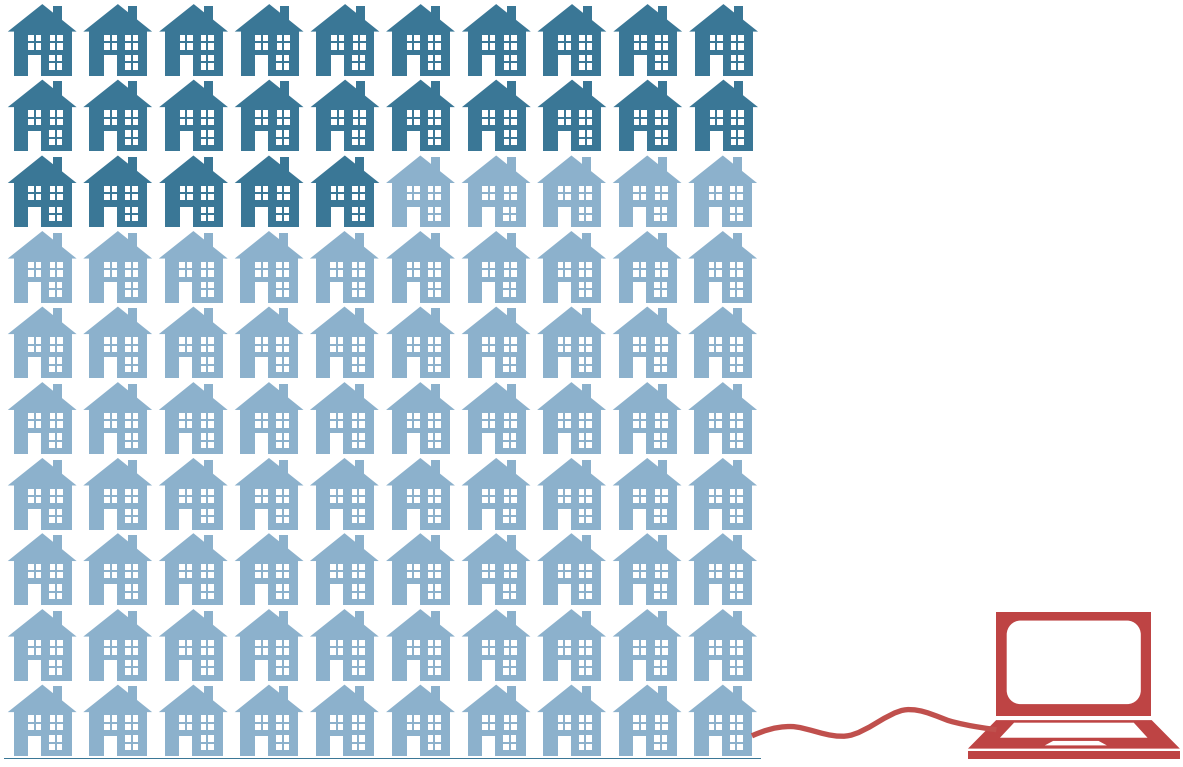
Further Analysis of the Household Electricity Use Survey

The Potential for Smart Meters in a National Household Energy Survey

7 October 2013



Steven Firth and Jason Palmer

CAMBRIDGE ARCHITECTURAL RESEARCH LIMITED

Loughborough University

INTRODUCTION

Now is the time to investigate and take advantage of the benefits that Smart Meters can bring to meeting the challenges of managing and reducing household energy demand. Recent large-scale monitoring studies funded by the Department of Energy and Climate Change, including the 2011 Energy Follow Up Survey and 2011 Household Electricity Survey, have developed an expertise in collecting and analysing the energy demands of households. In 2010-12 the Research Councils UK Energy Programme invested £22m in on-going research projects, the BuildTEDDI programme, creating a wealth of current academic expertise in Smart Technologies and energy demand.

Over the next few years the UK roll-out of Smart Meters will accelerate, promoting industry growth in this area and providing consumers with the technology to record their own energy use patterns in detail. The combination of these events represents a unique opportunity for further studies on Smart Meter data and the potential benefits to households, energy services providers and policy makers. By driving forward research and innovation in this area, the UK can take a world-leading role in the transition to a Smart Energy future.

This report provides an overview of one approach to maximising the benefits of Smart Meters, by establishing a National Household Energy Survey. This would recruit a representative sample of consumers who agreed to give remote access to their meter data for anonymised analysis and reporting, and to provide other useful data.

In this report we:

- Introduce the nature of Smart Meter data, together with examples of actual Smart Meter readings
- Discuss the potential policy applications of Smart Meter data, with a number of examples of how current and future policies can benefit
- Describe the opportunities to gather additional information using Smart Meter data, through disaggregation techniques to infer individual household energy demand end uses
- Set out a strategy for a National Household Energy Survey, based on Smart Meter data. This includes an approach to fundamental principles, recruitment and selection, technical requirements, on-going data collection, consumer engagement, data protection, and estimated costs
- Recommend as a next step conducting a small-scale pilot to test the benefits, costs and limitations of different technology approaches

KEY RECOMMENDATIONS

- Undertake a small-scale study to explore the potential for disaggregation of Smart Meter gas and electricity readings, to fully exploit the potential benefits of the collection of Smart Meter data. This would involve capturing high resolution measurements of the individual energy demand end uses in a sample of 10 to 20 homes. Making the final datasets openly available would allow any interested parties to develop novel solutions using Smart Meter readings.
- Retain and exploit the expertise gained in recent household energy demand surveys (including the 2011 Energy Follow Up Survey, the 2011 Household Electricity Survey and the BuildTEDDI research projects) for designing an approach for a Smart Meter-based National Household Energy Survey.

CONTEXT

Three challenges that arise from the study of household energy demand are:

1. How to reduce demand
2. How to shift demand
3. How to evaluate and model the impact of policy

Smart Meters offer new opportunities to meet these challenges, by providing detailed evidence of the magnitude and timings of energy demand in homes.

Table 1 shows the additional data available from a home with Smart Meters. There are two main options for collecting the data recorded by Smart Meters. A 'Wide-Area Network' (WAN) will be used by energy companies to transfer periodic (monthly, daily or half-hourly) meter readings for billing and other purposes. The 'Home-Area Network' (HAN) provides more frequent electricity readings (every 10 seconds) to an in-home display. The HAN can also provide 10 second consumption and other data to a consumer access device CAD (an internet-connected data logger similar to a broadband router box), to be purchased and installed in the home. The number of meter readings from the WAN and HAN options are many orders of magnitude higher than from current quarterly manual meter readings.

Table 1: Comparison of meter reading methods

Meter reading method	Technical maximum frequency of readings		Maximum possible readings per year	
	Gas	Electricity	Gas	Electricity
Manual meter reading	Quarterly	Quarterly	4	4
Smart Meter data collected by energy companies (via WAN)	Half hourly	Half hourly	17,520	17,520
Smart Meter data collected in-house (via HAN)	Half hourly	Every 10 seconds	17,520	3,153,600

Table 2 shows the common end-uses of gas and electricity in homes. It is these end-uses, and the energy demand associated with these end-uses, that are important in the study of household energy demand. Smart Meter readings are an aggregate total of these end-use demands and can provide insights into these demands.

Table 2: Common end-uses of gas and electricity demand in homes

Fuel	Smart Meter readings	Common end-uses
Gas	Half hourly (via WAN & HAN)	Gas boilers (for space heating and water heating) Gas room heaters and fires (for space heating) Gas cookers
Electricity	Half hourly (via WAN); 10 second (via HAN)	Storage heaters (for space heating) Immersion heaters (for water heating) Pumps (for central heating) & fans (for ventilation) Electric showers Cold appliances (fridges, freezers, fridge-freezers) Wet appliances (washing machines, tumble dryers, dishwashers) Information, Communication and Entertainment appliances (TVs, set-top boxes, DVD players, PCs, laptops, mobile phones) Cooking appliances (electric cookers, microwaves, kettles) Lighting

AN EXAMPLE OF SMART METER DATA

Figures 1 & 2 show half hourly gas and 10 second electricity Smart Meter readings recorded in the same house on the same day. The shape and nature of these graphs is driven by the multiple end-use energy demands of the household over the day. The graphs provide insights into magnitude and timings of the end-use energy demands of the household. An immediate question is *how can this Smart Meter data be used to inform policy design, to aid policy evaluation and to contribute to meeting the challenges of household energy demand?*

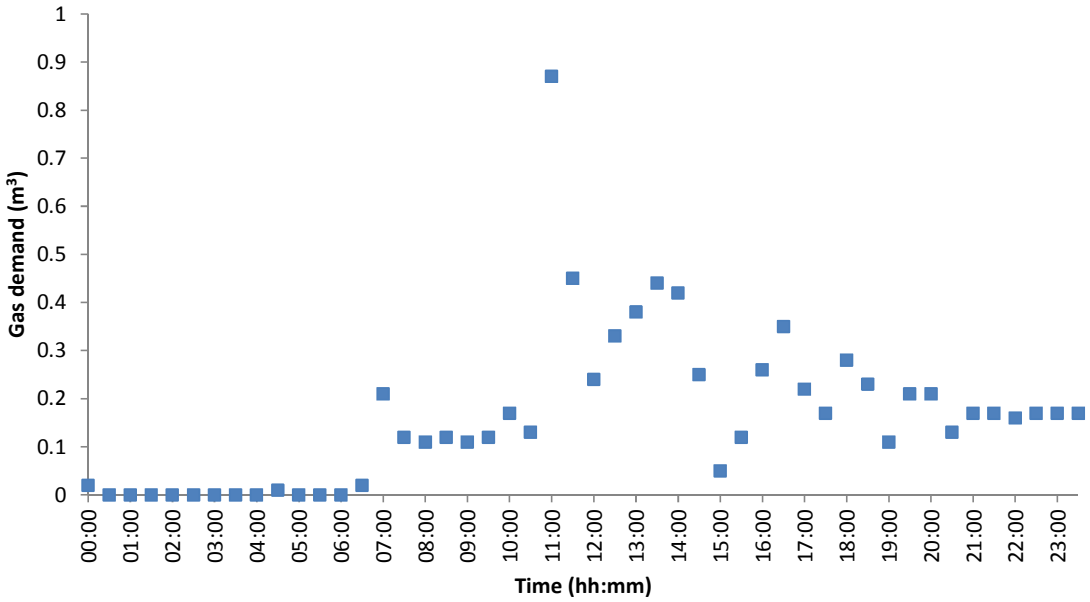


Figure 1: Example of half hourly gas readings from a single house for a single day (3rd March 2013)

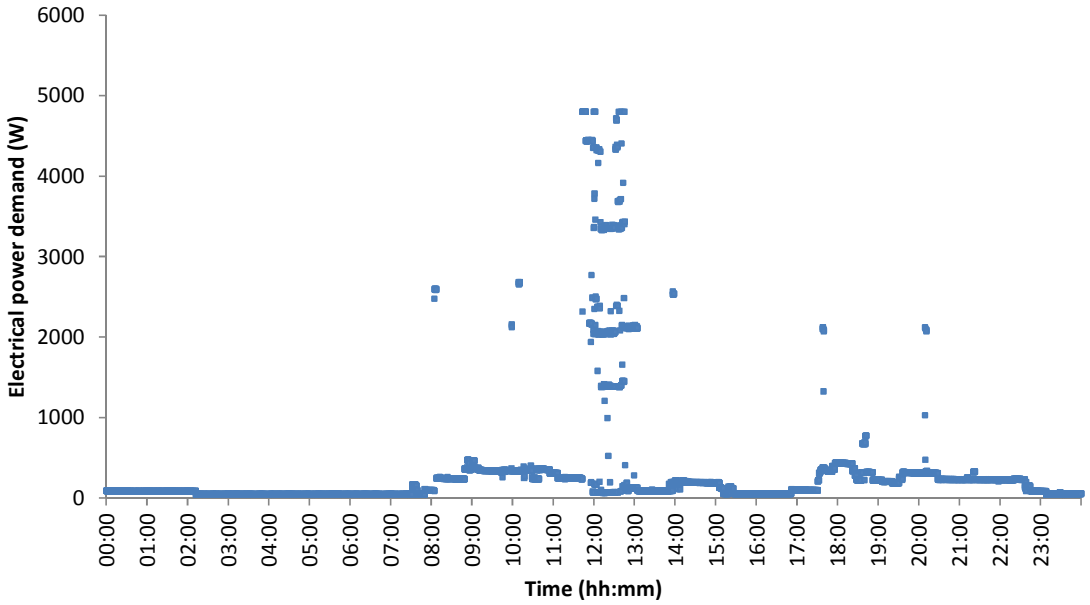


Figure 2: Example of 10 second electricity readings from a single house for a single day (3rd March 2013)

POTENTIAL POLICY APPLICATIONS OF SMART METER DATA

To inform policy, Smart Meter data needs to be collected. To provide a starting point for discussion, a data collection strategy might include:

- A large representative sample of homes, say 1,000 to 10,000, to provide statistical validity in the results
- Data collection using the Home-Area Network, providing half hourly gas meter readings and 10 second electricity meter readings.
- On-going data collection over several years, providing longitudinal results and year-on-year comparisons
- Instantaneous access to the Smart Meter readings, to allow immediate analysis of current events (e.g. heat waves, cold snaps, price rises)
- Up-to-date knowledge of the buildings, the households and the appliances

Table 3 gives a number of potential policy applications which would be possible using the data collected from such a survey. These come in addition to industry applications such as National Grid or system operator forecasting, or detailed consumer information allowing Energy Companies to offer improved products and tariffs.

Table 3: Examples of policy applications of Smart Meter data

Smart Meter readings	Examples of policy applications
Half hourly gas	1. Evidence on the current overall gas demand of households. This provides a base-line on which to base future policy. (This is a step change improvement in accuracy and timeliness on current statistics - e.g. NEED, DUKES – which rely on weather-corrected, quarterly and possibly estimated meter readings, are classified as domestic consumption based on an arbitrary cut-off, and are reported at least a year after the consumption has taken place). 2. Evidence on the drivers of gas demand in households over time, based on analysis using the building characteristics, household characteristics, local climate and price changes over time. 3. Evidence of the impact of heating energy efficiency policy. Using before and after data, the wide-scale evaluation of energy-saving interventions can be evaluated (e.g. triggered by the Green Deal). 4. Evidence on the timings of heating system use at the half hourly level, of particular importance to peak loads if domestic heating is electrified in the coming years. 5. Evidence for use in creating national models of gas demand in households – to predict the impact of upcoming trends and future policy options, such as renewable heating, demand shifting and household responses to seasonal temperatures. 6. Evidence on the impacts of changing gas prices and tariff structures for consumer energy bills and for overall gas consumption in households
10 second electricity	7. Evidence on the current overall electricity demand of households (similar to 1. above) 8. Evidence on the drivers of electricity demand in households over time (similar to 2. above) 9. Evidence of the overall impact of policy on energy-efficient appliances. Using before and after data, the wide-scale evaluation of energy-saving interventions can be evaluated (e.g. triggered by purchasing new energy-efficient appliances). 10. Evidence of the impact of policies on specific appliance groups (e.g. energy efficient lighting, cold appliances etc.) (as 9. above, if disaggregation of 10 second data is possible and sufficiently robust) 11. Evidence on the timings of appliance use at the 10 second level, to inform the potential for demand shifting electricity peak loads. 12. Evidence for use in creating national models of electricity demand in households – to predict the impact of upcoming trends and future policy options, such as new appliances, on-site micro-generation and demand shifting. 13. Evidence on the impacts of changing electricity prices and tariff structures for consumer energy bills and for overall electricity consumption in households 14. Over a period it might be possible to track the gradual improvement in energy efficiency of products such as fridges and freezers and develop better targeted replacement incentives. 15. Help to design/trial a robust electricity demand reduction scheme based on year on year reductions in consumption. 16. Help to design/trial a robust electricity demand response system based on variable pricing of electricity.

COLLECTING AND DISAGGREGATING SMART METER DATA

Figure 3 shows an example of the technical set-up which could be used to collect Smart Meter data. This is based on using the Home Area Network and a Consumer Access Device installed in the home.

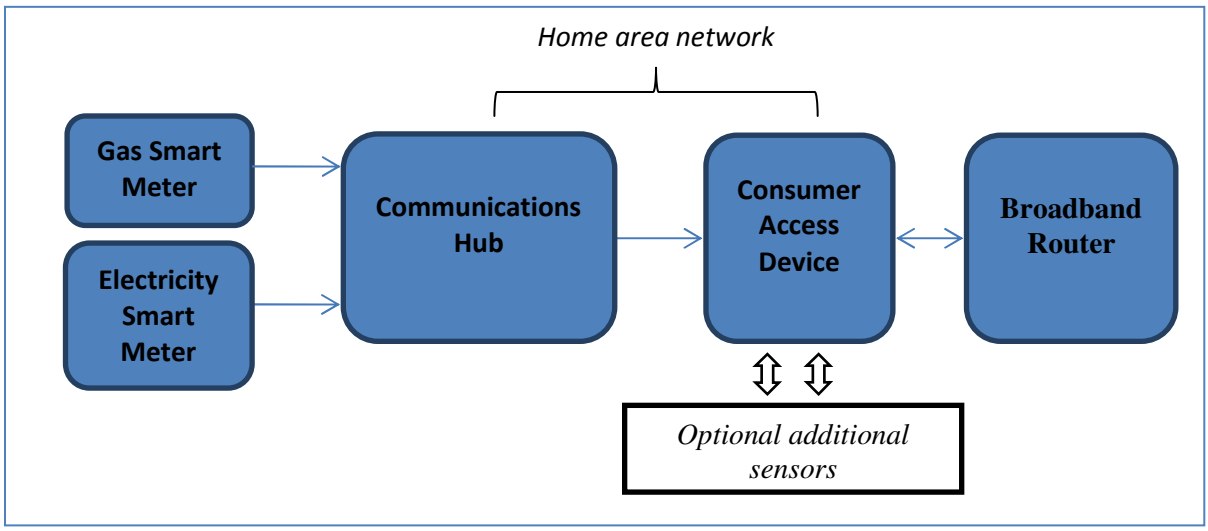


Figure 3: Schematic of Smart Meter data collection technical set-up

Gas and electricity Smart Meters record the total or 'whole-house' energy demand of the household, equivalent to the sum of the energy demands of all the individual end-uses. These 'whole-house' readings are useful, however much more insightful results are available if the energy demands of the individual end-uses (such as space heating, cooking and lighting) are estimated or recorded.

Three approaches to capturing individual end-use energy demand are:

1. **Estimate the individual end-use energy demands using only the Smart Meter readings**. This approach, known as *disaggregation*, was discussed by an Expert Panel as part of this work in April 2013. The challenge is both to identify an energy demand end-use correctly (i.e. identify the washing machine rather than the dishwasher is in use) and to quantify the energy demand of individual usage or cycles to a reasonable degree of accuracy. This is very difficult, as many appliances may be in use at the same time and have different energy demand patterns for different modes of operation (such as different dishwasher programmes). However there is little research currently available on the disaggregation potential of using data recorded at the resolution of Smart Meter readings (half hourly gas readings and 10 second electricity readings). It is likely, but so far untested, that knowing the make and model of appliances being used in homes in advance could inform and improve disaggregation algorithms.

2. **Estimate the individual end-use energy demands using Smart Meter readings plus additional measurements**. Disaggregation can be improved by measuring additional, proxy variables which help the process of identifying and quantifying end-use energy demands. For example, the readings from a gas Smart Meter can be used to estimate space heating energy demand of a household; however by

also measuring the living room temperature it may be possible to significantly improve this estimate. These additional measurements require extra sensors to be installed in the home, which are linked to the Consumer Access Device. Other examples of additional measurements to aid disaggregation include:

- Heating system supply pipe temperature (at the gas boiler) and gas Smart Meter data to estimate space heating energy demand
- Room brightness and electricity Smart Meter data to estimate lighting energy demand
- Bathroom air humidity and electricity Smart Meter data to estimate electric shower energy demand
- Occupancy data and electricity Smart Meter data to estimate individual appliance energy demand

3. **Measure directly the individual end-use energy demands using dedicated sensors.** This approach removes the need to use disaggregation for estimating end-use energy demands from Smart Meter readings and instead provides accurate measurements. The additional sensors required are linked to the Consumer Access Device. Direct measurement options include:
    - Plug sensors to measure individual appliance energy demand
    - Current clamps to measure individual lighting circuit energy demand
    - Heat flow meters to measure space heating and hot water energy demands

Further research is required to evaluate the potential costs and accuracy of these three data capture approaches. In particular the complexity and added-value of measuring proxy variables such as temperature and occupancy has received little attention to date, and could prove instrumental in advancing our understanding of Smart Meter readings. Given the level of investment in the UK Smart Meter Roll-Out, a small-scale study to explore the disaggregation potential of Smart Meter readings would be of great benefit. One approach would be to fund a study which collects sufficient high quality data, at a suitable resolution, which allows others to develop their own disaggregation approaches.

A small-scale disaggregation study might include:

- A small sample of real-world, occupied homes (say 10 to 20)
- Individual measurements of all the end-use energy demands of the households, including heat meters for space and water heating and plug sensors for individual appliances.
- Whole-house gas and electricity measurements
- All measurement taken at a high resolution, say at least every 10 seconds.
- All measurements taken over a monitoring period of at least one year
- The measurements made publicly available, as the study progresses, for others to analyse. This would include full annotation and meta-data, and would attract the attention of academia and industry researchers.
- A report on the disaggregation potential of Smart Meter readings, specifically tailored to the UK's choice of half hourly gas readings and 10 second electricity readings

THE NATIONAL HOUSEHOLD ENERGY SURVEY

The UK's approach to the deployment of Smart Meters is ambitious and unique. The roll-out of Smart Meters to every UK home by 2020, combined with the consumer-driven focus, provides an unprecedented opportunity to study household energy demand in fine detail. This will provide a unique and comprehensive evidence-base for both future policy development and the evaluation of existing policies, placing the UK as world-leading in the transition to a low carbon economy.

Here we propose one approach to collecting and using Smart Meter data, via a National Household Energy Survey (NHES). This would rely on a much larger sample than the small trial above, and would be more representative. Before discussing the details, a number of fundamental principles of the survey are outlined below.

Fundamental principles of the National Household Energy Survey

- Energy data collection is based on Smart Meter readings. This provides two distinct advantages: firstly *it is possible to collect frequent gas meter readings*, which is otherwise difficult and costly to accomplish at scale; and secondly *the meter readings can be sampled at near real-time*, allowing for results which are current and reflect the present situation.

- Smart Meter data is collected anonymously and openly published soon after collection. *Open-access publication* allows the UK's world-leading academics and companies to work with the data in an open and free fashion, leading to innovations. *Publishing the data quickly* means the survey is responsive to the changing energy landscape and never out-of-date. Standard data publishing protocols, such as those used by the UK Data Archive, should be employed to ensure the data is usable and for others to access.

- The survey is on-going and open ended. This provides *a base-line and control group representative of UK homes, and tracks the future trends in household energy demand*. This group of homes can be used to monitor progress towards carbon reduction targets, and could be monitored over decades if needed.

- The survey builds on existing and previous household energy surveys, including DUKES, DECC regional statistics, NEED, the 2011 Energy Follow Up Survey (part of the English Housing Survey) and the 2011 Household Electricity Survey. *There is a great deal of established data collection methods and experience already available*, which can be drawn together in developing the NHES.

This approach takes advantage of the additional features which Smart Meters provide, namely the ability to take recordings over several years and to allow access to the readings in near real-time. A representative cohort of homes, providing base-line energy consumption over many years, has not been achieved by any previous studies. This approach allows the study to be responsive and to incorporate new elements into the data collection over time, which will provide a much richer evidence base for policy makers, academics and UK energy services companies.

STEPS TO ESTABLISHING & RUNNING THE NATIONAL HOUSEHOLD ENERGY SURVEY

Step 1: Recruitment and sampling

There are two main options to recruitment which have been used in previous, similar studies:

1. Recruit the households as a sub-sample of a larger, pre-existing survey. A precedent for this is the 2011 Energy Follow Up Survey, which studied a sub-sample (2,600 homes) as part of the larger 2011 English Housing Survey. In this case, the choice of sampling and recruitment are partially based on the larger, established survey.

2. Recruit the households independently, without drawing on a larger pre-existing survey. This approach was taken by the 2011 Household Electricity Survey, which employed a national survey company to recruit 250 households throughout England. Here the choice of sampling and recruitment is not constrained, but the full costs are borne by the survey.

Either option is possible. However the better approach may be to recruit in a similar fashion to the Energy Follow Up Survey. This has several advantages: i) the households are selected and recruited as part of the English Housing Survey; ii) much of the data collection on the household and building are carried out by the English Housing Survey; iii) the sub-sample of households can be compared directly to the wider English Housing Survey; and iv) the recruitment costs would be lower and the process simpler.

Recommendations for the NHES:

- To retain the expertise and knowledge gained from the 2011 Energy Follow Up Survey. There is an established process for recruiting households for energy studies as a sub-sample of the English Housing Survey, which would work well for the NHES.

- To establish a sample of, say, 1,000 to 10,000 homes *in stages over a number of years*. This could be done year-on-year by recruiting those households with Smart Meters already installed from the annual English Housing Survey. The recruited households will be studied longitudinally over many years.

- To determine the exact number of homes to be recruited as the survey progresses. The size of the sample depends on the uses and policy questions which the survey will be asked to answer, the variability of the phenomena under study, and the acceptable level of uncertainty. The on-going nature of the NHES allows further households to be recruited year-on-year to meet future demands.

Step 2: Technical requirements

Using Smart Meters as the primary means of data collection in the NHES provides two advantages: i) the costs of the metering is not borne by the survey, as the meters are already present in the home; and ii) it is possible to have frequent gas meter readings, which have not been collected at scale by previous projects and are essential in improving our understanding of heating system use and timings.

There are three Technology Levels of increasing technical complexity to capture data on the energy demand of household energy end-uses:

1. High resolution Smart Meter data only. This involves installing a Consumer Access Device (CAD) within the home and connecting it to the broadband router. The CAD communicates with the Smart Meters and enables the data to be collected and exported.

2. Smart Meter data and additional proxy measurements. As 1., above, plus additional sensors to aid the disaggregation of the Smart Meter data. The additional sensors communicate with the CAD and the data is collected and exported in the same fashion as the Smart Meter data. An example of a proxy measurement is a temperature sensor in the living room, to help identify heating system use from gas Smart Meter readings.

3. Smart Meter data, additional proxy measurements and additional energy end-use measurements. As Point 2, above, plus additional sensors which measure the exact energy demand of individual household energy end-uses. An example of an energy end-use measurement is individual appliance plug monitors, which measure the exact energy demand of fridges, washing machines and other appliances.

Recommendations for the NHES:

- To commission a small-scale study to determine the benefits, limitations and costs of the three Technology Levels above. This would involve a small sample of homes (10 to 20) in which the household end-use energy demands are monitored in detail, and potential disaggregation techniques can be tested.

- To identify and install a flexible data monitoring solution in the study homes, which can be adapted and enhanced in the coming years. One option is to install Technology Level 1 across all homes in the NHES, and install Technology Level 2 and 3 in a smaller sub-sample.

- To draw on the experience of the £22m RCUK-funded BuildTEDDI programme of research projects currently underway, which are utilising many different Smart Meter and household energy monitoring solutions. This, and other initiatives, can directly inform the design and choice of the technical approach to the NHES.

Step 3: Installation Visit and Other Activities

Installation Visit & Follow-Up Data Collection: The 2011 Energy Follow-Up Survey installed monitoring equipment in participants' homes following the English Housing Survey main data collection visits. In the NHES, a similar visit by a trained installer takes place to install the monitoring equipment. This visit includes:

- Installation and on-site testing of the Consumer Access Device
- Installation of any additional sensors
- Further data collection of the building and household characteristics (by questionnaire or interview) if required
- An appliance survey, to record the number, type, make and model of the household appliances (which could be completed by the householder themselves)

Further data collection also takes place in the months and years following the Installation Visit, in particular to record changes to the building (e.g. a Green Deal retrofit), the household (e.g. a change in occupancy) and household appliance purchases and upgrades. It is important to maintain the option, if needed, to go back to households to ask questions to help explain patterns of energy use.

Consumer engagement: The NHES aims to create a longitudinal 'base-line' of household energy demand and requires participants to remain involved for many years. The sample should, as far as is possible, have the same energy demand characteristics the general population. One approach could be to provide incentives (such as an annual payment) for participation in the survey; however this significantly increases the annual costs. The offer of feedback on a household's energy demands is not desirable, as this may lead to a change in the patterns of their energy demands. (Indeed, the Hawthorne effect may even apply without feedback: households that know they are under scrutiny may change their behaviour. This is something that could be investigated by comparing against aggregate energy use by all homes.)

Data protection and privacy: There are precedents and existing procedures for data protection and data security, such as employed in the English Housing Survey, the 2011 Energy Follow Up Survey and the 2011 Household Electricity Survey. The procedures here should be drawn on to develop an approach to ensure the NHES recorded data is anonymous and secure.

The Government has developed a data access and privacy framework to provide clarity about the ways in which energy consumption data from smart meters can be accessed, by whom, for which purposes, and the choices that consumers should have about this. In particular, the framework establishes rules controlling access to energy consumption data by energy suppliers, network operators and third parties. The framework is described in the Government Response[1] to consultation on data access and privacy, published in December 2012. The voluntary basis of the survey would ensure compliance with these rules.

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/43046/7225-gov-resp-sm-dataaccess-privacy.pdf

Recommendations for the NHES:

- To retain the knowledge gained and lessons learned from previous household energy demand studies, in particular the 2011 Energy Follow Up Survey and the 2011 Household Electricity Survey, to support the design of the NHES installation visit, the design of installer training, on-site data collection, consumer engagement and data protection.

- To employ 'survey managers' who will contact the participating households over time and capture any changes to the building, household and appliances. This is essential for understanding the impacts of household energy efficiency policies and the trends in future household energy demand.

ESTIMATED COSTS OF THE NATIONAL HOUSEHOLD ENERGY SURVEY

Table 4 shows the estimated costs for one example version of the National Household Energy Survey. In this version, each home also has a room temperature sensor and three plug sensors installed, to aid the disaggregation and understanding of the Smart Meter data. These costs are estimates based on expert knowledge, and could be refined through a separate detailed study of monitoring equipment and survey costs.

Table 4: Estimated costs for one example version of the NHES

Item	Estimated cost	Notes
Survey Design and Project Management	£100,000	To design the survey, prepare training materials and provide project management during the installation phase.
1 x Gas Smart Meter	None – already installed	Records half hourly 'whole-house' gas demand
1 x Electricity Smart Meter	None – already installed	Records 10 second 'whole-house' electricity demand
1 x Consumer Access Device	£25 per household	Communicates with the gas and electricity Smart Meter Connected to the home broadband router A flexible solution which allows the connection of additional sensors
1 x Wireless Temperature Sensor	£30 per household	Records 1 minutely room temperature to aid the disaggregation of the gas Smart Meter data Connected to the Consumer Access Device
3 x Wireless Plug Sensors	£40 per household (£13.33 per sensor)	Records 1 second energy demand of three appliances to aid the disaggregation of the electricity Smart Meter data Connected to the Consumer Access Device
Data transfer and storage	£2 per household per year	To provide data storage for the readings gathered from each house. The raw data from each home is captured and stored, to maximise the future benefits and innovations.
Installation visit	£225 per household	To install the equipment and gather additional data on the building, the household and the appliances.
Full time 'survey managers'	£60,000 per 500 homes per year	Assumes one person at a cost of £60,000 (salary+overheads) for every 500 homes in the survey To trouble-shoot monitoring problems. To be a point-of-contact for participating households. To regularly collect additional survey data including building retrofits, occupancy changes and appliance upgrades.
Replacement equipment	£10 per household per year	To provide replacements for faulty monitoring equipment
2 x full time 'data analysts'	£100,000 per year (£50,000 per person)	To construct the data base for storing the recorded data. To provide the analysis to inform policy. To monitor the data streams and quickly identify any problems with the data collection.
Analysis by academics and industry	None – staff already in place	Further analyses on a wider range of areas are possible if the data is made available in a timely and open source fashion.

Tables 5 and 6 below give estimated 'one-off' and 'on-going' costs for a 1,000 and 10,000 home version of the NHES.

For a sample size of 1,000 homes, this version of the NHES results in a one-off cost of £420,000 and an annual on-going cost of £232,000.

For a sample size of 10,000 homes, this version of the NHES results in a one-off cost of £3.3m and an annual on-going cost of £1.42m.

Table 5: One-off (initial) costs for 1,000 and 10,000 homes

Item	Estimated cost	Costs for a 1,000 home survey	Costs for a 10,000 home survey
Survey Design and Project Management	£100,000	£100,000	£100,000
1 x Gas Smart Meter	None – already installed	£0	£0
1 x Electricity Smart Meter	None – already installed	£0	£0
1 x Consumer Access Device	£25 per household	£25,000	£250,000
1 x Wireless Temperature Sensor	£30 per household	£30,000	£300,000
3 x Wireless Plug Sensors	£40 per household (£13.33 per sensor)	£40,000	£400,000
Installation visit	£225 per household	£225,000	£2,250,000
	TOTAL:	***£420,000***	***£3,300,000***

Table 6: Annual on-going costs for 1,000 and 10,000 homes

Item	Estimated cost	Costs for a 1,000 home survey	Costs for a 10,000 home survey
Data transfer and storage	£2 per household per year	£2,000	£20,000
Full time 'survey managers'	£60,000 per 500 homes per year	£120,000	£1,200,000
Replacement equipment	£10 per household per year	£10,000	£100,000
2 x full time 'data analysts'	£100,000 per year (£50,000 per person)	£100,000	£100,000
Analysis by academics and industry	None – staff already in place	£0	£0
	TOTAL:	***£232,000***	***£1,420,000***