IEA HPP Annex 42: Heat Pumps in Smart Grids

Gap Analysis

27 June 2014

Report compiled by:

Delta Energy & Environment

Table of Contents

Table of tables / figures

This report is Task 4 of 4, and is the culmination of analysis carried out in three other reports which all form part of this project:

Task 1: This consists of a UK market overview and an analysis of the smart-ready capabilities of heat pumps on the UK market – and expected to come to the UK market

Task 2: This report summarises the major UK modelling studies which have investigated issues linked to the use of heat pumps for load shifting. This report assesses the extent to which these modelling studies have sufficiently addressed DECC's core questions in relation to this project – and identifies areas of further work which would support DECC's core questions.

Task 3: This report summarises the major UK demonstration projects involving heat pumps in load shifting. It assesses the extent to which DECC's core questions are being tested and identifies areas of further work.

Task 4 (this report): The aim of this report is to summarise the assessments of modelling and demonstration projects in Tasks 2 and 3, and make recommendations on where the evidence gaps are which warrant further work in order to fully answer DECC's core questions.

1. Executive Summary & Recommendations

DECC needs to understand the following core question:

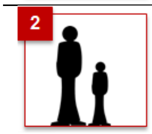
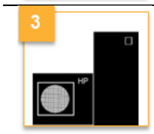
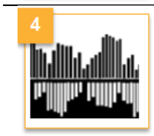
"What are the best methods of shifting peak demand with a heat pump system?"

In order to address this question, the first stage is to identify all of the methods to shift demand with a heat pump system (investigated previously in Task1). A full understanding of each of these methods, the factors affecting them and their application in the UK, will enable DECC to draw conclusions as to the best methods to implement in the UK.

The purpose of the Gap Analysis is to investigate the extent to which each of these key issues has been explored in UK modelling studies and demonstration projects, and highlight the outstanding 'evidence gaps' which need to be filled in order to have a full understanding. We present a detailed list of gaps and recommendations related specifically to modelling studies and demonstration projects in the Tasks 2 and 3 reports.

Here we present the high level outcomes of our aggregated gap analysis, identifying the key evidence gaps, and highlighting the relative priority level of importance of each gap in order to answer DECC's core question.

FIGURE 1: THE FIVE MOST IMPORTANT GAPS

	Gap 1: How do the characteristics of the building, the thermal store, and the external environment influence heat pump electricity usage when shifting heat pump operating times to avoid peaks?
	Gap 2: How does end-user behaviour influence heat pump electricity usage when shifting heat pump operating times to avoid peaks?
	Gap 3: What emerging technologies could enable heat pump flexibility – and how?
	Gap 4: What are the non-technological mechanisms of achieving peak shifting with heat pumps (e.g. price signals), and how much flexibility can they provide?
	Gap 5: What standardisation for communication infrastructure could enable peak shifting with heat pumps?

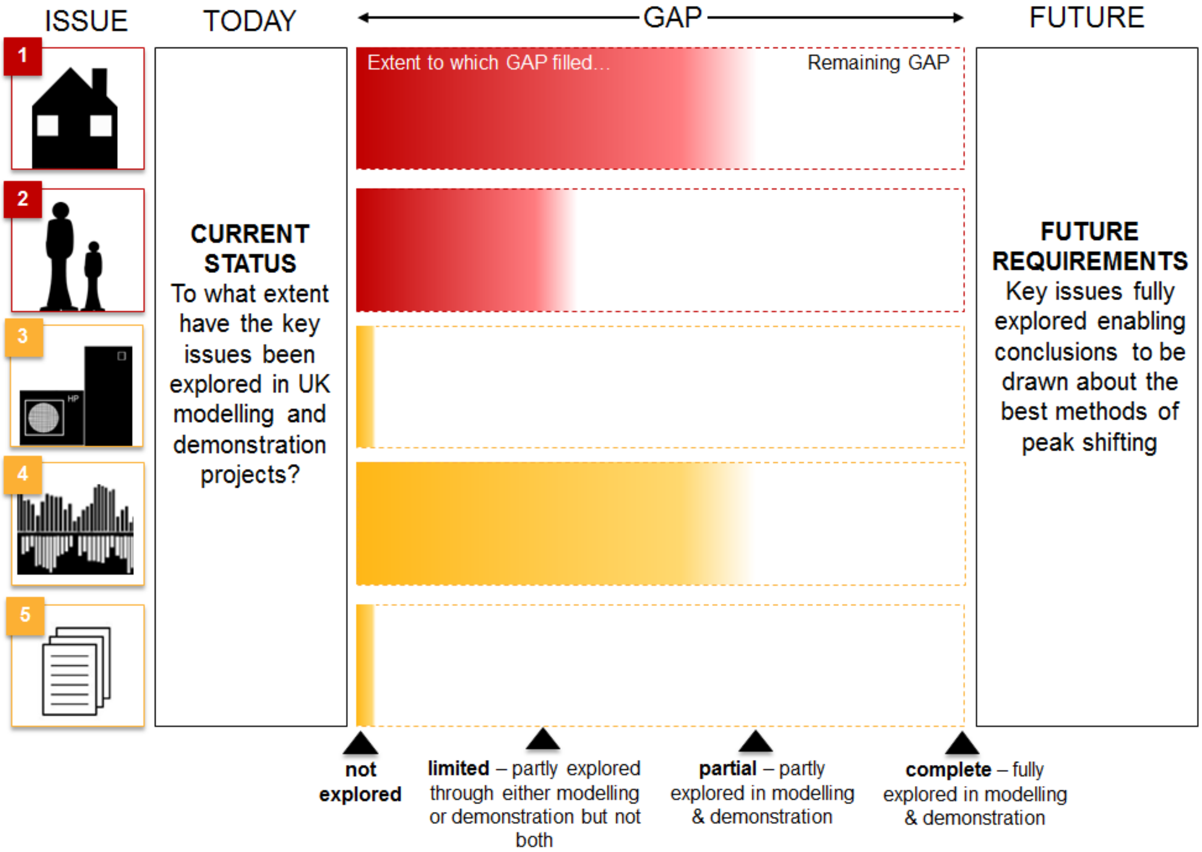
KEY: RELATIVE IMPORTANCE OF EACH GAP

1st **priority gaps** *are those we believe are critical because they form the foundation layer of information upon which DECC can begin to address its core question.*

2nd **priority gaps** *are those which can add depth to this foundation layer of priority information by helping to identify and enable specific technologies and market mechanisms which can help to capture heat pump flexibility in the optimal way in the UK context.*

FIGURE 2: SIZING THE GAPS

For each main issue we illustrate the extent to which this has been explored and tested in the UK via modelling and demonstration projects.



On the following page we present an overview of each of these identified gaps, discussing why it is important, and what actions could be required in order to fill the gap.

1st PRIORITY

Gap 1: How do the characteristics of the building, the thermal store, and the external environment influence heat pump electricity usage when shifting heat pump operating times to avoid peaks?

Why is it important? It is critical in order to quantify the impact of these factors on the potential flexibility which can be captured across the UK building stock

Priority actions:

- Develop wider data sets from further UK field trialling and modelling, to better understand how heat pump demand patterns vary in different sectors in the building stock, and how this affects flexibility potential – enabling targeting of the best building segments for peak shifting (e.g. a field trial comparing the different rates of heat loss in a range of building types – and therefore the length of time for which a heat pump can be switched off for without affecting comfort).
- Test control mechanisms and system design options for integrating heat pumps and storage, to find the optimum solutions across the UK building stock (e.g. aiming to minimise storage volumes and enable flexibility, while maintaining heat pump efficiency and end-user comfort).

Possible additional actions:

- Investigate options for use of weather forecasting to optimise flexibility potential
- Further modelling (& trials) to better understand dynamics of HP operation and its impact on the grid – aiming to gather higher resolution data to more accurately represent how variations in heat pump electricity demand during peak shifting affect the distribution grid.

1st PRIORITY

Gap 2: How does end-user behaviour influence heat pump electricity usage when shifting heat pump operating times to avoid peaks?

Why is it important? It is critical in order to quantify the impact of these factors on the potential flexibility which can be captured across the UK building stock

Priority action:

- Develop wider data sets from further UK field trialling, to better understand the impact of end-user characteristics in different demographic groups on the flexibility which can be delivered from heat pumps e.g. focus on specific technical challenges of shifting heat pump operation while maintaining thermal comfort; investigate the amount of temperature reduction end-users will accept; investigate the impact of end-user behaviour on heat pump operating patterns.

2nd PRIORITY

Gap 3: What emerging technologies could enable heat pump flexibility – and how?

Why is it important? It will enable clearer quantification of the different levels of flexibility which may be captured using different technology solutions

Possible actions include:

- Modelling and field testing to better understand flexibility potential with hybrids in UK (what technical requirements will there be for hybrids if they are to be able to switch between heat sources in response to external signals).
- Test the use of modulation in response to dynamic signals in UK homes (e.g. how does modulation of the HP down to e.g. 30% capacity affect the length of time electricity demand can be reduced relative to complete shut-down)
- Assess the balance between cost and flexibility enabled through different levels of smart-readiness (in the heat pump, or in interface technologies such as Home Energy Management Systems (HEMS)

2nd PRIORITY

Gap 4: What are the non-technological mechanisms of achieving peak shifting with heat pumps (e.g. price signals), and how much flexibility can they provide?

Why is it important? It will enable clearer conclusions to be drawn regarding the flexibility potential from different control / influence methods

Possible actions include:

- Test methods for automated response to Time of Use (ToU) tariffs in the UK
- Explore how different types of ToU tariffs may be able to encourage HP manual response through customer behavioural change
- Explore whether specific heat pump ToU tariffs should be developed

2nd PRIORITY

Gap 5: What standardisation for communication infrastructure could enable peak shifting with heat pumps?

Why is it important? It will provide the future direction certainty which the heat pump, energy and ICT industries require to invest in developing equipment and mechanisms which can potentially enable peak shifting with heat pumps in the UK

Possible actions include:

- Work towards set of (open?) standards for communication channels, protocols & information models for the UK (aligned with UK smart home concept / smart meter roll-out).

NB: It is likely to be challenging to develop a single standard for e.g. communication protocols, but there is a need for at least 'communication of the direction' so that manufacturers can build in the required capabilities

2. DECC's key questions

DECC's primary aim is identified as the following:

- **DETERMINING THE BEST METHODS FOR PEAK SHIFTING WITH A HEAT PUMP SYSTEM:** This entails understanding what technological and market mechanisms can be used to enable the use of heat pump flexibility (i.e. shut-down or ramp-down time) to manage peak congestion on the grid.

To answer the above question, investigation is required into peak shifting mechanisms, which can be grouped as follows:

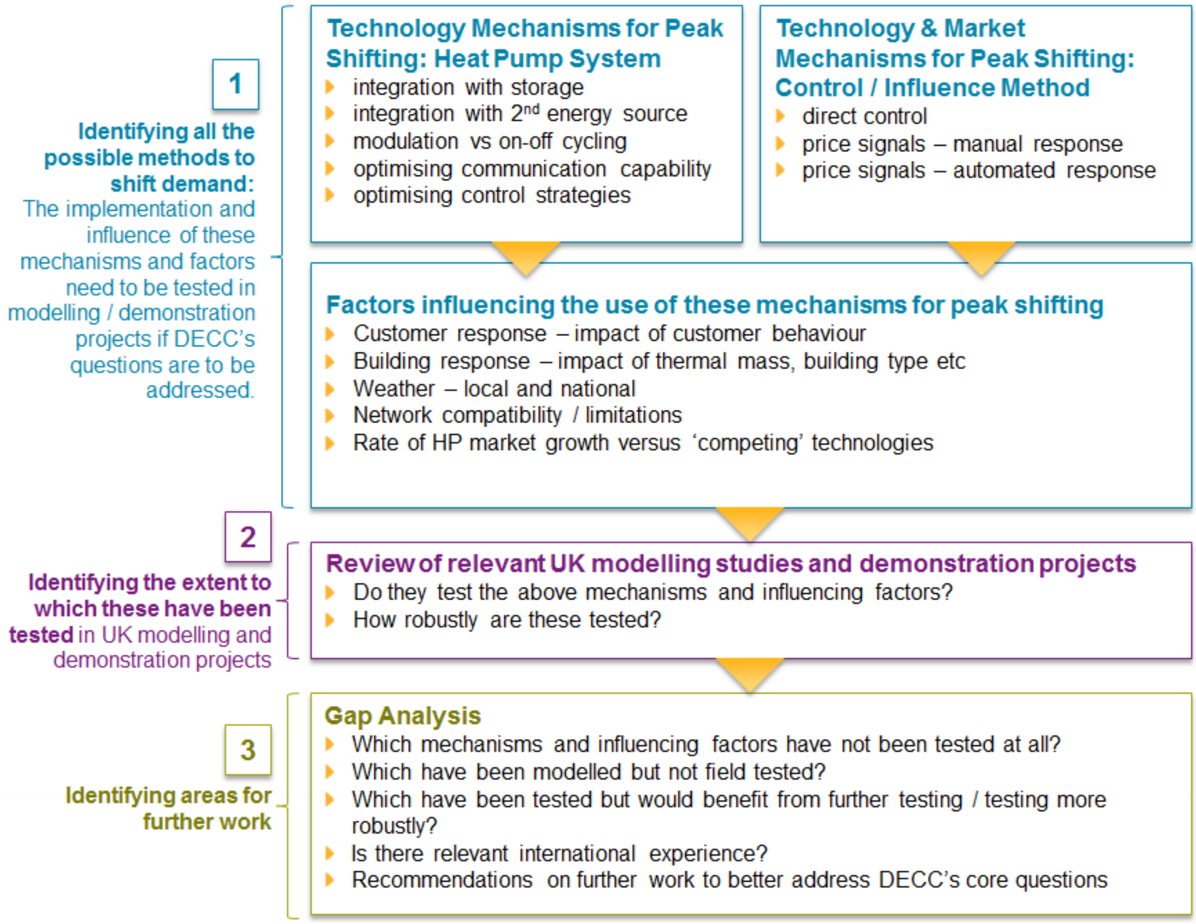
- **OPTIONS FOR THE HEAT PUMP & HEATING SYSTEM:** What are the options regarding the dynamics of the heat pump operation and design of the heat pump & heating system which can enable flexibility for peak shifting? Which options create most opportunity for peak shifting? (e.g. modulating the HP down rather than full shut down, integration with storage, using a hybrid).
- **OPTIONS FOR THE CONTROL / INFLUENCE METHOD:** What different mechanisms can be used to control / influence the heat pump operation, and which can best enable flexibility for peak shifting? (e.g. influence through price signals versus direct control; automated response versus manual)?

There are three important factors which significantly influence the success of the above peak shifting mechanisms. These factors must also be taken into account in demonstration projects (and modelling studies) if the findings are to be robust, and if conclusions are to be drawn regarding the suitability of the methods tested for peak shifting:

- **CUSTOMER RESPONSE:** How do customers (end-users) respond to different methods of control or influence of their heating system operating times, and what can be concluded about the impact of customer response / behaviour / occupancy patterns on flexibility achieved?
- **BUILDING RESPONSE**: How do the characteristics of the building (e.g. thermal mass, insulation levels, size, age…) affect how much flexibility can be achieved?
- **INFLUENCE OF EXTERNAL ENVIRONMENT**: How much does the weather influence flexibility / storage potential, and what is the role for using weather forecast data at a local level to better optimise heat pump operating patterns?

3. Gap Analysis Methodology

FIGURE 3: METHODOLOGY FOR DEVELOPING GAP ANALYSIS



Our approach to the gap analysis is based on our understanding of DECC's key questions, as presented in Chapter 2, and will be structured in the following way:

1. Identifying all the possible methods to shift demand: In Task 1's analysis of Smart-Ready products we assessed several layers of heat pump functionality which could be considered to support or influence the available heat pump flexibility for use in peak shifting. Based on our knowledge of existing projects and studies both in the UK and internationally we add to this market mechanisms (e.g. price signals) also used as methods for shifting demand.

2. Identifying the extent to which these have been tested in the UK: Task 2 and Task 3 use the above list of methods as a framework, and compares each modelling study and demonstration project, assessing the extent to which each of the methods listed above has been tested. This includes both how widely it has been tested (e.g. in 1,000 homes or 10 homes) and how robustly (e.g. is it dynamic and with sampling at sufficient resolution)

3. Identifying areas for further work: Based on steps 1 and 2 we will identify where the gaps are in testing the various methods, and make recommendations on where further work could help to answer DECC's wider questions.

4. Summary of UK Modelling Studies and Demonstration Projects

In Tables 1 and 2 on the following pages we present the summaries of the review of modelling studies and demonstration projects as presented in the reports for Tasks 2 and 3.

KEY: TABLE 1, MODELLING STUDIES - WHAT DOES THE RATING MEAN?

Rating	Description	Rating	Description
✔ (green)	Issue addressed, and in a robust way	✔ (green outline)	Plan to address issue fully based on current literature – but modelling still on-going
✔ (amber)	Issue addressed, but only on limited scale / not robustly	✔ (amber outline)	Plan to address issue partially – but modelling still on-going so it may yet be covered in more robustly
✘ (red)	Not addressed at all	✘ (red outline)	No plan to address this issue based on current literature – but modelling still on-going

KEY: TABLE 2, DEMONSTRATION PROJECTS - WHAT DOES THE RATING MEAN?

Rating	Description	Rating	Description
✔ (green)	Issue addressed, and in a robust way	✔ (green outline)	Plan to address issue fully – but project not yet running so risk this could change
✔ (amber)	Issue addressed, but only on limited scale	✔ (amber outline)	Plan to address issue partially – but project not yet running so risk this could change
✘ (red)	Not addressed at all		

TABLE 1: SUMMARY TABLE OF UK MODELLING STUDIES

This summary table highlights the key gaps in the current modelling studies from the UK, described in detail in the Task 2 Report.

	Element Energy/Redpoint (2012)	Imperial College/NERA (2012)	Smart Grids Forum: Workstream 3	DECC: Follow up to household electricity survey
Do the study aims try to tackle DECC's core questions?				
Flexibility	✓	✓	✓	✓
Customer response	✓	✓	✗	✓
Building Response	✓	✓	✗	✓
Heat Pump Response	No specific aims ✗	only economic ✓	No specific aims ✗	✓
Assumptions - robustness				
Power supply	✓	economic perspective not technical ✓	✓	✓
HP integration with storage	✓	✓	✓	✓
HP operation & performance	✓	✓	✓	✓
Building dynamics	✓	✓	✗	(based on small sample) ✓
Occupancy patterns	✓	✓	✗	(based on small sample) ✓
Would additional simulations add critical insight to answer DECC's questions?				
Under different scenarios?	only with development of HP part ✗	only with development of HP part ✗	only with development of HP part ✗	only with development of HP part ✗
With higher sampling rate?	✗	✗	✗	✗
With further development of heat pump part of model?	detailed HP module should be added ✓	more detailed characterisation of HPs ✓	detailed HP module should be added ✓	develop with wider sample of real HP data ✓
Key gaps	Needs HP module built into model which considers the impact of different types of HP (e.g. ASHP/GSHP) performance, end use characteristics, storage volume and random end-user behaviour.	HP part of model needs to be developed to consider differences between operation in retrofit or new build, the interaction of the HP with storage, and random end-use behaviour.	Advancement of the low voltage (LV) model to incorporate HPs (& EVs) in a less simplistic way – specifically needs to consider building dynamics and variations in end-user characteristics	Is based on a small sample of real data – wider sample would be beneficial. Should consider HP dynamics (e.g. differentiation between HP types & retrofit / new build).

TABLE 2: SUMMARY TABLE OF UK DEMONSTRATION PROJECTS

This summary table highlights the key gaps in the current demonstration projects from the UK, described in detail in the Task 3 Report.

	Customer Led Network Revolution	NEDO Smart Community Manchester	Low Carbon London
Is the study already collecting data?	since winter 2013 ✓	✗	since 2012 ✓
Do the study aims try to tackle DECC's core questions?			
Understanding the value of HPs for peak shifting	✓	✓	HPs only monitored ✗
Understanding control / influence methods	✓	✓	✗
Understanding customer response	✓	✓	ToU tariffs ✓
Understanding building response	✓	✓	✗
The demonstration project: How robust / scalable is it?			
Inclusion of HPs (high / medium / low #s)	450 HPs monitored ✓	600 HPs monitored ✓	18 HPs monitored ✓
Inclusion of HPs being controlled / influenced (#s)	19 HPs controlled ✓	600 HPs controlled ✓	No HPs controlled ✗
Range of heat pump types controlled	Only 1 type ✓	At least 2 types, varying system configurations ✓	✗
Range of building types & occupancy patterns where HPs installed	(though limited range of homes with *controlled* HP) ✓	potentially large # of existing Homes with HP ✓	✓
Range of mechanisms tested for capturing HP flexibility (e.g. storage, modulation, hybrid)	Only on-off cycling with storage, but potential to use modulating in the future ✓	TBC, likely to test modulation & on/off; with & without storage; hybrids ✓	✗
Range of control / influence mechanisms tested	Testing direct control & ToU tariffs ✓	Direct control tested ✓	Different tariff structures tested but not for HPs ✗
Need for further work?			
Will the data provided provide some insight to all of DECC's questions?	The research questions are well-aligned to provide *some* insight to all key question ✓	based on planned outcomes – but v early stages ✓	no shifting of HP demand being tested ✗
Could new analysis of the existing data answer DECC's questions?	e.g. understanding flexibility potential from different types of building ✓	**?** – too early to say	✗
Key recommendations: Gaps	▶ Test revised ToU tariff rates – design more around the HP ▶ Automated response to flexible tariffs ▶ Investigate business models to reduce the upfront cost	▶ Testing flexibility potential through influencing e.g. with ToU tariffs ▶ Focus on the customer proposition or value to customer within business model analysis	▶ Attempt to control / influence operating times of HPs as well as collecting monitoring data

5. Extent to which different peak shifting methods have been tested

We highlight all the methods for peak shifting in Table 1 below, and assess whether these have been tested in UK modelling / demonstration projects, and how robustly they have been tested. Full discussion of these is in Section 6.

Modelling studies are said to be robust if:

- They include clear assumptions about
  - power supply
  - HP / storage interaction
  - HP operation / performance
  - Building dynamics
  - Occupancy patterns
- They are dynamic:
  - Include sufficiently detailed assumptions (above) to capture the real dynamic nature of HP operation and response
  - Are high enough resolution / with high enough sampling rate to capture the dynamic operation and response
- They model a range of scenarios relevant to DECC's core questions (not only one scenario)

Demonstration projects are said to be robust if:

- They are of sufficient scale – i.e. a large number of heat pumps / buildings included
- They include a wide range of building types
- They include several heat pump types which are typical of the heat pumps installed – or likely to be installed – in the UK
- They include a range of occupancy patterns
- Ultimately, we assess how 'scalable' a demonstration project is – can conclusions be drawn from this study about the implementation of tested mechanisms in whole UK building stock?

TABLE 3: GAP ANALYSIS SUMMARY - HOW WELL HAVE DIFFERENT METHODS OF PEAK SHIFTING BEEN TESTED IN UK MODELLING AND DEMONSTRATION PROJECTS?

The table below presents a summary, which is discussed in more detail on the following pages.

Method of peak shifting	Modelling Studies		Demonstration Projects		International experience?	Recommendations for further UK work
	Modelled?	Robust-ness	Field Tested?	Robust-ness		
HEAT PUMP SYSTEM: TECHNOLOGY MECHANISMS FOR PEAK SHIFTING						
Enabling flexibility through integration with storage	✓ (orange)	✓ (orange)	✓ (green)	✓ (orange)	Netherlands (1) Denmark (2) Belgium (12) Germany (14) ✓ (orange)	▶Explore ways to minimise storage volumes whilst still enabling flexibility ▶Test optimum HP / storage integration options for UK
Enabling flexibility through integration with 2nd energy source	✗	N/A	✗	N/A	Finland (4) Netherlands (1) ✓ (orange)	▶Modelling and field testing to better understand flexibility potential with hybrids in UK
Enabling flexibility through use of modulation instead of on-off cycling	✗	N/A	✗	N/A	France (3) ✓ (green)	▶Test the use of modulation in response to dynamic signals in UK homes
Enabling flexibility through heat pump smart-ready capabilities	✗	N/A	✓ (green)	✓ (orange)	Netherlands (1) Denmark (2) France (4) ✓ (green)	▶Assess balance v cost & flexibility enabled through different levels of smart-readiness
CONTROL/INFLUENCE METHOD: TECHNOLOGY & MARKET MECHANISMS FOR PEAK SHIFTING						
Direct Control – automated response	✓ (orange)	✓ (orange)	✓ (green)	✓ (orange)	Netherlands (1) Denmark (2, 6) France (4) ✓ (orange)	▶Work towards set of (open?) standards for communication channels, protocols, information models for the UK
Price signal (e.g. ToU tariffs, peak pricing, hourly pricing) - automated response	✗	N/A	✗	N/A	Sweden (9) Finland (10) ✓ (green)	▶Test automated response to ToU tariffs in the UK
Price signal (e.g. ToU tariffs, peak pricing, hourly pricing) – manual response	✗	N/A	✓ (green)	✓ (orange)	France (11) ✓ (orange)	▶Explore how different types of ToU tariffs may be able to encourage HP customer behavioural change

Method of peak shifting	Modelling Studies		Demonstration Projects		International experience?	Recommendations for further UK work
	Modelled?	Robust-ness	Field Tested?	Robust-ness		
FACTORS INFLUENCING THE ABILITY OF THE ABOVE MECHANISMS TO BE USED FOR PEAK SHIFTING:						
Customer response – impact of customer behaviour & occupancy patterns	✗	N/A	✓ (green)	✓ (amber)	Denmark (2) Belgium (12) ✓ (amber)	Develop wider data sets from further UK field trialling, to better understand characteristics
Building response – impact of thermal mass, insulation levels, size, age etc	✓ (amber)	✓ (amber)	✓ (green)	✓ (amber)	Denmark (2) ✓ (amber)	Develop wider data sets from further UK field trialling, to better understand and target flexibility potential in the building stock
Network compatibility	✓ (amber)	✓ (amber)	✓ (green)	✓ (green)	Belgium (6) ✓ (green)	Further modelling (& trials) to better understand dynamics of HP operation and its impact on the grid
Impact of external environment - weather	✗	N/A	✗	N/A	Germany (13) ✓ (amber)	Investigate options for use of weather forecasting to optimise flexibility potential

KEY: TABLE 3, GAP ANALYSIS SUMMARY - WHAT DOES THE RATING MEAN?

Modelling: Has it been modelled?		Modelling: Robustness	
Rating	**Description**	**Rating**	**Description**
✔ (green)	Modelled	✔ (green)	Modelled with detailed characterisation of heat pumps
✘ (red)	Not modelled	✔ (orange)	Modelled with partial characterisation of heat pumps
Demonstration Projects: Has it been field tested?		**Demonstration projects: Robustness**	
Rating	**Description**	**Rating**	**Description**
✔ (green)	Tested in UK field tests	✔ (green)	Tested on large numbers of heat pumps to date (i.e. 100s)
✘ (red)	Not tested in UK field tests	✔ (orange)	Tested on limited set of heat pumps to date (i.e. 10s) – or with similar technologies (e.g. storage heaters)
International experience			
✔ (green)	Field tested specifically on heat pumps and with full assessment of the key questions for DECC on this issue		
✔ (orange)	Field tested but may be on electric storage heaters instead of heat pumps and/or may not be cover full assessment of the key questions for DECC on this issue and/or trials still at early stages.		

6. Discussion: Comparing Methods of peak shifting with extent of testing in UK modelling and demonstration projects

In the discussion below, summarized in Table 3, we highlight all the methods for peak shifting, and assess whether these have been tested in UK modelling / demonstration projects, and how robustly they have been tested.

6.1. Heat Pump System: Technology Mechanisms for Peak Shifting

Enabling flexibility through integration with storage

Modelling		Demonstration projects		International experience?	
Modelled	Robustly?	Field tested	Robustly?		
✔ (orange)	✔ (orange)	✔ (green)	✔ (orange)	Netherlands, Belgium, Denmark	✔ (orange)

UK experience

In modelling studies, storage is assumed to be included, but the dynamics of the heat pump and storage interaction are modelled in a relatively simple way which does not reflect the dynamics of real operation (e.g. including heat up times). In the CLNR project (17), storage is included as a bolt-on to the Neura heat pumps, with additional thermal sensors added to the storage tank which enables the control system to know how much heat is available. In the NEDO project (16 - which is not yet running), there is likely to be a mixture of buildings with and without storage – which could provide interesting data (also since some homes will have hybrids). However it is too early to say how well this will address the issue fully.

International experience

From international smart heat pump projects, the inclusion of a storage tank as part of a heat pump system is almost always the essential tool for enabling flexibility and this has been tested relatively well in combination with on/off cycling of the HP – usually with additional temperature sensors retrofitted to existing tanks as in the CLNR project. Examples of where this is tested include Powermatching City (1), Linear (12 – only direct electric) and EU Ecogrid (2). However, in most cases storage has been a binary variable (yes / no), with room for further analysis of operating patterns and dynamics.

Recommendations for the UK

- **A key UK challenge is finding available space for storage tanks – so further research on ways to minimise storage volumes whilst still enabling flexibility is key** (as well as better understanding of the UK building stock to identify the realistic space available for storage). The requested storage volume in demonstration projects in Europe from a purely DSR point of view is often as much as 1,000 litres (e.g. requested by northern powergrid for CLNR, quoted in a smart project in Sweden involving NIBE heat pumps, and quoted in a Fraunhofer ISE project - 14). This volume is impractical for ordinary UK homes (usually around 300 litres has been used). Progress is being made in the UK on this topic now. The **i-STUTE project**[1] should go some way to addressing some of these questions - the part of the project developing a high efficiency electric heat pump is aiming to develop integrated storage and DSR capabilities. If this can be developed as a solution which works for DSR with relatively small volumes of storage it will be a very positive step. Through **DECC's heat storage innovation competition**[2], DECC is also funding feasibility studies and demonstration projects to test innovative solutions for compact heat storage, some of which are linked to heat pumps. For example, a demonstration project with 10 heat pumps installed with phase change material "heat batteries" from the developer Sunamp[3].
- **There is scope for further research into the optimum integration between heat pumps and storage.** In modelling studies to date there has not been detailed analysis of the dynamics, and demonstration projects tend to only test one heat pump / storage scenario. Further work will help better understand the dynamics and subtleties of the interaction between different HP / storage set-ups, so flexibility potential in different types of homes can be better understood. This work will also inform tank manufacturers about what is required - most demonstration projects we have assessed (including internationally) have to retrofit thermal sensors into existing storage tanks so the heat pump control systems are able to better predict available flexibility, and adjust the control algorithms accordingly.

---

[1] http://www.i-stute.org/
[2] https://www.gov.uk/government/publications/advanced-heat-storage-competition
[3] http://sunamp.co.uk/decc/

Enabling flexibility through integration with 2nd energy source

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✗	N/A	Finland, Netherlands ✓

UK experience

This has not been addressed in any modelling or demonstration projects in the UK. The NEDO project is due to include some hybrid heat pumps (from Daikin) though the details of how or if they will be used for peak shifting are yet to be determined.

International experience

This has been assessed to a limited extent. Powermatching City in the Netherlands (1) has “hybrid” systems with a heat pump and a boiler, where the boiler meets the peak load and the heat pump the rest – which is a simple way of removing HP consumption from peak times. There has been no more sophisticated investigation into e.g. the response of a hybrid to flexible tariffs. In Finland, the utility Fortum offers a customer service (‘Fortum Fiksu’ - 5) where the customers’ heating is automatically switched between oil and electricity depending on which is cheaper (based on nordpool spot prices). Although this is with electric heaters and not hybrids, its approach shows what could be possible for hybrid heat pumps once flexible tariffs are available.

Recommendations for the UK

There is scope for further modelling – and ultimately demonstration projects – to better understand what flexibility potential there could be with hybrids, and what the best mechanisms are through which to capture it. This is particularly relevant for the UK given the challenges of finding space for storage in many UK homes, plus the potential for heat pumps to create major demand peaks on the distribution grid in the UK.

Enabling flexibility through use of modulation instead of on-off cycling

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✗	N/A	France, Germany ✓

UK experience

This has not been addressed at all in modelling studies. In the CLNR demonstration project, on/off cycling has been the primary method of gaining flexibility, because the Neura heat pumps are not yet able to modulate down in response to an external signal. This is a long-term aim however.

International experience

EDF R&D in France has been carrying out trials with a major heat pump manufacturer (3) over the last 2 heating seasons, testing the modulation of heat pumps in response to dynamic signals – learnings from this trial will be valuable to DECC. A similar project is running in Germany led by E.ON R&D (15). In the NEDO project (16), Daikin heat pumps are to be used, which do have modulating potential. It is yet to be defined the way in which these will be controlled, but modulation is possible (similarly in the Smart Electric Lyon project in France there is potential for modulation to be used though it is also yet to be defined - 4).

Recommendations for the UK

Incorporating a modulating element in existing demonstration projects (and modelling projects once a HP module is incorporated) could be valuable. Modulation is another method through which some flexibility can be enabled whilst maintaining thermal comfort. The key advantage is that it may cut down the volume of storage required to capture flexibility, which has major benefits in the UK due to space limitations on tanks.

Enabling flexibility through heat pump smart-ready capabilities i.e. connectivity, communication & control

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✓	✓	Netherlands, Denmark, France ✓

UK experience

The only currently running UK trialling of directly controlled 'smart-ready' heat pumps is in the CLNR project (17), where the Neura heat pumps have the capability to respond to direct utility signals. This is one of the most advanced smart-ready heat pumps on the market, particularly because of its ability to communicate future available flexibility (see Task 1 report for more detailed analysis of the capabilities). Outcomes so far show that it is technically possible to shift heat pump operation away from peak times via direct control signals, with ramp down times of up to 2 hours. Wider testing on a greater number of heat pumps is required in order to draw more robust conclusions about the peak shifting potential with this method across the UK building stock, but it provides valuable first insight.

International experience

There are a large number of projects which have been testing the flexibility potential of heat pumps – in most cases with retrofitted control systems which mean the smart-ready capability is an add-on rather than built-in e.g. Styr din varmepumpe (SDVP, DK - 6), EU Ecogrid (2), powermatching city (1), PREMIO (7). These types of projects have provided valuable learnings on what smart-ready capabilities are required, and the next generation of smart HP projects now emerging in Europe feature heat pumps with built-in capabilities e.g. Daalderop in the Couperus smart grid project (8), local Danish manufacturers in follow up projects to SDVP (6). There is also the emergence of heat pumps in Scandinavia – particularly Sweden), which have the capability to alter their operating times according to nordpool hourly spot prices (9 - e.g. NIBE – built in capability; IVT / Bosch – available as an add-on). Further, HEMS companies are emerging with propositions to enable heat pumps to respond to such price signals (e.g. There Corporation – 10 - who have a commercial offering in Sweden and Finland, as well as a similar offering in Italy for HP/PV optimisation; and Passiv Systems who are developing a heat pump offering).

Recommendations for the UK

The UK's own CLNR project (17), alongside the forthcoming NEDO project (16) and the wide range of international experience provides significant insight. However, there are outstanding questions which could be tested in more depth in further work, in the context of the UK building stock, climate conditions, energy costs, energy markets and end-user characteristics:

- Is direct control of heat pumps with full built-in smart-ready capabilities the solution which can provide the most flexibility, most cost-effectively?
- Does the smart-ready capability have to be built in to the heat pump to maximise flexibility, or can it be within an external device such as a HEMS?
- Can smart-ready heat pumps which can respond to dynamic price signals rather than direct control signals[4] provide as much flexibility and/or provide a better end-user experience (i.e. be more cost-effective and better maintain thermal comfort)?
- What is the optimum balance between the cost of building in different levels of HP smart-ready capability, and the different levels of flexibility which can be achieved for peak shifting? For example, if there is no 2-way communication between the heat pump and the utility, the heat pump response must be estimated rather than quantified – the heat pump is lower cost[5], but to what extent does this mean the flexibility is harder to capture, or harder to create value from?

[4] NB Direct control signals can also be in the form of 'price signals', but here we refer to price signals which are transferred all the way to the end-user from e.g. hourly pricing tariffs.

[5] Cost differentials between heat pumps at different levels of smart-readiness are difficult to ascertain because there are relatively few smart-ready products. However we estimate the additional cost for a top level smart-ready heat pump is in the range 30-50% higher than for a 'normal' heat pump, based on conversations with manufacturers and experts.

6.2. Control / influence method: Technology and market mechanisms for peak shifting

Direct Control – automated response

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✓	✓	✓	✓	Netherlands, Denmark, France ✓

UK experience

In modelling studies there has been very little work simulating heat pump response in sufficient detail to draw conclusions regarding flexibility – modelling has looked at a wider network level and usually focuses on understanding network impact of heat pumps without much attempt to shift loads. In demonstration projects, the flexibility potential from direct control of heat pumps is being tested in the CLNR project (17) (though in a non-automated way at present where every home is individually dealt with), and will be potentially tested in NEDO (16) on a larger scale (where an ICT platform for controlling 100s of heat pumps at once is to be developed). One of the key challenges in the UK is that there are no clear standards defining e.g. communication channels, connection with smart meters, and how heat pumps should fit into the wider smart home context. Particularly CLNR and NEDO will add valuable learning on the practical implementation of these systems for control, but there are learnings also to be drawn on internationally.

International experience

There are several projects looking at different ways to directly control heat pumps, and on-going work to create more standardized solutions. Experience from the several projects in Denmark (such as Styr Din Varmepumpe - 6), projects using the powermatcher software (e.g. Powermatching City - 1, EU Ecogrid - 2), and projects in France (e.g. Smart Electric Lyon - 4), are creating some key learnings which should be considered in a UK context - particularly:

- **Standardisation work for existing IT platform – ways to control one heat pump** – e.g. Implementing an "information model" which describes what information the HP communicates to the server.
- **Developing common strategies for controlling many heat pumps** e.g. on-going work to develop IT tools at aggregator level for controlling a large number of HPs in a Virtual Power Plant (addressing both day-ahead & intra-day markets). This is complementary to what may be deployed in NEDO (16).
- **Developing standard communication channels** between smart meters, other in-home devices and the home

Recommendations for the UK

A barrier to many companies engaging in developing smart-ready products is a lack of standards. Manufacturers are reluctant to build in smart-ready capability until they are given clear direction on what is required. International experience shows that where manufacturers have 'built-in' capabilities rather than retrofitting control systems, the performance (and flexibility potential) is greater (compare for example the EU Ecogrid project (2) which has retrofitted controls, with the Copernicus smart grid project (8) which has Daalderop's built-in capabilities). Further work should use the learnings from the CLNR (17), NEDO (16) and other international projects, and work towards developing a set of standards for communication channels, information models and communication protocols which can be used in the UK. This should be aligned with work on UK smart home and smart meter roll out.

Price signal (e.g. ToU tariffs, peak pricing, hourly pricing) - automated response

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✗	N/A	Sweden, Finland ✓

UK experience

This is not being tested in CLNR (17 - where only manual response and direct control is tested), and it is not planned in NEDO (16 - where only direct control is being tested)

International experience

Examples of automated response include the heat pump manufacturer NIBE (9) in Sweden, who has built in the capability to automatically respond to hourly nordpool spot prices to their heat pump - optimising the operating patterns according to the electricity prices; and the HEM manufacturer There Corporation in Finland (10), who have developed an offering which can essentially connect the heat pump control strategy to the nordpool spot prices, influencing the operating patterns.

Recommendations for the UK

Test automated response to ToU tariffs in the UK.

Price signal (e.g. ToU tariffs, peak pricing, hourly pricing) – manual response

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✓	✓	France ✓

UK experience

This is being tested in CLNR (17), though the ToU tariff has not been designed around the heat pump, and has not been shown to have any impact on the behavioural patterns. In the Low Carbon London project (18), a traffic light system in the in home display is designed to make it easier for the customer to see when prices are expensive or low, making it easier for them to change their consumption accordingly. However, this has not been tested with heat pumps.

International experience

Most international experience has shown that it is difficult to encourage manual response to flexible tariffs with heat pumps (it is easier with more discretionary loads such as washing machines). EDF in France has offered a traffic light tariff system (11) for several years to some customers, which has had an impact on demand (though the effects on heat pump demand is not investigated).

Recommendations for the UK

International experience suggests that a focus on automated response should provide greater flexibility – however, manual response is both simpler and cheaper, so should not be ruled out. Learnings from how heat pump customers have (not) responded to ToU tariffs in CLNR (17), and how customers have been incentivised to respond to ToU tariffs in LCL (18), and with EDF in France (11), will provide some insight. Further work is recommended to better understand how different types of ToU tariffs may be able to encourage heat pump customer behavioural change.

6.3. Factors influencing the ability of the above mechanism to be used for peak shifting

Customer response – impact of customer behaviour & occupancy patterns

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✗	N/A	✓	✓	Denmark, Belgium ✓

UK experience

Customer response is relatively poorly understood, but arguably one of the most important influencing factors on flexibility. Modelling studies have not addressed this issue robustly - any customer response is understood only based on assumed demand profiles (which are based on very limited real data) and on the assumption that the thermal demand is always met. However, this approach does not take into account the impact of factors such as random human behaviour (e.g. manual over-ride) and the impact of changing occupancy patterns. Demonstration projects are necessary to better understand this, and to develop a larger data set to characterise end-use patterns. The on-going CLNR project will certainly add to this picture (though it is limited in scale). The analysis in the LCL project around the response to ToU tariffs will be of interest – though not taking into account heat pumps.

International experience

There is a lot of experience in the many European smart heat projects mentioned elsewhere (e.g. EU Ecogrid in Denmark - 2, Linear in Belgium -12) which will provide insight into customer behaviour – but there may be large differences between UK consumers and others in terms of behaviour, particularly related to heating.

Recommendations for the UK

Further data from field trials which can increase understanding of UK heat pump customers' behaviour and use patterns is necessary. There is limited field data analysing customer response in the UK, which could be used to inform further modelling studies for example.

Non-UK field data will give an insight, but the UK also has its own characteristic ways of heating homes (e.g. see Task 1 market report). The NEDO project (16) could potentially offer a lot of UK data – but at present its core research questions do not have a customer focus – there may be scope to influence how this data is analysed in order to better answer DECC's questions. There is also scope to look in more detail at, for example, the impact of PV tariff structures on consumer consumption patterns in the UK, to provide an indication of customer willingness to change. Further, projects with storage heaters rather than heat pumps may reveal more extensive UK evidence – for example, the SSE NINES project, or the experience with the Dimplex Quantum heater.

Building response – impact of thermal mass, insulation levels, size, age etc

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✓	✓	✓	✓	Denmark ✓

UK experience

Modelling work has typically modelled several building segments in the UK and included (to varying degrees) detailed demand profiles – although the demand profiles have been based either on a limited set of heat pump data (e.g. Further Analysis of the Household Electricity Usage Survey - 19) or been based on generic data combined with assumptions on heat pump uptake rates. Demonstration projects will provide insight where the data is analysed in such a way as to pull out differences in different types of buildings. The limiting factor is the small number of buildings within demonstration projects in which heat pumps are installed.

International experience

There is a lot of experience in the many European smart heat projects mentioned elsewhere which will provide some insight into the impact of building type on flexibility – where building types are comparable to UK buildings this could add value (e.g. many trials in Denmark – e.g. 2, 6 - where many homes may be older with high temperature radiators and therefore comparable to the UK).

Recommendations for the UK

Further data from field trials which can increase understanding of the range of building types in the UK stock, and their respective thermal responses, is necessary. There is limited field data in the UK - the NEDO project (16) could potentially offer a lot of UK data based on current plans.

Network compatibility

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
✓	✓	✓	✓	Belgium ✓

UK experience

All the modelling studies address to some extent the network impact of distributed generation (even if the specific impact of heat pumps is modelled in a relatively simplistic way). The LCL demonstration project (18) is monitoring power quality impact of heat pumps (though based on only 18 heat pumps). The CLNR project (17) is testing the impact of heat pumps on the distribution grid (more robustly as based on 100s of heat pumps). When the NEDO project (16) begins it will add further data.

International experience

Several of the international demonstration projects tackle this. Projects of particular interest include the Linear project in Belgium (12), which has a workpackage focusing on the LV network impact of clusters of distributed generation.

Recommendations for the UK

This aspect is relatively well addressed based on current – and anticipated – demonstration projects in the UK, at a generic network level but less so at a heat pump level. Modelling studies and demonstration projects should focus on uncovering more detailed insight into the dynamics of heat pump operation and how this affects the LV grid (e.g. to pick up subtleties such as response times of different types of heat pumps)

Impact of external environment - weather

Modelling		Demonstration projects		International experience?
Modelled	Robustly?	Field tested	Robustly?	
	N/A		N/A	 

UK experience

Most modelling and demonstration projects include some level of monitoring of outside temperature. However, none address the use of weather forecast data – which could play an important role in allowing the heat pump to be controlled more pro-actively – this promoting flexibility whilst maintaining end-user comfort.

International experience

It is relatively standard for heat pumps to have weather compensation built-in, and most demonstration projects include monitoring outside temperature. There may be projects emerging including the use of weather forecast data (e.g. RWE's wind-heat project with storage heaters – 13, and a Danish project with heat pumps which is just starting[6]).

Recommendations for the UK

Incorporating weather forecast data into heat pump control strategies has the potential to make flexibility easier to capture (the heat pump control strategy can be more pro-active to prepare for e.g. cold snap combined with a peak period), therefore impact on thermal comfort can be minimised). Further trials and/or market modelling in the UK should investigate the ways in which this can be used to optimise flexibility potential. Key issues to

[6] No reference currently available – information picked up from conversation with industry.

investigate include the use of local weather data, and defining the necessary granularity of weather forecasts which can make a difference – how big is error margin?

7. Reference materials

(1) Netherlands: Powermatching City http://www.powermatchingcity.nl
(2) Denmark: EU Ecogrid http://www.eu-ecogrid.net/
(3) France: EDF R&D working with a heat pump manufacturer to test the use of modulating heat pumps in response to demand response signals. No specific reference on this project but it is part of wider research at EDF R&D detailed here http://chercheurs.edf.com/programmes-de-recherche/reseaux-40572.html&page=1
(4) France: Smart Electric Lyon http://www.smart-electric-lyon.fr/
(5) Finland: Fortum Fiksu http://www.fortum.com/countries/fi/yksityisasiakkaat/energiansaasto/fortum-fiksu/pages/default.aspx
(6) Denmark: Styr din varmepumpe https://www.styrdinvarmepumpe.dk/
(7) France: Premio http://chercheurs.edf.com/programmes-de-recherche/reseaux/premio-un-test-grandeur-nature-pour-les-smart-grids-40584.html
(8) Netherlands: Couperus smart grid project http://www.rvo.nl/sites/default/files/Couperus%20smart%20grid_0.pdf
(9) Sweden: Smart-ready heat pump offerings from Swedish heat pump manufacturers such as NIBE – see Swedish website with NIBE Uplink offering http://www.nibe.se/Produkter/NIBE-Uplink/ and information on the service in English https://www.nibeuplink.com/. The information on the link between the NIBE UPLINK system and the electricity prices is in the NIBE presentation from the Delta-ee Heat Pump and Utilities Roundtable, Paris, February 2014 (contact Delta-ee for information).
(10) Finland: Offering from HEM company There Corporation http://www.therecorporation.com/solutions/
(11) France, EDF "traffic light" price tariffs https://particuliers.edf.com/gestion-de-mon-contrat/options-tarifaires/la-couleur-du-jour-2585.html
(12) Belgium: Linear http://www.linear-smartgrid.be/?q=en/home
(13) Germany: RWE wind-heat https://www.rwe.com/web/cms/en/1136046/rwe/innovation/projects-technologies/energy-application/wind-heating/
(14) Germany: Fraunhofer ISE, presentation from 11th IEA HP Conference, Montreal, May 2014
(15) Germany: E.ON R&D working with HP manufacturer testing modulation of HP for demand response, poster from 11th IEA HP Conference, Montreal, May 2014
(16) NEDO, Smart Community project, Manchester e.g. http://www.hitachi.com/New/cnews/130523a.html
(17) Customer Led Network Revolution (CLNR) http://www.networkrevolution.co.uk/
(18) Low Carbon London http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Low-Carbon-London-%28LCL%29/
(19) DECC, Further Analysis of the Household Electricity Usage Survey. Original reports here: https://www.gov.uk/government/publications/household-electricity-survey

URN 14D/258