Applied Energy 164 (2016) 871–881

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Measurement and analysis of household carbon: The case of a UK city

David Allinson [a,*], Katherine N. Irvine [b,c], Jill L. Edmondson [d], Abhishek Tiwary [e], Graeme Hill [f], Jonathan Morris [g], Margaret Bell [f], Zoe G. Davies [h], Steven K. Firth [a], Jill Fisher [c], Kevin J. Gaston [i], Jonathan R. Leake [d], Nicola McHugh [d], Anil Namdeo [f], Mark Rylatt [c], Kevin Lomas [a]

[a] School of Civil and Building Engineering, Loughborough University, Leicestershire LE11 3TU, UK
[b] Social, Economic and Geographical Sciences, James Hutton Institute, Craigiebuckler, Aberdeen AB15 8QH, UK
[c] Institute of Energy and Sustainable Development, Queens Building, De Montfort University, The Gateway, Leicester LE1 9BH, UK
[d] Department of Animal & Plant Sciences, The University of Sheffield, Alfred Denny Building, Western Bank, Sheffield S10 2TN, UK
[e] Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ, UK
[f] School of Civil Engineering and Geosciences, Cassie Building, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
[g] Centre for Energy, Environment and Sustainability, The University of Sheffield, ICOSS Building, 219 Portobello, Sheffield S1 4DP, UK
[h] Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NR, UK
[i] Environment and Sustainability Institute, University of Exeter, Penryn, Cornwall TR10 9EZ, UK

HIGHLIGHTS

- Median annual carbon emissions from household end-use energy demand was 6744 kg CO_2e.
- One third of the households were responsible for over half of the carbon emissions.
- There was considerable organic carbon stored in gardens.
- Emissions from transport, gas and electricity demands should all be considered.
- An individual emissions source cannot be used as a marker for high total emissions.

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 18 October 2015
Accepted 29 November 2015
Available online 7 January 2016

Keywords:
Domestic energy demand
Household emissions
Transport emissions
Organic carbon storage
Energy policy

ABSTRACT

There is currently a lack of data recording the carbon and emissions inventory at household level. This paper presents a multi-disciplinary, bottom-up approach for estimation and analysis of the carbon emissions, and the organic carbon (OC) stored in gardens, using a sample of 575 households across a UK city. The annual emission of carbon dioxide emissions from energy used in the homes was measured, personal transport emissions were assessed through a household survey and OC stores estimated from soil sampling and vegetation surveys. The results showed that overall carbon patterns were skewed with highest emitting third of the households being responsible for more than 50% of the emissions and around 50% of garden OC storage. There was diversity in the relative contribution that gas, electricity and personal transport made to each household's total and different patterns were observed for high, medium and low emitting households. Targeting households with high carbon emissions from one source would not reliably identify them as high emitters overall. While carbon emissions could not be offset by growing trees in gardens, there were considerable amounts of stored OC in gardens which ought to be protected. Exploratory analysis of the multiple drivers of emissions was conducted using a combination of primary and secondary data. These findings will be relevant in devising effective policy instruments for combatting city scale green-house gas emissions from domestic end-use energy demand.

1. Introduction

This paper addresses domestic sector energy consumption, and the measurement of household's carbon and emissions inventory in a UK city.

The Intergovernmental Panel on Climate Change have warned of the global dangers to people and ecosystems of continued green-house gas emissions [1]. Households are one of the largest contributors globally [2] and urban areas are responsible for in excess of 70% of global carbon emissions [3]. Reducing the emissions from households in our cities is a significant international challenge requiring not just energy demand reduction but also by an increase in carbon sinks using 'green space' [4].

* Corresponding author. Tel.: +44 (0)1509 223643.
E-mail address: d.allinson@lboro.ac.uk (D. Allinson).

http://dx.doi.org/10.1016/j.apenergy.2015.11.054
0306-2619/

The UK Climate Change Act of 2008 [5] has set a stringent target to reduce national carbon emissions by 80% (on 1990 levels) by 2050 and buildings, transport and planning have been identified as three key areas for action [6]. The measurement of carbon and emissions inventories has been recognised as a key component of policies aimed at emissions reduction [7,8]. There is significant variation in the carbon emissions from households [9] and their rank order distribution demonstrates a tail of high emissions [10]. Higher energy users have greater potential to save energy [11] and emissions reduction policy might therefore best focus on the high emitters first [12], but the identify of high emitting households is not clear.

Signatories to the Kyoto Protocol are required to quantify accurately the national organic carbon (OC) stocks, including those held within urban areas. Previous urban storage estimates in UK carbon inventories were based on untested assumptions and predicted extremely low levels of OC storage in cities and towns, including domestic gardens [13–17]. However, there is increasing evidence that these urban areas are storing much larger quantities of OC than previously recognised [18–22]. It has also been shown that urban gardens offer potential for increasing OC storage in vegetation, due to lower tree cover and a large proportion of small trees in the existing garden population [19]. A question remains as to what proportion of a household's emissions can be offset by their gardens.

There is currently a lack of data recording the carbon and emissions inventory at household level with previous studies limited to a single fuel (e.g. [23]), confounded by results aggregated over hundreds of houses (e.g. [24]), or carried out at the national scale (e.g. [25]). The magnitude of household emissions have been shown to be influenced by a variety of socio-demographic factors including income, vehicle ownership, size of house, the number of occupants and working from home [23,24,26–29]; but the patterns in univariate analysis have not been clear [27].

This paper addresses a gap in the literature by presenting household level carbon emissions and organic carbon inventory results calculated from measurements made during the 4 M project [12]: a study of 575 households across the mid-sized UK city of Leicester, which has a population 330,000 [30]. This custom inventory includes emissions from the 'direct energy' used by the household in their home and personal transport i.e. grid supplied natural gas, grid supplied electricity, and petrol and diesel used in household members' personal transport [31]. It also includes an estimation of the OC stored in the vegetation and soil of each household's garden.

The emissions are reported as an annual rate (kg CO_2e per year) while OC storage accumulates over centuries and is treated as a static total (kg CO_2e). All results are reported per household, rather than per capita, as many emissions, such as those from space heating, are shared within households [32] and follows the recommendation that "future research should perhaps focus more on the household and less on the individual consumer, as the key unit of analysis" ([33] p6118).

This study provides a first assessment of the distributions of carbon emissions, and OC stored in gardens, for different households. It seeks to understand those distributions using multiple, socio-technical characteristics. To the author's knowledge this is the first ever attempt to measure and analyse the variations in households' carbon *and* emissions inventory across a city.

2. Methods

2.1. Study location

Leicester is located in the East Midlands region of England (Fig. 1), it is the 13th largest UK city with c330,00 persons living in 123,100 households [34]. Gross disposable household income was £11,739 per head in Leicester in 2013, compared to a UK average of £17,559 [35]. The city encompasses a land area of approximately 73 km^2 (as defined by the unitary authority boundary) with urban roads, buildings, and other artificial surfaces covering 43% of the land surface while urban green space covers 57% (one third of which is green space in residential gardens) [20]. Leicester experiences average (1981–2010) monthly temperatures of minimum 0.9 °C in February and maximum 22.2 °C in July; annual averages range between 5.9 °C and 13.8 °C, with 1,438 h of sunshine per year and 675 mm of rainfall [36]. Annual carbon emissions within the scope of influence of the local authority (industry, commercial, domestic and road transport) were 5800 kg CO_2 per capita in 2009 for the then population of 304,700, compared with a national total of 6,400 kg CO_2 per capita [37].

2.2. Data collection

The analysis described here used data drawn from the 4 M multi-stage household study [12]. An initial household questionnaire was developed for delivery by an independent social research institute, The National Centre for Social Research (Natcen), using a face-to-face computer-assisted interview format. Questions were designed to collect details about the usage of private (individual/shared) and company cars, home energy use, garden management practices, type of dwelling (e.g. semi-detached, terraced), socio-demographics (e.g. gender, income, occupation) and household composition (e.g. number of people residing in household, age of household members). Additional consent was sought for acquiring

Fig. 1. The East Midlands (shaded grey) and Leicester (shaded black) within England.