Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 42

Heat Pumps in Smart Grids

Final Report

Operating Agent: The Netherlands

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Preface
This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) which is an Implementing agreement within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of over 40 Implementing Agreements.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)
The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the Heat Pumping Technologies Programme. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP collaborative tasks or "Annexes" in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex. The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

The Heat Pump Centre
A central role within the HPT TCP is played by the Heat Pump Centre (HPC). Consistent with the overall objective of the HPT TCP the HPC seeks to advance and disseminate knowledge about heat pumps, and promote their use wherever appropriate. Activities of the HPC include the production of a quarterly newsletter and the webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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Annex 42

Heat Pumps in Smart Grids

Final report

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Disclaimer:
The views expressed in this report do not necessarily reflect those of the individual project participants.

1 Executive summary

Heat pumps in smart grids can contribute to solutions for several energy system-related obstacles. Within the Annex 42 working group, we distinguish five main smart heat pump contributions:

1. Keeping grid load under control while renewable energy production grows to restrict or even avoid grid capacity investments.
2. Keeping grid load under control during extreme conditions (i.e. 'coldest week'), again avoiding grid capacity investments.
3. Increase self-consumption of renewable energy sources (achieving better grid balance and higher economic end user value).
4. Selling flexibility to the grid, for the benefit of balance responsible parties, grid operators, traders, etc.
5. Allowing for a higher share of heat pumps in the energy system without risking local overload problems.

Enhancing the *realisation* of these solutions has been the basic driver for the Annex 42 participants.

It turns out that there is a real – and often pressing – benefit in implementing smart grids in all participating countries. The table below summarizes the main recommendations and actions that should be considered when trying to stimulate further development of smart grids.

<table>
<tr><th>Challenge domain</th><th>Actions needed</th><th>Main stakeholders involved</th></tr>
<tr><td rowspan="2">Sources of value</td><td>Carry out field trials that implement a 'full market model', including complete financial handling of flexibility contracts. Governments may facilitate this by authorizing dispensation for obstructing legislation where appropriate.</td><td>DSOs, Aggregators, Energy suppliers, BRPs, Policy makers</td></tr>
<tr><td>Invest in development of new customer propositions. Possible directions are: monitoring & energy saving assistance, heating as a service, identifying alternate ('non-energy') benefits, increasing self-consumption of renewable energy.</td><td>Aggregators, Researchers</td></tr>
<tr><td rowspan="3">Technical barriers</td><td>Set up field trials to explicitly focus on building thermal mass. Preferably, flexibility limits should be tested without using any heat storage vessels at all.</td><td>Aggregators, DSOs, Researchers</td></tr>
<tr><td>Start quantifying building thermal mass potential for groups of buildings in relation to typical building characteristics (e.g. size, materials used, building codes, occupation, etc.)</td><td>Researchers, Manufacturers</td></tr>
<tr><td>Gain insight in end user behaviour patterns through field trials. How much demand response potential is actually available in a given end user group?</td><td>DSOs, Aggregators</td></tr>
<tr><td rowspan="4">Regulatory framework</td><td>Develop alternate taxation models, for instance taxing as a percentage of the commodity price, instead of adding a fixed tax tariff.</td><td>Policy makers, DSOs</td></tr>
<tr><td>Increase absolute energy price levels, either directly or indirectly through a CO_2 tax.</td><td>Policy makers</td></tr>
<tr><td>Enforce development of (open) communication standards.</td><td>Policy makers, Manufacturers, DSOs</td></tr>
<tr><td>Appreciate negative effects of energy market unbundling and stimulate market cooperation and information exchange to counter these effects.</td><td>Policy makers, TSOs, DSOs, BRPs, energy suppliers</td></tr>
</table>

Challenge domain	*Actions needed*	*Main stakeholders involved*
End user behaviour	Develop simple and effective business propositions, focussing on customer engagement rather than return value maximisation.	Aggregators
	Privacy and data integrity will grow to be more important. Explicitly address these issues in new business models.	Aggregators

Structure of the Annex work

The Annex 42 work has been split into several topics:
MARKET OVERVIEW – To gain a first understanding of the present status and future changes for heat pumps in smart grids for the participating countries.

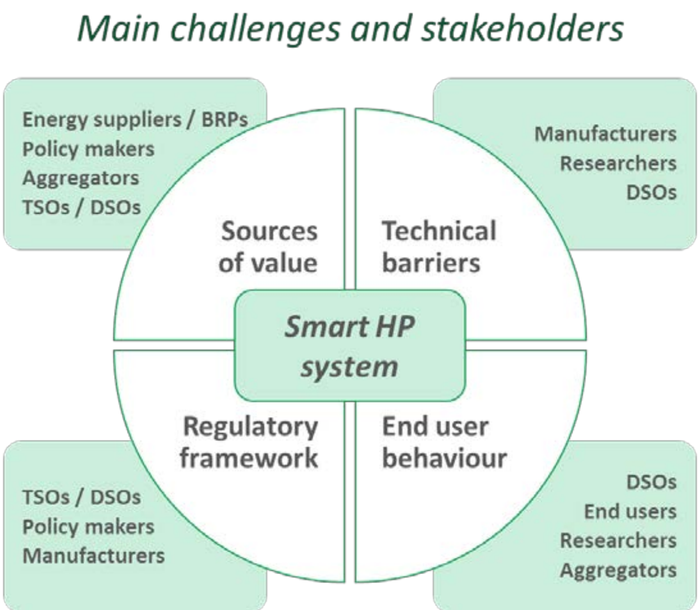
CASE SCENARIOS AND MODELLING – Through the definition of use cases for each participating country and subsequent modelling efforts, we have managed to give an overview of *sweet spots* for smart heat pumps, as well as extending our knowledge on situation-specific behaviour of heat pumps in smart grids. The commonality across all countries is the desire to explore the potential flexibility that can be provided by heat pump systems. Building on these cases, extensive modelling work has been performed by a number of participants. From these modelling studies, cross-country comparisons can be made on several distinct topics.

DEMONSTRATION PROJECTS – The Annex 42 working group has analysed the existing demonstration projects on heat pumps in smart grids in all participating countries. Together, these demonstration projects give a clear view on the feasibility of smart heat pump projects in terms of technical, regulatory and end-user issues, as well as the best ways to create value for all participants.

ROADMAP – Building on three years of Annex 42 work, a roadmap has been compiled containing (policy) recommendations for several different market stakeholders. This roadmap recommendations will now be discussed first, before giving an overview of the other parts.

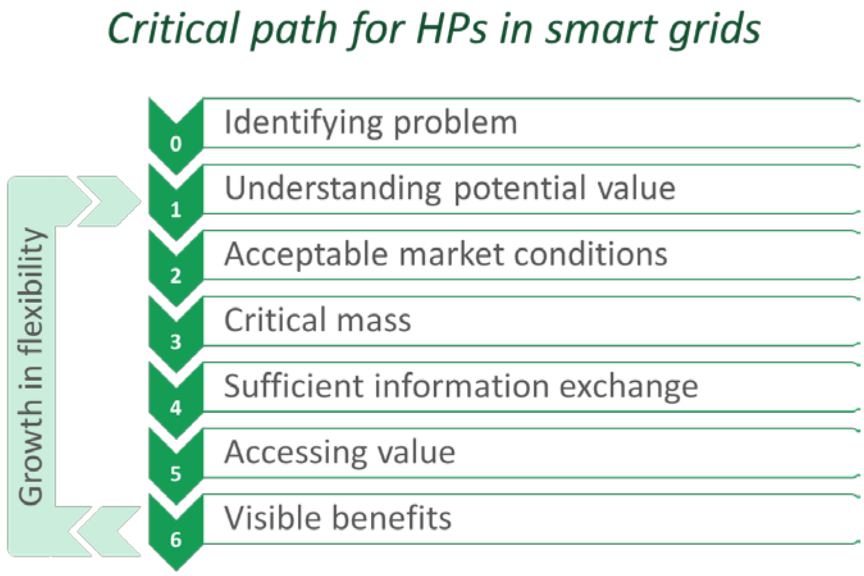
1.1 Roadmap

There are many challenges for heat pumps in smart grids, which can be split across four ‘challenge domains’. For each domain, a specific set of market stakeholders is in a key position to contribute to solutions and further help the market progress of smart heat pumps.[1]



[1] BRP = Balance responsible party; TSO = Transmission system operator; DSO = Distribution system operator.

Looking at the 'critical path' for smart grid applications, we have found that most countries do acknowledge various (future) problems within their respective energy markets. However, by failing to quantify and understanding the potential value of flexibility to solve at least part of these problems, there is little movement towards explicitly designing or enabling flexibility-friendly market conditions. That is: most countries are 'stuck' on the first rung of the critical path. However, some initiatives have found ways to progress along the critical path. Several of those projects are discussed in Part V.



The actions and recommendations outlined in the table below are a concise summary of the most pressing concerns obstructing the critical path. More details on the actions and underlying analysis can be found in Part II of this document.

1.2 Market overview

For each participating country, an extensive market overview has been carried out. Metrics were drawn up to give an indication of how well suited each country is to the development of heat pumps in smart grids. These metrics are analysed in detail in chapter 9. The table below gives an overall suitability score for each country. Notably, only France and Switzerland are at this moment reasonably well prepared for (large scale) smart HP implementation.

In both countries, pressing capacity and power management challenges are expected in the near future. Heat pumps already play a major role in the Swiss domestic heating sector, making for a natural factor to consider in solving these challenges. France has much experience with smart heating appliance management and now faces the challenge to apply this experience to heat pumps.

Country	*Score*	*Market snap-shot*
AT	±	**There is a potential smart HP need expected within the coming decade.** However, uptake of HPs by households has been modest, and end-users are not used to flexible tariffs. Energy system challenges justifying smart grids are not quantified, making it **difficult to devise solid business cases**. Flexible energy tariffs are not (yet) available. The potentially flexible component in electricity prices is presently around 1/3: too little to have a serious impact on end-user behaviour.

Country	*Score*	*Market snap-shot*
CH	+	**The need for flexibility is in a 2020-2030 timeframe** in Switzerland, related to managing load on the high voltage grid. **HPs are a large potential flexible resource** – The Swiss HP market is the most mature of all participant countries, with HPs the technology of choice in single family homes and making up around 40% of annual heating installs. End-users with HPs are used to the HP being shut-down at peak times. The greatest challenge is capturing flexibility from the older buildings (making up about a third of the building stock).
DE	±	Supply/demand balancing and grid congestion are recognised as a medium-term (5-10 year) challenge for which demand side flexibility will be needed. **The typical heating solution in Germany looks stronger than other markets in terms of potential flexibility** – large storage tanks and strong share of HPs (some of which are already remotely operated at peak times). However, **energy price structures do not currently encourage market growth or give benefits for end-users** from providing flexibility – this is the biggest challenge to overcome.
DK	±	**Denmark faces challenges within the next 5 to 10 years, related to managing and balancing production and load on the high voltage grid.** District heating covers 60 % of all households, but in non-district heating areas (30-40 % of the country), electrification (HPs) is the policy direction. **There are market barriers to overcome to increase the HP market share in non-district heating areas**, the main barrier is high electricity prices and low fossil fuel and biomass prices. Furthermore, the **very high share of taxes in consumer electricity prices** in Denmark do not encourage market growth.
FR	+	In France, **capacity margins and grid congestion are already a challenge** to manage. The electric heating market is Europe's largest, and HPs are a significant part of this. As a result, **there is a large potentially flexible resource, and there is a lot of experience in controlling or influencing operating times of electric heating**. The main challenge in France is translating what has worked for electric heating to HPs, and capturing flexibility in an aging building stock.
KR	±	**South Korea faces an immediate challenge to fill a capacity margin gap** which has already resulted in black-outs. Capturing demand-side flexibility is therefore high on the political agenda. For HPs to contribute to this flexibility, **market challenges must be overcome (e.g. end-users' preference for gas, and unattractive electricity tariffs), and the thermal storage potential in floor heating and the relatively young building stock should be tapped into**.
NL	−	In the Netherlands, **the need for flexibility is recognised, particularly for managing grid congestion in the medium-term**. However, similarly to the UK, the HP market is <1% of the heating market, and there are challenges of lack of space for storage. **The flexibility potential from HPs is therefore quite low – hybrids could be key to unlocking flexibility here.**
UK	−	**The UK will need demand side flexibility in the medium term (5-10 years), particularly to manage growing distribution grid congestion.** The HP market is expected to grow quickly in the next few years, but the **flexibility potential from HPs is constrained e.g. by the old, poorly insulated buildings, lack of space for storage, an end-user preference for gas, and 'spiky' heat demand patterns**. The availability of flexible tariffs, and the growth of hybrids, could be key to unlocking more flexibility potential from HPs.

Country	*Score*	*Market snap-shot*
US	±	**Demand response has historically had far stronger drivers in the US than in Europe**, so the market is more advanced, leading to greater experience with “3rd party control” (even if the use of HPs within demand response has seen only small-scale activity so far). The total HP market is huge - **but the dominance of air/air HPs (mostly in southern regions), and lack of storage, does create a constraint on potential flexibility. An emerging ground-source HP market and a growing DHW HP market offer greater kW demand levelling opportunities**.

1.3 Case scenarios and modelling

The topic of smart grids is too broad and multifaceted to allow drawing overall and clear-cut conclusions. The picture is even more complex due to the fact that every country considers somewhat distinct aspects of the topic, addresses diverse problems and, accordingly, searches for different solutions, while defining various factors to express the results. Additionally, various models and methods are used for these purposes.
Nevertheless, some interesting findings and results are discernible from the country reports. **Overall, it is clear, that heat pump technology will play an important role in the future energy system, commonly referred to as “smart grids”.**

The overarching topic, flexibility, can be divided into two sub themes: load shifting potential and length of off-blocks (times without the heat pump operation). These topics are closely connected, despite their individual specifics. Generally speaking, the flexibility describes how long a heat pump can be switched off without diminishing the comfort of the end users, or alternatively how much energy a heat pump can “absorb” from the grid, if forced to run.

The UK study underlines a **significant influence of building fabric on the amount of flexibility** that could be achieved across different building types. It was found that high levels of insulation were required to achieve more than a 1 hour DSR event in a typical UK house in a cold winter period. **Oversizing of a heat pump was the next most important factor.** In some cases, only a combination of the above increased the flexibility to 3 hour DSR events without compromising the thermal comfort of the occupants. From the other side, the current building fabric provides sufficient flexibility in combination with a 1°C internal temperature change to maintain thermal comfort during a 2 hour DSR, including during the coldest external temperatures in an average year. Thus, it may be concluded that **heat pump installations in existing buildings could provide a useful level of flexibility without additional intervention**.

The analysis from different countries indicated that a **substantial improvement of the flexibility for heat pumps in smart grids is possible through integration of thermal storages**: the operation times can be more concentrated and long off-blocks can be achieved (the average length of an off-block can be almost tripled already with the integration of a small additional storage system and a predictive control system). **However, a drawback of the additional storage** (in particular small volumes) **is a reduced heat pump efficiency**, which limits the financial benefit of the flexibility.

The Danish, Swiss and UK studies addressed the length of off-blocks. **How long a heat pump can be switched off depends predominantly on the thermal capacity of buildings**. The Danish project shows that the off time for most of the house types are above 5-6 hours at 5°C and 2-3 hours at -12°C outside temperature. The UK study shows that a standard construction with moderate levels of insulation is able to maintain thermal comfort with a 2-hour DSR event given a sufficient (4 hours) notice period and with a standard ASHP and no additional thermal storage. This comfort is maintained during an average cold winter period.
In order to maintain comfort during a 4-hour DSR event, an oversized (+50%) heat pump is required alongside an increased level of thermal storage, for example through thermal mass of the building fabric (+20%). A comparable result shows also the Austrian study, taking into account, however, a pooling aspect.

The German study underlines the conclusion - **a smart operation leads to higher overall electricity consumption,** mostly due to decreased HP efficiency and to additional storage heat losses caused by rising the operating temperatures.

The above paragraphs allow for the general conclusion, that **heat pump systems are able to provide a useful level of flexibility without significant interventions to the heating system or the building fabric**. With these additional interventions a greater level of flexibility can be achieved.[2]

1.4 Demonstration projects

The analysis of the key findings and challenges of the projects summarised by the Annex 42 participants has shown that there is one key challenge many of the projects have in common – the customer. Other recurring topics are of a more technical nature and relate mainly to a lack of standardisation and protocols for DR as well as the challenge of integrating automated- and direct control platforms with the controllers of the HPs.

Customer related challenges

Understanding the customers / participants in the trials, anticipating their behaviour and planning for its integration into the trial seems to be a key challenge for many trials.

Engagement is one key area where differences between the trials can be observed. On the one hand customers in some trials were found to have “small understanding and interest in heating technologies”, and were often found to show low levels of engagement. On the other hand, some trials report that customers “were interested in the project and gave a positive feedback”, or there was “very positive customer engagement and response as they were strongly involved in the trial”. Understanding better what differentiates these two diverging attitudes towards heating and the smart HP projects could provide important insights into if and how customer engagement with those technologies could be improved, e.g. by tailoring the message and incentives better to the target audience.

Another key area where a more in-depth comparative analysis of the different projects could provide important learnings on how to successfully implement smart grid solutions is the customer’s response to and experience to DR events and the smart technology. Here some stark differences were observed.[3]

Several trials report that:

- customers did not perceive any disruption to their comfort
- or measured success through customers not overriding the remote heating control function.

Other trials on the other hand found that their control systems were

- blamed for small comfort level violations
- did not sufficiently make clear the value from the controlled operation of the HP
- or were generally perceived as “obscure and complex”.

Understanding how to improve this perception of DR could prove to be the key to the further deployment of the technology in the residential sector.

[2] E.g. through employing specific characteristic of a building or/and heating system, as well as additional elements, like a buffer storage.

[3] References to specific projects are given in Part V.

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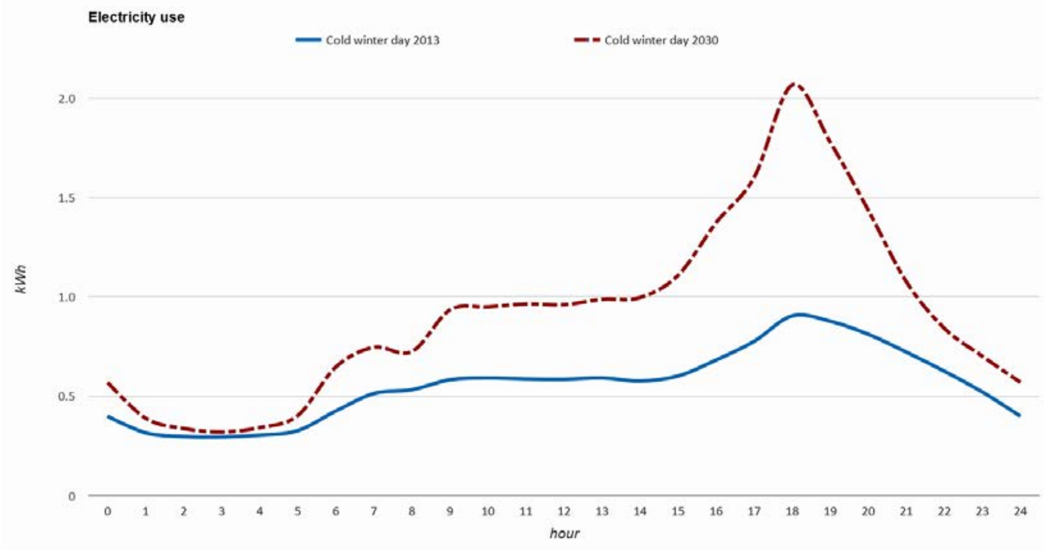
2 Foreword

The recognisable effects from climate change set mandatory requirements on energy conservation and use of renewable energy sources. Heat pump markets and policy makers in many countries have a focus on heat pumps for space heating and domestic hot water in the built environment. Therefore, there will be an increased need to adjust user-consumption to the production from the varying energy sources. Because energy consumption will become more tuned to the moment of availability, instead of the random like chosen moment of demand by the consumer/user. The graphs below give an impression of the electricity load change from a 'traditional situation' (no heat pump, solar PV, electric car) to the expected situation in the near future, when heat pumps and electric cars abound.

Figure 1 – Comparing a present-day winter situation for an average Dutch house (blue, continuous line) with a cold winter day in 2030 (red, dashed line). Without smart grids and flexibility, the grid load is expected to increase dramatically.



The figure emphasizes the need for smart girds, by means of determination of potential flexibility and load management and storage options. At the same time is offers a huge potential for handling electricity from renewable, intermittent, production by means of heat pumps.
Our energy system will have to change so significantly, that managing supply and demand to an unknown extend before will no longer be an optional requirement, but a strict need. Unlocking the potential of heat pumps related to smart grids with regard to managing peak loads and/or congestion management in the electricity system is therefore paramount.
Another necessity is to investigate how heat pumps can be implemented in connection with smaller thermal energy grids to smaller housing sectors or settlements. Before and during the execution of Annex 42 several projects have been started/carried out concerning the implementation of heat pumps in domestic housing in the countries of various participants. Amongst others the implementation of heat pumps in combination with district heating or district cooling and several smart city projects are being prepared.
Flexibility (and storage) are the essential elements for successful implementation of heat pumps in smart grids. Consequently, these subjects were main topics during several meetings within the Annex. Determination of implementation barriers for implementing the suggested systems in the case scenarios per country are the main activities of the Annex group. Furthermore, a roadmap has been drafted for smart connected heat pumps that tries to stipulate how the challenges are to be met. In the following chapters one can read valuable insights which have been achieved during the execution of the project. Insights on flexibility and/or load management with electrical heat pumps, and congestion management with hybrid heat pumps.

Peter Wagener
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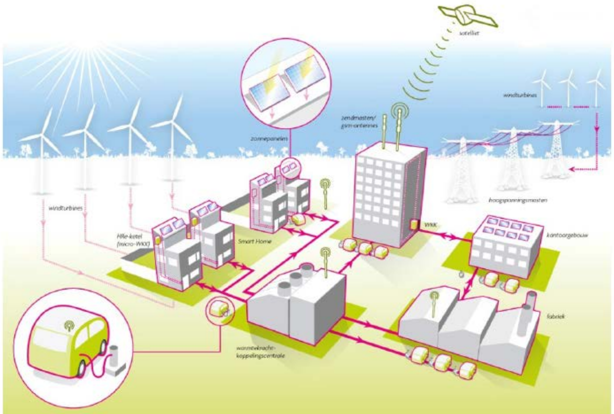
Operating Agent IEA HPT Annex 42 'Heat pumps in smart grids'

3 Annex 42 objectives and scope

Background

Heat pump markets are currently growing at a steady pace. The prices for energy and environmental concerns direct focus onto energy savings and use of renewable energy sources. Heat pump markets and policy in many countries have focused mainly on residential heat pumps for space heating and domestic hot water.
Just like wind power, photovoltaic, solar heating, biomass and other renewable energy sources, heat pumps will become more and more widespread in future energy systems in the built environment.



Therefore, there will be an increased need to balance end user energy consumption to the production from the varying energy sources. Energy consumption will become more tuned to the moment of availability, instead of the 'random' chosen moment of demand by the consumer/user.

At the working team meeting and the National Team Meeting of the IEA-Heat pump program in September 2011 in Nurnberg, Germany, smart cities and the contribution of heat pumps to sustainable cities were focal points of discussion. Many topics were discussed: how can heat pumps be implemented in Smart Cities and how can heat pumps be combined with thermal grids with multiple energy sources, heat pumps with multiple functions, e.g. domestic heating, heating or cooling of hot tap water and the management of the demand side.

Several projects have been carried out concerning the implementation of heat pumps in urban areas all over the world. Other projects have concerned the implementation of heat pumps in combination with district heating or district cooling and several smart city projects are being prepared. It is necessary to uncover how heat pumps can be implemented in smart cities, towns, urban areas or settlements in a smart and sustainable way, so the CO_2-reduction becomes as large as possible for the entire system. Obstacles to the implementation must be uncovered and experiences from existing smart cities type solutions have to be identified.

The potential scope of this discussion is enormous. However, within the possibilities of the Annex and the means available, the work has been focused on realistic targets. The objective of this annex was thus to gather information for (governmental and non-governmental) policy makers and decision makers on energy systems in urban areas concerning the possibilities and barriers related to the implementation of heat pumps in smart grids and therewith smart cities or in urban areas.

In particular, the work has focused on the following areas:

- Getting insight into the country specific opportunities and barriers for smart grid implementation projects;
- Creating a network of experts;
- Modelling realistic smart grid heat pump applications;
- Analyzing market structures and their role in smart grid success;
- Investigating finished and ongoing field trials for critical success factors;
- Compiling policy recommendations for officials, researchers and executives.

4 Structure of this document

This document is the final summary of all the work that has been done within the Annex 42 context over the last 3 years. As such, it presents a diverse set of perspectives on heat pumps in smart grids. Several documents containing country reports and more detailed analyses are distributed together with this summary (listed in appendix B).

This report starts with an introductory part on the principle benefits that are provided by heat pumps in smart grids.

The latest results can be found in Part II of this document: **ROADMAP FOR HEAT PUMPS**. In the roadmap, a set of recommendations has been compiled to further advance the market chances for heat pumps in smart grids. This part has been compiled from extensive group discussions, building on the other parts from this document. The roadmap should really be read as a guide on how to move forward with research, field trials, product development, regulatory issues and policy decisions.

Following the roadmap, the following content is presented in order:

PART III – MARKET OVERVIEW

A thorough assessment of the present market situation and future perspective for smart heat pumps. Within this document, only the summarising results have been included. Full country reports are available as separate documents.
To understand the chances for smart heat pumps in the participating countries, we have compiled a set of 'typical' case scenarios for heat pumps in smart grids. These scenarios obviously differ between the countries and highlight the *sweet spots* for smart grid applications. A complete description of these case scenarios is included in a separate document, presented together with this main report.

PART IV – MODELLING WORK

Building on the country-specific case scenarios, specific modelling work has been conducted by members of the Annex 42 working group. This part presents an overview of the modelling approaches and results.

PART V – DEMONSTRATION PROJECTS

The last part gives an overview of demonstration projects that have been carried out in the participating countries. These field trials have resulted in a wealth of knowledge about the practical implementation successes and failures of smart heat pump projects. Results from this part have been extensively used in compiling the roadmap.

Part I Introduction to heat pumps in smart grids

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5 Heat pumps and flexibility – a natural combination

In the last decade, heat pumps have made the transition from niche technology to widely accepted alternative for traditional heating by fossil energy-fuelled boilers. In a typical application, a heat pump is used to provide a relatively flat heating profile to a well-insulated house. For domestic hot water purposes (and sometimes also for optimising space heating) a storage vessel is often installed.
These characteristics make heat pumps ideally suited for incorporation in smart grids: by shifting the heat load, the electrical grid load can be dynamically adapted both upwards and downwards to suit external demands for flexibility. By joining a smart grid initiative, end users become active contributors to the energy system, rather than passive consumers of energy.

5.1 Stakeholders in a smart grid

Within Annex 42, we have focussed on the role of heat pumps in smart grids. For this purpose, the following stakeholder roles are relevant:

End user / customer

Uses heat pump for space heating and/or domestic hot water production. By joining a smart grid project, part of the heat pump control is left to other parties. Typically, a financial reward is received for

- Compensation of possible efficiency losses;
- Flexibility fee, either as a fixed 'participation reward' or variable, depending on the amount and timing of the delivered flexibility.

Aggregator

The aggregator is the intermediate party that negotiates between end user (that has no direct flexibility market access) and the flexibility market (e.g. congestion signals from DSOs, short-time energy market prices etc.). The aggregator makes a business proposal for the customer and is responsible for the administrative handling of flexibility contracts.

Distribution System Operator (DSO)

The DSO is responsible for building and maintaining the (electricity) grid infrastructure. In particular, the DSO is responsible for ensuring that the grid capacity is large enough to enable all houses to user their electrical appliances. When grid capacity is running short, the DSO can either invest in grid capacity extension, or set up a flexible smart grid project to lower peak demand. Although the latter option is strictly not allowed by most grid codes, DSO have been experimenting with smart grids during the last decade. Often, the market role of aggregator and DSO are united within the same organisation.

Balancing Responsible Party (BRP)

The BRP, finally, has an interest in smart grid systems to increase balancing reliability. By requesting intra-day 'flexibility batches' it is possible to finetune the electricity production/uptake balance to match the pre-agreed values.

5.2 What can flexible heat pumps achieve?

Heat pumps in smart grids can contribute to solutions for several energy system-related obstacles. Within the Annex 42 working group, we distinghuish five main smart heat pump contributions:

1. Keeping grid load under control while renewable energy production grows to restrict or even avoid grid capacity investments.
2. Keeping grid load under control during extreme conditions (i.e. 'coldest week'), again avoiding grid capacity investments.
3. Increase self-consumption of renewable energy sources (achieving better grid balance and higher economic end user value).
4. Selling flexibility to the grid, for the benefit of balance responsible parties, grid operators, traders, etc.
5. Allowing for a higher share of heat pumps in the energy system without risking local overload problems.

Enhancing the *realisation* of these solutions has been the basic driver for the Annex 42 participants.

Part II Roadmap for heat pumps

Creating a better market for heat pumps in smart grids

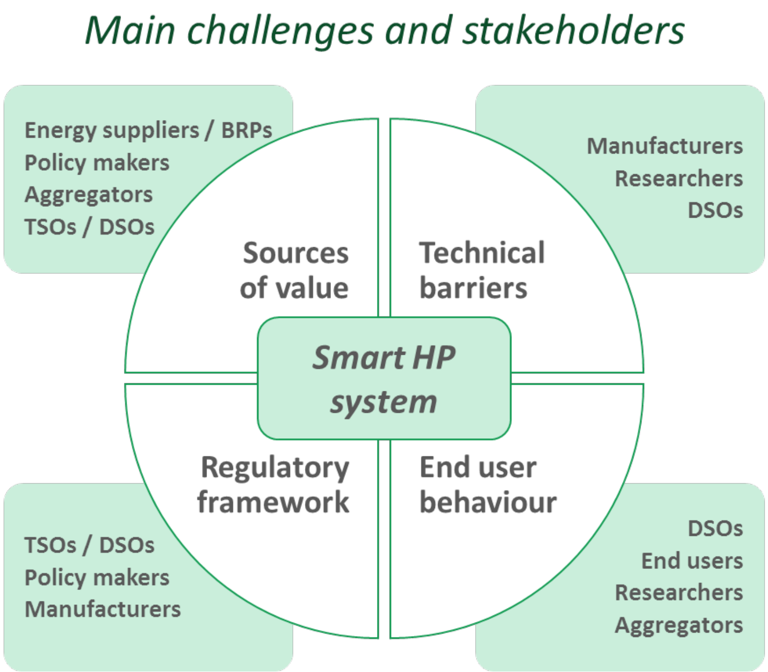
Table of contents for Part II

6 Introduction

6.1 Main challenge domains and stakeholders

Despite presenting a clear solution to several issues with the incorporation of heat pumps and renewable electricity production into the energy system, smart heat pumps are not yet widely employed.

There are several challenges that must be addressed, by different stakeholders. The diagram below sketches four main categories of challenges and the main stakeholders connected to those categories.



Sources of value

There are several ways to solve problems within the energy system using smart heat pump applications. These principle sources of value have been identified in chapter 5.2. Because of several different mechanisms, these sources of *social value* are not realized as an economic value or legal obligation. The most important blocking mechanisms are discussed in section 7.1.

Technical barriers

On the technical side, the basic principles of heat pumps inside smart grids are quite well understood. There is, however, still a lack of understanding on how to tap into the thermal storage potential of existing houses. This storage potential is not limited by the availability of storage tanks, but also strongly depends on the thermal characteristics (insulation & thermal mass) of the building stock. Other barriers include the design and implementation of the communication infrastructure and standards, as well as insight into the availability and feasibility of demand side response in real life applications. These issues are elaborated in section 7.2.

Regulatory framework

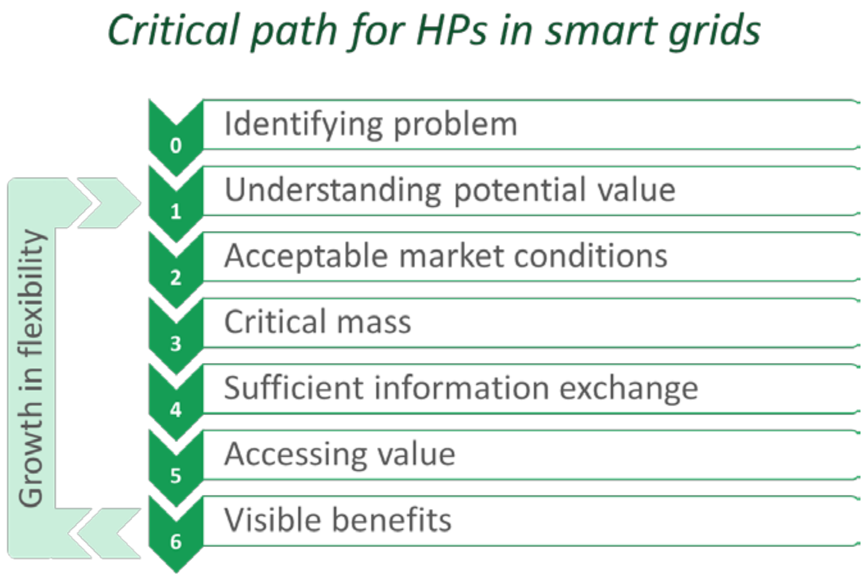
As smart grids constitute a relatively new technical concept in the energy system, the regulatory framework has not been prepared for its facilitation. There are three areas of special importance. First, the grid codes are generally not permissive of smart grid initiatives; smart grids simply do not exist within this context. Secondly, the energy market design – and in particular the price structure of electricity consumption and grid fees – is not tailored to an active role for end users. Lastly, there are many choices of a strongly political nature regarding the desired architecture and functioning of the energy system in conjunction with the development of the building stock. Section 7.3 discusses further details.

End user behaviour

Perhaps the most ‘fussy’ aspect of heat pumps in smart grids is end user behaviour (section 7.4). Since smart grid applications are typically still carried out in pilot projects, large scale experience with consumer behaviour is lacking. Comfort requirements and their link to building characteristics are still largely unknown. More important, however, is the question as to how to increase the knowledge and involvement of end users in smart grid projects.

6.2 Critical path

The group of participants in the Annex 42 working group is diverse: in many countries, progress has been made in several of the challenge domains. To compare this progress across countries, we use a *critical path* scheme as sketched below.



Success of heat pumps in smart grids is not a static factor, but depends on the development stage within the critical path. Identifying and acknowledging smart heat pumps as a solution to energy system problems is just the start: only after step 1 to 5 have been completed, the identified value sources can be accessed and visible benefits will be recognized.
In particular, acceptable market conditions for smart grids will have to be explicitly designed in many countries. The classical approach to customer-market interactions has generally focussed on protecting customers against financial risks and ensuring grid reliability. An active customer role has traditionally not been anticipated.
Even if the critical mass has been reached, allowing for a significant impact on the local energy system, there are currently no protocols or infrastructure for standardised and structured communications that are widely accepted as standard. Still, this infrastructure will be needed to ensure reliable communication between different actors within a smart grid, or even between different smart grid operations.

Judging progress in relation to this critical path, we must conclude that there is still a long way to go. All participating countries face or expect major problems related to grid congestion, (winter) peak power generation capacity or integration of RES. However, even understanding the concept of smart heat pumps as part of the solution (stage 1) has been proven difficult to realize on a country-wide scale.

There are some promising exceptions, though. The Dutch demonstration project “Energy frontiers Heerhugowaard” has tested a full market framework and ICT platform for a smart grid system including heat pumps and other technologies.[4] The leverage for realizing a successful project has been provided by a special permission to (temporarily) ignore certain legislation that currently formerly blocks formation of a complete flexibility market. The results and insights are promising: a clear drop in maximum power demand, decreasing local grid congestion. This project thus immediately moved on to stage 6. The demonstration project has been finalised now, but further improvements would certainly have been feasible.

[4] Energiekoplopers; Flexibility from residential power consumption: a new market filled with opportunities; Final report for 200 household smart grid field trial; 2016.

The Swiss TIKO project is one of the few companies already exploiting the value of heat pumps for demand response commercially. The project is owned by a large telecom / IT company, which has enabled a highly professional information campaign to a broad potential customer base. In addition to the smart functionality, customers can benefit from an additional suite of energy-related services. As a result, the project was directly kickstarted to stage 3 on the critical path. At the start of 2017, the project has over 10.000 participants and has obviously managed to progress through the complete critical path. There is proven customer value and a viable business case. Time will tell if the benefits are large enough to enable further expansion of the flexibility pool.

We conclude that the critical path can be successfully pursued, if the initial hurdles in terms of market model and market conditions can be overcome.

7 Obstacles, solutions and key stakeholders

7.1 Sources of value

Summarizing from chapter 5.2, there are at least five ways for smart heat pumps to generate value within the energy system.

1. Keeping grid load under control while renewable energy production grows to restrict or even avoid grid capacity investments.
2. Keeping grid load under control during extreme conditions (i.e. 'coldest week'), again constraining grid capacity growth.
3. Increase self-consumption of renewable energy sources (achieving better grid balance, higher economic end user value as well as psychological customer benefits).
4. Selling flexibility to the grid, for the benefit of balance responsible parties, grid operators, traders, etc.
5. Allowing for a higher share of heat pumps in the energy system without risking local overload problems.

These value sources are not effectively realized as economic incentives or legal obligations for parties to act. The next sections discuss the main causes for this lack of benefit materialization.

7.1.1 Energy system value

Number of systems threshold

The value of smart heat pumps is only fully realized when there are enough active systems to generate a measurable impact on the energy system. Therefore, efforts to realize smart grids will require a critical mass of systems and therefore a sustainable market for heat pumps in the country.

Economic value evaluation

In many cases, a clear economic driver underlies the value proposition of a smart grid. Local grid congestion problems have a clear and well-defined price: the engineering and building costs for extending grid capacity. It is not all easy, however, to translate these bulk cost reference into a reasonable price for day-to-day flexibility demands. In pilot projects, DSOs have been struggling to set a fair price on heat pump flexibility.
For market traders and balance responsible parties (BRPs), this problem is less of an issue, since an up-to-date price reference (in terms of market prices or imbalance fines) is generally available. This reference price can directly be translated into a bidding price for flexibility.

Conflicting value drivers

Several market players can claim a legitimate interest in buying or selling (local) flexibility. This will inevitably lead to conflicts of interest. Depending on current market prices, RES production and grid load, some market stakeholders may bid for *increasing* power consumption (e.g. to counter PV production), while others may want to *decrease* power consumption at the same time.
Resolving these conflicts eventually requires a policy decision on priority ranking between the parties involved. Local DSOs, being responsible for the physical integrity of the grid, may become leading in resolving these issues, or at least provide major input into the decision process.

AVAILABILITY OF DEMAND SIDE RESPONSE

Presently, there is no clear approach to assess availability and reliability of demand side response by end users. Although a large flexibility potential may be technically available at a certain time, the fraction of this potential that will be realized is generally very uncertain.

Recommendations

Actions needed	*Main stakeholders involved*
Start with large scale field trials (100s of participating houses) to increase the effect of collective value generation.	DSOs, Aggregators, Energy suppliers
Carry out field trials that implement a 'full market model', including complete financial handling of flexibility contracts. Governments may facilitate this by authorizing dispensation for obstructing legislation where appropriate.	DSOs, Aggregators, Energy suppliers, BRPs, Policy makers
Share information on the value assessment of flexibility demands without clear day-to-day market reference price (e.g. grid congestion).	TSOs, DSOs, BRPs, Researchers
Make policy choices on priority handling of DSO flexibility demands.	Policy makers, DSOs, Aggregators
Set up specific research to address availability and reliability of demand side response.	DSOs, Aggregators, Researchers

7.1.2 Customer proposition

Currently, very few successful customer propositions have been developed. In practice, end users may expect to experience some disadvantages by joining a smart grid initiative: efficiency of the heat pump will generally be sub-optimal and ideally, the heat pump should be somewhat oversized to enable maximum flexibility. Both effects will have a cost price for the end user.

Recommendations

Actions needed	*Main stakeholders involved*
Invest in development of new customer propositions. Possible directions are: monitoring & energy saving assistance, heating as a service, identifying alternate ('non-energy') benefits, increasing self-consumption of renewable energy.	Aggregators, Researchers

7.1.3 Aggregator proposition

The aggregator is currently in a *high risk, low reward* situation. Because most energy market models do not allow flexible price mechanisms for end users, other benefits and earning models must be developed. The threshold for real market impact by flexible heat pumps has not yet been reached and guaranteeing a certain amount and quality of flexibility is still a very difficult undertaking.

Recommendations

Actions needed	*Main stakeholders involved*
Set up large scale field trials to gather experience on: ● Statistics on availability and reliability of end user flex offerings; ● Matching end user appliance control structures to the main value driver in the project; ● Best business proposals for all parties involved.	Aggregators, DSOs

7.2 Technical barriers

The heat pump market is mature in terms of product research and optimization. Through years of experience with heating applications and air conditioning units, heat pumps are now generally extremely reliable appliances. Yearly sales reach nearly 100 million units per year (including air conditioning). On the product

reliability side, no major breakthroughs should be expected within the near future. Several research developments, however, indicate that significant gains in efficiency may still be obtained, especially if heat pumps are explicitly optimised for their intended application regimes (e.g. climate, heat demand pattern, source type).
While the product-related technical understanding is presently in good shape, there are still several issues to be tackled when applying heat pumps in smart grids. These issues are not directly related to heat pump quality and reliability itself, but rather arise from the integration of several components into a single smart energy system.

7.2.1 Storage capacity

Storage capacity is of tantamount importance for smart heat pumps. Only be allowing heat pumps to shift their heating load, is it possible to offer flexibility at all. This does *not* mean that a storage vessel is always needed for proper functioning. Because of the thermal mass present within the buildings themselves, there is a 'free' amount of thermal storage available in all situations. Depending on the size of the building's thermal mass, a (very) small shift in the building's *core temperature* may allow for significant energy storage.

Several questions are related to this building thermal storage potential.

- How can thermal mass be reliably estimated in new and existing buildings? And how can this storage be optimally used in conjunction with the insulation characteristics of the building?
- What is the potential of using building thermal mass for large-scale flexibility offerings?
- What is the effect on user comfort when using building thermal mass storage?

Recommendations

Actions needed	*Main stakeholders involved*
Set up field trials to explicitly focus on building thermal mass. Preferably, flexibility limits should be tested *without* using any heat storage vessels at all.	Aggregators, DSOs, Researchers
Deepen research on the relation between building temperature fluctuations and user comfort.	Researchers
Start quantifying building thermal mass potential for groups of buildings in relation to typical building characteristics (e.g. size, materials used, building codes, occupation, etc.)	Researchers, Manufacturers

7.2.2 Communication & infrastructure

With respect to communication, the main issue is a lack of standards for communication within a smart grid environment. Field trials are nearly always set up with dedicated soft- and hardware to allow communication with and controlling of appliances. Very few *plug & play* communication protocols are available.

In addition, there is no consensus as to which type and what amount of information is needed for effective heat pump controlling. There are two extreme positions on this issue:

1. 'Airport style' controls: each heat pump (viz. 'airplane') is explicitly told what to do by a central operator algorithm (viz. 'control tower'). End users largely hand over control to the central operator. System behaviour is completely controlled and dependent on a complete information position. Bidirectional and reliable communication is needed between central operator and end user appliance.
2. 'Highway style' controls: general information on desired flexibility and conditions is given by a central operator (viz. 'traffic signs'). The heat pumps (viz. 'cars') decide autonomously if and how to respond to the given market situation. System behaviour is determined by statistical principles reflecting the sum of individual users' behaviour, based on general status information. In principle, one-way communication from the central operator to end user appliances suffices.

Which of these two models will be more successful, has yet to be decided.

As a corollary to the first issue, the second major issue on communication is a lack of product standardisation. The 'Smart Grid ready' label carried by many heat pumps does not provide much useful information or guarantees on the best way to communicate with that appliance.

Finally, unreliable connectivity is still an issue in several field trials. With the increasing quality of the digital communication infrastructure, this problem can be expected to be largely solved within the near future.

Recommendations

Actions needed	*Main stakeholders involved*
Develop communication standards for smart grid appliances.	Aggregators, Manufacturers, Researchers, Policy makers
Conduct (field) research on the differences between 'airport style' and 'highway style' controls. In particular: what is the optimal balance between best flexibility performance (high information exchange needed) and high robustness (reduced information exchange needs).	Researchers, Aggregators
Develop *plug & play* smart grid appliances	Manufacturers
Gain insight in end user behaviour statistics through field trials. How much demand response potential is actually available in a given end user group?	DSOs, Aggregators

7.3 Regulatory Framework

7.3.1 Network codes

Network codes have not been designed with flexibility and demand side response in mind. Therefore, there is no incentive to develop smart systems, even though it could solve major grid-related problems. A long-term possible solution should consist of addressing smart grids explicitly in the codes. Meanwhile, much can be learned if governments give temporary exemptions to specific regulations blocking field trials. Such an exemption has led to valuable insight in smart grid market models in a Dutch field trial (page 48).

The cost structure underlying electricity grid developments also poses a barrier for smart grid applications. In most countries, network capacity investments are socialized over a large group of grid users. There is thus no strong incentive to locally avoid grid congestion problems, since eventually, capacity investments will have a tiny effect (if any) on grid tariffs.

Recommendations

Actions needed	*Main stakeholders involved*
Develop network codes for smart grid appliances.	Policy makers, DSOs
Experiment with 'regulation free' areas.	Policy makers, DSOs
Set up accounting structure to explicitly assign investment costs to local congestion problems (even if these costs are ultimately socialised among all grid users).	DSOs

7.3.2 Energy market design

The energy market design – and in particular the price setting of electricity in relation to natural gas – doesn't generally facilitate smart energy systems. There are several issues connected to the market, that line up to create a very hard business case for energy savings in general and especially for smart heat pump applications.

Energy prices and taxes

Governments have a considerable influence on energy prices. Directly through taxes and indirectly through controlling grid fees, governments control up to 80% of the electricity price. Most of the taxes and grid fees tend to be fixed costs for the end user. With such a high fixed price component, market fluctuations in the electricity price will hardly be noticed by end users. Even if real time tariffs would be allowed, the net effect on the instantaneous end user price would be all but negligible. A business case based on wholesale market price fluctuations is bound to be marginal for end users.

Ratio between electricity and gas prices

Apart from the price structure (i.e. % of 'flex' represented in the price), taxes also largely determine the ratio between electricity and natural gas (or heating oil). In all countries, electricity is more expensive than gas. To make a switch from a traditional boiler to a heat pump attractive, this price difference must be compensated by the better performance of the heat pump. A very high E/G ratio means that only exceptionally performing heat pumps will have a change of significantly outperforming boilers on a cost basis.

COSTS OF ENERGY AND CO_2

High energy prices tend to stimulate end users to save energy. A high absolute price level is therefore conducive to an increase in the heat pump market share, which creates a better playing field for smart grids. Generally speaking, energy and CO_2 prices are too low to really stimulate energy saving measures, renewable production and heat pump installation, without government intervention. Countries differ greatly in this respect and the energy price level tends to correlate with the development of the heat pump market in each country. High energy prices by themselves are, of course, not enough to kick-start the heat pump market if other factors (such as building quality, reference heating options, renewable regulations, etc.) still oppose market growth.

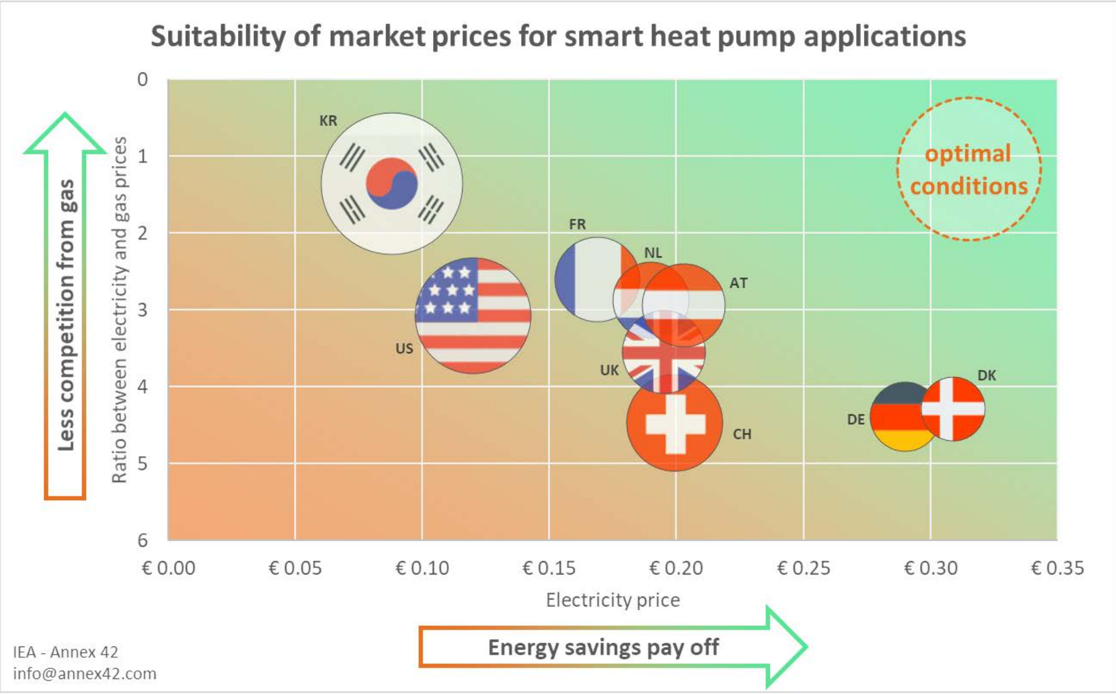
WHO PAYS FOR FLEX?

Flexibility is mostly a country-wide social issue. As an example: a local solution for grid congestion may also have a positive (i.e. flattening) effect on the macroscopic load profile, benefitting central electricity production plants. The question arises which party should pay for flexibility. The opposite effect, where several market stakeholders have conflicting flex demands, could also occur. Regulation that covers these issues has not yet been developed.

SUMMARY GRAPH

The graph below summarizes the status of electricity prices for all participating countries in this Annex. The x-axis shows the absolute electricity price level. The higher this price level is, the more conducive for energy savings and renewable heat production. There is a self-reinforcing loop here: countries that invest heavily in renewables tend to experience increasing energy prices; in particular for electricity. This ironically impairs the business case for heat pumps.
The y-axis shows the ratio between electricity and gas price. A high ratio means that traditional boilers compete strongly with heat pumps.
The bubble size indicates the percentage of the electricity price that is 'potentially flexible' (i.e. not fixed tax or grid costs). Large balloons indicate countries where wholesale prices are reflected very well in the end user price. There is a negative feedback here as well: Through higher energy taxes funding renewables, the potentially flexible part of the end-user price drops, leaving less room for smart grid business cases.

Figure 2 – Market suitability for smart heat pumps: a high ratio between electricity and gas price, means more competition for heat pumps. High electricity prices generally make renewable options more attractive. A small 'fixed part' (large balloon size) in the electricity price means that market price fluctuations are directly experienced by end users.



Recommendations

Actions needed	*Main stakeholders involved*
Develop alternate taxation models, for instance taxing *as a percentage* of the commodity price, instead of adding a fixed tax tariff.	Policy makers, DSOs
Develop a policy that stimulates a changeover to a renewable energy system by favouring electrification. (i.e. higher taxes on gas/oil, lower taxes on electricity)	Policy makers
Increase absolute energy price levels, either directly or indirectly through a CO_2 tax.	Policy makers
Develop market models to resolve flex/price conflicts between market stakeholders.	Policy makers, Aggregators, BRPs, DSOs, TSOs

7.3.3 Political choices

Ultimately, decisions on the energy market have a strong political component. Energy is, after all, of strategic importance. Apart from energy saving goals, taxes also serve to strengthen these strategic stakes. Furthermore, energy taxes also have a substantial impact on the distribution of household income and wealth. Therefore, political choices must be made to support a successful smart energy market.

Issues that deserve consideration are:

- Communication standards;
- Obtaining insight into social benefits from smart grids;
- Appreciate the effects of energy market unbundling;
- Stimulating reaching the ‘critical threshold’ for smart grid appliances.

Of the issues above, market unbundling is especially difficult to deal with. In the EU, energy grids, energy suppliers and energy producers have largely been split into autonomous organisations. The result of this unbundling is an increasingly complex playing field, where coordinated action to stimulate sustainable development becomes ever more difficult as market players continue to drift apart. In the US, by contrast, smart grid initiatives are much easier to coordinate, since energy production, transport and selling are still mostly combined within single organisations.

Although reversal of the unbundling strategy will not be feasible, appreciation of the negative effects and searching for specific ‘workaround’ solutions is strongly recommended.

Recommendations

Actions needed	*Main stakeholders involved*
Enforce development of (open) communication standards.	Policy makers, Manufacturers, DSOs
Map social benefits of smart grids and develop stimulating policies where appropriate.	Policy makers in cooperation with other market parties
Stimulate local heat pump cluster developments, to reach the ‘critical threshold’ more easily.	Policy makers, DSOs, Aggregators
Appreciate negative effects of energy market unbundling and stimulate market cooperation and information exchange to counter these effects.	Policy makers, TSOs, DSOs, BRPs, energy suppliers

7.4 End user behaviour

End user behaviour is a key ingredient for successful smart heat pump projects. Surprisingly, this aspect has received little attention in research and field trials. Of special importance are a better understanding of comfort requirements and more experience with motivating customers to participate in smart grid projects.

Comfort requirements

Comfort requirements are very subjective, situation dependent and motivation/expectation dependent. Up to now, data from demonstration projects have shown very different results (section What have been the common themes across the projects?18). Customer satisfaction is evidently strongly correlated with expectation management, the 'sense of involvement' and trust in the aggregator party.

Further understanding of the comfort requirements and on how to increase end user satisfaction is needed, as well as a more professional approach to the recruitment of and interaction with customers.

Business proposition

Demonstration project experiences suggest (page 48) that end users favour a simple business proposition. That means that a proposition involving a fixed reward may experience easier customer recruitment as compared to flexible (uncertain) return, even if the expected return value is higher in the flexible case. In addition, possible efficiency losses should be compensated for.

Customer involvement and motivation

Customer engagement is greatly increased if a 'compelling cause' (e.g. CO_2-reduction, allowing for a higher RES uptake, etc.) is clearly advertised. Even if the financial reward is modest, customers are willing to get involved, provided the reward is guaranteed (see paragraph above). Through extended services (e.g. monitoring, smart home packages, etc.) the customer experience may become positive enough to actually lead to peer pressure within smart grid areas. Much is to be learned from comparable utilities, such as internet or telecom providers. The successful Swiss TIKO-initiative (page 48) underlines this point.

Privacy and data security

Privacy has not yet been a prominent issue in demonstration projects. As the number of smart heat pumps grows, this issue may be expected to gain significant importance. Guaranteed privacy and data security will probably prove to be major factors in convincing end user to join smart grids. Especially since the potential impact of hostile systems hacks is enormous.

Control models involving limited data exchange will have an advantage over more complex algorithms in this respect. At the same time, *big data* analysis of customer use data will provide value by itself. Balancing these forces is a challenge that has nog been addressed yet.

Recommendations

Actions needed	*Main stakeholders involved*
To better understand comfort requirements, more 'social science' should be included in field trials. Get customers involved early on in process.	Aggregators, DSOs, Researchers
Develop simple and effective business propositions, focussing on customer engagement rather than return value maximisation.	Aggregators
Privacy and data integrity will grow to be more important. Explicitly address these issues in new business models.	Aggregators

Part III Market overview

Summary from country reports

Table of contents for Part III

8 Introduction and summary

These chapters give an overview of the domestic heating market situation in relation to the implementation of HPs in smart grids in all participating countries. This overview summarizes the main results for these countries and identifies common market trends and challenges and their impact on suitability for smart HP employment. An overview of market summary tables and detailed reports for each country are also available.

8.1 Common challenges across markets

Four main challenges are evident across most markets, and insight into how to overcome these will be valuable for all markets. We outline the four themes, and related common research questions.

Building characteristics

Technical limitations on HP flexibility by building characteristics are a recurring theme across most markets (in the existing building stock). It is particularly related to the reliance on high temperature radiators, coupled with aging and poor insulation. It means the amount of heat “storage capacity” within the building and building fabric itself is limited.

- How do different building types store heat, and how this can be tapped into to create flexibility?
- Is new build ultimately the only source of flexibility?

Limited storage

Limited physical space for storage tanks is a widespread problem in most markets

- What opportunities are there to capture flexibility with limited storage?
- What role will hybrid systems play?
- What can be learned from the use of modulation to capture flexibility from air/air HPs?

Economics

In all markets, the economic case for flexibility (for the end-user) is difficult to make. In some markets the electricity pricing or electricity-to-gas price ratio does not encourage increased use of HPs at all. And, in almost all markets, a limited share of the electricity price is ‘potentially flexible’, the bulk of the price being determined by fixed components such as taxes. End-user savings are thus generally limited.

- Is it possible to give any (financial or other) benefit to the end-user if they provide flexibility?
- How do country-specific regulatory environments and market structures influence how much benefit can be?

End-user perception

The preference for gas-fired boilers as main heating solutions (coupled with often negative perception of HPs) is common across nearly all markets, limiting the total potential HPs market size. There is also uncertainty over how end-users will react to 3rd party control of their HPs.

- How can flexibility be captured while maintaining positive perception of HPs amongst end-users?
- What are the best ways to influence end-user behaviour and stimulate willingness to participate in flexible HP operation?

8.2 Overall suitability scores

Building on a set of five scoring measures (developed further on in this document), the table below gives an overall suitability score for each country. Notably, only France and Switzerland are at this moment reasonably well prepared for (large scale) smart HP implementation.

Table 1 – How do countries compare in their suitability to capture heat pump flexibility?

Country	*Score*	*Market snap-shot*
AT	±	**There is a potential smart HP need expected within the coming decade.** However, uptake of HPs by households has been modest, and end-users are not used to flexible tariffs. Energy system challenges justifying smart grids are not quantified, making it **difficult to devise solid business cases**. Flexible energy tariffs are not (yet) available. The potentially flexible component in electricity prices is presently around 1/3: too little to have a serious impact on end-user behaviour.
CH	+	**The need for flexibility is in a 2020-2030 timeframe** in Switzerland, related to managing load on the high voltage grid. **HPs are a large potential flexible resource** – The Swiss HP market is the most mature of all participant countries, with HPs the technology of choice in single family homes and making up around 40% of annual heating installs. End-users with HPs are used to the HP being shut-down at peak times. The greatest challenge is capturing flexibility from the older buildings (making up about a third of the building stock).
DE	±	Supply/demand balancing and grid congestion are recognised as a medium-term (5-10 year) challenge for which demand side flexibility will be needed. **The typical heating solution in Germany looks stronger than other markets in terms of potential flexibility** – large storage tanks and strong share of HPs (some of which are already remotely operated at peak times). However, **energy price structures do not currently encourage market growth or give benefits for end-users** from providing flexibility – this is the biggest challenge to overcome.
DK	±	**Denmark faces challenges within the next 5 to 10 years, related to managing and balancing production and load on the high voltage grid.** District heating covers 60 % of all households, but in non-district heating areas (30-40 % of the country), electrification (HPs) is the policy direction. **There are market barriers to overcome to increase the HP market share in non-district heating areas**, the main barrier is high electricity prices and low fossil fuel and biomass prices. Furthermore, the **very high share of taxes in consumer electricity prices** in Denmark do not encourage market growth.
FR	+	In France, **capacity margins and grid congestion are already a challenge** to manage. The electric heating market is Europe's largest, and HPs are a significant part of this. As a result, **there is a large potentially flexible resource, and there is a lot of experience in controlling or influencing operating times of electric heating**. The main challenge in France is translating what has worked for electric heating to HPs, and capturing flexibility in an aging building stock.
KR	±	**South Korea faces an immediate challenge to fill a capacity margin gap** which has already resulted in black-outs. Capturing demand-side flexibility is therefore high on the political agenda. For HPs to contribute to this flexibility, **market challenges must be overcome (e.g. end-users' preference for gas, and unattractive electricity tariffs), and the thermal storage potential in floor heating and the relatively young building stock should be tapped into**.
NL	−	In the Netherlands, **the need for flexibility is recognised, particularly for managing grid congestion in the medium-term**. However, similarly to the UK, the HP market is <1% of the heating market, and there are challenges of lack of space for storage. **The flexibility potential from HPs is therefore quite low – hybrids could be key to unlocking flexibility here.**

Country	*Score*	*Market snap-shot*
UK	−	**The UK will need demand side flexibility in the medium term (5-10 years), particularly to manage growing distribution grid congestion.** The HP market is expected to grow in the next few years, but the **flexibility potential from HPs is constrained e.g. by the old, poorly insulated buildings, lack of space for storage, an end-user preference for gas, and ‘spiky’ heat demand patterns**. The availability of flexible tariffs, and the growth of hybrids, could be key to unlocking more flexibility potential from HPs.
US	±	**Demand response has historically had far stronger drivers in the US than in Europe**, so the market is more advanced, leading to greater experience with “3rd party control” (even if the use of HPs within demand response has seen only small-scale activity so far). The total HP market is huge - **but the dominance of air/air HPs (mostly in southern regions), and lack of storage, does create a constraint on potential flexibility. An emerging ground-source HP market and a growing DHW HP market offer greater kW demand levelling opportunities**.

9 Measuring suitability for flexible heat pump implementation

From the country reports, five main factors can be distilled which determine the changes of success for flexible HP applications. These differentiators are key in understanding the essential underlying needs to enable fruitful implementations of flexible HP. In the following sections, we first describe the five factors, as well as typical related market questions and “desired” status for optimal smart HP performance. We then zoom in on the different participant countries to score each of them individually. Together, the differentiators determine the overall suitability score of the country for (large scale) flexible HP implementation.

9.1 Differentiators and benchmarks

The table below defines our five criteria for market success. Most factors will be applicable to several or even all participating countries. Thus, they present a general benchmark for scoring countries in relation to smart HP potential.

Table 2 – Differentiators influencing the potential to capture HP flexibility

Differentiator	*Associated questions*	*Benchmark: optimal situation*
 Drivers for HP in smart grid / flexibility	• What is the flexibility needed for? E.g. managing distribution grid congestion; supply/demand balancing; energy security; ensuring capacity margins are met… • Immediacy of this driver (e.g. critical today? in 5yrs? in 10yrs?)	• The country faces an immediate challenge to which flexibility offers a solution (therefore policy & industry driven to stronger action)
 Potential size of flexible HP resource	• How many HPs installed? – today / projections for future • What type of HP system with what heat distribution system? • Use of storage?	• Large HP market / high growth • Hydronic HP & underfloor heating • Widespread use of storage

Differentiator	*Associated questions*	*Benchmark: optimal situation*
Building stock characteristics	• Age/thermal properties/insulation level • Building size (and/or single family versus multifamily house)	• New buildings, well insulated • No space constraints (i.e. for storage)
Energy pricing level & structure	• Energy prices / price ratios (do they encourage HPs?) • Tariffs – do HP tariffs exist? Is there experience with flexible tariffs?	• Low electricity price, high gas/other fuel prices encourage HP market growth • Flexible tariffs an enabler for HP flexibility
End-user impact	• Use of heating system / heat demand profiles • Experience of how end-users respond to 3rd party control? • Building ownership – what proportion owned	• Flat heat demand (not bursts of heat) • High level of experience to know how best to engage customers • Low proportion private rented properties (less control over choice of system, less incentive for savings)

9.2 Countries along the benchmark

The five differentiators as described above determine the total suitability score for each country. Scoring for each factor is done on a 5-step scale, from + (benchmark for differentiator is realized in optimal form) to − (benchmark is not met at all). The scores have been based on the individual country reports, which can be downloaded as appendix to this document. The table below shows the summarized results. One indicator stands out: in all countries participating in Annex 42, there is a strong or at least a moderate driver for flexibility. HPs in smart grids can definitely help to solve problems today or in the short-term future.

The other criteria, however, don't match this 'demand for smart HPs'. Especially the suitability of building stock and the price levels & pricing structure pose a serious overall hurdle. Overall, Switzerland and France score quite well, but the other countries face at best moderately favourable conditions for a growing flexible HP market. Especially South Korea, The Netherlands and the United Kingdom, are potentially missing out on smart HPs as a solution to grid congestion and capacity matching problems.

However, precisely because there are strong drivers for flexible HPs, the other factors may be strengthened either through policy decisions or market pressure. Thus, the situation may be expected to grow more positive over the next years.

Table 3 – Detailed comparison of countries with respect to five main differentiators for successful smart HP practice.

Country	*Drivers*	*Potential size*	*Buildings*	*Prices*	*End-user*	*Overall*
AT	+	±	+	±	−	±
CH	±	++	±	±	±	+
DE	+	+	±	−	+	±
DK	+	−	±	−	±	±
FR	++	++	±	+	±	+
KR	++	−	±	−−	−−	±
NL	±	−	−−	−	−	−
UK	±	−	−−	±	−−	−
US	++	±	−	±	±	±

10 To what extent are themes shared across markets?

Every market has its own unique characteristics, but there are also many common themes shared between some or all the participant countries. Some of these common themes have a positive influence on potential flexibility, and some a negative influence. We summarize these below. All findings have been compiled from the individual country reports, to whom interested readers are referred for further details.

10.1 How do the drivers for flexibility compare across markets?

There are two groups of drivers driving a need for demand side flexibility across partner countries:

- **Managing distribution grid congestion** is the primary reason for demand side flexibility being needed in the UK and the Netherlands. In France and Germany, it is also an issue. In these cases HP operating times need to be shifted to avoid peak times. Interestingly, a naïve stimulation of HP penetration may at first *increase* (potential) congestion problems.
- **Balancing supply/demand and ensuring security of supply** is the key issue driving the need for demand side flexibility in South Korea (where blackouts have already been a problem) and the US (with issues expected to grow in Germany and Denmark). In these cases, HP operation needs to be shifted to match generation patterns.

For some countries, the requirements for flexibility are in response to an immediate challenge – not a future challenge (e.g. in South Korea, France and the US), which means there is already strong political (and in some cases energy industry) engagement in capturing this flexibility.

10.2 What factors influence the potential size of the flexible resource from heat pumps?

There are some themes applying across groups of markets which are positive for the potential amount of flexibility which could be captured from HPs:

- **Emerging markets for hydronic HPs,** usually installed with storage tanks. The UK HP market is the market in Europe expected to see the fastest growth over the next 5 years.
- **Emergence of hybrids**, with an electric HP combined with a gas boiler – potentially create limitless flexibility as the system can switch from electricity to gas with no impact on the availability of heat. The UK and the Netherlands are expected to be buoyant in hybrids.
- **Advancements in smart-ready HPs**, or Home Energy Management systems integrated with HPs, which can accept dynamic signals from utilities and adjust HP operating patterns automatically – this enables HP flexibility to be captured.
- **Use of underfloor heating** – this is only widespread in new build in most markets, but maximises storage within the heat distribution system.

But there are negative characteristics, some of which are common across countries, which are a restraint on the size of the HP flexible resource.

- **Dominance of air/air HP** (in the US, South of France and Korea), which do not have storage. Though experience from the US shows that some flexibility can be captured here, it is far more limited than where there are hydronic systems with storage tanks.
- **Dominance of – and preference for - gas in the heating market** – especially in the Netherlands, the UK and Korea, it is difficulty for HPs to gain market share because of the availability of low cost gas. A smaller HP market means less flexibility. In addition, the well-developed gas infrastructure is mirrored by a relatively low-capacity electricity infrastructure not suited for large-scale electrical heating.
- **Reliance on high temperature radiators** – in the existing building market (which is the lion's share of the building stock), high temperature radiators are still common place in all markets which use hydronic heating. They do not provide the greatest flexibility. The exception is Korea, where there is a preference for high temperature underfloor heating – it is unclear the extent to which this could be turned into a positive storage resource.

10.3 How do the building characteristics and their impact on HP flexibility vary across countries?

In several countries, the building characteristics are moderately positive for promoting flexibility:

- **New, well-insulated buildings** are better suited for HPs (in Korea, most of the existing buildings have been built since 1990).
- **Homes with space available for storage** are key to maximising flexibility. France and Germany, for example, tend to have dwellings with large floor areas and space in e.g. cellars and basements for storage tanks.

But building characteristics are also working against flexibility in many cases:

- **Aging and poorly insulated buildings** which do not store heat limit flexibility. This is a pressing issue in the UK where more than half of existing buildings were built before 1960. In other markets (e.g. France, Germany, US), a large share of relatively old or high demand houses is also a limiting factor on flexibility.
- **Limited physical space for storage** (to enable flexibility) is an issue in the UK and the Netherlands, where homes are amongst the smallest by area in Europe. In Korea, the majority of dwellings are apartments rather than detached homes, which again creates space limitations.

There is still a knowledge gap common across all countries:

- ? There is a lack of information on **how much thermal mass is stored in different building types**, and how this can be tapped into to create flexibility.

10.4 How do energy prices and structures influence flexibility?

Energy prices and structures are arguably the principal element in defining how much benefit could come to a customer from providing flexibility. Some characteristics across markets are positive in this regard:

- **Availability of flexible tariffs as a control or influence method for demand response** – in France, 'whole day' flexible tariffs are available (e.g. a scheme run by EDF where red days = electricity is expensive, amber days = electricity is medium price, green days = electricity is cheap, designed to encourage end-users to avoid consuming electricity on certain days, and thus provide flexibility to the system), and in the US there is experience of small-scale roll-out of several flexible tariff types.
- **A high share of the electricity price is 'potentially flexible'** – the UK appears to have the best electricity price structure to maximise potential end-user savings on energy bills should flexible tariffs become available (the wholesale part – and thus the "flexible" part of the electricity price makes up the largest part of the total price).

But there are significant barriers common across most markets:

- **The electricity pricing or electricity / gas price ratio does not encourage increased use of HPs.** In the UK, the Netherlands and Germany electricity prices are at least 3 times the price of gas – so HPs struggle to compete, even considering that the SPF for a HP is of course higher than for a boiler. The outlook is particularly bleak now in Germany. A 'cumulative' electricity price structure in Korea means that users are charged more per kWh if they consume more electricity.
- **A low share of the electricity price is 'potentially flexible'**, meaning even with flexible tariffs, only small savings from the total end-user bill would be made - <50% of the electricity price is potentially flexible in Germany and the Netherlands. Government action may, however, greatly influence the 'non-flexible' price component by shifting, lowering or restructuring taxes.

10.5 How do the characteristics of the end-users influence the potential flexibility?

End-users are a critical link in accessing flexibility. Some common characteristics across markets are encouraging for flexibility:

- **High proportion owner occupier properties** (e.g. in the UK and US) mean end-users have control over the choice of heating system.
- End-users are used to the concept of 3rd party control of their heating system (e.g. pockets of experience in the US and France, as well as demo projects elsewhere).

But there are some challenges related to the end-user as well:

- **An end user preference for operating the heating system in bursts of heat** rather than at a constant level is a challenge for capturing flexibility in the UK. This preference can in turn partly be explained by the old housing stock.
- **High proportion of rented properties** where end-users have no choice (particularly in Korea)

Further questions are raised which warrant further investigation:

- **How will end-users react to 3rd party control?** – can we learn from experience in e.g. The Netherlands, France, the US?
- **Is it possible to give any (financial or other) benefit to the end-user if they provide flexibility?** This is being investigated in various demonstration projects, and the outcomes will be critical in influencing how much flexibility can be captured.

Part IV Modelling work

Table of contents for Part IV

11 Introduction

Electrical driven heat pumps are a key technology for decarbonization of the heat sector and a bridging technology between the heat and the power sector. If integrated into a smart grid, the flexibility of heat pumps can help to enable the transition towards a renewable heat and electricity sector. The main fields of applications for heat pumps in a smart grid are: integrating renewable electricity, supporting the grid or operating towards reducing the total cost of power generation.
The topic of smart grids is very broad and many-sided. Not least, because in several countries smart grids are seen as a solution for various local/country based problems. Also, the usage of heat pumps in the smart grids can be multifunctional. The results of the modelling efforts of the Annex underline the versatile character of the heat pumps in connection with smart grids.
The initial idea for these modelling studies was to compare the simulation results addressing one specific topic – flexibility of heat pumps, performed in various countries using comparable simulation models. A number of discussions have shown that this approach might not be obtainable. Knowing that, the decision has been made to let each partner to address the most significant problem or problems of the specific country.
In the light of the above, this part of the final report is not a comparison of various approaches for simulative solving of one problem but rather a compilation of results focusing on several issues. In case of repetition of topics, the outcomes have been pooled and compared. Some of them are connected or overlapping as regards their content.

In particular, the following topics have been addressed:

- Flexibility (CH, UK, DE)
- Load shifting potential (France, Germany, UK)
- Load peak reduction (Denmark, UK)
- Control strategies, model predictive control MPC (Germany, Austria, France, Switzerland)
- Length of off-blocks (Denmark, Switzerland, UK)
- Pooling (grid) of heat pumps (Austria, Germany)
- Load control, partial load (France)
- Economy (CH, AT(pooling))
- Increasingly intermitting RL (residual load) (DE, AT)

12 Overview

The following table shows the focused challenges as well as investigated aspects by countries participating actively in the modelling efforts.

Table 4 – Overview of modelling efforts.

Country	*Focused challenges*	*Investigated aspects*
Switzerland	Enlarge windows with guaranteed heat pump non-operation for residential heating to improve scheduling of load balancing with heat pumps Examine the potential to exploit thermal storages to shift loads of residential buildings for 6, 12 and 24 h Quantify the capability to follow an external control signal (exemplified in the price signal at the German EPEX SPOT market)	Influence of different building types, heat pump capacities and sensible thermal storages on the flexibility provision as defined above.

Country	*Focused challenges*	*Investigated aspects*
Austria	Increasingly intermitting RL (residual load) caused by Wind and PV power and HP´s possible contribution to balance RL by load shifting; possibility of heat pumps to participate in balancing markets; Investigate possible HP off-Intervals for a remote MPC for a SFH	impact of the heat pump integration on the network operation, Pooling of heat pumps and operation strategies for the pool, impact on heat pump efficiency and influence on comfort settings (e.g..: room conditions, availability of DHW) load shifting: providing flexibility for ancillary services (balancing market), balancing of spot-market fluctuations, peak shaving for the local grid
Germany	Increasingly intermitting RL (residual load) caused by Wind and PV power and HP´s possible contribution to balance RL by load shifting	Influence of system layout, dimensioning and control strategy on load shift potential as well as the system´s efficiency, Pooling of heat pumps
Denmark	Peak shaping by using heat pumps that utilize the internal heat storage (mainly floors and walls in residential buildings. Flexibility: Analyse of the flexibility that heat pumps can provide to the grid Interruptibility Grid impact on 10 kV grid.	Peak shaping by using heat pumps that utilize the internal heat storage (mainly floors and walls in resi-dential buildings. Flexibility: Analyse of the flexibility that heat pumps can provide to the grid Interruptibility Grid impact on 10 kV grid
France	Reducing the average level of the electricity demand during the coldest days of winter (typically 22 days/year) Shaving the daily peak between 18:00 and 20:00 (eventually 09:00 and 11:00) Filling the gap occurring at the end of the night Reducing the peak of PV injection on the grid Smoothing the intermittency of wind in winter	influence of system layout and control strategy on load shift potential
UK	A future scenario in which a high deployment of heat pumps creates a significantly higher peak demand in Winter resulting in a large additional requirement of grid capacity.	Influence of system design, dimensioning of HP, control strategy, internal temperature hysteresis, insulation and thermal capacity of the building, hybrid heat pumps (gas + ASHP) and conventional water thermal storage on load shift potential as well as the system´s efficiency, capital and running costs and CO2 emissions.

13 Main outcomes for each topic

The summary below is an attempt to present the outcomes of the project according to various topics. It must be noted that the categorization cannot be regarded as unequivocal, as each aspect can be considered from various perspective and some may be overlapping. Key conclusions from participating countries have been presented. They may not be directly comparable, as the outcomes may have been reached by way of different methods. To learn the details about the methodology used by each project partner, individual country reports should be consulted.

13.1 Flexibility

In literature, no consensus about a definition of flexibility could be identified. Therefore, here, three different measures have been utilised: First, the fraction of the day when the thermal comfort was maintained but the heat pump is not operating (to assess the capability to concentrate the heat pump operation times), the average length of the blocks with switched off heat pump (to assess the capability to shift loads in the other half of the day) and the electricity costs (to assess the capability to follow an external cost signal). (CH)

13.1.1 UK

Building fabric measures were found to have a greater influence on the amount of flexibility that could be achieved across different building types in the UK. Those specific factors investigated were thermal mass and thermal insulation. It was found that high levels of insulation were required to achieve more than a 1 hour DSR event in a typical UK house in a cold Winter period. Oversizing of the heat pump was the next most important factor and in some cases only a combination of increasing the flexibility with all three made 3 hour DSR events feasible without compromising the thermal comfort of the occupants.

13.1.2 Switzerland

The analysis indicated that a substantial improvement of the flexibility for heat pumps in smart grids is possible by the integration of thermal storages: the operation times can be more concentrated (the fraction of day without heat pump operation can be prolonged by up to 43 %), and long off-blocks can be achieved (the average length of an off-block can be almost tripled already with the integration of a small additional storage system and a predictive control system).

However, a drawback of the additional storage (in particular small volumes) is reduced heat pump efficiency, which limits the financial benefit of the flexibility enabled operation mode. Even if a highly dynamical electricity price such as the German Epex Spot price is considered, only energy cost reductions on the order of 20 % can be achieved. Given the small fraction of heating costs on the investment required for the additional thermal storage system and the higher capacity of the heat pump, long times for the return of investment are expected, which might hinder a broad adaptation of this approach. Therefore, incentives from electricity grid operators might be required to facilitate a widespread distribution.

For retrofitted old buildings (SFH100), the combination of heat pumps with thermal storages may improve the flexibility by up to 44 %.

For buildings with better isolation, the potential of flexibility optimisation is reduced (22 % for SFH45 – a single family house with an annual heating energy demand of 45 kWh/m2 corresponding to a modern building – and 24 % for an SFH15 – a single family house with an annual heating energy demand of 15 kWh/m² corresponding to a "Minergy" standard).

13.2 Load peak reduction

13.2.1 Denmark

The Danish project "eFlex" included 119 households with heat pumps. The customers were provided with a home automation system with an integrated control unit to interrupt the heat pump from operating during peak periods. The heat pumps were interrupted according to a price control scheme. The price was a combination of a spot market price, settled on North Pool day-a-head electricity market, a 3-step grid tariff and a regular public service obligation and tax fees. The price control scheme interrupted the heat pumps during price peak periods and released them to ordinary operation when prices decreased again. Simulations were made to show the impact and peak shaving effect on the grid when a large number of heat pumps where introduced on one feeder (i.e. a local stretch of the power grid).

The simulations regarding implementation of heat pumps in the grid, showed that the impact of interruption of heat pumps depends on the heat pump load in the grid and the configuration of the particular feeder in question. The simulation shows that noteworthy load shedding is taking place. The question is whether the load shedding is sufficient to significantly avoid a load peak and consequently postpone investment in grid reinforcement, compared to the investment required to initiate load shedding.

The simulation provides an estimate of the improved grid reserve capacity between 4 % and 9 %.

The Danish project shows that it is possible to perform a portfolio optimization that enables peak shaving of the consumption from the residential customers with heat pumps. By assuming a large penetration of heat pumps on a feeder containing residential customers can be conclude:

- The peak contribution from the normal household consumption is completely removed by the heat pump optimisation.

- The peak is reduced by approximately 18% in average for all household customers with heat pumps. The afternoon peak is reduced from approx. 4 kWh/h in the hour 18:00-19:00 to 3.3 kWh/h in the hour 23:00-24:00.
- The heat pump portfolio optimisation scheme can reduce the peak by 30% of the heat pumps own contribution in the peak.

13.3 Length of off-blocks

13.3.1 Denmark

In the Danish project, a total of 14 houses have been monitored in order to test the variation of the room temperatures. The heat pumps have been stopped in periods of different lengths - between 4 to 36 hours. Only periods where the stop is starting be-tween 4 pm and 5 am have been selected in order to minimize influence from solar gains in the first hours after the stop. Periods with ambient temperatures, less than 5 °C have been preferred but a few cases with ambient temperatures up to 8 °C have been included.
How long time a heat pump can be switched off depends in the investigated cases on the thermal capacity of the houses. The theoretical minimum switch off time with the room temperature still being comfortable can be calculated using knowledge on the time constant of the houses. The project shows that the off time for most off the house types are above 5-6 hours at 5°C and 2-3 hours at -12°C.
The possible switch off time of the heat pump will, however often be some hours longer than calculated using the time constant only, - especially if the house have be excess preheated – within the comfort band – prior to a switch off period. The reason for this is that the temperature of the house does not start to decrease right after the shutdown of the heating system as it takes time to cool down the heat emitters, - especially if the heat emitter is a heavy under floor heating system.

13.3.2 Switzerland

The Swiss study centers on residential heating systems with a single heat pump and a focus on single family houses of different building standard. To enable full-year simulations with high time resolution, the building dynamics as well as the behavior of the individual components have been modelled by analytical functions. Two different observation levels have been employed.
To quantify the potential of the system to shift loads over extended periods, the average length of blocks without heat pump operation is calculated. With this quantifier, the potential to shift loads over periods substantially longer than currently employed by utilities (shifts by 3 – 4 hours, at most 6 hours are customary) is explored.
Long off-blocks can be achieved. The average length of an off-block can be almost tripled already with the integration of a small additional storage system and a predictive control system.

13.3.3 UK

Current building fabric provides sufficient flexibility in combination with a 1°C internal temperature change to maintain thermal comfort during a 2 hour DSR, including during the coldest external temperatures in an average year. This therefore indicates heat pump installations in existing buildings could provide a useful level of flexibility without additional intervention. This hypothesis needs to be further tested with the full suite of building archetypes.

Standard construction with moderate levels of insulation (i.e. not more than cavity wall + loft insulation) is able to maintain thermal comfort with a 2 hour DSR event given a sufficient (4 hours) notice period and with a standard ASHP and no additional thermal storage. This comfort is maintained during an average cold winter period.
In order to maintain comfort during a 4 hour DSR event an oversized (+50%) heat pump is required alongside at least, an increased level of thermal storage, in this case through thermal mass of the building fabric (+20%).

Building fabric variables appear to have much stronger influence than heat pump capacity on whether the total system is able to maintain comfort during DSR events.

13.3.4 Austria

The potential HP-off-intervals (say for pooling) may be between approximately 5 h and 10 h but as the average ambient temperature goes below approximately -7°C the number of these potential HP-off-intervals drastically decreases. Due to the -- difficult to predict -- domestic hot water demand, it should be assured that the TES is loaded before suspending the HP operation over a longer interval.

13.4 Pooling of heat pumps

The flexibility of HPs is barely used in daily practice. A reason is surely that single HP units only offer limited capacity. Pooling of units is required to fulfil minimum requirements for market participation and allow for economies of scale. Hence, the technological approach used for integrating HPs must be cost efficient, reliable and simple enough to be deployed to a large number of units. Aggregators are seen as potential players that pool large number of HPs, to operate on markets or provide services to other actors in the power sector. For such aggregators, the question of how to control and operate a pool of residential HPs arises and finding an answer to this question is supported by the insights presented in this study.

Since individual HP units' electricity consumption is relatively small, pooling of a large number of HPs is required in order to actively participate in electricity markets or to provide services to the grid. Managing a pool of HPs requires fundamental knowledge about available power and energy as well as the response expected when controlled externally.

13.4.1 Germany

The external control signal that was used to trigger the different HP operation modes in the simulation bases on a discretization of the EEX[5] day ahead price for Germany from the year 2015. The threshold values that mark the price limits for each SG ready signal stage where chosen in a way that signal stage 2 is present 50% of the time of the year and that the time share of stages 3 and 4 is equal. Besides the relatively long signal durations which can reach up to 20 h the continuity of the EEX day ahead price only creates continuous changes in the signal stage. Neither does the signal stage change e.g. from 1 to 3 nor is a change from stage 4 to stage 1 possible. A simulation study using a pool of 284 HPs was conducted to examine the behaviour of the heat pumps. The SG-ready interface, which is implemented in over 900 market available HPs in Germany, was used for direct load control (DLC).

It was found that HPs sized according to today's procedures offer a significant electric shifting potential. The highest value was the 10.7 kWh per heat pump and load shift cycle. The availability of HPs for load shifting has a strong seasonal dependency, showing negligible shifting potential during summer compared to winter and changing season. An analysis of signal length leads to the conclusion that shifting intervals of between 15 min to 60 min are best suitable for HPs with respect to shiftable energy. For these signal durations, losses remain under 17% when not using the back-up heater. An analysis of the characteristic response showed further that shifting energy over a long period leads to losses up to 70%, depending on the SG-Ready signal used. The repeated application of trigger signals over a period of 12 hours leads to an increase in the amount of shiftable energy accompanied by a decrease in the annual load shifting efficiency by -15.6% on average.

At first glance using the back-up heater for load shifting seems an attractive option from the power system's point of view, as it yields high power and high shiftable energies, particularly for long activation times. However, using the back-up heater creates losses going up to 70% of the invested energy, generating additional costs.

A study of the characteristic response leads to the conclusion that achieving a constant increase in energy consumption over a period longer than 1-2 hours needs tailored control strategies, as the response towards an activation signal leads to a peak followed by a steady decline and a consecutive steady state phase. Furthermore, the regeneration period after an activation signal has to be considered, especially for the case of repeated triggering.

The SG-Ready interface allows more options for using the HP's flexibility than previously possible by just switching it off. This study shows, that the established control signals of SG-Ready offer a wide range of possibilities for DLC conducted by a pool aggregator and therefore are well suited to ease the integration of renewable energies into the grid.

13.4.2 Austria

In the Austrian report, it was shown that the flexibility from heat pumps can be used in a pool and at the household itself with a local smart control algorithm. Moreover, the direct control of a heat pump pool for balancing markets and the indirect coordination of several heat pumps that indirectly control themselves on the same price signals was analysed. The cases (heat pump and building configuration) were the same five cases for the analysis of the economic results of the pooling and the grid impact of the pooling, whereas the local control was modelled for one case. Both a local heat pump control as well as the central control by an aggregator shows economic benefits for the flexibility from the heat pump system. When the flexibility is used to lower the costs by reacting on day-ahead spot market prices, the saving potential of all heat pumps - on the

[5] European Energy Exchange spot market

energy part of the household energy price - is around 23-35% (pool simulation for cases 2a-4; EPEX Spot 2015) respectively 21-32% (local control; EXAA 2015) depending on the simulated case. Moreover, the flexibility can also be used to participate in the tertiary balancing market. To participate in this market, the pooling of heat pumps is necessary to fulfil prequalification requirements. In the tertiary balancing energy market the pool can generate higher revenues of 25 to 125 € per heat pump depending on the flexibility of the single heat pump for heating of normal and low-energy houses (case 2a-4) and on the bidding strategy.

The flexibility potential is very limited during summer (only limited flexibility form hot water consumption). Especially from June to August the potential for balancing markets is nearly zero and the potential for cost savings is limited as well. From November to March, the heat pump pool has the highest flexibility potential for both energy and balancing markets.

The results from performed grid simulations and calculations concerning heat pumps in low voltage grids show that an increasing penetration of heat pumps can have a negative impact on the supplying low voltage grid and may lead to grid congestions. No grid congestions were observed in the current and real heat pump penetration in the investigated grids – even if all heat pumps operate synchronised. In the future heat pump penetration scenarios, grid congestions were experienced in all grids via short term violation of voltage limits and overloading of grid assets. For this study, no grid reinforcement was assumed for the investigated grids, so these future heat pump penetrations scenarios are assumed to be realised in the “near future” in the next 10 to 20 years. On the long term, the DSO has to refurbish his grids every 50 years, and at this time a grid reinforcement can be done easily to make the grid fit actual and future requirements. The comparison of different heat pump operation strategies in the one year simulations showed that the impact of coordinated heat pump operation can impact the operation of the low voltage grid, but it poses not an immediate threat to system security in the analyses grids. Summing up, the already known fact was approved that a coordinated, synchronised behaviour of heat pumps can have adverse effects in low voltage grids compared to an uncontrolled autonomous operation of heat pumps. In real-life the DSO has not all information than that is available in the simulation environment, therefore, he will be more conservative. It must be stressed that the simulation results also showed a high sensitivity on the assumed simulation input parameters like load and generation profiles as well as heat pump characteristics and heat pump operation strategies. To obtain reliable results, more investigations have to be done in this topic.

When the heat pump is coordinated in a pool, aggregator and the households want to cover their costs and ideally want to have some profits. To have a positive busi-ness case the optimization and ICT connection cost from both aggregator and household have to be low. To have a business case for a longer period, it has to be ensured that the comfort settings of the customers are met. This has to be consid-ered when designing the architecture for the control of the heat pumps.

13.5 Load shifting potential

13.5.1 Germany

In the German study, different control strategies were examined in order to achieve load shifting. The set point temperatures of the heat storages were lifted during a specific period of time to increase the heat pump’s electric demand. These overheated heat storages are the key to reduce the electric demand during other time periods, but to do so it is necessary to keep the storage temperature at high level until the time to reduce the electric demand has come. In addition, several buildings are represented which differ by their construction type, BS-H volume and heat transfer system.

Four control strategies for load shifting were examined and analysed with regards to benefits (potential to shift load) and costs (reduction of efficiency). The control strategies were intended to differ in their load shifting potential.

In order to illustrate the load shift, the electrical power consumption was represented distributed by signal stage in which the energy was drawn. Regarding the effect on load shifting of the different strategies, the trend is the same with whatever strategy: the power consumption is barely reduced in stage 1 (the heat pump receives the signal to reduce the electric demand, any operation is stopped immediately but only as long as the storage temperatures are within the limits of the normal hysteresis, if the storage temperature falls below the hysteresis, the heat pump returns to conventional operation), while a consequent amount of the electricity consumption can be shifted from stage 2 (the heat pump is operated conventionally) towards stage 3 (the heat pump is supposed to increase its electric demand during the corresponding time period compared to conventional operation). Only the consumption in stage 4 (similar to stage 3 but with back-up heater) keeps increasing from control strategy A to D. The changes in building construction result in predictable differences of the absolute consumption values, but on a relative scale the observed trends are similar. Changes in the HPS equipment on the other hand seem to have a redundant role on load shifting based on the absolute as well as relative values.

The major share of the additional buffer storage losses can be assigned to the heat-ing period control and is not caused by enhanced heat transfer due to higher storage temperatures.

The longer the time span of increased set point temperatures lasts, the more heat has to be provided at this high temperature to compensate storage losses as well as heat demand of room heating and DHW. This reduces the overall efficiency of the heat pump system.

The smart operation leads to higher overall electricity consumption, mostly due to the decreasing HP efficiency and to the additional storage heat losses caused by rising the operating temperatures.

13.5.2 France

Even without buffer storage, air to water heat pumps offer a load shift potential matching the needs to curtail the daily peak demand in winter.

It would be relevant to be able to perform load control of heat pump systems in order to adjust the power consumption. Partial load would also allow increasing the duration of load shaving without degrading the comfort of the inhabitants. The impact of partial load on the heat pump efficiency has to be studied in detail.
Generally speaking, heat pump systems should be more flexible in order to support smart control which is not the case today.

14 Conclusion

As highlighted at the outset, the topic of smart grids is too broad and multifaceted to allow drawing overall and clear-cut conclusions. The picture is even more complex due to the fact that every country considers other aspects of the topic, addresses diverse problems and, accordingly, searches for different solutions, while defining various factors to express the results. Above that, various models and methods are used for these purposes.
Nevertheless, some interesting findings and results are discernible from the country reports. **Overall, it is clear, that heat pump technology will play an important role in the future energy system, colloquially called "smart grids".**

Three topics - flexibility, load shifting potential and length of off-blocks (times without the heat pump operation), are particularly closely connected, despite their individual specifics. Generally speaking, the flexibility describes how long a heat pump can be switched off without diminishing the comfort of the end users, or alternatively how much energy a heat pump can "absorb" from the grid, if forced to run.

The UK study underlines a **significant influence of building fabric on the amount of flexibility** that could be achieved across different building types. It was found that high levels of insulation were required to achieve more than a 1 hour DSR event in a typical UK house in a cold winter period. **Oversizing of a heat pump was the next most important factor.** In some cases, only a combination of the above increased the flexibility to 3 hour DSR events without compromising the thermal comfort of the occupants. From the other side, the current building fabric provides sufficient flexibility in combination with a 1°C internal temperature change to maintain thermal comfort during a 2 hour DSR, including during the coldest external temperatures in an average year. Thus, it may be concluded that **heat pump installations in existing buildings could provide a useful level of flexibility without additional intervention**.

The analysis from different countries indicated that a **substantial improvement of the flexibility for heat pumps in smart grids is possible through integration of thermal storages**: the operation times can be more concentrated and long off-blocks can be achieved (the average length of an off-block can be almost tripled already with the integration of a small additional storage system and a predictive control system). **However, a drawback of the additional storage** (in particular small volumes) **is a reduced heat pump efficiency**, which limits the financial benefit of the flexibility.

The Danish, Swiss and UK studies addressed the length of off-blocks. **How long a heat pump can be switched off depends predominantly on the thermal capacity of buildings**. The Danish project shows that the off time for most of the house types are above 5-6 hours at 5°C and 2-3 hours at -12°C outside temperature. The UK study shows that a standard construction with moderate levels of insulation is able to maintain thermal comfort with a 2-hour DSR event given a sufficient (4 hours) notice period and with a standard ASHP and no additional thermal storage. This comfort is maintained during an average cold winter period.
In order to maintain comfort during a 4-hour DSR event, an oversized (+50%) heat pump is required alongside an increased level of thermal storage, for example through thermal mass of the building fabric (+20%). A comparable result shows also the Austrian study, taking into account, however, a pooling aspect.

The German study underlines the universal relation - **a smart operation leads to higher overall electricity consumption,** mostly due to decreased HP efficiency and to additional storage heat losses caused by rising the operating temperatures.

The above paragraphs allow for the general conclusion, that **even without extra measures heat pumps can run flexibly to some extend,** allowing the load shift and/or off-blocks of several hours duration. Specific characteristic of a building or/and heating system, as well as additional elements, like a buffer storage, can increase the flexibility.

The behavior of heat pumps in the smart grid can be considered for a single unit or a pool of installations. The flexibility of HPs is barely used in daily practice. A reason is surely that single HP units only offer limited capacity. Pooling of units is required to fulfil minimum requirements for market participation and to allow for economies of scale.

When a heat pump is coordinated in a pool, aggregator and the households want to cover their costs and ideally want to have some profits. To have a positive business case, the optimization and ICT connection cost from both aggregator and household have to be low. **To have a business case for a longer period, it has to be ensured that the comfort settings of the customers are met.** This has to be considered when designing the architecture for the control of heat pumps. Particularly, the Austrian and German studies are addressing the topic of pooling heat pumps.

Both a local heat pump control, as well as a central control by an aggregator show economic benefits for flexibility of the heat pump system. When the flexibility is used to lower the costs by reacting on day-ahead spot market prices, the saving potential of all heat pumps - on the energy part of the household energy price - is around 21-35% depending on the simulated case (Austrian study).
Moreover, the flexibility can also be used to participate in the tertiary balancing market. To participate in this market, the pooling of heat pumps is necessary to fulfil prequalification requirements. In the tertiary balancing energy market the pool can generate higher revenues of 25 to 125 € per heat pump depending on the flexibility of the single heat pump for heating of normal and low-energy houses and on the bidding strategy.
Further outcome is that the **flexibility potential is very limited during the summer** (only limited flexibility from hot water consumption). Especially from June to August the potential for balancing markets is close to zero and the potential for cost savings is limited as well. From November to March, a heat pump pool has the highest flexibility potential for both energy and balancing markets.
The results from performed grid simulations and calculations concerning heat pumps in low voltage grids show that an **increasing penetration of heat pumps can have a negative impact on the supplying low voltage grid** and may lead to grid congestions. No grid congestions were observed in the current and real heat pump penetration in the investigated grids – even if all heat pumps operate synchronised. In the future heat pump penetration scenarios, grid congestions were experienced in all grids via short term violation of voltage limits and overloading of grid assets.
Apart from detailed considerations and results, **the technological approach used for integrating HPs must be cost efficient, reliable and simple enough to be deployed to a large number of units**.

Provided conclusions cannot be regarded as exhausting all topics and aspects addressed in the country reports. For instance, one may mention issues like control strategies, increasingly intermitting residual load, economy or load peak reduction. The comprehensive information in this respect may be found in the individual country reports.

Part V Demonstration projects

Smart heat pumps in the field

Table of contents for Part V

15 Summary

The demonstration projects that have been carried out in the participant countries are analysed with four key questions in mind (see box below). After the analysis of the market status (Part III), the identification of typical case scenarios (detailed in a separate Annex 42 report) and conducting several modelling studies (Part IV), these chapters discuss demonstration projects. A full list of demonstration project details is included with this document as a separate appendix.

Key questions:

1 What is the value of heat pumps for peak shifting and other demand side response (DSR) measures?
2 What control and influence methods, technologies and protocols are required to provide reliable DSR?
3 What is the response of customers to DSR events?
4 What is the technical potential of heat pump systems in residential buildings for providing flexibility to different elements of a smart grid?

This part summarises 36 case-studies for which a detailed summary was provided by the participants. In doing so we have found that the first three core questions have already been addressed in projects across different countries, but that there are differences with regards to the levels of detail to which they have been considered in each country. Only the fourth element, the technical potential of heat pump systems for demand response purposes has not been addressed in a significant share of projects (around 40%). Whereas we consider it likely that the building response is often understood on an individual building's level, little information seems to have been gathered as to what this means for the availability of demand response capability in the total residential building stock.

Some projects should be highlighted in this report, as they are particularly far advanced on the critical path to a smart heat pump system (see section 6.2). These are in particular the Dutch project "Energy frontiers Heerhugowaard" which has tested a full market framework and ICT platform for a smart grid system including heat pumps and other technologies, as well as the Swiss company TIKO which is one of the few companies already exploiting the value of heat pumps for demand response commercially (in Switzerland).

A key challenge that was common across many of the projects was related to the individuals participating in them. These challenges related on the one hand to the engagement of the participants in the trial and on the other hand on the perception of the demand response interventions. The varying results which were achieved across the summarised projects in both these fields suggest additional research is required. Both into how the engagement of individuals into demand response can be increased (or how disengagement becoming a barrier can be avoided) and how demand response interventions are commonly perceived by individuals and how they should therefore be presented to them.

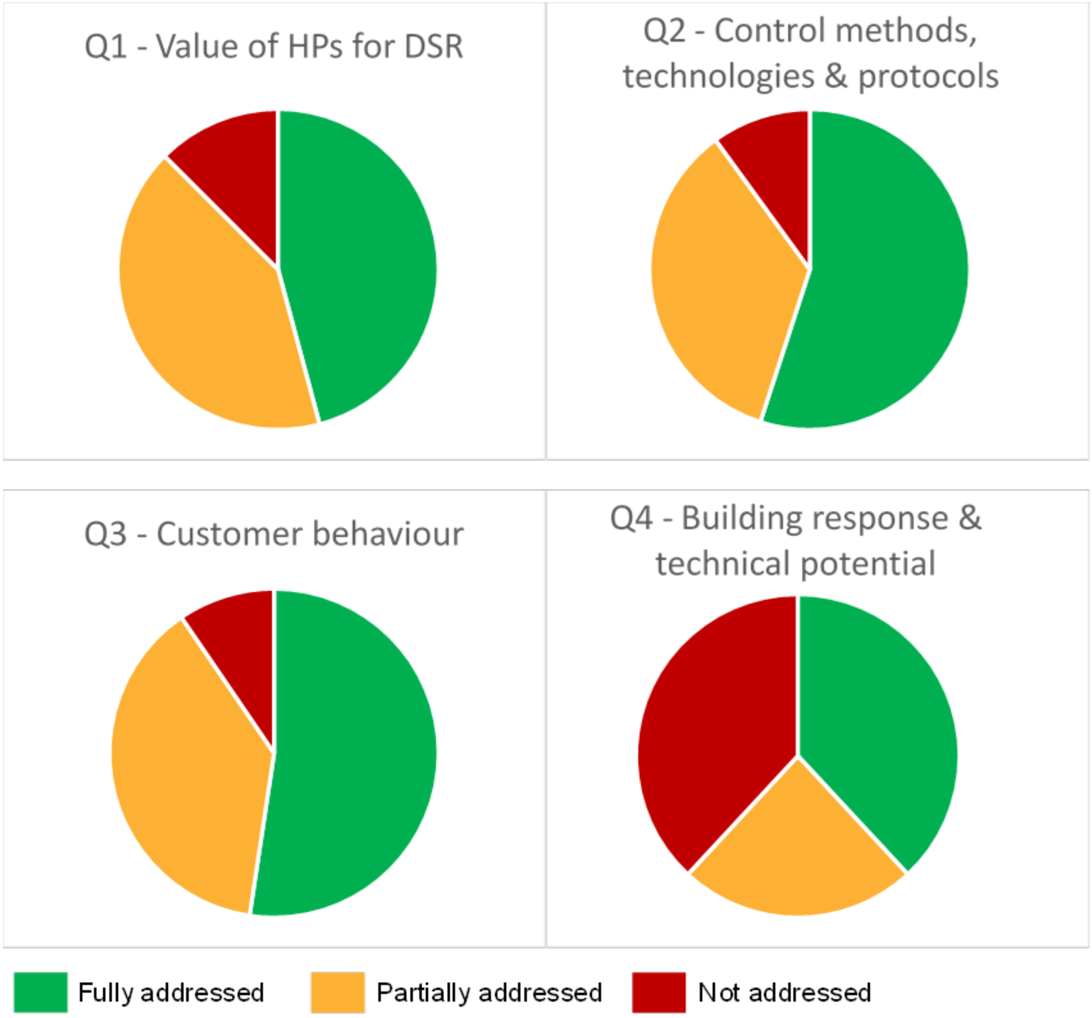
16 Analysing demonstration projects: Which of the core questions have been addressed in field projects?

Throughout the work on Annex 42 the participants have strived to bring answers to key questions regarding the use of heat pumps (HPs) in smart grids. These have been:

1 What is the value of heat pumps for peak shifting and other demand side response (DSR) measures?
2 What control and influence methods, technologies and protocols are required to provide reliable DSR?
3 What is the response of customers to DSR events?
4 What is the technical potential of heat pump systems in residential buildings for providing flexibility to different elements of a smart grid?

As part of Task 4 the Annex 42 participants have collected and summarised a range of 36 smart grid demonstration projects including heat pumps, which fully or partly addressed at least one of the key questions. The graphic below summarises the focus of the demonstration projects with respect to these key questions.

Figure 3 – Focus areas of demonstrations projects.



What becomes clear from the analysis is that questions one, two and three, regarding the value of demand response, the technical requirements of delivering it and the customer's role and response have been quite thoroughly tested, with around 90% of the 21 rated projects having fully or partially addressed these questions.[6]

Only the question of building response and the resulting technical potential for flexibility shows a larger share of around 40% of projects which have not addressed this topic at all. It is not completely clear what underlies this result. This suggests that there is still research potential in this area. Since demonstration projects are typically carried out in similar building types within one country (although they vary strongly from country to country, from relatively new buildings with large floor area, underfloor or other low-temperature heating systems, to existing buildings retrofitted with heat pumps in smaller social housing). The building-related technical potential has often been understood quite well in the individual building types, but the diversity of the building stock within and in between the different markets means that more research on a wider variety of buildings could be required to assess the total potential for flexibility from smart heat pumps in a particular country.

[6] Please note that this refers to projects where the rating has been submitted by the contributing authors only. Projects where the ratings were not available have not been considered in the analysis.

The following table provides an overview if and which of the core questions have been addressed by demonstration projects or commercial activities in the participating countries.

Table 5 – Core questions of Annex 42 addressed in demonstration projects.

++ Issue addressed in a robust way.

\+ Plan to address issue fully, but project not yet started / completed.

± Issue addressed on limited scale.

− Plan to address issue partially, but project not yet started / completed.

−− Issue not addressed at all.

Project	*Value of smart HPs?*	*Control methods, technologies & protocols?*	*Customer response?*	*Building response & technical potential for flexibility?*
AT – Austria				
SCDA	±	++	++	++
SMGS Hit	++	++	++	++
CH – Switzerland				
WARMup	N/A	N/A	N/A	N/A
Tiko	N/A	N/A	N/A	N/A
Gridbox	N/A	N/A	N/A	N/A
GridSense	N/A	N/A	N/A	N/A
SoloGrid	N/A	N/A	N/A	N/A
Adaptricity	N/A	N/A	N/A	N/A
Lucerne UASA	N/A	N/A	N/A	N/A
DE – Germany				
EnVisaGe	N/A	N/A	N/A	N/A
Flexible Power-To-Heat	N/A	N/A	N/A	N/A
DK – Denmark				
READY	++	++	++	++
EcoGrid 2.0	±	++	++	++
Control-Your-Heat-Pump	−−	±	±	±
HEATUP	+	+	+	+
HPCOM	−−	+	−	−
Demonstration of new business model for sale of heat from heat pumps	++	±	±	−−
DREAM – Phase 1	+	−−	+	−−
FR – France				
PREMIO	±	±	±	−−
Smart Electric Lyon	−	−	−	−−
EDONICE	++	++	±	−−

Project	*Value of smart HPs?*	*Control methods, technologies & protocols?*	*Customer response?*	*Building response & technical potential for flexibility?*
NL – The Netherlands				
Couperus smart grid	±	±	−	++
Energy frontiers Heerhugowaard	±	±	++	−
Ice of Columbus	±	±	−	±
Powermatching City II	++	±	++	±
KR – South Korea				
Jeju Smart Grid Test-Bed	N/A	N/A	N/A	N/A
Jukdong Zero Energy House	N/A	N/A	N/A	N/A
Jincheon eco-friendly energy town	N/A	N/A	N/A	N/A
UK – United Kingdom				
NEDO	+	+	−	+
Low Carbon London	−	−	±	−
Customer Led Network Revolution	++	++	++	++
Seamless	++	++	++	±
FREEDOM	+	+	+	−
US – United States of America				
Commercial HVAC Advanced DR	N/A	N/A	N/A	N/A
Next-Generation Residential HPs	N/A	N/A	N/A	N/A
Controllable HP Water Heaters	N/A	N/A	N/A	N/A

17 Which smart HP interventions have been tested in the different projects?

Another key differentiator with regards to the various demonstration projects and commercial activities which have been or are being carried out in the participating countries of Annex 42 are the types of smart HP interventions and topics have been tested. The clear “winners” in this category are peak shaving and shifting, as well as the use of dynamic tariffs as a reason and/or means to control the HPs.
With regards to the applied control methods, 14 projects opted for direct control of the systems, whereas 17 projects used automated response (some projects used more than one type of control method).

Seven smart HP intervention types were differentiated across the various projects summarised by the national contributors to Annex 42:

- Peak Shaving / Shifting: Moving demand peaks to hours with lower demand or shedding the demand without “replacing” it (“shaving” the peak off). This is usually used to avoid overloading individual network sections which could lead to power outages.
- Standardised ICT Infrastructure: A range of projects focused on the development, implementation and use of standardised ICT infrastructure, a key enabler of a future smart power system.

- Dynamic Tariffs: Hourly or half-hourly priced tariffs, with the price structure varying in response to the expected demand and supply (in particular from renewable generation), usually using day-ahead pricing.
- Renewables Integration: The increasing supply of inflexible power generation from renewable energies will require flexibility on the demand side (and from other generators) to avoid curtailment of generation. This can be at system level, but in many of the projects summarised in this report is done at building level, for example through maximising the self-consumption of PV electricity generated on site.
- Load Aggregation: Generally, demand response requirements on a wider network level are far bigger than the flexibility provided by individual customers (Mega-Watts as opposed to Kilo-Watts). For customers to be able to participate in demand response their flexibility needs to be pooled by an aggregator and offered on the demand response markets as a solid block. This also helps increase reliability of the DR.
- Islanding/Autonomy: This intervention type focuses on reducing the reliance on the grid as far as possible, through increasing self-consumption of renewable electricity generated on site. This is achieved by shifting demand and often also in combination with heat and/or battery storage technologies.
- Business Models for DR: A successful smart HP system will require business models to be established to pay for the management of the system and distribute the value generated by offering the flexibility.

Table 6 – Smart HP intervention types.

Project	*Peak Shaving / Shifting*	*Standardi-sed ICT Infrastruc-ture*	*Dynamic Tariffs*	*Renewa-bles Integra-tion*	*Load Aggrega-tion*	*Islanding / Autonomy*	*Business Models for DR*
AT – Austria							
SCDA	●		●				
SMGS Hit			●				
CH – Switzerland							
WARMup			●				
Tiko	●		●		●		●
Gridbox	●					●	
BKW Home Energy	●			●		●	
GridSense	●			●		●	
SoloGrid	●		●			●	
Adaptricity	●					●	
Lucerne UASA	●		●			●	
DE – Germany							
EnVisaGe	●			●	●		
Flexible Power-To-Heat	●		●	●			
DK – Denmark							
READY	●		●		●		
EcoGrid EU 2.0			●		●		
Control-Your-Heat-Pump		●					
HEATUP		●	●				
HPCOM		●					
Demonstration of new business model for sale of heat from heat pumps							●

Project	*Peak Shaving / Shifting*	*Standardised ICT Infrastructure*	*Dynamic Tariffs*	*Renewables Integration*	*Load Aggregation*	*Islanding / Autonomy*	*Business Models for DR*
DREAM – Phase 1			●				
FR – France							
PREMIO	●		●		●		
Smart Electric Lyon	●		●				
EDONICE	●						
NL – The Netherlands							
Couperus smart grid	●		●	●			
Energy frontiers Heerhugowaard	●		●	●			
KR – South Korea							
Jeju Smart Grid Test-Bed			●	●			●
Jukdong Zero Energy House				●			
Jincheon eco-friendly energy town				●			
UK – United Kingdom							
NEDO	●	●			●		●
Low Carbon London			●				●
Customer Led Network Revolution	●		●	●			
Seamless			●				
FREEDOM	●		●				
US – United States of America							
Commercial HVAC Advanced DR	●						
Next-Generation Residential HPs	●						
Controllable HP Water Heaters	●						

18 What have been the common themes across the projects?

The analysis of the key findings and challenges of the projects summarised by the Annex 42 participants has shown that there is one key challenge many of the projects have in common – the customer. Other recurring topics are of a more technical nature and relate mainly to a lack of standardisation and protocols for DR as well as the challenge of integrating automated- and direct control platforms with the controllers of the HPs.

Customer related challenges

Understanding the customers / participants in the trials, anticipating their behaviour and planning for its integration into the trial seems to be a key challenge for many trials.

Engagement is one key area where differences between the trials can be observed. On the one hand customers in some trials were found to have “small understanding and interest in heating technologies” (DK

Business Model demonstration), and were often found to show low levels of engagement (Couperus, NL; LCL, UK; CLNR, UK). On the other hand, some trials report that customers “were interested in the project and gave a positive feedback” (Control-Your-Heat-Pump, DK), or there was “very positive customer engagement and response as they were strongly involved in the trial” (EFH, NL). Understanding better what differentiates these two diverging attitudes towards heating and the smart HP projects could provide important insights into if and how customer engagement with those technologies could be improved, e.g. by tailoring the message and incentives better to the target audience.

Another key area where a more in-depth comparative analysis of the different projects could provide important learnings on how to successfully implement smart grid solutions is the customer’s response to and experience to DR events and the smart technology. Here some stark differences were observed.

Several trials report that:
- customers did not perceive any disruption to their comfort (TIKO, CH; SCDA, AT)
- or measured success through customers not overriding the remote heating control function (PREMIO, FR).

Other trials on the other hand found that their control systems were
- blamed for small comfort level violations (although these were apparently at least partly due to customer behaviour, SMGS Hit, AT or READY, DK)
- did not sufficiently make clear the value from the controlled operation of the HP (CLNR, UK)
- or were generally perceived as “obscure and complex” (DREAM, DK).

Understanding how to improve this perception of DR could prove to be the key to the further deployment of the technology in the residential sector.

Part VI Reference material

Table of contents for Part VI

A List of participants

Table 7 – Participants in the Annex 42 working group

Country	*Organisation*	*Organisation type*	*Name*
NL	BDH	Consultancy, *operating agent*	Peter Wagener
NL	BDH	Consultancy	Dennis Mosterd
NL	BDH	Consultancy	Paul Friedel
NL	Alliander	DSO	Vincent Dekker
NL	Alliander	DSO	Rob Goes
NL	TNO	Research institute	Richard Westerga
AT	TU Graz	University	Martin Pichler
AT	Austrian Institute of Technology	Research institute	Andreas Zottl
AT	Austrian Institute of Technology	Research institute	Tara Esterl
CH	Hochschule Luzern	University	Jörg Wörlitscheck
DE	Fraunhofer ISE	Research institute	Danny Günther
DE	Fraunhofer ISE	Research institute	Marek Miara
DK	Danish Technology Institute	Research institute	Svend Pedersen
FR	EdF	DSO	Anne-Sophie Coince
KR	Korea Institute of Energy Research	Government	Gilbong Lee
UK	Dept. for Business, Energy & Industrial Strategy	Government	Oliver Sutton
UK	Delta-EE	Consultancy	Lukas Bergmann
US	Electric Power Research Institute	Research institute	Ron Domitrovic
US	Oak Ridge National Laboratory	Government	Van Baxter

B Additional documents

1 Market status summary per country
- 1.a Market overview Austria
- 1.b Market overview Switzerland
- 1.c Market overview Germany
- 1.d Market overview Denmark
- 1.e Market overview France
- 1.f Market overview South Korea
- 1.g Market overview Netherlands
- 1.h Market overview United Kingdom
- 1.i Market overview United States

2 Case scenarios per country

3 Overview of demonstration projects

C Glossary

Table 8 – Commonly used abbreviations

Abbreviation	*Definition*
BRP	Balancing Responsible Party
COP	Coefficient of Performance (of a HP)
DHW	Domestic Hot Water
DR / DSR	Demand Response / Demand Side Response
DSO	Distribution System Operator
(S)HP	(Smart) Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
RE(S)	Renewable Energy (Sources)
SG	Smart Grids
SH	Space Heating

SPF	Seasonal Performance Factor (of a HP)
ToU tariff	(flexible) Time of Use tariff
TSO	Transmission System Operator

Table 9 – Heat pump type indicators

Code	*Meaning*
A	(outside) Air
B	Brine (ground source)
E	Exhaust air
W	Water

e.g. A/W = air-to-water system
E/A = exhaust air-to-air system

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