# Heat pumps connected to the smart grid
## *What is the potential, and why do we need it.*

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**Abstract:**
This paper describes the role that heat pumps can fulfill in and peak shaving and managing the load of electricity grids generated by renewable energy sources. Much R&D is already being performed, but there is much more to explore in this field. This paper tries to give an overview of these developments.
The current developments in smart grid projects are discussed, after which we investigate the combination of thermal grids and electricity grids, where heat pumps are the linkage between those two. After that we elaborate on why and how heat pumps can be connected to a smart grid and the potential it can bring to flexibility of the electricity grid.
Consequently we follow with an insight in Annex 42 from the Heat Pump Program of the International Energy Agency (IEA), which is specifically organized around this topic and currently running. That insight will also give an overview of projects that have to do with the subject. Finally this paper will provide some guidance of what should be developed to connect heat pumps into smart grids successfully and make the most use of its possibilities.
There is no doubt this paper will be non-comprehensive and partially or sometimes even incomplete, therefore all readers are encouraged to send in remarks, important projects we oversaw, or scientific developments in this field. Since we as the Operating Agent of Annex 42 are the authors of this paper, and will process al valuable input into the discussions with the participating countries; South Korea, The Netherlands, France, Denmark, The United Kingdom, United States of America, Germany, Austria and Switzerland.

**Key words: Heat pumps, smart grids, demand management, peak shaving, flexibility, energy storage.**

## 1 Introduction

### 1.1 Introduction of what heat pump technology can bring to the development of smart grids.

This paper describes the role that heat pumps can fulfill in managing the load of electricity grids generated from renewable energy sources and peak shaving. Much research and development (R&D) is already being performed, but there is much more to explore in this field. This paper tries to give an overview of these developments.

The current developments in smart grid projects is discussed in paragraph 1.3. Paragraph 1.4 discusses the combination of thermal grids and electricity grids, where heat pumps are the linkage between those two. Chapter two elaborates on why and how heat pumps can be connected to a smart grid and the potential it can bring to flexibility of the electricity grid. The following chapter is an insight in annex42 from the Heat Pump Program of the IEA, which is

specifically on this topic and currently running. The fourth chapter will give an overview of projects that have to do with the subject. Chapter five will give some guidance of what should be developed to connect heat pumps into smart grids and make the most use of its possibilities.

There is no doubt this paper will be non-comprehensive and incomplete , therefore all readers are encouraged to send in remarks, important projects we oversaw, or scientific developments in this field. Since we, the authors of this paper, are the operating agent of annex42 we can use this information to be put into discussion with the participants.

## 1.2 The impact of heating

Fossil fuel is still our main source of energy and the effect is an unsustainable world with a rising temperature. Decarbonisation, energy-efficiency, roadmaps and technology policies all indicate that our world is in need of a sustainable energy system in response to climate change. Every day thousands of professionals are working to achieve of facilitate the transition to a sustainable energy system so there is no doubt that this is already a substantial industry. But most studies, outlooks and scenario's also indicate that this transition is currently at a to slow pace to meet the goals set by the European Union[1].

There are two main options to achieve a sustainable world: 1) reduce our need for energy , 2) generate energy sustainable. Heat pumps can do both by reducing the amount of final energy needed for heating by utilizing renewable energy (heat) sources from e.g. outside air, soil, ground- or surface water. Furthermore heat pumps have the potential to be fully sustainable if the electricity for heat pumps is generated by renewable energy sources (RES's)[2]. The final energy consumption used for heating is about 47% of the total world consumption so the potential for heat pumps is substantial[i] to reduce this AND open the possibility to generate heat fully sustainable.

## 1.3 Smart grids and smart grid projects

RES's such as wind- and solar power generate electricity which in short term is predictable, but not controllable like hydro power, gas fired turbine's and coal power plants. Wind and solar power are so called Intermittent Renewable Energy Sources (IRES). This introduces a new challenge to the TSO's and DSO's transporting and distributing electricity over the grid; the supply of IRES does not follow the demand for energy and can be produced locally. This sparked a whole new area of R&D to develop smart grids; an electricity grid that is flexible and can balance supply and demand by monitoring and controlling supply AND demand.

[1] For instance the 20-20-20 goal to reduce greenhouse gas emissions in 2020 by 20% from 1990 levels, raising renewable generated energy consumption to 20% and a 20% improvement of the energy efficiency and the 2050 roadmap to reduce greenhouse gas emissions by 80% in 2050 from 1990 levels and for electricity generation almost 100% in 2050.

[2] There are several other types of heat pumps which use a different 'fuel' to drive the heat pump for instance natural gas or waste heat, but they are not part of the scope in this paper.

The main focus today in terms of budget spent in this field is on smart meters[ii], but smart grids are much more than that. The term 'smart grids' is a broad term with different definitions but in general smart grids can be described as described in the table underneath.

| What can smart grids bring or do? | And how? |
|---|---|
| Integrate:<br>• more renewable energy sources<br>• electric vehicles<br>• local generation | Demand response |
| More efficient and reliable, can prevent or restore outages | Automatic grid reconfiguration |
| Consumer control over consumption & participate in the e-market | Comprehensive monitoring and controlling energy flows |

*Table 1: Different aspects of smart grids*

In general grids are made smart by making the components in the grids, including generation and applications, smart. And the components are made smart by adding information and communication technology (ICT) to it.

The need for smart grids and smart grid technologies is also stated by a recent study on impacts of large-scale Intermittent Renewable Energy Sources: *"New technologies and demand side management is needed to increase system flexibility when modeling low-carbon systems."*[iii]

The Joint Research Centre (JRC) made an overview of smart grid projects in Europe with the following main conclusions:[iv]

1. 281 smart grid projects were identified across 30 countries with a total investment of €1.8 billion and €0.5 billion in 2011 alone.
2. The budgets per project are growing, from 27% in 2006 to 67% in 2012 of projects with a budget larger than €20 million.
3. The UK, Germany, France, Italy and Denmark are the most active investors in smart grids, mainly led or initiated by DSO's and utilities. Aggregators and retailers play a limited role.
4. 23% of the smart grid projects are focused on consumer engagement with typically up to 2000 consumers involved, mostly volunteers. Consumer resistance in participation is still significant and acknowledged as key issue in multinational projects. Denmark and Germany are leading with projects focusing on consumer engagement. The main factor for motivating consumers is reduction of the energy bill and environmental concerns.
5. Almost all of the budget is funded, 55% of the total budget comes from non-private capital. The limiting factor for private investment is uncertainty over the business case for smart grid applications,

6. The uncertainty of the business case is invoked by:
   Policy related or non-technical barriers:
   a) A lack of standardized control and communication solutions.
   b) No clear defined roles and responsibilities in new smart grid applications.
   c) The sharing of costs and benefits among participants.
   d) Consumer resistance to participation in trials.
   e) The range of regulatory arrangements in Europe hampering replicability of project results in different countries.
   f) The need for new contractual arrangements

   Technical barriers:
   g) Clear rules for technical validation of flexible supply/demand transactions by system operators
   h) Technical and commercial arrangements for the exchange of physical and market data
7. Focus on storage as an flexibility option is one of the key themes of the main projects started in 2012.

From these main conclusions it can be derived that the stage of European smart grid development is in the R&D phase with demonstrations on a small scale. The main issue is that through solutions on a micro scale, a macro problem is trying to be solved, with no real benefits on a micro scale (which is a classical system failure of technical innovation systems).

Demand response appliances and smart meters are solutions to solve the problem of integrating more IRES and distributed energy resources (DER), on first sight the problem of TSO's and DSO's, which have no direct benefit for consumers. Consumers that will always look for the most simple solution, together with the installer.[v]

It is essential valid business models are developed to create benefits for consumers or policy measures are taken, otherwise the large scale roll out of smart grids will have a substantial delay. Countries that already encounter curtailment [3]of RES, such as Denmark and Germany are therefore pushing to roll out smart grids and seek business models to attract the consumer to participate.

The development path of smart grids is not an R&D path for a single technology and it is not straightforward. The large-scale roll out of smart grids demands a paradigm change where a multitude of new and existing technology's from different fields are developed, combined and integrated to facilitate the transition to a smart grid. Therefore international collaboration, integration and standardization is much more important than in a technology development path where the technology is not an integral part of a larger system.

[3] Curtailment is the effect that total amount of installed capacity of a IRES is higher than the grid can accept to maintain system security of the grid, because some non-RES units must be necessarily dispatched due to security or system constraints.

## 1.4 Heat pumps as a link to a 2nd energy circle

In the above mentioned paragraphs it is identified that heat is a substantial part of the world energy consumption and electricity grids have to be converted to communicating smart grids. Smart grids can also be referred to as an energy circle, since supply and demand are connected throughout the grid and energy flows between it directed by communication technology. This means , although in much of the research and projects being done are focused on electricity grids, this *does not have to mean an electricity grid per se*. A thermal grid with appliances generating heat (or cold) or extracting it on a shared thermal distribution grid can also be made smart: communication an monitoring of all the appliances or the behavior of the building, outside temperature, forecast etc. to distribute thermal energy. This could be referred to as the 2nd energy circle.

The advantage of the 2nd energy circle is that it is much easier to store energy in this grid and 'smart' technologies are for the large part already widespread common technologies. Almost every building with heating uses a thermal hydraulics grid to distribute heat. Furthermore a thermal grid is simpler in behavior; temperature, pressure and flow are the main aspects, where electricity has phases, frequency, ground, voltage and current to control. The Renewable Heating and Cooling platform (RHC) has released an strategic research innovation agenda (RHC-SRIA) where so called cross-cutting technologies[4], need to be developed on a technology roadmap. Large scale demonstration of smart thermal grids and next generation sensible energy storage is put on the agenda for 2014 – 2016, which endorses the above mentioned point.

Heat pumps can generate heat and cold with electricity with the additional use of thermal-RES. This means heat pumps are a very effective, so not the only interesting, linkage between the two energy circles, electricity and thermal grids. Furthermore it provides the possibility to store electrical energy from IRES very effectively and making the 1st energy circle much more flexible. Another advantage of the 2nd energy circle is that is does not have to be a large scale grid to function, this means roll out of these smart grids is simpler and had to do with less parties involved.

Or, as Heinrich Huber, deputy head of Sustainable Thermal Energy Systems from the Austrian Institute of Technology (AIT) states:
*"A new generation of intelligent networks based on real-time bi-directional communication between generators, consumers and storage facilities. Urban smart grids will, in the future, include both electrical and thermal networks and incorporate heatpumps as interfaces between these networks.*[vi]*"*

[4] RHC defines cross-cutting technologies as: District heating and cooling, thermal energy storage, hybrid systems and heat pumps.

## 2 Heat pumps connected to smart grids

### 2.1 Why should heat pumps be connected to a smart grid?

As described in chapter one, heat pumps have a substantial potential for generating heat and are the link between smart energy grids and the 2nd energy circle, smart thermal grids, where storage is a viable option. This means both peak shaving as well as demand response is possible on an aggregated large scale with heat pumps.

Thomas Nowak, the secretary general of the European Heat Pump Association (EHPA) also endorses this[vii]:
*"Properly designed and managed grids will help to avoid, and eventually overcome, inefficient use of energy and energy waste. Most, if not all, heat pump systems include thermal storage, and all of them have a control unit. If properly designed and connected, these two components make heat pumps the perfect enabler for future smart cities. Heat pumps can store superfluous surplus electricity in the form of thermal energy. Depending on their design, heat/cold is stored in tanks, in the ground, in floor/wall heating systems or in concrete cores using the mass of the building. Smart heat pump systems are distinguished from their standard variants by the ability to incorporate user behavior, climate data and pricing signals into their control systems. Operating them when (cheap) surplus electricity is available will avoid this electricity being wasted. Operating them in off-peak hours will reduce peak-load demand. Over time, they build up a picture of energy supply and demand patterns inside and outside their own building boundary. Adding all this information together contributes to an improved overall system understanding. If grid operators knew when and where storage facility is available, it would be possible to integrate much larger shares of wind and solar electricity. While 'the advantage of smart' has been demonstrated in several studies, the majority of today's heat pumps cannot properly communicate with their surroundings. This lack of understanding goes both ways: most grids do not provide pricing signals and are not equipped to receive and analyze information from heat pumps."*

## 2.2 Heat pump technology implementation and storage

An integrated approach is essential when implementing heat pumps as well as implementing smart grids. The above given approach is for implementing just one heat pump into a home.[viii]

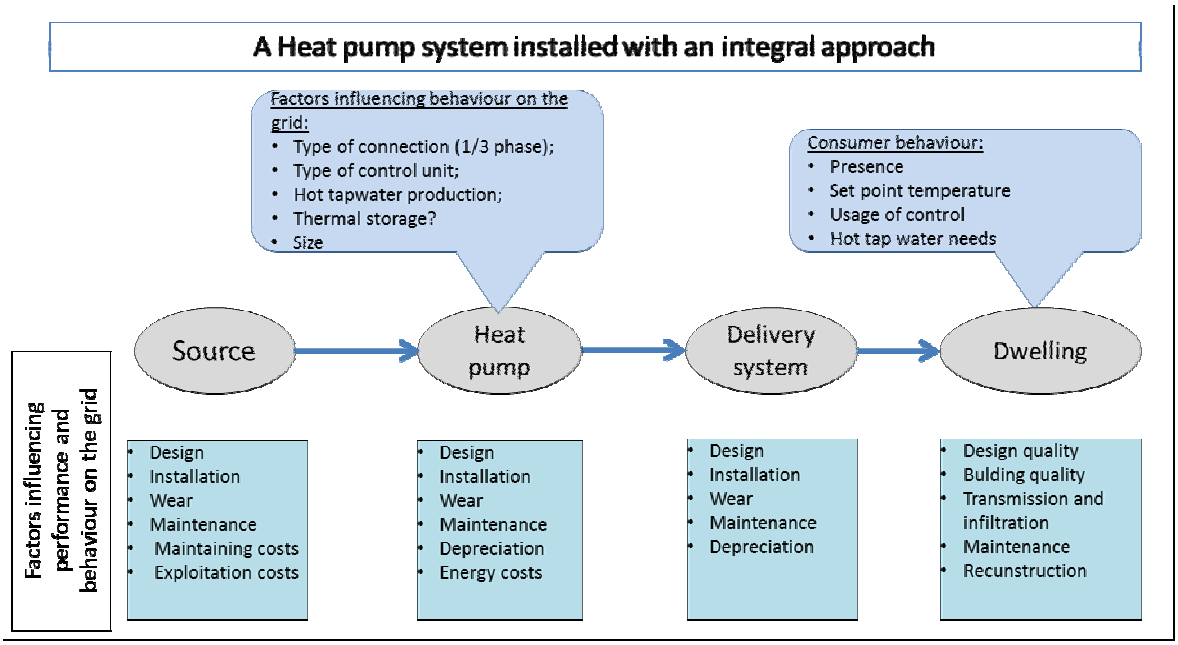



*Figure 1: Overview of aspects and factors influencing the behaviour of a heat pump on the grid*

An integrated approach also implies that you look further than a single dwelling. What could a HP do in a neighborhood setting, combined with E-mobility, CHP, demand management, on-site RES etc.

Pitfalls:

1. Automating small problems into big ones (automation amplifies the good, the bad and the ugly)
2. Technical integration is not straightforward (understand each other and cooperation is crucial → protocols and standards)
3. Ignoring change management (new technology, new integrations will result in new processes which ask for training and expectation management)

## 2.3 Smart heat pumps

Not only the grid, but also the heat pump needs to be smart to fully utilize possibilities for demand side management. The smarter a heat pump is (more functionality, control and communication options) the bigger the opportunities when it is integrated in a smart grid. Therefore several 'levels of smartness' can be identified for heat pumps. The table underneath presents several aspects of smart heat pumps.

| 'Smart' aspect | Dimensions |
|---|---|
| Heat pump functionality | Inverter-driven compressor which can ramp down rather than switch off |
| | On/off |
| Control strategies: building thermal mass & storage | Pre-heat algorithms |
| | 'Learning' building thermal response |
| | Optimising integration with storage |
| Control strategies: outside environment | Weather compensation & variable capacity |
| | Responding to weather forecast data |
| Control strategies: energy price | Responding to dynamic price signals |
| | Responding to pre-set price (& CO2 signals?) |
| Communication capability | 2-way communication |
| | 1-way communication |
| Speed of response to communication signal | Dynamic response (minutes) |
| | Needs advanced notice (hours/days) |
| Communication protocol | |
| | |
| | |
| Thermal storage | Sensible heat storage (water tanks) |
| | Advanced heat storage technologies e.g. phase-change materials |
| Integration with 2nd energy source | bivalent system with set-point control to switch from HP to other source |
| | hybrid which can switch between energy sources according to price, $CO_2$ |
| | Sophisticated controled hybrid heat pumps which can switch between sources in response to dynamic tariffs. |

*Table 2: Different options how to make a heat pump 'smart'*[ix]

## 2.4 The scale of things; a simple example

To illustrate what the potential is for demand response when heat pumps are connected to the grid, some simple example calculations has been made to illustrate effects.

### 2.4.1 Switching from gas fired boiler to an electrical heat pump

The effect for heating a typical Dutch single family detached home with hot tap water production on the electricity connection when switching from gas fired boiler to an electrical heat pump with a water boiler storage is shown underneath.[x]

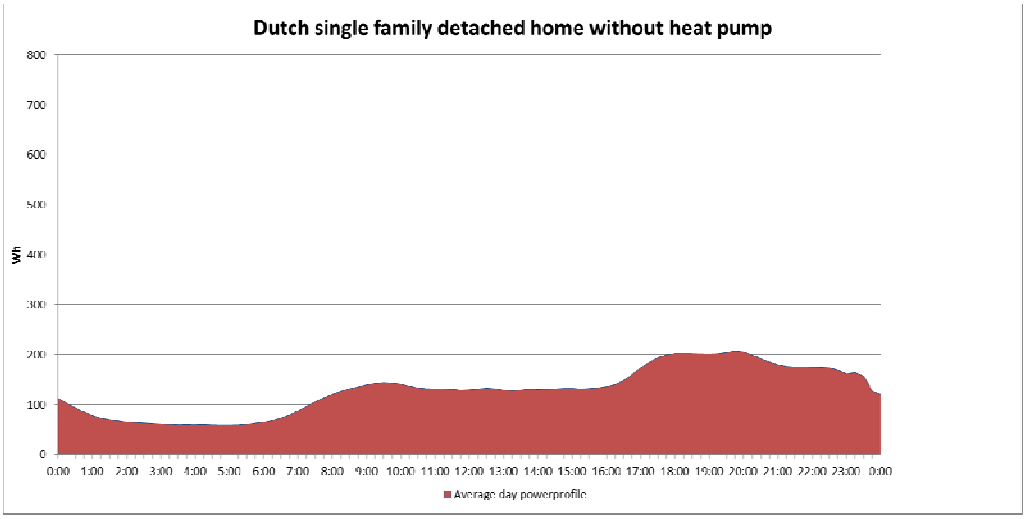



*Figure 2: The average daily household power consumption profile of a Dutch single family home*

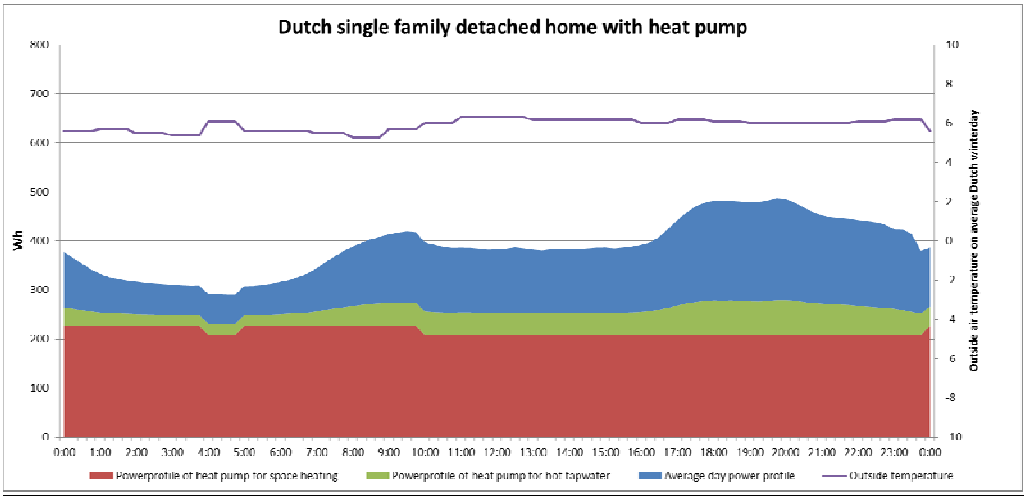
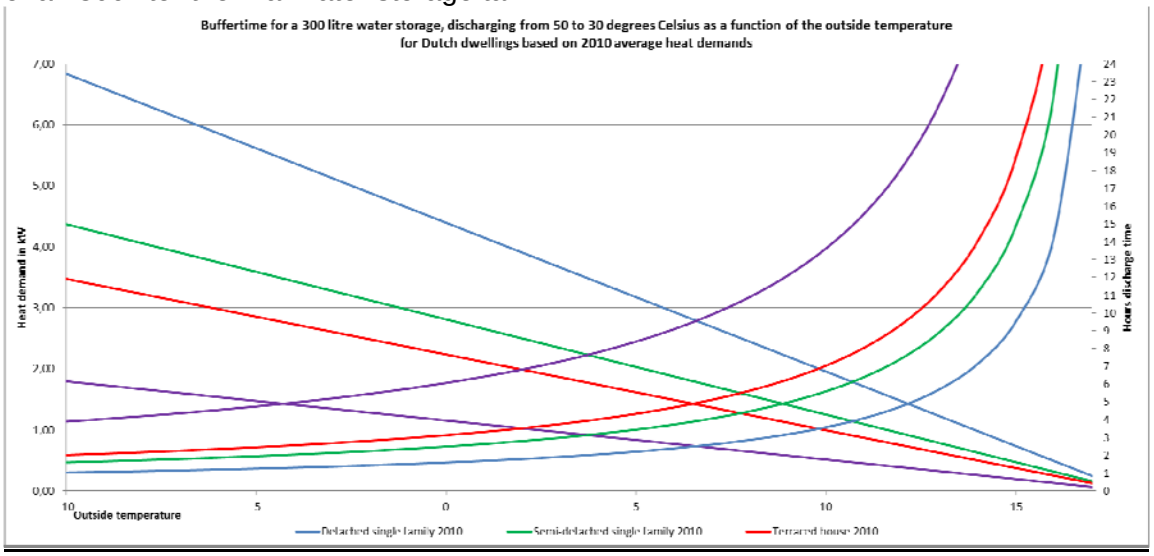



*Figure 3: The average daily household power consumption profile of a Dutch single family home, where heat- and hot tapwater demand have been added in terms of electrical power consumption from an installed heat pump on an average winter day*

Note that this is a theoretical power profile based of an average singe family household, based on the demand for electricity, heat and domestic hot water. Actual behavior of a heat pump will differ greatly from the type of control, size of the heat pump, delivery system, building mass, etc. etc. The graphs are to show that the impact on the average power demand when switching from a gas fired boiler to an electrical heat pump is considerable. It also implies that if storage can provide for a shift of a few hours, the entire typical peak in the evening can be shifted to midday or night.

### 2.4.2 The effect of insulation on heat demand and buffer time

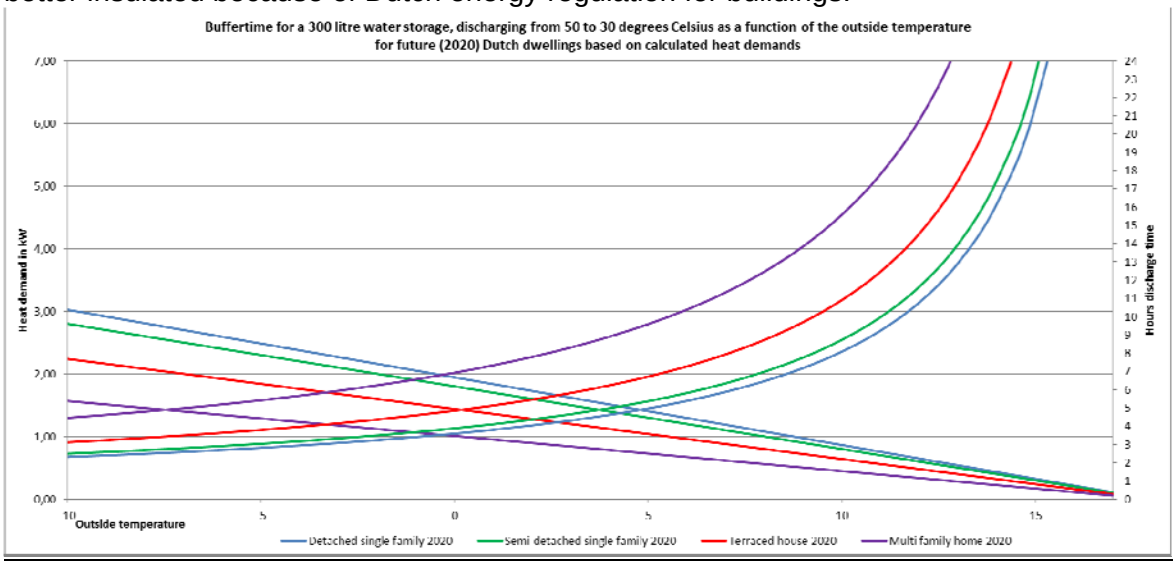
The average Dutch building stock can be characterized into four types of residential dwellings; Detached single family, semi-detached single family, terraced housings and multifamily homes. These housings have different heat demands, since transmission surface differs (among other factors). The graph underneath illustrates what the effect is of differences in building stock and the effect of the outside temperature on the discharge time of an 300 liter thermal water storage tank. [xi]




On the x-axis the ouside temperature is shown in degrees Celsius from -10 to 18°C. The left Y-axis shows the heat demand in kW and the right Y-axis shows the discharge time in hours. The straight lines are the heat demands for the different type of dwellings, lower outside temperatures require higher heat demands. The curved lines show the discharge times for the different type of dwellings. The higher the outside temperature, the lower heat demand and this results in longer discharge times.

Again this is to illustrate effects, for instance heat loss of the boiler and hot tap water production is not taken into account. It does clearly show the large differences in the building stock.

The same graph is produced but now for future building stock. Newly build homes are much better insulated because of Dutch energy regulation for buildings.




It clearly shows that discharge times rise and therefore also the potential for shifting demand.

## 3 Annex 42: Heat pumps in smart energy grids

### 3.1 Why this annex and who is in?

In the executive committee (ExCo) of the Heat Pump Programme (HPP) of the IEA it was admitted that heat pumps in smart energy grids is an undeveloped area of research. It is not the technological research that forms a barrier; much technological research is being done in this field. But the integration of heat pumps in smart grids and the potential it can bring is where more development is needed. Heat pumps in smart grids encounter the same challenges as stated in paragraph 1.3; uncertainties in the business case invoke for the large part non-technical or policy related barriers.[xii]

This called for the need for the definition of a new annex, annex42: 'Heat pumps in smart energy grids'. It was put into effect with the first meeting in the renewable energy house in Brussels on the 16th of May 2013. The operating agent is Business Development Holland. It seems an very important topic since more than ten countries have joined this annex. Underneath the countries and institutes that have joined annex42 can be found.

| **Country:** | **Institute:** | **Confirmation status:** |
|---|---|---|
| Denmark | Teknologisk Institut of Denmark | Confirmed |
| Germany | Fraunhofer ISE | Verbally confirmed |
| South-Korea | Korea Institute of Energy Research (KIER) | Confirmed |
| France | Électricité de France (EDF) R&D | Confirmed |
| United Kingdom | Department for Energy & Climate Change (DECC)<br>and<br>DeltaEE | Confirmed |
| USA | Oak Ridge Laboratory<br>and<br>Electric Power Research Institute (EPRI) | Confirmed |
| Austria | Austrian Institute of technology (AIT) | Verbally confirmed |
| Switzerland | Hochschule Luzern (HSLU) | Verbally confirmed |
| The Netherlands | TNO Innovatie and Alliander Asset Management /Innovation Dept. (national team)<br>BDH (Operating Agent)<br>RVO (ExCo member of HPP) | Confirmed |
| Sweden | KTH Royal Institute of Technology Sweden | In progress |
| Finland | TBA | In progress |
| Japan | The Heat Pump Technology Centre of Japan (HPTCJ) | Questionable |

### 3.2 What is the main goal and what is the output of Annex 42?[xiii]

The main challenges regarding the electricity grids in the future are defined in annex42 as:
1. Electrical load management issues
2. Energy load from supply of sustainable energy sources

The main goal is to produce new knowledge regarding heat pumps in smart grids which cannot already be obtained in running projects or studies.

The expected output is a situation-, region- or country- specific implementation model so readers can decide what the best options are in a given situation to implement heat pump systems, the best ways to implement them into an electrical grid, possible controlling strategies to balance the electricity grid and the potential heat storage capacity. The results will also indicate research topics for further projects.

The results of Annex 42 will be useful for:
- Policy and decision makers (both national and local government) for energy systems in urban areas
- Housing companies
- Grid companies (Distribution Service Organizations, DSO's) & energy suppliers
- Installation consultants
- HP manufacturers / control designers
- Researchers in the HP / SG field

### 3.3 The main research topics of Annex 42[xiv]

The topic of annex42 is a broad topic that had to be narrowed down. To define a scope, in the first meetings of annex42 research questions were defined that will be answered during the execution of annex42:
1. What is the potential 'peak shave' capacity of both electrical and thermal loads for the different flexibility options?
2. What are the potential thermal storage options that can be connected to heat pumps and its capacity?
3. What are the costs of different technology options for flexibility (thermal storage, hybrids)?
4. What is the time scale to balance peak considering the different storage options and how does it affect control strategies?
5. What is of will be the acceptability to households? (comfort, technology, pricing, feeling of control)
6. What are the best control strategies? How to balance between the peak / highest COP / Comfort / economy (since they can be conflicting). Furthermore how much flexibility and potential for E-load reduction will it give?

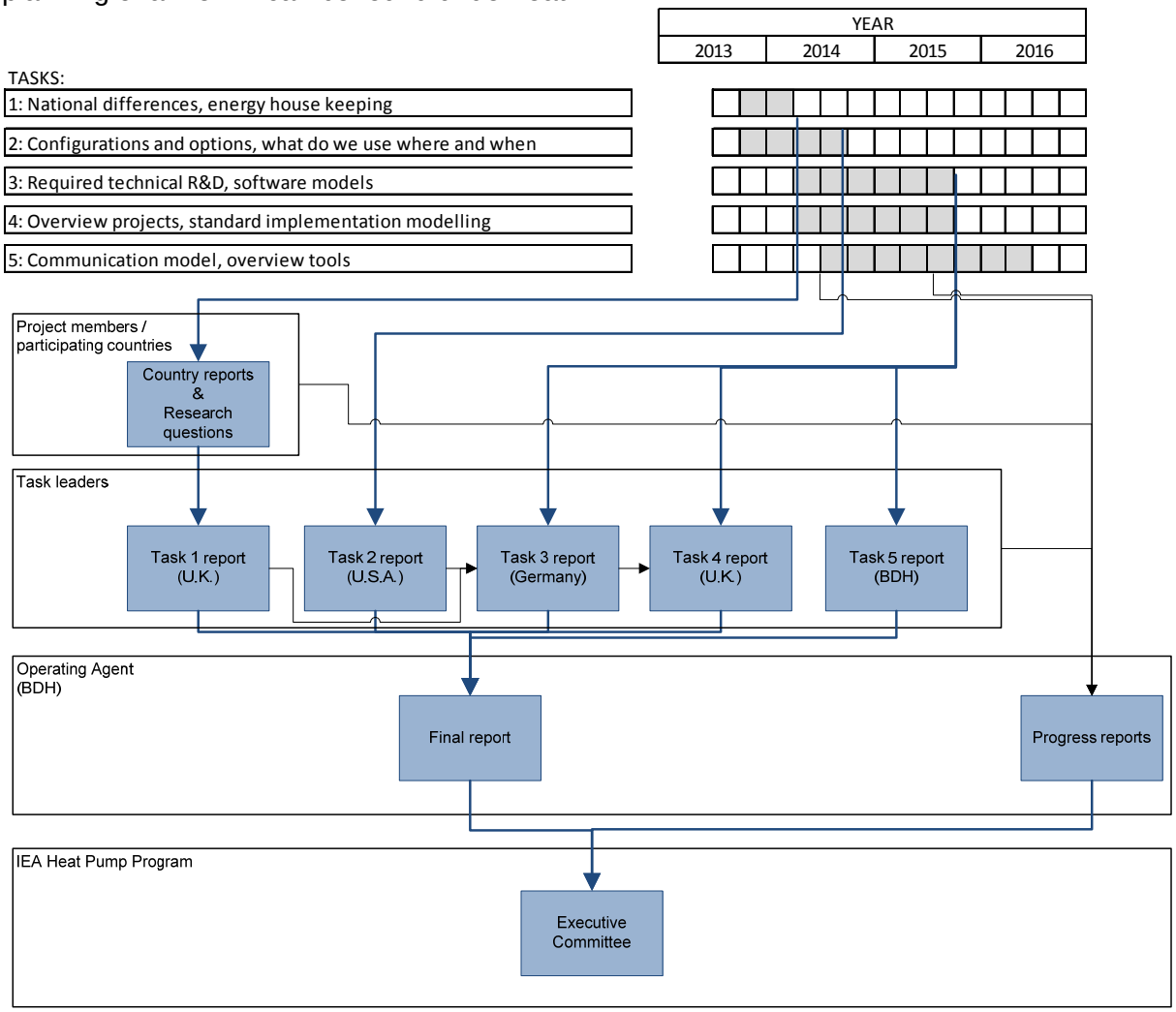
Also a general approach was defined in the first meetings to guide the search:
1. Observe and study running projects
2. Combine the information
3. Order and structure the questions and answers that are imposed in the projects
4. Produce new knowledge out of the combinations AND/OR test models that have not been tested in the running projects.

It was also defined what will be outside the scope to the annex42 to prevent misunderstanding of what is being done and what not:
1. No gas grid implementation issues, just the description that there is potential for hybrid HP's (hybrids ARE included in the annex as an Electricity grid balancing option).
2. No large thermal grid controlling options. Large thermal grids are included as storage option and its potential capacity, but *how to* control this, or controlling strategies are NOT included.
3. Power to gas (this is storing electricity by using this power to produce hydrogen and reform this into gas) is not included as an option to balance the E-grid
4. Not E-storage as balancing option (batteries etc.)
5. Not the integration of other sustainable energy production options and modeling of balancing this flexible energy supply.

6. Not smart cities. Although the term ‘smart cities’ is mentioned in the legal text; this was used as an introduction to heat pumps in smart grids as a part of smart cities. We will focus on heat pumps in smart grids not smart cities (this is a much broader subject where economy, mobility, environment, people, living and governance is included.

## 3.4 Structure and planning

Annex42 is divided into five tasks, with each task being run by a task leader. The tasks and planning of annex42 can be found underneath.




It is important to note that this annex is not strictly defined in terms of the (search) path that will give us answers to the stated research questions. This route was chosen in the meetings together with the members, because this is not a technical annex, but much more focused on overcoming non-technical barriers, which are much harder to describe, identify and solve (or show the potential). This means actions and decisions are made up per meeting, because the outcome of each step determines which next step is to be taken.

## 4 What is being done: Smart grid projects with heat pumps

In this chapter projects are identified that have to do with heat pumps in smart grids. It is a mere sum up of projects from different sources, that are not extensively described, since all projects can be found on the Internet. The list gives an overview what is being done by whom.

### 4.1 Projects identified by the Joint Research Centre of the EU

| **Project Name** | **Leading Organization** | **Main Implementation** | **Category** |
|---|---|---|---|
| Increased energy supply flexibility and efficiency by using decentralised heat pumps in CHP stations | Technical University of Denmark | Aalborgværket, Aalborg | Demonstration |
| Trials with heat pumps on spot agreements | SydEnergi | Esbjerg | Demonstration |
| Intelligent Remote Control for Heat Pumps. ForskEL 10469 | Nordjysk Elhandel A/S | Aalborg | R&D |
| Heat Pumps as an active tool in the energy supply system. ForskEL 10490 | Technical University of Denmark | Kongens Lyngby | R&D |
| Smart neighboring heat supply based on ground heat pumps. ForskEL 10688 | Municipality of Solrød | Solrod Strand | R&D |
| From wind power to heat pumps | Energinet.dk | Fredericia | Demonstration |
| READY - Smart Grid ready VPP controller for heat pumps | Nordjysk Elhandel A/S | Aalborg | R&D |
| PowerMatching City II | RWE/Essent | Hoogkerk | Demonstration |
| PREMIO (FR, 2008-12) | CAPENERGIE | Lambesc | Demonstration |
| Linear | Vlaamse Instelling voor Technologisch Onderzoek N.V. | Field tests in Flanders, Flemish Region | Demonstration |

*Table 3: Smart grid projects in Europe, where heat pumps are involved.*[xv]

## 4.2 Projects identified by the members of Annex 42

### 4.2.1 U.K.

| Filled in by: | **Penny Dunbabin** |
|---|---|
| Official name of the project: | |
| Initiator: | |
| Executing organization or institute: | |
| Country or location | |
| Time frame: | |
| Scope of the project: | |
| Project scale: | |
| Description: | a) Modelling of residential heat pump electricity demand superimposed on measured electricity demand profiles for the UK household sector + discussion of potential for peak demand shifting (our peak demand occurs at around 6pm in the winter – usually in January. There are also local peak demands in summer, eg in London, due to air-conditioning).<br><br>b) Results from a study using heat pumps with remote controls operated by the energy supplier. The plan is to install 600 air-source heat pumps, 100 of which will have thermal stores. The operator will investigate the effect of remote control on indoor temperature and the residents' comfort levels. At present, 408 heat pumps have been installed, 8 of which have thermal stores. Two areas of the local network that currently have programme-funded heat pumps deployed on them have been identified as target areas for network monitoring to understand effects of these units on the local grid infrastructure. This project will be complete in 3 years' time. |
| Other remarks: | |

### 4.2.2 Germany

| Filled in by: | **Zaphod Leitner** |
|---|---|
| Official name of the project: | Potenziale der Wärmepumpe zum Lastmanagement im Strom und zur Netzintegration erneuerbarer Energien |
| Initiator: | federal ministry for economics and technology (BMWi) |
| Executing organization or institute: | Ecofys Germany GmbH (Dr. Christian Nabe, Bernhard Hasche, Markus Offermann, Dr. Georgios Papaefthymiou)<br>Prognos AG (Friedrich Seefeldt, Nils Thamling, Henri Dziomba) |
| Country or location | Germany |
| Time frame: | 2011 |
| Scope of the project: | Study |
| Project scale: | |
| Description: | Electric compression heat pumps are increasingly used in Germany. Combined with hot water storage tanks they provide a high theoretical potential for Demand Response to compensate fluctuating Renewable Energy production.<br>An analysis has been carried out to evaluate the potential of heat pumps for storing heat and electricity. The analysed heat pump systems are classified by technology, plant capacity and dimensioning. Plant efficiency and storage losses were taken into account to asses the advantages of positive and negative balancing power povided by smart controlled heat pump systems. The study results in recommendations for further actions and technical optimization. |
| Other remarks: | |

| Filled in by: | **Zaphod Leitner** |
|---|---|
| Official name of the project: | Regenerative Modelregion Harz |
| Initiator: | federal ministry for economics and technology (BMWi) |
| Executing organization or institute: | Project coordination, virtual power plant, energy management: Fraunhofer IWES, University Kassel<br>Business models, energy management: CUBE Engineering GmbH, in.power<br>Grid operators: E.ON Avacon, envia, Vattenfall Transmission<br>Municipal utilities: Halberstadtwerke, Stadtwerke Blankenburg, Stadtwerke Quedlinburg, Stadtwerke Wernigerode<br>Wind farm operator: RKWH<br>ICT related companies: Siemens AG<br>Research for grid operation: University Magdeburg, Fraunhofer IFF |
| Country or location | Kassel Germany |
| Time frame: | 2008 - 2012 |
| Scope of the project: | Analysis of a virtual power plant |
| Project scale: | 18 partners |
| Description: | In a competition for the technology promotion initiative “E-Energy: An ICT-based energy system of the future” by the federal ministry for economics and technology (BMWi) and the federal ministry for environment, nature conservation and nuclear safety (BMU) consortia in six model regions were selected. One of these winners is the project “Regenerative Modelregion Harz (RegModHarz)” (regenerative model region Harz). The objective of this project is the technical and |

| | |
|---|---|
| | economic development and integration of renewable energy sources (RES) by deploying modern information and communication technology (ICT). The project deals with the creation of an efficient energy infrastructure with a maximum share of regional renewable energies as well as with their organization and operation under market conditions. Within this project, grid operators, energy suppliers, municipal utilities, wind farm operators, universities, research institutes and RES/ICT related companies will develop tools, infrastructures and strategies to supply a complete district with electricity solely from Renewable Energies. In the Renewable Model Region district Harz (RegModHarz), different renewable energy producers, controllable consumers and energy storage devices will be coupled by a variety of means such as electronic market places and distributed control mechanisms to a large virtual power plant (VPP). |
| Other remarks: | |

| Filled in by: | **Zaphod Leitner** |
|---|---|
| Official name of the project: | Modellstadt Mannheim |
| Initiator: | Bundesministerium für Wirtschaft und Technologie (BMWI) |
| Executing organization or institute: | IFEU: Markus Duscha (AS-Leitung), Lars-Arvid Brischke, Ruben Korenke, Corinna Schmitt<br>DREWAG: Stephanie Einspender, Holger Hänchen, Max Pham, Robert Weißenborn, René Zimmer<br>IBM: Andreas Herdt, Christian Panzer, Detlef Schumann<br>IWES: Timo Fischer, Mariam Khattabi, Jan Ringelstein, Patrick Selzam<br>IZES: Hermann Guss, Uwe Klann<br>MVV: Michael Handschumacher, Jürgen Hermanns, Andreas Kießling, Christian Mayer, Michael Pawlowicz, Oliver Prahl, Volker Stelzner<br>PPC: Christine Müller, Stefan Sender, Thomas Wolski<br>PSE: Thomas Große Böckmann<br>UDE: Mike Trautmann |
| Country or location | Mannheim/Dresden Germany |
| Time frame: | 2008 - 2012 |
| Scope of the project: | Analysis of a smart Smart Grid |
| Project scale: | 1000 Households |
| Description: | The project "*Modellstadt Mannheim"* focusses on the creation of a smart power grid. The main goal was to achieve a free market of energy open to every participant and independent from conventional functionalities. Participants are consumers, producers, energy traders, distribution network operators, energy service companys, energy storage providers or metering point providers. |
| Other remarks: | |

4.2.3 U.S.A.

| Filled in by: | **Ron Domitrovic** |
|---|---|
| Official name of the project: | Analysis of Capabilities of Variable Capacity Heat Pumps for Demand Side Management |
| Initiator: | Electric Power research Institute, Southern Company, Tennessee Valley Authority, Duke Energy, CenterPoint Energy |
| Executing organization or institute: | Electric Power research Institute |
| Country or location | U.S.A. |
| Time frame: | Ongoing, through ~2015 |
| Scope of the project: | Laboratory and field analysis of variable capacity heat pumps for the provision of energy efficiency and demand management resources. |
| Project scale: | ~several systems evaluated in laboratory conditions & ~10-20 systems evaluated in the field at various locations & climates across the U.S. |
| Description: | Variable capacity HPs offer new flexibility to heat pump systems, enabling them to be applied in non-traditional climates and to be used for advanced load management. This project evaluates the capabilities of various manufacturers' variable capacity heat pumps in the lab and in the field for these new capabilities. |
| Other remarks: | |

### 4.2.4 South-Korea

| Filled in by: | **Minsung Kim/Junhyun Cho** |
|---|---|
| Official name of the project: | Development of Smart Energy Network Technology |
| Initiator: | Korea Institute of Energy Research(KIER), Minsung Kim |
| Executing organization or institute: | Korea Institute of Energy Research(KIER) |
| Country or location | South Korea |
| Time frame: | Ongoing, 2012 ~ 2014 |
| Scope of the project: | - Demonstration of Industrial Thermal Energy Network in the “KIER Daejeon campus”<br>-Targeting energy consumption (for HVAC) in KIER headquarter to reduce 30% |
| Project scale: | 10 buildings will be thermally connected with the ‘Exhaust Gas R&D Center(Coal Power Plant, 10 MW thermal , 2 MW electrical)’ as a thermal station. Heat pumps are included. |
| Description: | Remodeling ‘Exhaust Gas R&D Center’ into industrial thermal station having combined heat and power plant<br>Maximize energy efficiency by connecting Exhaust Gas R&D Plant to Heat Supply Plant<br>Scheduling experiment of the R&D plant to match heat demand of KIER Daejeon campus |
| Other remarks: | The energy network in KIER will be an innovative project where not a project has been carried out where heat demand varies greatly in laboratory and building complex |

### 4.2.5 Austria

| Item | Explanation |
|---|---|
| **Filled in by** | Michael Hartl (AIT, Austria) |
| **Official name of the project** | SmartCityGrid: CoOpt |
| **Initiator(s)** | FFG (National Funding Agency in Austria), Call is named *e!mission* |
| **Executing organization(s) or institute(s)** | AIT<br>Friederich Kupzog (Friederich.kupzog@ait.ac.at) |
| **Country or location** | Austria |
| **Time frame** | 04/2014 – 10/2014 |
| **Scope of the project** | Operating of grids with load shifting through model predictive controller |
| **Project scale** | Two real office buildings and four virtual office buildings and multifamily buildings |
| **Description** | The project aims at optimizing energy efficiency and increasing coverage of demand by renewable energy within electricity networks and buildings through model predictive control and prognosis. The validation of the developed methods and strategies is performed on existing building (ENERGYBase, SOL4). Beside validated optimization methods and models the sustainable impact and useful outputs for planning and operation of smart city distribution networks will be the central findings of this project |
| **Other remarks** | |

## 5 What do we need to make it work?

### 5.1 Virtual Power Plants – Mixed asset power plants

*A virtual power plant is a linkup of small, distributed power stations, like wind farms, CHP units, photovoltaic systems, small hydropower plants and biogas units, but also of loads that can be switched off, in order to form an integrated network. The plants are controlled from one central control room. Demand response is a mechanism to adapt electricity demand to grid conditions or in response to market prices. In many projects, the notion of VPP is used extensively, encompassing coordination both of DERs (supply side) and demand response.*

Virtual Power Plants combine supplies to act as one supply OR combine demands to act as one demand reduction. This needs to be integrated into an mixed asset virtual power plant: which combines supply, demand AND storage.

### 5.2 Online monitoring and data collection

The smarter a heat pump is, the higher the potential for reliable demand response when connected to the grid. Online monitoring and data collection is a very important first step in making heat pumps smart. It is also the conclusion of manufactures and installers of heat pumps that online monitoring and servicing is even an necessary step when installing such systems[xvi]. It can prevent efficiency loss, out of boundary failures, malfunctioning, etc.

If monitoring data from heat pumps was to be collected in a shared database, it can deliver very valuable information for the potential of managing loads or shifting peaks. The effects are:

1. Monitor electricity power usage and build up usage profiles to design smart energy concepts.
2. Constant monitoring of the performance factor to see the real performance and not the theoretical performance.
3. Insights in user and building behavior and its effect on energy use.
4. Planned preventive maintenance based on the real load curve instead of time interval maintenance or responding to failures.
5. Heat pumps with electrical resistance heating back-up, functioning on this back-up will not go unnoticed.
6. Uncovers the real time potential of demand side management with heat pump and storage.

### 5.3 A flexibility index

Flexibility of the grid is the key and the more flexible a smart grid is, the more demand and supply do not have to be balanced. Demand side management and peak shifting are important aspects for a smart gird, where heat pumps combined with storage is an option to achieve this. But there are several other technologies and appliances that can enlarge the flexibility of the grid.

But how can all these technologies and appliances be rated in terms of flexibility, so a grid operator can map and judge the different options. And maybe even more important; what is flexibility and what is it worth?

The development of a flexibility-index for systems connected to the smart grid, could deliver more clarification in this issue. Flexibility in the grid has the potential to invoke a whole new set of business opportunities, for grid operators, but also for new parties. If flexibility can

reduce loads or prevent grid extensions or reinforcements, flexibility will have value. And that value can be scaled with a flex-index.

A flex-index also gives the option for unambiguous communication about smart grid options. The higher a component of systems scores on the flex-index, the more flexibility it can give an the more it will be worth to implement (or attract consumers to participate).

There are more dimensions in defining flexibility, such as:

1. How much capacity can be switched on or off?
2. How long can this capacity be switched off?
3. Can the option vary in capacity?
4. How frequent can this be done in one day and on what days of the week?
5. Does the flexibility option also lower the total demand needed?
6. Is there a storage option and with what capacity?
7. What is the ramp up and ramp down speed?

This means it is probably not possible to develop a single scale flex-index, but nevertheless, also a multi scaled flex-index that is uniformly known and accepted will greatly reduce the uncertainties in the business models of smart grids or smart components.

### 5.4 Standardization, protocols, business models, legislation, economics of scale

The technology is clearly nog the main barrier in implementing both heat pumps and smart grids. And both heat pumps and smart grids have more or less the same non-technical barriers; Consumers and installation companies will always choose the simplest option and fear upfront costs more than total costs of ownership advantages.

Standardization of concepts and solutions will prevent failure costs, will bring down the cost price of installations and the acceptance of installers. Protocols will ensure all connected technologies can communicate in the same way with each other.

Business models to attract consumers, where legislation can enforce investments of help to make business models attractive. And economies of scale will further reduce cost prices and will enhance the observability and acceptance of heat pumps and smart grids.

### 5.5 Combined solutions

There will not be one winning technology on the transition to a low carbon future. This also counts for heat pumps, there are numerous combinations and configurations of heat pumps possible.

## 5.6 Development needs identification by the Renewable Heating and Cooling platform

Only the relevant technology roadmap development needs are selected from the RHC-SRIA

Priority Group I: implementation 2014 – 2016:

| **Research and Innovation Priorities** | | **Technology focus** | **Predominant application** |
|---|---|---|---|
| CCT.3 | Automation, control and long term reliability assessment | Hybrid System | Residential buildings |
| CCT.6 | Next generation of sensible thermal energy storages | TES | Residential buildings |
| RHC2 | Standards, tests and benchmarking of system efficiencies | | Residential buildings |
| CCT17 | Large scale demonstration of Smart Thermal Grids | DHC | All |

Priority Group II: implementation 2016 – 2018:

| **Research and Innovation Priorities** | | **Technology focus** | **Predominant application** |
|---|---|---|---|
| CCT.8 | Increased storage density using Phase Change Materials (PCM) and Thermochemical Materials (TM) | TES | Residential buildings |
| CCT.14 | Improvements in Underground Thermal Energy Storage (UTES) | TES | Industrial Processes |
| RHC.1 | Developing standards for the overall system design and for hydraulic and electrical interconnections of different building components | | |

Priority Group III: implementation 2018 - 2020

| **Research and Innovation Priorities** | | **Technology focus** | **Predominant application** |
|---|---|---|---|
| **CCT.7** | Improving the efficiency of combined thermal energy transfer and storage | TES | Residential buildings |
| **CCT.19** | Develop and roll-out DHC driven white goods and low temperature solution for domestic hot water preparation | DHC | All |
| **CCT.21** | Optimised integration of renewable energy sources in DHC systems and enhancement of thermal energy storage at system level | DHC / TES | All |

## 6 Conclusion and remarks:

All of the uncertainties about smart grids business model also apply to uncertainties in the business model of fitting in heat pumps in smart grids resulting in the following barriers:

Policy related or non-technical barriers:

a) A lack of standardized control and communication solutions.
b) No clear defined roles and responsibilities in new smart grid applications.
c) The sharing of costs and benefits among participants.
d) Consumer resistance to participation in trials.
e) The range of regulatory arrangements in Europe hampering replicability of project results in different countries.
f) The need for new contractual arrangements

Technical barriers:

g) Clear rules for technical validation of flexible supply/demand transactions by system operators
h) Technical and commercial arrangements for the exchange of physical and market data

The focus of research must change to overcome this barriers. Annex 42 tries to start this, but the path is not defined, therefore all input, suggestions and feedback are welcome.

The following assets should be developed to overcome this barriers:

1. Mixed asset virtual power plants
2. Online monitoring, data collection and sharing of heat pump systems
3. A flexibility index
4. Standards, protocols and business cases
5. Combined solutions
6. Smart storage and storage materials

## 7 References

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