IEA HPT Programme Annex 42: Heat Pumps in Smart Grids

UK Executive Summary

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Table of Contents

Table of tables / figures

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1. Executive summary

Meeting the UK's decarbonisation targets will require flexibility and one of the ways of providing this is through demand side response.

Meeting the UK's decarbonisation targets will lead to an increasing need for demand side response (DSR) in the electricity system, as intermittent renewable generation meets increased demand from electrified heat.

In particular the potential demand peaks from heat pumps in a largely decarbonised future building stock could turn out to be a significant future challenge, both in terms of available generation and the capacities of the transmission and distribution networks.

Assessing the ability of heat pumps to be both part of the challenge as well as its solution was a key driver for the UK to participate in Annex 42. BEIS's aim for the project was to explore the best methods for peak shifting with a heat pump system and understanding the capacity of the UK building stock to provide flexibility when heated with heat pumps.

The UK recognised a number of different research gaps in this area, many of which have now been addressed.

The research carried out by UK participants in Annex 42 (mainly Delta-ee, the University of Ulster, the Energy Technologies Institute and the Energy Systems Catapult) included:

- A summary of the current electricity system and heat pump market situation;
- An analysis of existing research into the smart operation of heat pumps in the UK (modelling and field trials);
- The modelling of demand response scenarios with heat pumps in buildings representative of the UK's housing stock;
- The development of a Roadmap towards a smart heat pump system.

The research concluded that the key driver for heat pump flexibility in the UK is the need to reduce grid congestion (particularly winter and daily peaks) in order to alleviate the impact of the increased penetration of the technology in the building stock under most decarbonisation scenarios.

As this issue will arise on a wider scale within the next 5-10 years, the majority of systems available in 2014 were not able to be used for demand response. This however is changing, with more and more heat pump control systems being able to be connected directly to the internet or through a gateway, which is an important enabler for flexibility.

The analysis of existing research showed that there were significant gaps in the UK's body of academic research and R&D around the impact the UK's building stock's thermal characteristics have on heat pump flexibility. Another important topic that was only partly addressed through many of the studies was the impact of individual behaviour on DSR events and the acceptance of DSR by consumers. Several of these questions have since been addressed.

The UK's modelling study showed that, in an average winter, large parts of the housing stock should be able to provide flexibility in the case of a DSR event, without any upgrades to the thermal properties of the building or the heat pump being required. In the harsher conditions of a 1-in-20 winter however, significant improvements of both the thermal mass and the insulation are likely to be required in many UK buildings in order to achieve sufficient levels of flexibility.

Similar results have been found in both ongoing and completed field trials, with in particular the Manchester Smart Communities field trial having successfully demonstrated the ability of heat pumps to provide demand side flexibility in the UK. More results of this study, including the impact that individual behaviour can have on DSR availability and will be published at http://www.gmsmartenergy.co.uk.

Last but not least the Roadmap report identifies the key elements that need to be in place in order to enable a smart heat pump system and shows that the UK is on the right track to being able to achieve such a system. Nevertheless, important steps still have to be made in order to enable smart heat pumps in the UK. These are summarised below.

Results from other participating countries provide interesting learnings regarding the ability of heat pumps to be aggregated, but other learnings are difficult to apply in the UK directly.

The results from other participants show that heat pumps can be successfully used to provide demand response. However, results regarding the level of flexibility (e.g. for how a heat pump can in general be switched off before the room temperature drops below the comfort limit) are difficult to apply to the UK, due to the different characteristics of the building stocks. The same is the case for findings on the economics of DSR with heat pumps.

Nevertheless, some general conclusions can be drawn from the other participants' research:

- The level of flexibility is strongly dependent on the thermal characteristics of the building, with increased thermal mass and insulation levels having a positive effect on the switch-off times. The same is true for additional thermal storage.
- The right balance between increased flexibility and possible detrimental effects for the heat pump's efficiency has to be found.
- Most value from DSR can currently be derived from services to the distribution networks and participation in the balancing and reserve markets.
- Value from optimising the operation of a system based on the wholesale market price is restricted by the fact that the actual market price of electricity generally only makes up a very small share of the overall electricity price.

The following key findings and recommended actions can be derived from the work under Annex 42

- Providing demand response with heat pumps is possible in current buildings, but limited to average winter temperatures → **In order to meet the key objective, i.e. expanding the availability of heat pump demand response to 1-in-20 winters, significant improvements to the UK housing stock's thermal properties are required (increased insulation and thermal mass).**
- Modelling studies and field trials show that DSR can successfully be provided with heat pumps → **An important question that remains to be answered for the UK is the occurrence of conflicting DSR requests from the balancing responsible party (National Grid) and the distribution network operators and their impact on the availability of DSR.**
- The value that is placed on demand side response with heat pumps in the UK is currently unclear and market mechanisms providing such a value as an incentive for both customers and aggregators are either insufficient or non-existent → **In order to enable and incentivise the development of a smart heat pump system the UK should:**
  - **Keep on track with the roll-out of smart meters, which are a key infrastructure for the billing of demand response**
  - **Provide a clear market framework for flexible demand to foster business model innovation**

    - **Increase the flexibility of energy prices for flexible demand systems like heat pumps**
- Many knowledge gaps identified in our work for Annex 42 have now been partially addressed, but the understanding of key elements like the need for building stock improvements is still insufficient → **There should be ongoing support for both academic and commercial R&D into the building stock's suitability for DSR, smart heat pump control technologies, heat storage solutions suitable for the UK market and the requirements and behaviours of end-customers.**

2. Background and aims of Annex 42

In decarbonisation scenarios and strategies across the UK and Europe, heat pumps (HPs) are being recognised as a key technology in the building sector.[1] The technology provides great opportunities for reducing heating related greenhouse gas emissions, but its wide-spread deployment would also create new challenges in the electricity distribution and generation sector. Operating heat pumps in a "smart" way, as part of a wider smart grid, would help to address many of these challenges (e.g. local grid congestion, demand peaks, renewable integration, etc.).

The aim of Annex 42 was to address the question of what role heat pumps can play in a smart grid. Specifically:

- To what extent heat pumps can be used as a tool to alleviate some of the challenges of a largely decentralised and renewable electricity system
- How to manage the impact of increased electricity demand due to heat pumps' increasing penetration of the heating market

This common interest was shared by all 9 participant countries and the 19 participating organisations of the Annex 42 working group, although the key drivers for exploring the questions were different from country to country. The participating countries, organisations and their key drivers for heat pumps in smart grids are summarised below:

Table 1: Participating countries, organisation and key motivations

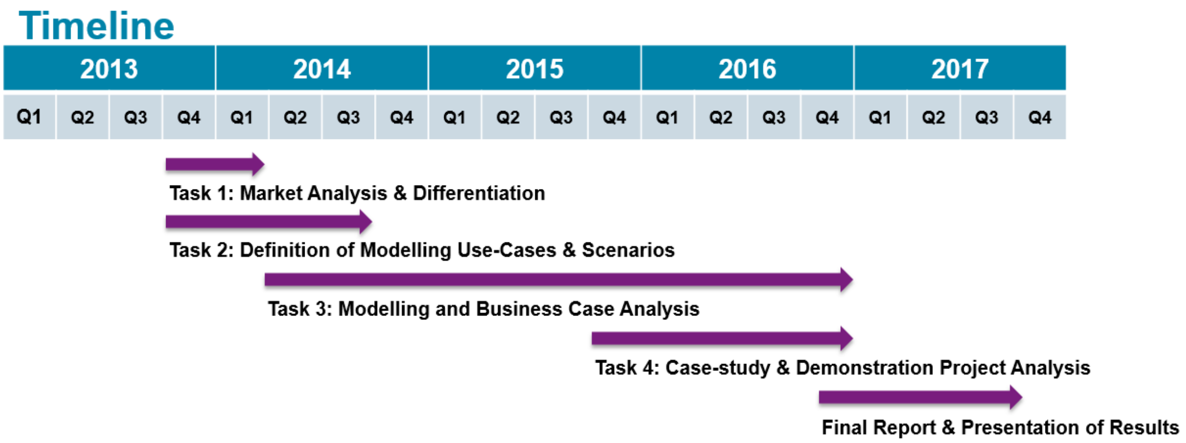
Country	Participating organisation(s)	Drivers for HP in smart grids
	BDH, Berenschot, Alliander, TNO	Managing distribution grid congestion. An issue within the next 5-10years.
	AIT, TU Graz	Austria is already well underway to realise its 2020 goal of 34% renewable energy use. To accommodate the increasing RES-share, flexible smart grids could play an important role. The main challenge is expected to arise within the next 5-10 years. Presently, part of the RES can still be exported to neighbouring countries.
	Hochschule Luzern	Primary driver is the increasing renewable generation (avoiding/delaying high voltage grid upgrade – expected to be 6bn Swiss francs by 2020). Not an immediate challenge - 2030 is the key policy milestone.
	Fraunhofer ISE	Balancing supply and demand, and reducing the need for grid upgrade investments. A challenge in the medium term (5-10 years).
	Danish Technological Institute	Increasing renewable generation around 37.6 % of the electrical consumption was produced by wind turbines in 2016 and it will increase to 50 % in 2020. The challenges regarding balancing the production and the high voltage grid are expected between 2020 and 2025.
	EDF	Managing increased net demand variability due to uptake of renewables and strong, decrease/shift winter peak demand. An immediate challenge in some regions.
		Maintaining capacity margins / balancing supply & demand. An immediate challenge (black-outs already a problem).
	Department for Business, Energy & Industrial Strategy; Delta Energy & Environment; Energy Technologies Institute; University of Ulster; Catapult	Reducing distribution grid congestion (particularly winter peak and daily peaks, driven by the expected HP market growth). An issue within the next 5-10years (post 10 years, supply/demand issue become a greater driver).

[1] E.g. Fraunhofer ISE (2015), BEIS (2017)

	EPRI Electric Power Research Institute; Oak Ridge National Laboratory	▶ Security of supply is the biggest issue, leading to relatively long history of demand response in the US. ▶ An immediate challenge.

The project ran from May 2013 to September 2017, when the final report was published by the IEA HPT Secretariat. The work schedule was divided into four different tasks and a writing up and presentation phase, as summarised below. Delta-ee was commissioned by BEIS (then DECC) to support the work on Annex 42 through the writing of a number of reports which fed into the Annex 42 tasks 1 and 4 (see Figure 1), as well as drafting the reports summarising the contributions of all participants to these two tasks. The UK's contribution to tasks 2 and 3 were prepared by BEIS in co-operation with the Energy Technologies Institute and the Energy Systems Catapult. 11 workshops were held throughout the Annex, in order to co-ordinate the participants' work.

Figure 1: Work tasks and timeline of Annex 42



All contributions of Delta-ee to Annex 42 can be downloaded following this link:
https://www.delta-ee.com/consultancy/public-studies.html

3. Summary of the UK's activities in Annex 42

BEIS and Delta-ee contributed to the research in the Annex in many different ways, leading to a set of 10 deliverables (including this report) being produced throughout the duration of the project. The main findings of these deliverables have been briefly summarised below and download links have been provided for each of the documents.

Table 2: UK Annex 42 deliverables and key questions they answer

Key question	Deliverable	Download
▶ What are all the possible technology & market mechanisms for peak shifting with heat pumps? ▶ How 'smart' do heat pumps need to be?	Analysis of "smart-ready heat pump" requirements and UK products.	Download Link
▶ What is the UK market status for HPs? ▶ What are the UK-specific factors influencing the use of DSR mechanisms for peak shifting?	UK market report – Analysis of the characteristics of the heating market, building stock and end-users and their influence on the use of heat pumps for peak shifting.	Download Link
▶ To what extent have these peak shifting mechanisms been tested in the UK already in with heat pumps?	Review of relevant UK modelling studies (2014). Review of relevant UK demonstration projects	Download Link Download

	(2017 update).	Link
Where is further research required to inform decisions on how to utilise heat pumps for peak shifting in practice?	Gap analysis – Recommendations for further work.	Download Link
Where is further research required to inform decisions on how to utilise heat pumps for peak shifting in practice?	Task 3: Modelling and Technology - Analysis of smart driven heat pumps in typical use cases based on calculation and simulation	Publication pending
What are the key steps the UK needs to take in order to achieve a smart HP system?	Roadmap to a smart HP system	Download Link
What is the status of the different participating countries' HP markets and how big is the opportunity for DSR from heat pumps?	Task 1 Summary Report (Market Reports)	Download Link
What smart HP related projects have been carried out in the participating countries and what can be learned from them?	Task 4 Summary Report (Demonstration Projects)	Download Link
What was the UK's role in Annex 42 and where can I find information about the research carried out under the project?	UK Annex 42 Summary Report (this report)	Download Link

3.1. The UK Market Report

The UK market report summarises the context of the UK heat pump market and its potential role in a future smart grid. Its key findings are that the UK is facing an increasing need to reduce peak demand and find new ways to balance supply and demand in a market that is increasingly dominated by intermittent renewable generation technologies. This is both a challenge and an opportunity for heat pumps.

In order to support the transition to an almost fully decarbonised heating sector in 2050, the UK energy infrastructure will require heavy investment in the upcoming years. The investment in the metering infrastructure, in the form of the smart meter roll-out, is already underway and although there are currently still very few tariffs promoting demand-side flexibility, this will change with the increasing penetration of smart meters in UK homes.

The report expected material growth in the UK heat pump market, which did not materialise, possibly in part due to the delays of the RHI subsidy and the significant drop in oil prices in late 2014. In order for heat pumps to be able to realise their full potential for demand-response, the report identifies a number of challenges which need to be overcome:

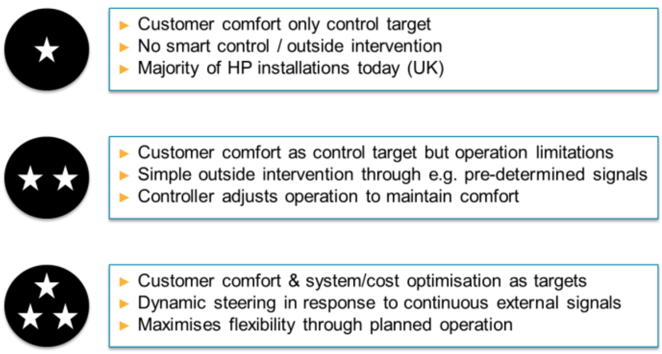
- **The UK building stock needs to be made more suitable for heat pumps** (and their flexible operation).
- **Heat pumps will have to enter the "on-gas" segment of the building stock,** in order to reach a meaningful market penetration and therefore critical mass for large-scale use in demand-response scenarios. This remains a formidable challenge due to the dominance of gas in UK heating.
- **The typical operating patterns for heating in the UK are not well-suited to heat pumps**, and could lead to demand spikes on the network. This differs from operating patterns in other countries.
- **Customer barriers remain a challenge** to more wide-spread uptake of the technology. For example, upfront cost and technology awareness and trust.
- **Ensuring quality of installation remains a challenge** – including ensuring the availability of sufficiently trained installers.
- **The UK's single-phase supply creates challenges** with connecting heat pumps to the distribution network.

The full UK market report can be downloaded here: https://www.gov.uk/government/publications/heat-pumps-in-smart-grids

3.2. Smart-Ready Requirements and Product Overview

Delta-ee's review of the availability of smart-ready heat pump products in the UK found that at the time of the review in late 2013, very few truly "smart-ready" products were available on the UK market. In order to analyse and classify the UK market offering, a framework was established that categorised the heat pump products by their level of "smartness". The three levels identified are shown below:

Figure 2: The three levels of smart-ready heat pumps



The most common 'smart' capability built into (or available with) heat pumps in the UK in 2013 was internet connectivity and remote control via an app. Very few products were already able to respond to DSR signals based on a flexible tariff. Relatively little is expected to have changed in this regard, as the key driver for the development of smart grid capabilities, i.e. the flexible tariffs which make the smart operation of a heat pump attractive from a customer point of view have not yet materialised. The report concludes that heat pumps will need to interface with smart meters to unlock value for customers or utilities from their flexibility, and that there is a growing trend towards home energy management systems (or smart home devices) used as the potential interface between the heat pump and the aggregator or ancillary services provider.

The full smart-ready requirements and product overview report can be downloaded here: https://www.gov.uk/government/publications/heat-pumps-in-smart-grids

3.3. Modelling study and demonstration project review + gap analysis

The analysis of existing UK research into the use of heat pumps in a smart grid by Delta-ee and the University of Ulster was split into three parts:

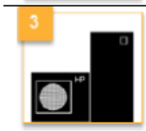
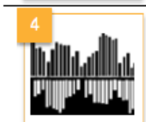
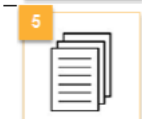
- **An overview of smart grid field trials** including or planning to include heat pumps.
- **A review of four major UK modelling studies** considering the use of heat pumps in demand-side response applications.
- **A gap analysis** across the existing body of research into the use of heat pumps in smart grids at that time – used to suggest where further research should be focused.

At the time of the first analysis of demonstration projects, there were three major smart grid projects involving heat pumps live or about to start in the UK. These were the Customer-Led Network Revolution (CLNR), the NEDO Greater Manchester Smart Communities Project and the Low Carbon London project. This analysis has since been updated and now also includes the FREEDOM project (see page 18). Key findings from the initial demonstration project review were that **a relatively limited number of mechanisms for the control / influence of heat pump operating times were used throughout the different projects** and that there was **a lack of focus on the customer** and understanding of what motivates them to provide flexibility. Some of these gaps have been or are being addressed in subsequent demonstration projects.

The review of the modelling reports included four modelling studies of the future UK energy system, which also included heat pumps (Element Energy/Redpoint (2012), Imperial College/NERA Economic Consulting (2012), Element Energy/GL Noble Denton/et.al. (2012) & Element Energy (2014)). However, it was found that the value of the modelling studies for answering the core questions that BEIS wanted to address through the participation in Annex 42 was limited. The main reasons for this were that **none of the studies had a specific aim relating to heat pumps for use in peak shifting** and that **the modelling of heat pump dynamics was relatively simplistic**, with all projects facing the challenge that there was a **lack of consistent and granular heat pump data** (e.g. from field trials) to adequately represent the dynamics of heat pump performance and the factors which influence it.

In the gap analysis it was found that there were five major gaps in the UK's research into heat pumps in smart grids at the time, two of which were critical:

Figure 3: The five most important research gaps identified under Annex 42

	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?

Of these five gaps, only gap number one and number four had been partially addressed through both modelling and demonstration projects, with the other gaps remaining largely unaddressed. This analysis fed into the UK's modelling exercise under Annex 42.

The full reports can be downloaded here:

Modelling review - https://www.delta-ee.com/downloads/901-iea-hpp-annex-42-heat-pumps-in-smart-grids-task-2-review-of-modelling-studies.html

Demonstration project analysis - https://www.delta-ee.com/downloads/902-iea-hpp-annex-42-heat-pumps-in-smart-grids-task-3-demonstration-projects.html

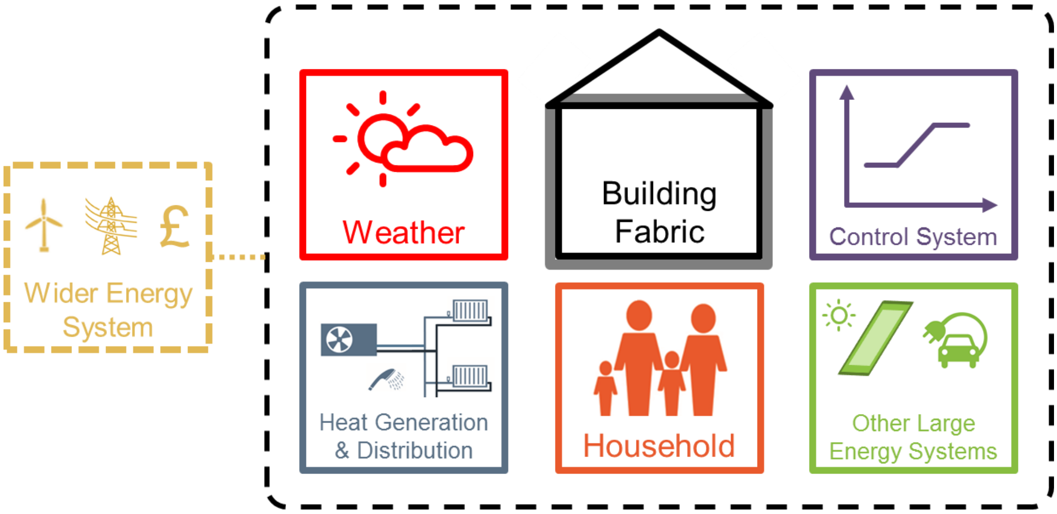
Gap analysis - https://www.gov.uk/government/publications/heat-pumps-in-smart-grids

3.4. Modelling and Technology

The UK's contribution to Task 3 of Annex 42, which was mainly related to the modelling of heat pumps in smart grids was carried out by BEIS in collaboration with the Energy Technologies Institute (ETI) Smart Systems & Heat Programme delivered by the Energy Systems Catapult.

The modelling exercise looked at six building archetypes which are representative of around 40% of the UK housing stock and analysed the impact of variations of several key parameters on the level of flexibility that can be provided by heat pumps in the UK (see graphic from the report on the initial results below). A series of DSR events was tested for each building archetype.

Figure 4: Key system parameters tested in the modelling



The initial modelling results showed that:

- **Current levels of building fabric provide sufficient flexibility in combination with a 1°C internal temperature change to maintain thermal comfort** during 1-3 hour DSR events, including during the coldest external temperatures in an average year.
- However, during DSR events occurring in a particularly cold winter (with the future electricity system target design being a 1-in-20 winter[2]) the indoor temperature is not being maintained within the 1°C band without additional measures such as high insulation, increased thermal mass, oversized heat pumps or hybrids being deployed.
- **Increasing building thermal mass above standard building practice seems to provide a greater degree of flexibility** than increasing the capacity of the heat pump and therefore warrants more detailed analysis in the full scope of modelled scenarios.
- **The results of the modelling so far suggest that additional efforts need to be made to improve the thermal properties of significant shares of the UK building stock**, in order to successfully deploy heat pumps as demand side response tools on

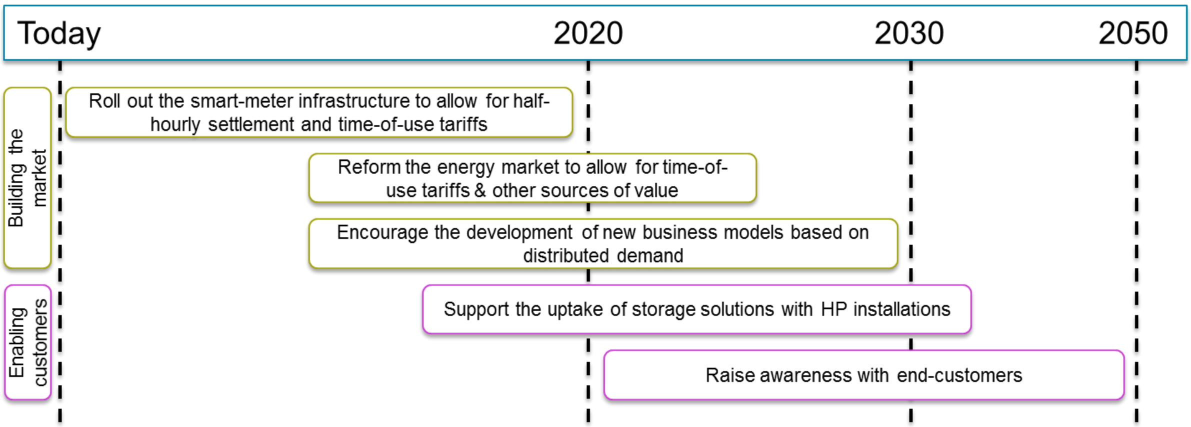
[2] An approximation to these design conditions was made in the modelling

a wider scale during a 1-in-20 winter. The **modelling study should be continued in order to determine the exact improvement needs for a smart heat pump system in the UK**.

3.5. UK Roadmap to a smart heat pump system

The final deliverable developed by Delta-ee under Annex 42 is a Roadmap towards a smart heat pump system. The report shows that **a critical element of achieving a smart heat pump system is the development of a strong regulatory framework which fosters business model innovation and the creation of value from distributed smart demand assets**. Sufficient security and incentive needs to be provided to utilities, heat pump manufacturers and consumers alike, in order for them to make the necessary investments in technology, IT infrastructure and heating systems that are required to roll-out a smart heat pump system.

Figure 5: The critical path for reaching a smart heat pump system between now and 2050



The report concludes that policy makers should:

- **Develop a stable regulatory framework** which fosters business model innovation.
- **Leave the decision on the exact level of communication required between the different parts of the smart grid to the relevant industry bodies**, such as norms and standards committees and/or industry initiatives which are already developing communication standards to solve these issues.
- **Provide ongoing support for research and development** around smart heat pump control technologies, heat storage solutions for the UK market and the requirements and behaviour of the end-customer.
- **Consider providing initial financial support** for the uptake of storage solutions and smart heat pump technologies or service offerings if required.

4. Highlights of the work in other participating countries

4.1. Flexibility provided by thermal storage in combination with model predictive controls

The Swiss modelling study focused strongly on the effects that the inclusion of buffer tanks and model predictive control have on the flexibility provided by a heat pump system. The study assessed three main aspects of flexibility:

- The hours per day that the heat pump is not running or running at partial load while comfort levels are being maintained (to assess the capability to "condense" the heat pump operation times into shorter time slots).
- The length of "off-blocks", which is the average duration of the time blocks during which the operation of a heat pump can be interrupted while comfort levels in the building are maintained (in order to determine the capability to shift loads to other times of the day).
- The ability of the system to follow a price signal by using the above factors in order to optimise its load profile and the amount of savings that can be generated from this.

The study found that for a retrofit building with an energy demand of 100 kWh/(m^2·a), the total off-time (i.e. the fraction of the day during which the heat pump is not running) can be prolonged by up to 43%. For buildings with a lower energy demand, the potential for flexibility optimisation is reduced to 22-23%, due to their higher flexibility to begin with. For all buildings, the combination of predictive control and increased storage was able to achieve off-block duration of more than 6 hours. In the case of the retrofit building this was equivalent to tripling the original off-block duration. It is to note however that achieving these improvements in flexibility required the use of significant amounts of technical thermal storage, with storage sizes of between 1,000-8,000 litres having been tested in the study.

However, one negative effect of the increased storage capacity is a reduction in the efficiency of the heat pump, which limits the cost savings that can be achieved through a more flexible operation. This meant that a maximum of around 20% cost-savings on the spot-market prices was achievable, suggesting high payback-times for such a system (as long as other benefits, such as reduced network impacts are monetised).

Applicability to the UK: Low

At first glance the findings of the Swiss modelling study seem to partly mirror the findings of the UK modelling, with both studies finding that an increased heat storage capacity within a building provides higher flexibility. However, we think that the results of the Swiss study have only limited, if any applicability to the UK. This is mainly due to the fact that the Swiss study used technical storage (i.e. water tanks) of often quite considerable sizes (up to 8m^3/8,000l) to increase the storage capacity of the buildings in their study.

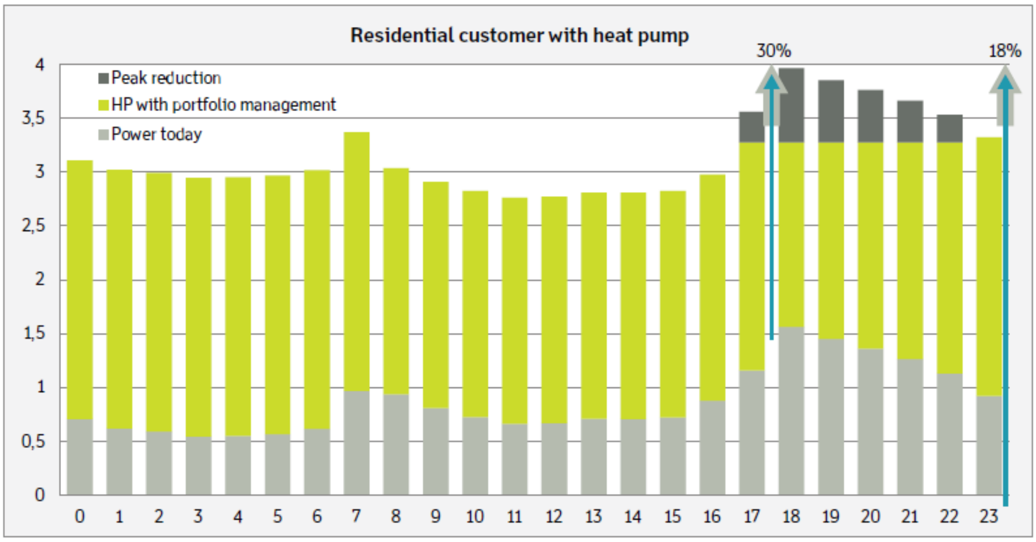
With space at a premium in UK homes and hot water tanks having been removed to be replaced with more compact combi-boiler systems over the last few decades, this is not a feasible solution in the UK unless new, more compact technologies become available. The findings are also not transferable to the UK, as the use of technical storage has less or even no impact on room temperatures compare to using the thermal mass of the building. Also, charging times can be significantly reduced by increasing the output temperature of the heat pump. The difficulty in deploying the same levels of technical storage in the UK as in Switzerland makes the findings of the Swiss study inapplicable to the UK market.

4.2. Peak load reduction

The Danish contribution to Annex 42 involved results of a field trial which fed into a simulation study. The “eFlex” trial involved 119 households with heat pumps that were equipped with a smart home system with the ability to control the heat pump based on a price signal. The price signal was a combination of the day-ahead price of the Nordpool Spot Market, a 3-tier grid charge component and the regular taxes and levies. The control strategy was based on an interruption of the heat pump operation during high price periods, with the heat pumps running according to their own control logic.

The results of the field trial fed into a simulation of the impact of a high penetration of heat pumps on a single feeder and the ability of the systems to provide peak load reduction. The simulation study found that the optimisation of the heat pump operation was able to completely negate the peak contribution of the normal household consumption on the feeder. As figure 18 below shows, on average the interruption of the heat pump operation can contribute to a total reduction of the peak load of a single customer by almost 18%, with the heat pump itself reducing its consumption by up to 30% within the hour of the highest peak. By aggregating the customers on the feeder into 6 groups, full peak load reduction is achievable on the feeder.

Figure 6: The effect of ideal optimisation of many customers by portfolio management projected to one single customer. The figure shows that it is possible to reduce the peak from the household incl. heat pump by 18%, which equals a reduction of approx. 30 % of the heat pump’s own contribution to the peak. (Source: Danish Task 3 Report)



Applicability to the UK: Partially

The results of the Danish Annex 42 contribution are partly transferable to the UK. The study clearly shows that the control of a heat pump pool can yield significant peak load reductions, even with a relatively simple, unidirectional tariff signal. The ability of the heat pumps to provide peak load reduction is transferrable to the UK, but the level of load reduction achieved in the Danish study is not transferrable. This is because the extent of the peak load reduction is highly dependent on the building stock characteristics (as shown e.g. in the UK modelling study, see page 10). Further comparison of the Danish and UK building stock characteristics would be required in order to better assess the applicability of the Danish results to the UK.

In addition to this, the level of reduction occurring will be dependent on the price signal received by the heat pump pool. The Danish report makes no mention of cases where the price signals received from the spot market and the grid operator could be adverse (a scenario which according to a Dutch field trial occurs in about 16% of all DSR cases, see page 18). This could be a challenge in the UK.

4.3. Length of off-blocks

Aside from the UK's modelling, the length of off-blocks was assessed in the Danish study, the Swiss and the Austrian modelling studies. All studies show that the average length of the achievable off-blocks increases with the improvement of the thermal characteristics of the houses (i.e. thermal mass, technical storage and insulation). The Danish study found that the length of off-blocks in the monitored houses was between 5-6 hours at 5°C outside temperature and 2-3 hours at -12°C outside temperature. Results from the Swiss study suggest that by using a combination of technical storage and model predictive control strategy, all house types can achieve off-blocks of more than 6 hours, with the most highly insulated buildings achieving off-blocks of more than 12 hours. In the Austrian study, the length of off-blocks at temperatures above -7°C were between 5-10 hours, but decreased rapidly at lower temperatures. The study found that due to the difficult to difficulty in predicting domestic hot water demand, it is preferable that the hot water tank is fully charged before a longer DSR event occurs.

Applicability to the UK: Low

As discussed above, the applicability of the results from both the Danish and the Swiss simulation studies which are dependent on the thermal characteristics of the building are not considered applicable to the UK unless further comparisons of these characteristics with the prevailing thermal characteristics of the UK building stock have been carried out. Also, the Swiss modelling study is highly dependent on the use of technical storage, which for reasons of space constraints seems not applicable to current UK homes (see point 4.1 above).

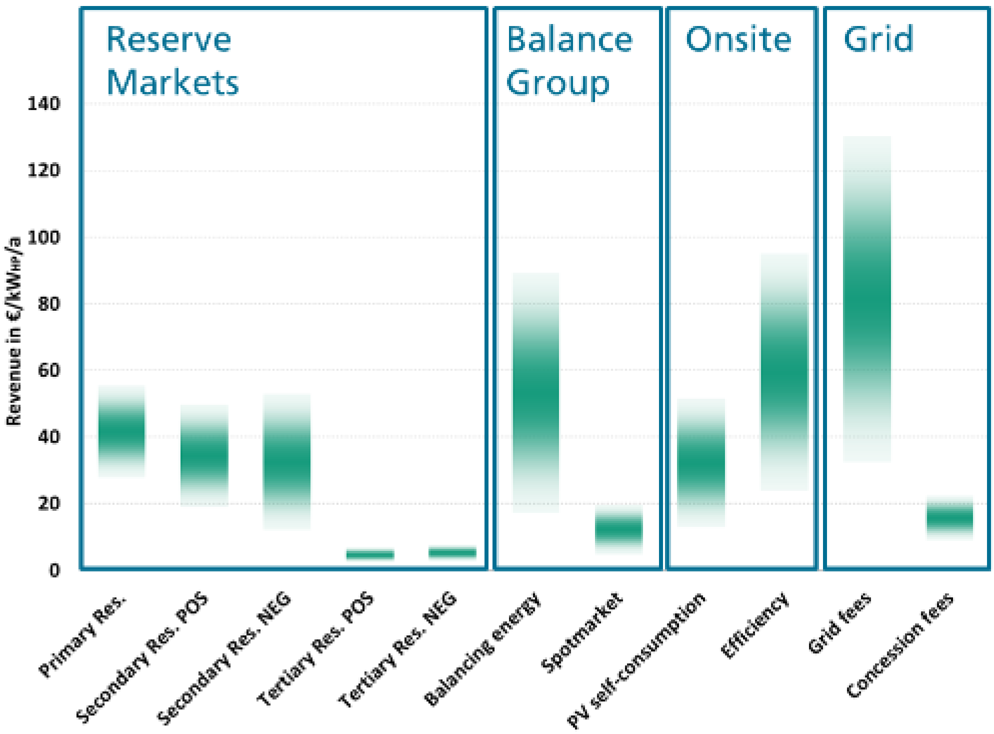
4.4. Pooling of heat pumps and economics of direct load control

Both the Austrian and the German modelling efforts focused on the pooling of heat pumps by an aggregator in order to supply ancillary services to the electricity system, with both also considering the economics of such a system.

The German study used the already existing SG-Ready interface in a simulation study of a pool of 284 heat pumps for direct load control (DLC). As the focus of the German team was on the integration of increasing levels of PV energy into the German market, the modelling concentrated on the provision of negative balancing energy (i.e. increasing the operation of the heat pump, e.g. through increasing the temperature set points). The study finds that DLC is feasible when using this interface, but that any DLC events of more than 1-2 hours do require tailored control strategies, as the initial peak response from the pool starts to tail off before reaching a steady-state phase, due to an increasing number of systems reaching their maximum heat storage capacity. The effect of the adjusted operational profile on the efficiency of the unit was also considered. It was found that the load shifting patterns used in the study decreased the efficiency of a heat pump by around -15.6% on average and up to 70% when the back-up heater was used in order to provide extra capacity.

With regards to financial benefits, the German study found that in different markets up to 140€/kW_{el} of heat pump capacity can be achieved (with a typical 12kW heat pump having approximately 3-4kW_{el}). The majority of these savings are currently already available in the German market through the introduction of heat pump tariffs which allow the grid operators to prevent the unit from running for up to 3x2hrs per day. As compensation the customer on this heat pump tariff benefits from significantly reduced grid fees. What has not yet been considered in this study is to what extent this value can be combined with additional values which are available in other flexibility markets. It should also be noted that, if the electricity price were to be made fully flexible (i.e. relative instead of nominal fees and taxes were applied), the savings from following the spot market prices would be increased. The reason for this is that the spot market price currently only makes up a small fraction of the German electricity prices, with the majority being taxes and levies.

Figure 7: Estimated annual revenue opportunities per kW_{el} of switchable HP demand in 2015 (Fischer et.al. – Presentation at the 12th IEA Heat Pump Conference, Rotterdam, 2017)



In the Austrian modelling report, both the economics and the impact of heat pump pooling on the low voltage grid are being assessed. It was found that by optimising the heat pump operation profile based on a day-ahead price signal from the EPEX Spot market, the electricity costs for running the system were being reduced by 23-35% (this covers the electricity component only, thus the overall reduction in cost is lower, as the grid and tax components currently are steady). This reduction equates to 11€ of savings for a domestic hot water heat pump and around 53€ for a space heating heat pump. On the tertiary reserve market the systems were able to achieve higher revenues of 25€ and 125€ respectively. The Austrian team also studied the impact of pooled heat pump operation on the low voltage grids. It was found that under current heat pump penetration rates, no problems occur from the simultaneous operation of all heat pumps within one sub-grid. However, in all future heat pump penetration scenarios grid congestion leading to short term violations of voltage limits and overloading of grid assets. But these will only occur within the next 10-20 years.

Applicability to the UK: Partial

The results from the Austrian and German studies only have mixed applicability to the UK situation, which is due to:

- The differing key drivers for flexibility in the three markets as mainly negative balancing power was supplied in Germany and Austria, whereas the UK is mainly interested in positive balancing power at the moment. This makes the behaviour of the heat pumps under the DSR scenarios difficult to compare.
- The market prices in both the UK's wholesale electricity markets and its balancing power and reserve markets do not coincide with Germany's or Austria's market prices, which makes the economic results difficult if not impossible to compare. A very interesting question with regards to this topic, is the ability of stacking revenue from different sources also has not been addressed in the study.
- It can be retained that the simultaneous operation of heat pumps on a single feeder can lead to overloading and grid congestion on that particular part of the network. This is in line with UK studies on the topic and suggests that either grid upgrades or active management of the grid loads will be required to cope with this increased demand.

4.5. Load shifting potential

The load shifting potential from heat pumps was mainly studied in the German, French and UK modelling studies. The study found that in the German context heat pumps sized to today's standards can provide a significant electric load shifting potential, with an upper limit of up to 10.7 kWh per heat pump and load shifting cycle. Load shifting potential is negligible in summer compared to the winter and the shoulder seasons. Similar findings regarding the seasonality of the load shifting potential were made by the Austrian modelling study.

The French modelling study mainly focused on the provision of direct-control positive balancing power at winter peak demand times (i.e. shifting the consumption of the heat pump) and the provision of negative balancing power on summer peak supply times (i.e. shifting the consumption of the heat pump to times of oversupply, for example by PV). It was found that load shifting was achievable in both cases and that even without a buffer tank, air-to-water heat pumps offer a load shift potential which meets the daily peak demand curtailment needs in France.

Applicability to the UK: Low

The load shifting potential in the UK, France and Germany is not comparable, as all three countries have very different climatic, construction and system design challenges (thus it is common in Germany to operate heat pumps in combination with large storage tanks for space heating and hot water). However, the results of the two studies suggest that the load shifting potential from heat pumps is higher in winter and shoulder periods than in the summer, as the load shifting potential in summer is mostly limited to shifting the electricity demand for hot water production into the hours of high solar PV production, unless the heat pump is also used for cooling.

4.6. Highlights of research and commercial developments outside of Annex 42

In each of the 11 workshops held throughout the project, there was a structured exchange both on the interim results of the research projects of the individual participants, as well as on developments outside of Annex 42 but with relevance to the topic of heat pumps in smart grids.

Some notable highlights of both R&D and commercial projects outside of Annex 42 include the Dutch field trial and market framework development project USEF (Universal Smart Energy Framework), the development of a distributed demand-side response platform including residential heat pumps by the Swiss telecoms and network joint-venture tiko, or the development and testing of variable tariff models by the Austrian company aWATTar. Examples of activities in the UK include the Greater Manchester Smart Communities field trial, the FREEDOM (Flexible Residential Energy Efficiency Demand Optimisation and Management) field trial as well as the emerging use of storage heaters and other residential loads for demand-side response in a virtual power plant by OVO subsidiary VCharge.

USEF

The "Universal Smart Energy Framework" is a market platform allowing the co-ordination of market interests in a smart grid.

The framework was successfully trialled in the "Energiekoplopers" trial, where it was found that it allowed the aggregator to effectively reduce the peaks in the power grid. It also showed that at only 16% of DSR events there are conflicts between DSO and BRP.

More info: https://www.usef.energy/

Freedom Project

The FREEDOM project is a UK field trial currently under way in Bridgend, Wales, which will investigate the performance and usability of hybrid heat pumps for demand response.

The trial will see hybrids installed in around 70 homes and fitted with an aggregated demand response control system.

More info: IEA HP Congress Paper / Western Power Distribution Project Website

VCHARGE

VCharge is a UK start-up that has recently been acquired by the utility OVO.

VCharge operates a Virtual Power Plant combining residential and commercial switchable loads, such as storage heaters, air-conditioning systems, etc. and sells this flexibility in the UK reserve markets.

More info: http://vcharge-energy.com/

tiko

tiko is a joint-venture between Swiss telecoms provider Swisscom and the Swiss utility Repower.

The company has developed a successfully operating virtual power plant solution which uses heat pumps and other residential loads to offer energy in the reserve markets.

More info: http://www.tiko.ch

GM SMART ENERGY

The Greater Manchester Smart Communities field trial was a trial of more than 500 heat pumps and hybrids that were connected to a central control platform in order to provide ancillary services to the power grid.

The project successfully demonstrated the ability of the system to provide the requested flexibility to the markets.

More info: http://www.gmsmartenergy.co.uk/

aWATTar

awattar is an Austrian energy supplier which is offering hourly flexible electricity tariffs to its customers. The energy supplied is 100% renewable.

The company is working with established heat pump players in the Austrian market to deliver this innovative offering to the customer.

More info: https://www.awattar.com/

5. Learnings for the UK

The key findings from the UK's contribution to Annex 42 and the analysis of other participants' findings are as follows:

1. Both the UK modelling study and results from other modelling studies in the participating countries have shown that DSR with **heat pumps is possible in many of today's buildings**, whether positive or negative balancing energy is required or a flexible hourly tariff is to be followed.
2. However, **the length of time of such DSR events during which no violation of the comfort standards occurs**, in particular in case of events where positive balancing energy is required and the heat pump is switched off, differs strongly between countries, as it is **very dependent on the thermal characteristics of the building**. Findings from other countries on this topic are deemed to only have a low applicability to the UK.
   The UK modelling that has been carried out on this subject suggests that **there is a need to further improve the thermal characteristics of the UK's building stock**, as it is difficult to maintain comfort in a wide enough range of DSR events.
3. The modelling studies and field trials carried out under the umbrella and outside of Annex 42 show that **the aggregation of heat pumps can be done successfully in order to provide DSR**. Pools of heat pumps can be managed in a way that ensures that a minimum DSR capacity is provided and that no grid congestion occurs. However, an important question, the number of times that a conflicting need for DSR (one for positive, one for negative balancing energy) from the network and the balancing responsible party occurs has only been addressed in the Dutch USEF field trials, where it was found that these events occur around 16% of times DSR is requested. This is a topic that merits further research.
4. **With regards to the value that the market currently places on DSR from heat pumps it is difficult to provide reliable answers for the UK from the research carried out under Annex 42**. Whereas some countries have looked at the value of

DSR from a monetary perspective, the results of this research are not thought to be applicable to the UK context, as the findings refer to electricity and balancing prices in other spot markets and the underlying variability of the energy prices differs from the one in the UK.

A **common conclusion that can be drawn from the studies is that values derived on the balancing markets and grid management services are potentially higher than those derived from a flexible operation of the heat pump based on a wholesale market price signal alone**. A key reason for this is that the variable share of the electricity price is not a dominating share of the total price of electricity. Therefore, the achievable overall savings, although wholesale electricity cost reduction of up to 35% was achieved in some of the studies, are not large enough, as the non-flexible price components dominate. In the UK for example, wholesale costs only account for around 36% of the typical electricity bill (Source: Ofgem 2017), reducing the achievable savings from following a flexible tariff to around 12.6% of the overall electricity costs.

5. In order **to enable and incentivise the development of a smart heat pump system that provides vital ancillary services to the energy system, policy makers in the UK should focus on three key variables**. Firstly, the required metering infrastructure (smart meters) for billing hourly or half-hourly consumption needs to be deployed. Secondly, the necessary market design for settling energy demands on actual instead of standardised load profiles need to be implemented in a clear and long-term market framework in order to foster business model innovation and thirdly, tariffs for smart DSR enabled devices such as heat pumps should have a higher share of flexible price components, e.g. by handing through the Distribution Use of System (DUoS) rates for grid usage or even applying relative rather than nominal taxes and levies to the price.

In the meantime, **there should be ongoing support for both academic and business R&D into smart heat pump control technologies, heat storage solutions for the UK market and the requirements and behaviours of end-customers**. The development of distributed DSR business models across Europe and other markets (e.g. the USA) should be followed closely and the development of technologies and business models for the UK market should be supported with R&D funding where possible.