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Domestic thermal upgrades, community action and energy saving: A three-year experimental study of prosperous households

Nicholas Bardsley[a], Milena Büchs[b], Patrick James[c], Anastasios Papafragkou[c], Thomas Rushby[c], Clare Saunders[d], Graham Smith[e,*], Rebecca Wallbridge[f], Nicholas Woodman[c]

[a] School of Agriculture Policy and Development, University of Reading, Whiteknights, Reading, UK
[b] Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK
[c] Faculty of Engineering and the Environment, University of Southampton, Highfield, Southampton SO17 1BJ, UK
[d] Environment and Sustainability Institute (ESI), University of Exeter, Penryn, Cornwall TR10 9FE, UK
[e] Centre for the Study of Democracy, University of Westminster, London W1T 3UW, UK
[f] School of Social Sciences, University of Southampton, Highfield, Southampton SO17 1BJ, UK

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ABSTRACT

A three-year field experiment was conducted with 185 prosperous households to assess whether behavioural interventions by a community environmental group during and after thermal upgrades (cavity wall and/or loft insulation) can achieve reductions in households' energy use, including reductions in direct and indirect rebound. The engineering interventions on the thermal efficiency of dwellings appear effective in reducing energy use in both treatment and control groups: a direct rebound effect is estimated to be at most 40 per cent from the engineering interventions. However, across a range of measures of energy use, we observe no significant effect of the community behavioural intervention across the total lifetime of the project. Qualitative data collected on similar community groups suggests substantial constraints on their capacity to realise reductions in energy use amongst households.

1. Introduction

As part of efforts to reduce greenhouse gas emissions from fossil fuels and concerns over energy scarcity and fuel poverty, a range of government programmes in the UK have aimed to encourage improvements in the energy efficiency of buildings. These have focused particularly on disadvantaged households and hard-to-treat homes and include the Decent Homes Programme introduced in 2000, the Carbon Emissions Reduction Target (CERT, 2008–2011), the Community Energy Saving Programme (CESP, 2009–2012) and the Energy Company Obligation (ECO) (2013-present). It is estimated that over a million properties have benefited from these schemes (Dowson et al., 2012: 299). In contrast, the Green Deal programme, operated from 2012 to 2015, targeted the owner occupied and privately rented sector, but was less successful primarily because of its unattractive financial structure (Dowson et al., 2012: 300–1).

There is widespread evidence that the potential resource savings from technical energy efficiency interventions are not fully realised. Partly this is because households do not understand fully how the fabric of their dwellings have changed and how to alter their behaviours accordingly (Galvin, 2014, 2016). "Rebound effects" (Polimeni et al., 2008; Sorrell et al., 2009) arise partly when increased consumption of the goods and services energy provides offsets the savings that would occur under unchanged consumption. For example, households may increase their use of spatial heating if it becomes cheaper to heat their rooms. Hong et al. (2006) observed a 35% increase in energy consumed for spatial heating in poorer households, following thermal improvements under the UK's Warm Front policy. The authors attributed this partly to comfort taking (that is, rebound), where occupants heat a greater proportion of their dwelling and/or heat to a higher temperature, and partly to shortcomings in the implementation of the improvements. There is, though, a research gap on the response of more prosperous households following thermal improvements. That said, to achieve sustained and substantial energy use reductions plausibly implies changes beyond technological intervention, to include efforts to change attitudes and behaviours of households.

Numerous initiatives have sought to address householders' behaviour and encourage energy saving, including: information campaigns; feedback on energy use through (smart) metering; improved billing or energy audits; utility demand response programmes to shift residential

* Corresponding author.
E-mail address: g.smith@westminster.ac.uk (G. Smith).

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loads; and community initiatives that promote energy saving. Amongst these approaches the relative efficacy of non-tailored (Abrahamse et al., 2005, 2007; Clinton et al., 1986; Dwyer et al., 1993: 291; Steg, 2008: 4450) versus tailored and carefully designed feedback (Brandon and Lewis, 1999; Darby, 2006, 2010; Hargreaves et al., 2013; Ehrhardt-Martinez et al., 2010) has been most widely analysed.

In comparison, the behavioural impact of community action has had less attention. This is the subject of our analysis, namely: the role that community action can play in reducing household energy consumption during and after insulation interventions. Our study is innovative in at least two senses. First, we focus on more prosperous households that do not qualify for government assistance (e.g. Warm Front). Most research on thermal upgrades has focused on lower income households (e.g. Hong et al., 2006), with less attention given to those households that are responsible for significantly more energy use – which have been the primary target of the UK government's recent Green Deal initiative. Second, at the centre of our analysis is a novel controlled field experiment conducted by an interdisciplinary research team over three years with middle-income households in the south of England. Our aim is to analyse the overall effect of the activities of a local community group promoting energy conservation amongst households over this period. This is complemented with comparative qualitative analysis of similar community initiatives around the UK. Our research question is thus: Can informal behavioural interventions by a community environmental group during and after thermal upgrades achieve reductions in prosperous households' energy use, including reductions in direct and indirect rebound? If such community engagement is effective in reducing energy use, then there may be potential to scale up to regional or national level, complementing traditional government schemes that focus solely on technological interventions.

In the next section of the paper we review the current evidence base of the impact of community groups on pro-environmental behaviour change. We then present our research design and approach to measurement. This is followed by the analysis and findings from the experiment. These results are then contextualised with findings from similar community initiatives. We conclude with consideration of their implications for future programmes of community action to reduce household energy use.

2. Community action for pro-environmental behaviour change: state of the literature

In recent years, there has been considerable interest in the role of community-based organisations as possible mediators of pro-environmental behaviour change (Büchs et al., 2012; Georg, 1999; Hargreaves et al., 2008; Heiskanen et al., 2010; Howell, 2012; Middlemiss and Parrish, 2010; Middlemiss, 2008; Peters et al., 2010; Seyfang, Haxeltine, 2012; Seyfang and Smith, 2007). They are believed to be effective because of the 'bottom-up', voluntary nature of actions promoted by these initiatives (Peters et al., 2010: 13); the greater levels of trust that community initiatives enjoy (Fudge and Peters, 2011: 801f., 805; Hale, 2010: 256); and greater 'reach' that these initiatives have within society compared to government or business action (Gardner and Stern, 1996: 143; HM Government, 2010: 3). Critical to community action is the group interaction that helps normalise new behaviours: social interaction features prominently in theories of social practices to account for the social constitution and generation of norms and identities (Wenger, 1999; Reckwitz, 2002; Shove et al., 2012). Social interaction fostered by community groups is therefore considered to have potential to transform household practices in ways that save energy (see for example Georg, 1999; Hargreaves, 2011; Hargreaves et al., 2008; Hobson, 2003 and Nye and Hargreaves, 2010).

There is evidence that environmental community initiatives increase pro-environmental behaviours. For example, evaluations of the Global Action Plan (GAP) Ecoteams approach, which involves short, practically-oriented small group exercises, provide quantitative evidence based on both reported behaviours and measured energy use. This indicates that participants reduced household waste and electricity consumption and increased recycling (Davidson, 2010; Hargreaves et al., 2008; Nye and Burgess, 2008; Staats et al., 2004). Reviews of community waste programmes report a reduction in waste or increase in recycling rates (Cox et al., 2010: 204; Gardner and Stern, 1996: 156ff.; Sharp and Luckin, 2006) and DEFRA's evaluations of the Environmental Action Fund projects found that several of them have encouraged reductions in waste and home energy use (Department for Environment, Food and Rural Affairs DEFRA, 2009: 4, 7f., 73).

There are, however, weaknesses in the current evidence base. First, it is often unclear whether the particular community initiative instigated change, because studies rarely have the necessary design to control for other factors. Second, much existing research in this field focuses on community groups that target people who are already interested or even engaged with environmental causes. Arguably, to achieve wider societal changes, community groups would need to go beyond their typical activities, extending their reach to engage and instigate behavioural change amongst members of the broader public to realise the level of sustained energy savings required to tackle climate change. There may be good reasons to expect community intervention to make a difference if they engage members of the general public, but this has yet to be examined systematically.

Psychological and sociological theories are suggestive that it is at moments of disruption that stable household behaviours and social practices are more likely to be amenable to change (Bamberg, 2006; Guy, 2006; Shove et al., 2012; Verplanken and Roy, 2016). Thermal upgrades to properties are one possible point of disruption as households undergo audits and installation of insulation by contractors. From a socio-technical perspective, the material change that insulation represents provides an opportunity for change in household energy-related practices. But an engineering intervention alone is not necessarily enough to shift well established practices, since practices consist of other 'elements' that also need to change. Following Elizabeth Shove and colleagues (2012), we also need to see concomitant shifts in energy competence and the meanings and identities associated with energy consumption (Gram-Hanssen, 2011, Ropke 2001; Guy, 2006). This is the opening for community groups. There is emerging evidence that building on the informal networks of embedded community groups (as opposed to creating new ones) can be critical for effective communication necessary for households to reflect on and reorder established patterns of energy consumption (Cinderby et al., 2014; McMichael, Shipworth, 2013). Our focus on more prosperous households means that they are more likely to be higher in social capital: the types of community and organisational level networks and volunteering activity which foster community and individual action (Clifford, 2012; McCulloch et al., 2012; Mohan, 2012).

3. Research design

3.1. An experiment with matched treatment and control areas

We conducted a field experiment using a matched treatment and control area, summarised in Table 1. A village where a community environmental group (CEG) is active was matched with a nearby control site with no CEG but otherwise similar characteristics. The CEG

Table 1
Core experimental design.

Treatment	Control
Home insulation upgrades	Home insulation upgrades
Energy measurement equipment	Energy measurement equipment
Self-reports on travel and consumption	Self-reports on travel and consumption
Interactions with community greening group	

consists of a group of residents formed with the aim of promoting environmental awareness and reducing greenhouse gas emissions locally. Households in both settings received free loft insulation and/or cavity wall insulation delivered by a private contractor, along with energy monitoring equipment installed by the university-based research team. Loft and cavity wall insulation are among the cheapest and simplest engineering improvements per unit of potential energy saving (EST, 2010).

The CEG was tasked with engaging households on their energy use both through its usual community activities and specific events for project participants, supported by the research team. Our intentions were that the CEG be proactively involved, rather than simply acting as a front for the researchers; that it would be the type of local initiative that government or local authorities could replicate with similar groups as part of a dwelling thermal upgrade roll-out programme; and that it be well-informed scientifically. The CEG agreed to run at least one householder event per project year focused on energy saving (in its broadest sense) for all project participants in their settlement (hereafter the Treatment Group; TG). Administrative and planning support was offered by the researchers, plus assistance with costs.

The study is situated in the South of England, UK. Characteristics of potential matched settlements were assessed by their Output Area Classification (OAC) profile produced by the UK's Office of National Statistics (Vickers and Rees, 2007). The OAC characterises small areas using a *k*-means clustering algorithm run on 41 variables in the following categories: demographics, household composition, housing, socio-economics, and employment characteristics. The general requirements for both treatment and control groups were two-fold. First, households would be prosperous enough to not qualify for Warm Front assistance, since such households have been studied previously (Hong et al., 2006). Rather, we were targeting privately owned dwellings, with higher incomes than Warm Front recipients. Secondly, the residential building stock would generally be in need of thermal upgrades.

The TG settlement was selected on these criteria, along with the presence of an active CEG willing and able to work with the researchers. Fifty percent of the Output Areas (OAs) of the TG were in Supergroup 4, 'prospering suburbs'. A set of potential matched Control Group (CG) settlements was then selected using Geographic Information Systems (ArcGIS®) to locate settlements with clusters of at least 3 Supergroup 4 OAs. Additional criteria were then applied. First, there was to be no comparable CEG or explicit community action around environmental concerns. Second, the settlement had to be large enough for a target combined sample size of 200 households. Finally, it had to be close enough to the TG to control for weather conditions yet sufficiently far to be a distinct, non-bordering community. Once potential matches were identified, site reconnaissance visits were conducted by the research team to compare the characteristics of the housing stock, and to check for any salient differences not captured in the OAC. The two settlements selected are approximately 10 miles (16 km) apart by line of sight distance, in the same county. In both cases, most of the residential building stock was constructed between 1960 and 1990 and likely to be poorly insulated.

Recruitment was conducted via leafleting in both locations, and additionally via email and word of mouth through the CEG's networks for the TG.[1] Households were offered a free insulation package and energy monitors (AlertMe™) in return for participation. Only households needing either cavity wall and/or loft insulation were enrolled. Each requirement was met where possible, with the aim of bringing all project dwellings to comparable insulation levels. In the majority of properties, when loft insulation was added this was a 'top up' measure to increase the depth of insulation to 300 mm. The realised sample size at the start of the project was 185 households: 75 households in the TG; 110 in the CG.[2] An imbalance in sample sizes occurred because we had overestimated the number of suitable TG dwellings: there were larger than expected numbers of properties that could not be insulated effectively or which had already been insulated. We were able to compensate partially by increasing CG recruitment. Key prior characteristics of TG and CG sample households are compared in Table 2. There are no significant differences on any of the measures. We infer from this that the matching is very good, and constitutes a high level of control for a field experiment.

Drawing on the Local Authority Level English Indices of Deprivation,[3] we can place the two settlements in the 10% least deprived local authorities in the country. Analysis of the three waves of the core sample of the Citizenship Survey (2007–2010) indicates that these are the sort of areas in which at least half of the adult population formally volunteers. While this does not mean that they volunteer directly in the communities in which they live, these are settlements populated by the kind of people who are likely to get involved in community activities (Clifford, 2012; McCulloch et al., 2012; Mohan, 2012).

The CEG organised one project-specific event per year that TG householders had agreed to attend as part of their participation in the project. There was no way that householders could be forced to attend, but there was extensive communication reminding householders of the events through email, postcards, occasional energy-focused newsletters and word of mouth via the CEG. The CEG also organised occasional ad-hoc meetings held in participants' homes on different aspects of energy saving which attracted a small proportion of householders. Postcards and newsletters were sent to all households to inform non-attendees and remind attendees of the key messages from the events. These project-specific events ran alongside the usual environmental activities of the CEG to which householders from the TG were invited. Over the three-year period of the project, these included two community greening events, an apple festival and a talk on climate change by an academic from a nearby University. The project had a stall at each event.

The content of the annual householder event was inspired by examples of activities from other community groups analysed in the comparative stream of research (see 3.3 below) and co-designed with CEG members. The first event was focused on home energy usage and was timed to coincide with the start of the heating season. By this time (mid-October 2011), over 80% of insulation upgrades were completed and AlertMe™ electricity monitoring systems had been installed in all households. Those households awaiting insulation upgrades were aware that it was imminent. The combination of insulation and monitoring installation and new heating season offered a clear point of disruption for the community group to exploit. This first meeting went beyond typical 'hints and tips', providing households with an understanding of how the envelope fabric of their home had changed and what that meant for their energy consumption. The aim was to provide both technical knowledge and motivation to shift established behaviours. For example, one activity helped participants interpret the data generated by their new AlertMe™ electricity monitoring system to identify different electrical loads. A subsequent activity involved the ranking of related energy saving measures. Finally, the meeting focused on the impact of the thermal upgrade on both heat loss and thermal comfort, with particular attention to central heating controls (both timers and thermostats). The 'take home' message was for participants

[1] Such word of mouth promotion, we believe, would be a predictable feature of any larger scale initiative involving community groups. It would have been artificial to keep the recruitment procedures strictly identical between the TG and CG.

[2] The final sample sizes at the end of the experiment are 62 (TG) and 91(CG) due to attrition, mostly because of households moving away from the settlements.

[3] https://www.gov.uk/government/statistics/english-indices-of-deprivation-2015 File 10.

Table 2
Prior characteristics of participating households in treatment and control locations (mean values, unless otherwise indicated).

Location	Adults (mean no.)	Children (mean no.)	Senior citizens (mean no.)	Gross income (£) (mean)	Loft insulation depth (mm)*	% with no loft insulation	Floor area (m^2)
Treatment	1.8	1.2	0.2	52,600	90	32	107
Control	2.0	0.9	0.2	52,400	85	27	118

* mean for households with insulation.

Table 3
Annual household meetings.

Topic	Date	Attendance rate (%)[a]	Content[b]
Home energy and AlertMe™	Oct 2011 & Feb 2012	69	– Introduction to project – Drivers of home energy consumption – Introduction to AlertMe™ – Group activity on how to interpret AlertMe™ electricity consumption data – Quiz on electricity and heating saving opportunities – Take home tips for domestic energy savings
Reducing carbon footprints	Nov 2012 & Feb 2013	53	– Presentation on climate change and impacts – Presentation and discussion of UK energy reduction pathways – Interactive session on reducing emissions in different areas of carbon footprint, including food, travel and wider consumption. – Brief overview of activities of CEG and how to join.
Greening the village	Nov 2013 & Feb 2014	40	– Presentation on climate change and impacts – Presentation of visioning exercise – Interactive session and group work on visioning a low carbon future, using maps of village. Key questions: How would you like your village to be? How could it be improved? – Presentation of examples from other low carbon communities.

[a] 11 households attended none of the meetings.
[b] Materials are available on request.

to turn down their thermostats by 1 degree (an action associated with around 10% reduction in energy demand for heating). Subsequent household meetings extended consideration of energy use to overall household activity using a carbon footprint tool (year 2), and finally a visioning event on a low carbon future for the village (year 3). Table 3 summarises the activities in each meeting. Each meeting provided an opportunity for householders to gain both the competence and motivation necessary to take action. In this way, the meetings incorporated engagement practices popularised by Global Action Plan, Carbon Conversations and Transition Towns. In all cases, a participant-centred approach was adopted, in which householders completed exercises in small groups supplemented with presentations from the CEG and the research team.[4] Each event was run three times, on different days and times with crèche facilities made available, to give all project participants in the TG an opportunity to attend.

3.2. Measurement

The aim of the experiment is to analyse the differential effect of community action on household energy use in a broad sense. In the first place, we aim to compare direct home energy use – domestic electricity and gas consumption (space heating, cooking and domestic hot water) – across the treatment and control groups. Second, we aim to compare direct rebound from heating savings across the two groups, namely the extent of energy savings (in this case gas) when the service it provides becomes cheaper through energy efficiency gains following thermal treatment of dwellings. Third, we aim to analyse indirect rebound: the increase in energy consumption from other goods and services following efficiency improvements. An example of indirect rebound would be using the money saved on heating bills to take an additional flight. To achieve this range of objectives, a number of complementary data collection methods were implemented.

Energy savings across the lifetime of the project were calculated from a combination of gas and electricity readings from each household. Data points one year before the installation of insulation upgrades were reconstructed through household utility bills obtained from suppliers with household consent. This was complemented with a final electricity and gas reading taken at the end of the project for each household. In all cases, only actual meter readings were used. Estimated readings obtained from suppliers were identified and disregarded due to concerns about accuracy. In order to separate hot water from heating (where both were gas fuelled) a pair of gas meter readings were taken from each house approximately a month apart in summer. We associate the difference in gas usage during the summer with hot water use (and in some cases cooking) only.

Our intention had been to make more use of the data from the AlertMe™ monitors to analyse home energy consumption and direct rebound across the two groups. A great deal of time and effort was put into installing AlertMe™ equipment in each household before the insulation upgrades. AlertMe™ monitors recorded electricity consumption, lounge temperature and boiler activity, the latter two measures realised through temperature sensors which upload data via the monitor hub. Data was relayed to a central database run by the energy monitoring company via the internet. Unfortunately, the equipment proved to be fairly unreliable and unstable, with the internet connection often dropping, requiring the system's communication hub to be rebooted. Initially we contacted households and asked them to reboot the hub when we noticed that their AlertMe™ was offline, but this was a time-consuming process and many households were unable or unwilling to fulfil this task. A technical solution was thus devised, with engineers returning to each household and installing a timer plug that automatically rebooted the AlertMe™ once a week – and in a few cases broadband routers were upgraded in an attempt to mitigate unstable

[4] Materials are available on request.

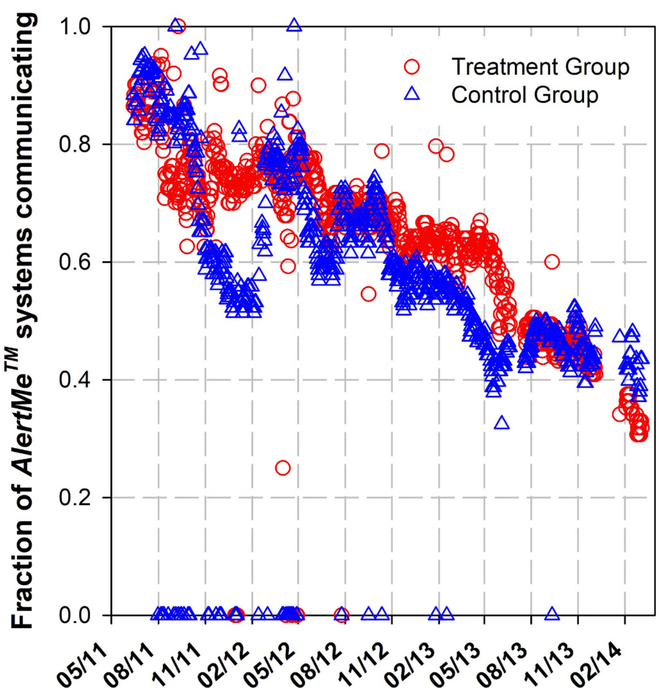

Fig. 1. Status of AlertMe™ monitoring system hubs 2011–2014. Note: 1 = all hubs active.

internet connections. However, problems with reliability still remained as can be seen in Fig. 1.

Calculations of direct rebound for each household require us to model the theoretical savings for each property following insulation. A detailed physical and energy survey for each dwelling was undertaken at the point when the AlertMe™ systems were installed. The data collected included: dimensions and construction of the thermal envelope (floor and roof, external walls, windows and doors) and details of the space and water heating system (boiler make and model, hot water cylinder and insulation). As is often the case with rebound studies, we cannot measure how successfully upgrades were implemented. Our estimate of direct rebound is therefore best regarded as an estimate of its upper bound. Structural variation in household types, such as post-insulation changes in occupancy, household size and health will also affect the precision of the estimation.

We do not offer a direct measure of indirect rebound or proxy as it can be spread across too many activities. Instead, we provide an analysis of spending and saving intentions from the household energy and expenditure surveys: participants were asked to state how they intended to use any energy savings made via reduced energy bills.[5] This is not a proxy for indirect rebound, but is something that one would expect to be affected if the behavioural propensity for indirect rebound changes. We expect subjects who are less prone to indirect rebound to be more likely to intend long term savings from reductions in energy bills, deferring consumption.

Finally, we measured personal (rather than work-related) transport usage via private vehicles and flights, again through the energy and expenditure survey. For private transport, participants were asked to report their vehicle mileage readings during each survey update and, for the year preceding participation (y0), MOT mileage data. Changes in vehicles were also recorded. Flights were self-reported by origin and destination.

The survey was administered initially through interview by a social scientist at the same time as the AlertMe™ system was being installed. Households were asked to update the survey online every 4 months, and were survey-interviewed again at the project's close. The response rate for the online survey updates ranged from 94% for the first update to 68% for the final one. The average response rate was 84%. The two face-to-face survey interviews enabled more detailed data collection on energy use (including transport usage) covering the periods one year prior to the project and the final year, compensating for non-response on key items during the 4-monthly updates. A social network survey was also administered at the beginning and end of the project (see Saunders et al., 2014)

3.3. Comparative qualitative research

Alongside the field experiment, comparative qualitative research was conducted on community groups engaged in energy saving activities, including the CEG involved in the experiment. This was intended both to generate insight into the processes at work in the experiment and to inform us about the generalisability of the results.

The qualitative fieldwork included two phases. In phase one, semi-structured interviews were conducted with 35 organisers of CEGs in Great Britain; phase two comprised 74 interviews with participants from 7 of the CEG initiatives, including TG participants. In addition, 7 interviews were conducted with CG participants, where no CEG was operative. There was a mix of initiatives from affluent and deprived areas and with different aims, ranging from a focus on energy saving in the home to a more comprehensive focus on carbon footprint reduction and community level action in response to climate change. Interviews with organisers covered questions on aims of the initiative, strategies of attracting interest and engagement with participants, as well as perceptions of and barriers to success. Interviews with participants included questions on their experience of involvement, and practices governing energy use in the home, travel and wider consumption.

4. Results

4.1. Home energy (Utilities)

Our experimental results comparing gas and electricity usage across the two groups are summarised in Table 4. The table shows rates of direct home energy use measured one year before the installation of insulation upgrades (and before the household meetings with the CEG), compared to the rate of use in the final year of the project

Rates of use pre- and post- installation are estimated by OLS regression on the utility bill data points for each household.[6] The figures for gas use are normalised by Heating Degree Days (HDDs). A base temperature of 15.5 degrees C is assumed for the HDD calculation, such that if the ambient temperature is above this value, the internal gains of the dwelling means no heating is required. Hourly ambient data from a nearby weather station are used to calculate the actual number of HDDs for study periods pre- and post-insulation deployment to enable normalisation of measured gas usage data.

The third column of the table reports a two-sided hypothesis test:

$$H_0\colon\ D_T - D_G = 0;\quad H_1\colon\ D_T - D_G \neq 0$$

where D_T and D_G are the differences between pre- and post-installation usage rates in treatment and control groups respectively. Using the (non-parametric) Wilcoxon rank sum test, we find no evidence of a difference in changes in energy use between the treatment and control groups. However, the signed rank test statistic for pre- versus post-installation usage is highly significant across both groups.

While analysis of the treatment effect of the community intervention ought to include all households whether or not they attended the meetings (since they are all subject to the same voluntary behavioural intervention), we undertook additional analysis on the relationship between attendance at household meetings and energy saving. However, there was no clear relationship: the results become sub-statistical because of the small size of the subgroups. For example, we regressed the energy

[5] The survey instrument can be found in the supplementary materials.

[6] See Fig S1 in the supplementary materials.

Table 4
Household gas and electricity use, 1 year prior to installation (y0) and in the final year of the project (y3).

	Treatment household		Control household		p-value (difference in differences)
	Mean (SE) kWh/dd (gas) kWh/d (elect.)	total kWh	Mean (SE) kWh/dd (gas) kWh/d (elect.)	total kWh	
Gas: inclusive					
y0	7.6 (.41)	18,044	8.0 (.44)	19,175	
y3	6.6 (.38)	13,410	7.0 (.39)	14,409	0.95
N	42		70		
p-value (y0–y3)	0.00		0.00		
Gas: heating					
y0	4.9 (.34)	11,796	5.5 (.36)	13,068	
y3	4.1 (.27)	8296	4.6 (.32)	9361	0.72
N	34		57		
p-value (y0–y3)	0.00		0.00		
Electricity					
y0	15.0 (1.29)	5491	15.0 (.97)	5466	
y3	12.0 (.95)	4391	12.7 (.75)	4650	0.99
N	36		41		
p-value (y0–y3)	0.00		0.00		

Notes:
1. p-values in this and subsequent tables are for the 2-sided Wilcoxon rank sum test (difference in differences) and 2-sided Wilcoxon signed rank test (y0–y3).
2. reduced sample sizes reflect missing data and sample attrition over 3 years (n2).
3. The absolute reduction in kWh gas use is influenced by the number of degree days (DDs) in a heating season. For y0 (1/6/2010-1/6/2011) there were 2382 degree days and for y3 (28/7/2013-28/7/2014) there were 2047 (British Atmospheric Data Centre, Chilboton Facility). The base temperature used is 15.5 C.

saving measures against meeting attendance, but the coefficients on meeting attendance are not significant at the 10% level.

4.2. Direct rebound from heating savings

To estimate direct rebound, the values for each household's theoretical saving on spatial heating are first calculated. To determine the technical change in envelope thermal performance, the U-value change (W/m^2K heat loss) of the roof and/or wall elements is calculated. The SAP NHER U-value calculator (NHER Plan Assessor version 1.2) is used to calculate the change in U-value of the insulated elements, combining survey data with typical year of construction details. It is assumed that there were no other material changes to the building envelope during the study period and that the insulation measure changes have a negligible effect on the overall air infiltration rate of the building (i.e. we assume that heat losses through ventilation are unchanged).

To calculate the theoretical energy savings from the insulation measures, *Qheatingsave_theoretical*, we again take a HDD approach. The change in heating load is estimated as follows:

$$Qheatingsave\_theoretical = [(\Delta Uvalue \text{ wall}\cdot Area \text{ wall}) + (\Delta Uvalue \text{ roof}\cdot Area \text{ roof})]\cdot\Delta\theta$$

where, *ΔUvalue wall* is the change in the U-value of the cavity wall, *ΔUvalue roof* is the change in U-value of the roof and $\Delta\theta$ is the number of HDDs during the period. Again, a base temperature of 15.5 degrees C is assumed for the calculation as explained in Section 3.1 above.

The delivered space heating to a dwelling over a period, *Qspaceheating_actual*, is calculated as follows:

$$Qspaceheating\_actual = (gas\ consumption \cdot \eta boiler) - (no.\ days \cdot DHW\ heat\ demand\ per\ day)$$

where *ηboiler* is the efficiency of the boiler, determined from the SAP boiler database[7] and *DHW heat demand per day* is the domestic hot water heat demand per day, determined from the paired gas readings

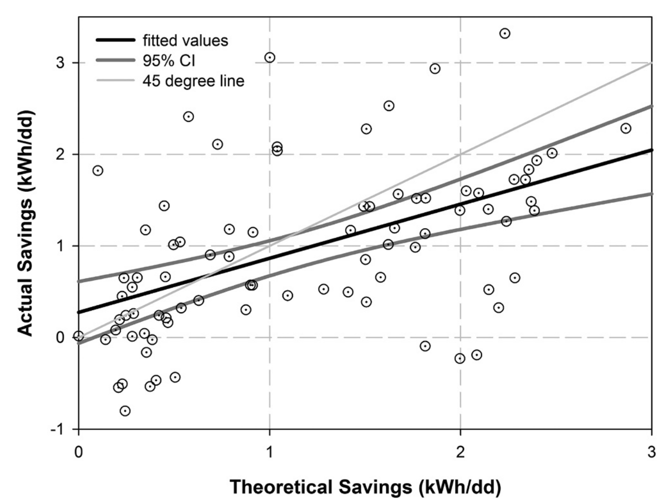

Fig. 2. Actual and theoretical reductions in spatial heating energy (kWh/dd) for each household following dwelling fabric upgrade.

for each dwelling outside of the heating season. It is assumed that DHW usage (and gas cooking if present) remains unchanged throughout the year and so can be applied as fixed per day offset (as delivered heat accounting for boiler efficiency) in the calculation.

The reduction in *Qspaceheating_actual* per HDD between pre-and post insulation upgrade periods is compared to the predicted *Qheatingsave_theoretical* per HDD to determine the performance gap. In Fig. 2, we plot theoretical saving on spatial heating (assuming the engineering savings are fully realised) and the actual change in usage. The 45 degree line is shown, because if an observation lies below this line, the households appear to exhibit rebound, whereas if they lie above the line they appear to make more savings than the dwelling interventions can account for. OLS regression of actual on theoretical savings returns is calculated as follows:

$$Qspaceheating\_actual = (0.5\cdot Qheatingsave\_theoretical) + 0.30\ kWh/HDD$$
(N = 85; F(1, 83) = 18.4; p = 0.00; R-sq = 0.18–0.22).

7 www.ncm-pcdb.org.uk/sap/.

That is, an increase in theoretical saving of 1 kWh is associated with an increase in actual savings of 0.5 kWh (95% c.i. $0.31 < x < 0.72$), or removing two outliers (as in Fig. 2) 0.6 kWh (95% c.i. $0.35 < x < 0.83$). This implies estimates of mean direct rebound of 50% and 40% respectively. There is no significant difference between TG and CG on either regression parameter if we estimate for TG and CG separately.[8]

An alternative to using the HDD approach would have been the UK's Standard Assessment Procedure (SAP), which enables heating demands to be estimated using actual occupancy parameters, rather than taking an assumed household heating profile. This approach would potentially deliver a more accurate estimate of individual household rebound level than the simpler HDD method applied here (which may over or under estimate theoretical savings at the household level due to specific household traits). However, in terms of an overall average rebound estimate for a group of middle income households, the two approaches would be expected to be consistent and therefore we have used the simpler HDD approach, which has wider transferability to other studies. In low income households, an HDD approach to estimating heating demand will not hold true as households are often under-heated due to financial constraints. In this study, however, where households had an average income of £56,000, under-heating as a result of financial constraints is unlikely and households will heat to, or near to, assumed temperature set-points. The average thermal change of a dwelling following insulation upgrades in both the control and intervention groups was 54.0 W/K. The occupancy and dwelling size profiles are the same in both groups, for this well-matched case (Table 2), which means regardless of the actual heating profile (providing it is the same across both groups) a direct comparison can be made. We see no difference in the reduction in heating demand between the two groups. In other words, there is no observable effect from activities of the CEG.

4.3. Indirect rebound

The analysis of spending and saving intentions from the household energy and expenditure surveys are shown in Fig. 3. We expect subjects who are less prone to indirect rebound to be more likely to intend long term savings from reductions in energy bills, deferring consumption. In neither treatment nor control group do we observe evidence of changes in savings intentions between the initial and final survey reports (Chi-square test; $p = 0.50$ (treatment), $p = 0.98$ (control)). Inspection of Fig. 3 shows that the savings intentions of both groups are similar and stable over the course of the project.[9]

4.4. Energy use for transport

Information on personal (rather than work-related) transport energy is shown in Tables 5 and 6, derived from the energy and expenditure survey. kWh for vehicle use are obtained straightforwardly using mpg data: reported mileage plus the calorific content of petrol and diesel. As Table 5 shows, there are no statistically significant differences between treatment and control group in how vehicle mileage and associated energy use and emissions changed during the project. However, in both groups there is evidence of reductions in energy for private motor vehicle transport over the course of this project.[10]

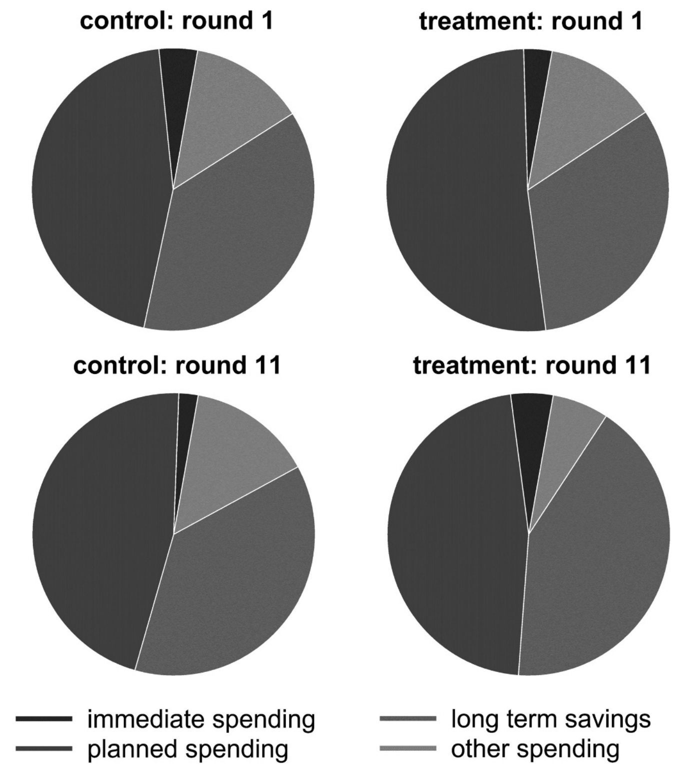

Fig. 3. Categorisation of households by intended use of prospective savings.
Notes:
1. Excludes households who left the study prior to completion.
2. Round 1 refers to a household's first interview, between December 2010 and March 2012 with 97% before October 2011. Dates vary because households were recruited over a period of time. Rounds > 1 have fixed dates; round 11 opened April 30, 2014.

Table 6 presents the data for flights for the households in TG and CG. There are no significant changes in passenger km, and therefore energy use in flights, in either group.

5. Discussion

This is a rare long-term study of household energy consumption that focuses on the role that community groups can play in reducing energy use. Below we reflect on the findings for the different aspects of energy use across the three years and then place our findings in context, drawing on insights from our comparative study of community-based energy initiatives across the UK.

5.1. Overall results

We find no evidence of an effect of the behavioural intervention by the CEG over the three-year study period on households' energy use in spatial heating, electricity or transport. Direct energy use within the home, both spatial heating and electricity, did fall, but by similar amounts in both intervention and control groups. Rates of rebound were also similar across the two groups. Energy consumption for motorised vehicles also fell by comparable amounts in both groups. This illustrates the importance of the control settlement, without which researchers might misleadingly infer effects of behavioural intervention. Prices to households of gas, electricity and motor fuels were increasing over the period, which complicates interpretation of the reductions observed. We lack specific data on indirect emissions from consumption of other categories of goods and services, although we find no evidence of changes in consumption through our survey question on savings intentions.

[8] The coefficient on '*Qheatingsave_theoretical*' is 0.77 for the TG and 0.42 for the CG estimations, but the associated 90% confidence intervals overlap. The coefficient should be interpreted as an upper bound on rebound, because installation quality was not measured for the insulation work.

[9] Further information on savings intentions is given in Fig S2 in the supplementary materials. This is consistent with a lack of change in either group in consumption behaviour and therefore associated emissions.

[10] Information was also collected on journeys other than by car or plane (see the survey in the supplementary materials), but was found to be of insufficient quality to report.

Table 5
Household mileage and energy use from private motor vehicles.

	Treatment mean (SE)	Control mean (SE)	p-value, diff. in differences (Wilcoxon rank sum)
Vehicle km			
y0	31,931 (4986)	31,628 (4019)	0.59
y3	23,349 (2729)	24,873 (2105)	
N	34	57	
p-value (y0–y3)	0.06	0.14	
Vehicle kWh			
y0	21,966 (3171)	22,471 (3367)	
y3	14,907 (2014)	15,044 (1322)	
N	34	55	
p-value (y0–y3)	0.02	0.02	0.76

Notes:
1. Excludes households who left the study prior to completion and households with inadequate data.
2. Excludes travel for work, but includes commuting to work as the latter can be viewed as a consequence of accommodation choices.
3. N varies for vehicle mileage (control group) because of missing information for vehicle mpg. Mpg figures are from UK Vehicle Certification Authority online database ‘imperial combined’ figure (http://carfueldata.dft.gov.uk).

Table 6
Household mileage and energy use from plane journeys.

	Treatment mean (SE)	Control mean (SE)	p-value, diff. in differences (Wilcoxon rank sum)
Passenger km			0.49
y0	11,828 (2419)	17,168 (2500)	
y3	16,119 (3716)	18,862 (2712)	
N	62	91	
p-value (y0–y3)	0.45	0.98	
Flight kWh			
y0	12,495 (2555)	18,135 (2642)	
y3	17,028 (3926)	19,924 (2865)	
N	62	91	–

Notes:
1. Excludes households who left the study prior to completion.
2. Passenger km are calculated using Geodesic distances from reported origin to reported destination, with each journey multiplied by the number of participating household members.
3. kWh are estimated from person flight km using the approximation in MacKay (2008: 35-7) assuming 80% occupancy.
4. Since kWh are inferred directly from passenger km there are no further statistical tests to report.

5.2. Direct home energy use

Both spatial heating use and electricity use appear to have fallen by around 16% and 14% in the intervention and control groups respectively (sample weighted averages from Table 4, rows 2 and 3 respectively). It is natural to attribute these reductions to the technical interventions used by the project, namely thermal efficiency improvements and energy monitoring equipment respectively. However, we must consider alternative explanations and comparisons with other results in the literature. That spatial heating use fell following insulation improvements contrasts strongly, in particular, with the results of the official evaluation study of the UK's Warm Front policy (Hong et al., 2006). Likely explanatory factors for this contrast include the different socioeconomic group studied here and selection of more favourable interventions.

Warm Front targeted vulnerable and low-income groups, who were likely to have exhibited ‘spatial shrinkage’ prior to improvements. That is, before improvements occupants would typically heat only a small proportion of a dwelling or heat to a lower temperature (Teli et al., 2016). Since thermal efficiency improvements lower the cost of heating a room, householders would plausibly ‘comfort take’ by heating more of the dwelling after insulation upgrades. Here we are studying ‘prospering suburbs’, a relatively high income group likely already to be heating a large proportion of the dwelling. Our preferred estimate of direct rebound shown in Fig. 2 (a mean loss of 40% of each additional kWh engineering saving) is still substantial but implies most savings are realised. As noted earlier, direct rebound can only be estimated with low precision because of natural variation, evident in the high level of dispersion in Fig. 2.

Changing fuel prices over the period of the project offer a further explanation of reductions in home energy use. It is reasonable to ask, however, whether the households in the study saved energy at a higher rate than the background rate that reflects both behavioural responses to higher prices and an underlying trend towards improved energy efficiency. For this purpose, it is instructive to analyse UK MLSOA data on gas and electricity use (Department of Energy and Climate Change DECC, 2015a; Department of Energy and Climate Change DECC, 2015b). The data for the location of both TG and CG settlements for the corresponding time period are shown in Fig. 4, alongside those for the South East of England.

The project's data collection window is shown by the rectangle in Fig. 3. Using the mean savings rate observed from 2009 to end 2013 we infer a background savings rate of 5% for electricity and 9% for gas in the region in which the project took place. This compares with an estimated

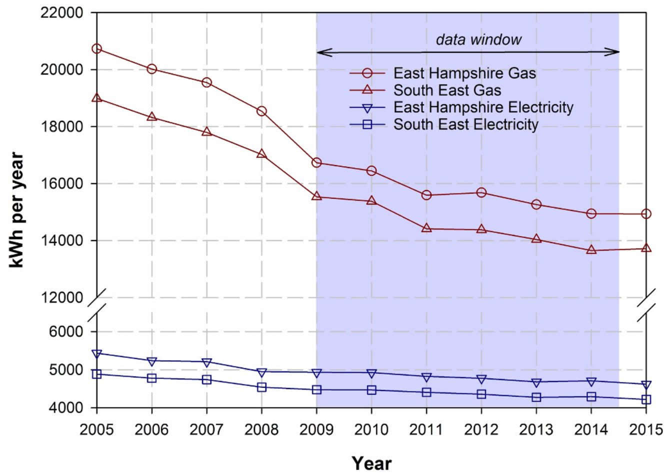

Fig. 4. Household average gas and electricity usage rates in East Hampshire and the South East of England, 2005–2015 (kWh/yr).

average 13% saving on annual gas usage and annual electricity usage among project participants calculated using the figures in row 1 of Table 4. Table 4 figures are degree-day-corrected, whereas the MLSOA data are not. The uncorrected reduction for the project households is 24%. Thus, it appears that the savings realised under the project are higher than the background rate, although we are unable to state a confidence interval for the reductions, and cannot test for statistical significance as this would require access to the underlying MLSOA data.

5.3. Energy use for transport

Table 5 records a sizeable reduction in energy used in private motor vehicles, specifically around one third comparing the final year of the project to a 1 year period preceding it. This decrease seems to have occurred approximately equally in both treatment and control groups; the test statistic for differences in differences is not significant. The reductions shown in household mileage are lower than the reductions in CO_2e and kWh, reflecting increases in efficiency when householders exchange their vehicles for newer ones. Given the likely relative price elasticity of demand (transport generally accounts for a larger share of household budgets than other forms of energy consumption), we find it plausible to attribute the reductions in mileage to petrol and diesel prices, which were increasing over the period of the study. From 2010–2013 UK, petrol retail prices increased from an annual mean of £1.16 per litre to £1.34, part of a longer trend of relative price increases since 2001. Prices then subsequently fell slightly over the period 2013–14 (see DECC 2015, table 4.1.1, which shows similar price movements for diesel). Over the same period wages rose only 2% p.a. or less (Office for National Statistics ONS, 2015, 2017).

In contrast, Table 5 records no reduction in flights in either group, even though airfares to UK consumers were also increasing strongly over the period: around 36% nominal increase in fares from 2010 to 2013, comparable to those in motor fuels (ONS 2015, Figure A). The lack of response to a similar proportional increase in price may reflect that air travel is a much smaller component of a household's budget. It is also tempting to speculate that for this group (of generally relatively affluent citizens), price elasticity of demand may be low for flights because of the perceived importance of foreign travel as a leisure activity (Barr et al., 2010; Hibbert et al., 2013).

5.4. Why is there no apparent effect of the community behavioural intervention?

As set out in the introduction, there are reasons to expect community groups to be effective in altering household practices to save energy because they have direct communication channels with other people in their communities, are likely to be trusted and can foster interaction on energy issues. Such characteristics are widely assumed to encourage the emergence of new attitudes and behavioural norms. This is even more likely at points of disruption such as household thermal upgrades and in more prosperous settlements where there is higher social capital. How then can we explain that we observed no material difference in reductions of energy use across the intervention and control groups over the course of this study; neither did we find differences in direct or indirect rebound (measured through stated intentions of households) or travel related energy use?

A first explanation points to important differences that community groups face in engaging the wider public as compared to ‘environmentalists’. The latter group is more susceptible to climate change and other environmental frames. From the outset, the CEG perceived a lack of resonance with the local community of climate change as a frame for its activities, believing that households were more likely to be motivated by potential monetary savings. Thus, the framing of events mixed climate change and monetary savings as the main motivating forces. Arguably, in discussions, the latter tended to dominate conversations amongst participants, with some concern amongst CEG members that they did not want to be seen as haranguing fellow villagers over climate change. The framing around monetary savings might also have been reinforced by the way in which the marketing of home insulation upgrades tends to prioritise individual benefits over wider, pro-environmental motivations. However, framing pro-environmental action as delivering monetary or other individual benefits has been found to be less effective in promoting more significant behaviour change, especially over longer time periods and for more difficult actions such as reducing heating, driving or flying. Such activities are often associated with losses of comfort or other individual disbenefits (Corner and Randall, 2011; Crompton and Kasser, 2010; de Groot and Steg, 2009; Howell, 2013). It is an open question about the effect that monetary motivations will have on more prosperous households, where energy costs are relatively low when compared to other types of households. An alternative approach to framing that focuses more broadly on existing community interests as a way into working on pro-environmental behaviour change has also been suggested, although there is no systematic evidence of its impact on energy consumption (Cinderby et al., 2014).

A second explanation is that despite the funding and support made available, the CEG lacked capacity to engage in more extensive energy saving activities (such as personalised household energy audits) beyond the minimum of one householder event per year for the project, additional to its normal activities. The CEG is purely voluntary and members are generally ‘cash rich but time poor’, so could not extend their operations significantly without risking burnout of its members. The three-year project timeframe meant that we witnessed many of the lifecycle problems of voluntary groups, with individual levels of commitment waxing and waning at various points. For example, one key local activist withdrew from the CEG part way through the project, for a mix of family reasons and general disillusionment with climate change action in the wake of the weak commitments from the UNFCCC Conference in Copenhagen.[11]

The question then arises as to whether the constraints in engaging members of the wider public facing our CEG are typical of such groups, or whether its framing and limited project activities were a result of the happenstance of the particular personalities and life situations of the CEG members. The qualitative research stream was intended to inform

[11] Faced with this constraint the research team had to decide whether or not to drive additional activity themselves. We decided not to do so, on the grounds that we were interested in what happens when a typical CEG leads the community intervention, rather than having an artificial program led by researchers.

us about the generalisability of the experimental results.[12]

Through interviews with organisers of community environmental groups across the UK, the comparative work stream identified two tendencies. First, a tendency for the level and intensity of engagement by CEGs that aim to engage the broader community (such as in the treatment group) to be less frequent and intense compared to those groups that engage participants who already have a strong environmental identification and thus stronger motivation for action. Second, interviews exposed a consistent picture of the challenges associated with framing energy saving. A distinction can be drawn between a cautious framing for broad audiences and transformational framing for a narrower audience that already identified environmental concerns (Büchs et al., 2015). Organisers perceive the strong environmental framing of energy saving as a responsibility and the associated demanding set of actions (such as consuming, flying and driving less), implied by the urgency of climate change, as alienating for general audiences. There is a reluctance to engage general audiences with more challenging climate frames that organisers believe to be more likely to produce disengagement without behaviour change. Organisers tended to prefer to frame energy saving in softer ways, emphasising financial benefits of reducing energy consumption, and promoting less demanding actions that had less impact on existing practices and lifestyles. Such an approach is rationalised as a first step towards more radical changes in lifestyle. Organisers frequently referred to a social and political context that emphasises freedom of choice, and where there is little government progress on climate change, as one that is not conducive to a stronger message. The tendency to emphasise financial benefits and new technology, and avoid worrying messages about climate change was general, but particularly pronounced in less affluent areas.

We do not intend to imply that effective behavioural intervention by community groups is impossible, and there were indeed examples of groups studied in the qualitative work stream that had taken a more radical approach. However, these tended to be working with participants that were already environmentally engaged. It is possible that more intensive engagement would have resulted in greater energy saving. There is evidence that bringing people together more regularly and/or in smaller groups (Davidson, 2010, 2008;) or giving people tailored information (Abrahamse, 2007) can have more significant effects. However, there is also conflicting evidence, for example, on the lack of long-term effects of tailored information (Büchs et al., 2018) and home energy visit programmes (Revell, 2014). But like many of the groups in our comparative research, the CEG suffered from the challenge common to voluntary environmental groups of time and capacity to take on additional activities beyond its routine endeavours.[13]

The intervention settlement had been selected partly on the basis that it had a relatively active environmental group as judged by the long established regional climate change action group that had a good understanding of local dynamics. Funds and other support were also made available to the CEG to undertake its energy-related activities. We therefore find it plausible that our results would generalise to similar initiatives.

6. Conclusions and policy implications

Over a three-year period, we monitored the impact of a CEG that targeted relatively prosperous members of the public whose dwellings had received thermal upgrades. We find no evidence of the effects of this community-led behavioural intervention on energy use, and specifically direct and indirect rebound, measured in terms of home energy and transport usage.

The households in our study did reduce measured gas and electricity use following home insulation, in both treatment and control groups, at a rate that appears superior to the background rate of energy saving. This contrasts with results from the evaluation of Warm Front, where energy use increased following insulation improvements. Direct rebound appears substantial though, bounded at an estimated 40–50% of each additional kWh theoretical savings. We cannot quantify indirect rebound effects, though behavioural intervention appears not to have had an impact judging by savings intentions.

Methodologically, our results indicate the importance of a control group, typically lacking in earlier research studies of community interventions on energy saving. In the absence of a control group, one might have inferred large effects on driving behaviour, for example. Substantively the results suggest that the incorporation of community engagement strategies based around local household energy events alongside thermal upgrade programmes will not foster the behaviour changes necessary for required levels of household energy saving. A more intensive and individually-tailored community engagement strategy may have had a different outcome, but that would have required many more resources – in particular time, which is often scarce for local community groups. It is not enough then simply to add volunteer-led community action to engineering-led programmes. Instead more substantial policy intervention is required if we are to meet the levels of emissions reductions laid out in the UK's Climate Change Act.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2018.11.036.

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[12] For a more detailed analysis of the impact of framing generated through the comparative analysis, see Büchs et al. (2018).

[13] To clarify, some of the CEGs interviewed did engage project participants more intensively in energy-related activities, but this was for activities that were part of their core mission. In contrast, the CEG took on the energy project in addition to its normal activities.

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