally packaged. **Table 4** lists the packages that were developed for testing in DECoRuM; all measures are acceptable for Green Deal financing. Lowering the thermostat, a behaviour change measure, was also tested and presented to residents but not packaged. Primarily, the reason for this is that the packages were designed to reflect measures with capital costs so that the packages could be tested for Green Deal finance suitability.

Table 4. Carbon Reduction Packages

Package	Measures
Fabric improvement package	Wall insulation (cavity or solid), loft insulation, floor insulation, double glazing, draught proofing
Fabric and heating upgrade package	**Fabric package** + high efficiency condensing boiler, hot water cylinder insulation, pipework insulation, heating controls
Fabric, heating and electricity package	**Fabric and heating upgrade package** + energy efficient lighting and appliances, photovoltaic system, solar hot water system

An important key driver for refurbishment is capital cost. DECoRuM uses low and high estimates of the capital costs for each measure to indicate a likely range for the cost-effective carbon saving potential (the mean is taken from these two figures). The overall capital cost for community wide implementation of a certain package is calculated, based on the potential of each house within the community. **Figure 2** shows the mean capital costs and energy cost reduction potential for each package in the two most common house types in Community E. The Pre-1930s terraced housing represents 28 per cent of the dwellings in the mapped area and 1930-1949 semi-detached represents 18 per cent.

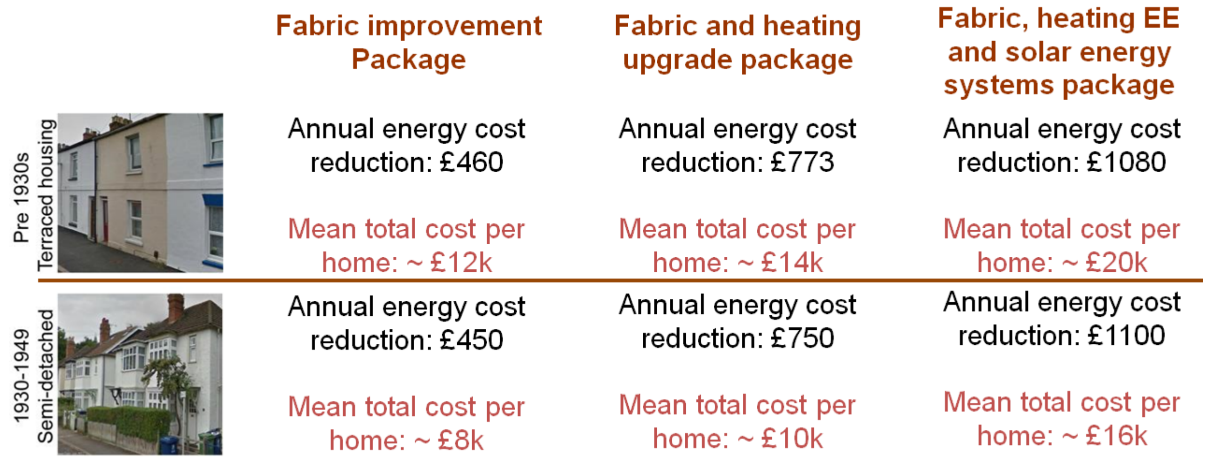

Figure 2 Package capital costs and reductions for Pre-1930s and 1930-49 house types in Community E.

The mean total cost for each home only considers those dwellings which could benefit from a measure in each package, though not all measures in the package need to be applied to qualify for the package in the model. Immediately as is seen in figure 2, Pre-1930s cost more to retrofit. This is attributed to the solid wall exterior of the house type, which will require solid wall insulation. The cost for solid wall insulation for each home is taken from the mean of external and internal insulation. Due to the nature of the data collection, especially where no questionnaires are filled, the model does not have the capability to assess whether internal or external insulation is a better choice for a particular dwelling. Annual cost reductions are a combination of a reduction in fuel costs and feed-in tariff (FiT) and Renewable Heat Incentive (RHI) (paid from April 2014) payments for PV and solar hot water respectively. Differing FiT payments, as per EPC grade, per house, are calculated into the total figure.

Carbon reduction packages and the Green Deal

Each carbon reduction package is then tested for Green Deal finance (theoretical) approval, specifically; will each package meet the *Golden Rule* on a house-by-house level? The Golden Rule is the central mechanism for determining which measures (to complete a package) are able to be financed through the Green Deal. The rule: "Estimated savings must be greater than or equal to repayments." This, however, is not a guarantee but a calculated intent (DECC, 2012).

DECoRuM has the capability to calculate whether a package will meet the Golden Rule after measures are modelled and energy use reduction and energy cost reductions are calculated. The model calculates whether the annual fuel cost savings are less than the annual payback over the life of the measure(s). **Figure 3** shows the Golden Rule compliance for each package for Community E. As an example, a large portion of the terraced housing in the southeast section of the Fabric Package map do not meet the Golden Rule primarily because the cost of solid wall insulation and new double glazing together is too high in relation to the potential savings. In order to qualify some dwellings will need to consider alternative combinations of measures. It is also important to point out that the cost for solid wall insulation, as mentioned above, is an average fixed cost between external and internal wall insulation; opting for internal wall insulation would likely reduce the capital cost for the overall package. Alternatively, the strip of homes in the northeast section of the Fabric Package map (next to the legend) meets the Golden Rule. Most of these dwellings are 1930-49 semi-detached (**figure 2**) requiring cavity wall insulation, a less expensive measure.

Figure 3 Golden Rule compliance for each package in Community E.

DECoRuM modelling demonstrated a fairly wide range of Golden Rule compliance between the communities (**table 5** – the packages are numbered in the order they are listed in **table 4**). Communities A, B and C, as communities, appear to be easier targets for the Green Deal. Communities A and C specifically have more reduction potential, partially due to the size of the dwellings and the majority using oil for heating. Community B, on the other hand, for the Fabric Package, requires little up-front cost whereas all homes are cavity wall (many already insulated – table 2) and many already have double glazing (the second most costly fabric measure following solid wall insulation). Community D, comprised of 94 per cent solid wall terraced housing, presents a challenge in meeting the Golden Rule for the Fabric Package. Package 3 clearly becomes more difficult due to the cost of PV and solar hot water systems (poor solar orientation is also calculated into the reduction in solar systems impact). FiT and RHI payments do not count toward reduction of savings to calculate the Golden Rule. A dwelling could use the Green Deal finance to install PV and collect the FiT but if a home is performing poorly according to their EPC, e.g. worse than D, their FiT is reduced, thereby encouraging fabric improvement first (or in conjunction). The Green Deal also only covers a portion of the capital cost for PV depending on how much electricity is actually (calculated) used in the dwelling.

Table 5. Percentage of Homes in Each Community Satisfying the Golden Rule (per Package)

Community	Package 1	Package 2	Package 3
A	91%	91%	65%
B	100%	87%	13%
C	84%	79%	64%
D	29%	27%	11%
E	54%	48%	31%

DISCUSSION

Outputs from DECoRuM, maps of estimated energy use and CO_2 reduction potential of individual households, were used to provide energy feedback to householders (on a community level) through workshops, wherein the local community also had access to expert information and advice on taking action to reduce energy use through individual discussions and group presentations. The maps, along with thermal imaging surveys of the houses, used to make energy use visible by highlighting areas of heat loss and potential areas for fabric improvements, gave householders a clear view of the impacts different refurbishment measures and packages have had or may have on the energy performance of their house. The workshops also helped to gather more data from householders (using questionnaires), to further refine the model.

The communities are using the findings from the carbon mapping, along with thermal imaging and the MME studies to inform the householders in the community on effectiveness of work already done and also highlight areas for improvement. The carbon mapping is specifically useful for the community groups to pinpoint areas of high energy use, problem households and promising areas for Green Deal finance. The application of packages, the calculated impact, and costs, as shown through carbon mapping, establishes DECoRuM as a useful tool for Green Deal assessors, local authorities and the low carbon community groups intending to implement large scale retrofits.

It is important to remember that there are many combinations of carbon reduction measures and they do not need to follow the packages as defined in this study. It is likely that many more homes will be able to find a package that will fit their home and meet the Golden Rule. There are also a large number of ‘border line’ cases (houses which almost meet the Golden Rule). This highlights the importance of adopting a holistic approach that includes both technical improvements and behaviour change measures; one which the Green Deal is attempting to provide through energy saving advice (DECC, 2012a). This approach, where effective, would ensure that most of the predicted energy savings are achieved in practice and the Golden Rule will be met.

CONCLUSION

Carbon mapping has emerged as a valuable approach for strategic planning, evaluation and implementation of community and neighbourhood scale domestic refurbishments by rapidly measuring, modelling, and mapping and managing energy use and CO_2 emission reductions on a house-by-house level. Bespoke site specific mapping of current energy consumption and visualisation of the potential for energy savings can enable the uptake of carbon reduction measures. The model can help local authorities, community groups and householders to prepare for future change and policy mechanisms such as the national Green Deal programme and the ECO. The specific area-based approach can serve as a tool to scale-up the uptake of low energy domestic refurbishments, by providing Green Deal providers, local authorities, community organisations and householders with information on the technical and economic feasibility of deploying a suite of best practice refurbishment measures. Findings from this study are also relevant for practitioners and researchers engaged in tracking and assessing impact of large-scale area-based domestic refurbishments and the future effectiveness of the Green Deal after implementation.

Similar work includes the development of DECoRuM-Adapt, a next step for DECoRuM created to assess future climate impact, overheating risk and adaptation measure effectiveness. The assessment of the climate change risk allows for the further evaluation of mitigation measures to optimise the home's refurbishment to be thermally comfortable now and in the future (Gupta and Gregg, 2013). To further benefit research in this area, future work in urban modelling would include analysis of modelling outputs with socio-economic data to track the effect of refurbishments on fuel poverty.

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