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Nyborg, Sophie; Røpke, Inge

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Heat pumps in Denmark – from ugly duckling to white swan

Sophie Nyborg
Technical University of Denmark (DTU), Department of Management Engineering, Division of Technology and Innovation Management, Diplomvej, Building 372, 2800 Kongens Lyngby, Denmark

Inge Røpke
Center for Design, Innovation and Sustainable Transition (DIST), Department of Development and Planning, Aalborg University Copenhagen, A.C. Meyers Vænge 15, 2450 København S, Denmark

Introduction

Globally, the smart grid is seen as an important part of the low carbon transition of the energy system. In Denmark, this transition mainly entails integrating more wind power into the system and using electricity for heating (heat pumps) and transport (electric cars). Therefore, residential heat pumps are considered essential infrastructure technologies in the smart grid because they are ideal for the flexible consumption of an increasing amount of intermittent wind power and are well suited to delivering system balance services.

In Denmark, attention on heat pumps has resulted in increasing research into how flexible heat pumps are regarding energy consumption. In recent years, many R&D projects have been launched that investigate various aspects of their smart grid readiness and flexibility potential (Insero Energy 2013: 5), including user studies such as the eFlex and the 'From wind power to heat pumps' projects (Nyborg & Røpke 2013, Energinet.dk 2012). However, a precondition for exploiting heat pumps as flexible agents in the energy system is that they actually enter people's homes in sufficient number. In 2010, the Danish Energy Association (DEA) said they expected 300,000 heat pumps to be installed in Denmark by 2025 (Energinet.dk & Dansk Energi 2010) and in 2012, the government initiated a complete phase-out of oil burners by 2030 – aiming for a conversion to, among other things, heat pumps. Unfortunately, the dissemination of heats pumps has not matched expectations. Therefore, studies that explore the drivers of and barriers to a more widespread uptake of heat pumps in Denmark are arguably needed.

Until now, most Danish studies that explore this area have focused on the current status of the dissemination of heat pumps, their actual efficiency performance and the technical potential for further dissemination (COWI et al. 2011a, COWI et al. 2011b, Pedersen & Jacobsen 2013, Olsen et al. 2010) as well as the potential from the perspective of private finances (COWI et al. 2011a), the socio-economic effect of further dissemination (Rambøll 2011) and alternative business models for selling heat pumps (e.g. EXERGI Partners et al. 2014). A limited number of Danish as well as international user studies have focused on homeowners' motivations for and obstacles to buying a heat pump, as well as their experiences with the installation process and the daily operation of the heat pump (Epinion 2010, Publikum Kommunikation & inVirke 2010, Energitjenesten et al. 2012, Heiskanen et al. 2014b, Caird et al. 2012, Bjørnstad 2012, Roy & Caird 2013). A few studies have taken a more qualitative approach to studying users and the dissemination of heat pumps by focusing on, e.g. the development of new comfort practices and the implications for energy consumption (Christensen et al. 2011) or the domestication of heat pumps in everyday life and user innovations (Juntunen 2014, Hyysalo et al. 2013b, Nyborg in progress).

Nonetheless, there is a lack of studies that embrace a more socio-technical approach to understanding how heat pumps are gaining a place in society as a result of contingent, emergent and complex historical processes (although see e.g. Kiss et al. 2012, Nilsson et al. 2005). Notably, heat pumps in Denmark have not received sufficient attention in this regard. Within the field of science and technology studies (STS), it has long been argued that existing technological systems that fulfil societal functions are not dominant *because* they have an inherent technological supremacy or *because* they reflect efficient market processes. Rather, they are 'configurations that work', i.e. they are a result of the co-evolution of several heterogeneous elements such as markets and user practices, cultural values, policy and regulation, techno-scientific knowledge and infrastructures, etc. (Geels 2002). The theoretical framework for this paper draws upon this STS tradition and, in particular, upon actor-network theory (ANT), which also highlights issues of agency, controversy and power in the development of technological systems and scientific facts (Callon & Latour 1981, Callon 1986b).

This paper elucidates why heat pumps have not become as successful today as wind energy has, even though Danish heat pump manufacturers once had a leading position in Europe in terms of technological development – and despite the fact that both heat pumps and wind energy started out as 'ugly ducklings' 40 years ago. Although heat pumps have recently become popular, they are still far from becoming the success story and white swan that wind energy has developed into[1].

Thus, this paper sets out to answer the following research questions:

- Why was the substantial potential of the heat pump to green the Danish energy system not realised a long time ago?
- What can be learned about the current barriers to the heat pump by looking at its history in Denmark and the struggles that have been part of its development? How are current issues related to this? Have the barriers been overcome?
- What is the probability that heat pumps will be disseminated and become successful in the future?

The empirical material for this paper is based on 10 interviews with actors who have been or are presently related to the heat pump sector as well as desk studies of current and historical reports and documents related to heat pumps in Denmark. This study also draws on 24 interviews with homeowners enrolled in two recent heat pump/smart grid demonstration projects: the eFlex and the 'From wind power to heat pumps' projects (results from these projects are mainly reported in other publications with users as the main focus).

In tracing the history of heat pumps in Denmark, our focus has mostly been on small, electrically-driven ground source heat pumps or air-water heat pumps as they are currently

[1] The development of the heat pump in Denmark differs considerably from its development in Sweden and Finland. A comparative study would thus be very informative, but it is beyond the scope of this paper, although we hope that the paper will provide input to such a comparative study.

being discussed as a replacement to oil burners. Moreover, they have the greatest flexibility potential in the smart grid because the heat produced can be stored in central heating systems and buffer tanks. However, over time, air-air heat pumps have also been promoted as relevant for the conversion of electrically-heated houses, including summerhouses. These three types of heat pump mainly exploit low temperature heat from the sun, which is stored either in the ground or the air, and use electricity to compress it to a higher temperature through a refrigerant circuit system. Through this process, around 3.5 to 5.5 kWh of heat is produced every time 1 kWh of electricity is used. The heat is either delivered to a central heating system, used to produce hot water, or sent directly to the indoor air.

In the following, we first present the conceptual framework based on ANT. Then we provide an outline of the current situation in Denmark concerning heat pumps, followed by an historical account of the development that led to this situation. Based on this account, the research questions are analysed, and finally, the probability of having a heat pump fairy tale in the future is considered.

Conceptual framework

To answer the research questions, we need to explore the history of heat pumps in Denmark and outline how heat pumps came to play their present role within various networks. ANT offers a useful toolbox for telling such a story. This paper is informed by some core ideas, but does not engage in debates in the field.

ANT focuses on *how* social phenomena come into being. Whereas much other social theory is interested in highlighting the *whys* of the social, ANT explores the hows (Law 1992, Law 2009). Nothing is taken as given: phenomena such as class and nation state are not considered as explanatory foundations or given aspects of social structures, but as effects of social *processes*. These processes are described in terms of relationships and interactions between heterogeneous actors – humans, devices, nature, ideas etc. Through the interactions, *networks* are formed where the elements define and shape each other. The dualism between humans and objects is transgressed: everything – people, machines, ideas etc. – is treated symmetrically and explored as interactional effects. Furthermore, *materiality* is emphasised in relation to the social since almost all interactions are mediated through objects.

When relationships form networks, social order is created. The process is considered as a *struggle* where human actors may or may not engage intentionally, while natural or human-made actors engage because of their teleological construction. The successful struggle may result in a network that comes to look like a single point actor, referred to as an *actor-network* or a *configuration*. When a network acts as a single block, the network behind it is concealed or *black boxed*. But since the ordering is an uncertain process of overcoming resistance, a configuration is always contestable and uncertain.

The process of ordering is also described as a process of *translation*. This process can have a prime mover, a translator, that attempts to enroll other entities into a so-called *actor-world*: 'An actor-world associates heterogeneous entities. It defines their identity, the roles they should play, the nature of the bonds that unite them, their respective sizes and the history in which they participate' (Callon 1986a: 24). An actor-world can be seen as a vision that forms the basis for translating and enrolling entities into an actor-network. The translator serves as

a spokesman for other entities and is a strategist that tries to problematise other potential competing identities of the entities. In this process, the translator is seen as implementing a *program of action*. Translation is thus 'the capacity of certain actors to get other actors – whether they be human beings, institutions or natural entities – to comply with them', (Callon 1986b: 201). If the translation is successful, other potential actor-worlds are displaced.

ANT does not distinguish between micro and macro as something pre-defined. But distinctions between big and small and between different levels can emerge as relational effects. When networks emerge, become black boxed and relate to other networks, large configurations can be created, sometimes characterised as *macro-actors* (Callon & Latour 1981) that may be powerful in the sense that they have considerable agency. The *power* is an effect of the network and the black boxing, and not the explanatory foundation, and the power may be challenged by resistance in the form of anti-programs and competing translations.

Much research explores what makes some translators more successful than others, and what makes some configurations more durable than others. Materiality is key to the arguments. For instance, the durability of configurations is strengthened when social relations are embodied in inanimate materials such as texts and buildings. Similarly, important tools for persuasion in the process of translation are *inscriptions* that form a bridge between observational studies (e.g. in laboratories) and the phenomena that translators talk about. Inscriptions take the physical form of graphs, calculations in tables, reports etc., and they have many advantages compared with the direct observations. For instance, they can easily be reproduced and moved, they keep their form (referred to as *immutable mobiles*), and their materiality is helpful when supporting reality claims. A configuration gains strength when it includes a *calculation centre*, a centre for a flow of inscriptions. Inscriptions form a part of a broader group of *interessement devices*, which include all sorts of devices that are used in the enrolment process (Callon 1986b).

All these concepts provide some heuristics for studying the actors and struggles involved in the shaping of, for instance, the energy system, but the importance of empirical studies is emphasised, including the need to consider the variety of strategies that emerge when exploring a specific story.

The ANT perspective is applied in our chronological story about heat pumps. In addition, we sum up and analyse the insights by cutting across the historical account and focusing on various aspects of the story in a more explanatory way. This goes beyond the traditional ANT focus on *how* and deals more with *why*, because this is considered a useful basis for a forward-looking discussion of the future perspectives for heat pumps. The approach is inspired by analyses of the development of wind energy where the activities of the actors are considered in relation to different interconnected arenas such as policy, design, and users (Garud & Karnøe 2003, Karnøe in progress). By considering similar, but slightly modified, arenas in relation to the heat pump story, various explanations of the far less successful story emerge.

Having presented our conceptual framework, our story starts by describing the current attempts to organise an actor-world where heat pumps play a key role. Starting with a minister who tries to translate 'the deep desires, the technical knowledge and the needs and aptitudes of a large number of actors' (Callon & Latour 1981: 288).

Heat pumps – today's political darling

On 2 October 2013, the Association of Manufacturers of Heat Pumps in Denmark (AMHP) held a well-attended conference dubbed 'the Heat Pump Day', which they organised in collaboration with, among others, the DEA. The programme included such nobility as the general secretary of the European Heat Pump Association and the Minister for Climate, Energy, and Buildings, Martin Lidegaard.

The conference focused on the role that heat pumps play in Danish energy policy and the minister was keen to assure the audience that he saw a very significant role for heat pumps in Denmark as he started his presentation: 'As I was just saying on the way from my new Tesla – by the way, a really cool electric car, I must say! – the heat pump is one of my absolute darlings' (Lidegaard 2013). His love for heat pumps, the minister explained, was sparked by the energy agreement the government had reached in parliament 18 months prior to 'the Heat Pump Day', which stated that Denmark should double its investments in energy efficiency; double the share of renewable energy in the energy system by 2020, and then 'construct the smartest and most modern electricity system in the world.' The heat pump plays a crucial role in all three overall objectives, he emphasised, since 'it's effective, it can help us balance renewable energy and can even be used proactively in relation to the future smart grid.' Moreover, the minister pointed out that 'it's something that people can understand, you can afford to buy it as an ordinary homeowner [and] you can see on your bill what you get out of it.' In short, there are only good reasons for promoting heat pumps, the minister said. Accordingly, the government supported this promising technology in several ways by, e.g. reducing taxation on electricity, introducing a quality assurance scheme for installers of renewable energy technologies and initiating the phase out of individual oil burners.

However, despite the political enthusiasm and high expectations, heat pumps are not entering Danish homes 'at the speed that is desired and was expected' as recently expressed by the DEA. The association assessed that there could be a total potential of 600,000 heat pumps in Denmark as an alternative to 'fossil fuel heating forms' (Catalyst Strategy Consulting 2013), i.e. individual oil and gas burners. However, the current annual sales figures are not encouraging if Denmark is to reach such a goal in time to meet the vision of being 100% independent of fossil fuels by 2050. According to the DEA, the few thousand heat pumps currently being installed per year only amounts to 5% of the potential (Catalyst Strategy Consulting 2013) and compared to Sweden, Norway and Finland the diffusion of heat pumps is modest.

Thus, it seems that the heat pump is not everybody's *darling* in Denmark. Actually, it is *not* always easy to understand and use. As one of our homeowners expresses it: 'the heat pump itself out there is a little bit hard to adjust… I don't think the manual is very user friendly…' Moreover, a heat pump is *not* something an ordinary homeowner can necessarily afford. Many houses on the outskirts of Denmark have such a low market value that it is simply not possible for homeowners to get a loan for a heat pump. Finally, the apparent savings on the energy bill or clarity concerning 'what you get out of it' do not exist for the installers of heat pumps as they face costly green training programmes, which may not pay off due to a lack of

demand, while for homeowners, benefits such as savings on energy bills do not always transpire.

Accordingly, as we will demonstrate, the transformation towards 'smart grid heating systems' does not depend on single factors such as users' 'investment willingness', but involves a variety of interacting human and non-human actors that are not so easily translated and which have an influence on the fate of heat pumps, e.g. wind turbines, groundwater, electric cars, oil prices, households, technical standards, installers and handbooks. These actors are called upon as allies for various action programs or they help to reveal leaking black boxes.

The following tells the story of the attempt to build a heat pump network in the midst of a major socio-technical transition of the Danish energy system; it will be a story about an unstable network that fills just a little corner in a much bigger battlefield between a powerful fossil fuel based action program and emerging resistances in the shape of renewable energy and its allies. The story demonstrates the precariousness of the development of such systems as unforeseen action programs enter the battlefield and change the fate of many actors.

A history of heat pumps in Denmark

The history of heat pumps in Denmark is long and complicated. Therefore, Table 1 provides an overview of the main milestones.

Period	1970s Kick-off	1980s Up and down	1990s Struggle	2001-2007 Dismantling	2008- A new start?
Major events	Oil crisis Gas found in the North Sea	Second oil crisis Gas project in trouble	Global warming acknowledged	2001 Change of government: attack on environmental policies	Government changes signals
Energy planning priorities	Independency: From oil to coal and nuclear Gas project Heat planning (collective)	Independency: Nuclear out Energy savings District heating CHP Promotion of gas project	Reduction of $_{CO2}$ emissions: Increased focus on CHP + wind Negative focus on electric heating	General critique of environmental agenda: Reduced focus on wind	Renewed focus on CO2: Emergence of smart grid discourse
R&D support for HP	1974-79 Research programme	Comprehensive programme 1980-90 Test station	Research on system integration of HP (limited interest from other actors)	Decommissioning of test station	Smart grid programmes incl. HP
Regulation, subsidies, taxes influencing HP	1979 Subsidy	Increase of electricity taxes Subsidies: 1981 20% 1982 10% 1985-88 0% 1988 10% 1988 Ban on electric heating	Increase of electric. taxes 1993: Subsidy removed in collective supply areas. Outside: 15% 1994: Quality assurance scheme for installers	Abolition of subsidies	2008 Campaign to promote HP 2009 HP allowed closer to water supply 2010 Subsidy to scrap oil burners
Framing of HP: HP proponents	Energy efficiency Independence from oil Renewable energy		Addition: Environmentally-friendly interoperation with renewables		
Framing of HP: Electricity companies	Promotion of HP as energy saving		Lack of interest		HP in the smart grid
Framing of HP: Grass roots	Not renewable / Fossil-dependent / Related to incumbents				HP acceptable as users of renew. energy
HP technology, industry	From tailor-made to first mass production	Quality improvements 1997 Lodam wins competition		Requirements related to subsidy disappear: low quality HP and installations	Few manufacturers left Imports
Sales of HP	Late 70s-early 80s: promising	Large decline in home market Large exports	Home market low. Exports continue	Lack of home market: reduced competitiveness	Low sales

Table 1: Aspects of the Danish energy history, interpreted from the perspective of heat pumps. Colouring: Traffic light signals.

1970s: Energy crisis and new plans: kick-off

When does the story of heat pumps in Denmark begin? This is, of course, impossible to say since they are the effect of a wide range of networks that extend back in time.

However, in reality not much happened in the development of heat pumps in Denmark until the international energy crisis of 1973/1974, which shook the otherwise stable fossil-fuel based system, resulting in numerous leaking black boxes. This sparked a massive effort to reduce energy consumption and the country's dependency on imported oil and gas through subsidies for energy savings, campaigns and research programmes (Aagaard 1999b).

Thus, in August 1974, an energy research programme for heat pumps was granted DKK 1.4m by the then Ministry of Trade. At the time, practical experience with heat pump installation was limited in Denmark. In the preceding twenty years, only around 200 heat pumps for single-family homes had been installed and 'a large share of these installations have in this same time period either been put out of operation or are functioning very unsatisfactorily' (Westh 1977: 102).

In April 1976, the Danish Energy Agency was established to administer the new political focus on energy and in May the Minister of Trade, Erling Jensen, presented the first comprehensive energy plan for Denmark, 'Danish Energy Policy 1976' (DE-1976), which had three main points. First, to convert from oil to coal and other alternative energy sources, mainly nuclear power; second, to establish a nationwide gas grid with natural gas from the North Sea and; third, thorough heat planning should be conducted in all counties and municipalities to achieve energy savings (Meyer 2000).

Grass roots emerge

Renewable energy only played a modest role in the Government's energy plan (planned to cover 4% of primary energy by 1995). However, during the summer of 1976, a small group of researchers from physics and engineering departments drafted a counter plan, which excluded nuclear power and argued for a more modest growth in energy consumption and for renewable energy to account for 12% of primary energy provision (Meyer 2000).

The alternative plan received much media attention and was actively promoted by the two new anti-nuclear grass roots organisations OOA (the Organisation for Information on Nuclear Power) and OVE (the Organisation for Renewable Energy), which regarded nuclear power as representing 'alienation, concentration [of power] and the risk of sabotage' (Beuse et al. 2000: 25). Their main aim was to promote renewable sources through information campaigns and by lobbying politicians. They widely distributed inscriptions on renewable energy which helped to problematise the program of the powerful electricity system and in translating politicians and civil society. It meant a lot to the grass roots movement to 'do-it-yourself' and build their own wind turbines or solar heat panels. The anti-nuclear movement was part of a wider critique of established society: 'It was often discussed how utilising renewable energy resources and organising energy provision in accordance with principles of decentralisation and democracy was the key to utopia for future society' (Beuse et al. 2000: 40). In 1976, as a result of the resistance to nuclear power among the population, the Danish Parliament decided to postpone its introduction, and in 1985, they finally agreed that Denmark should not have nuclear power (Meyer 2000).

Heat pumps not part of renewable energy utopia

Meanwhile, the first mass-produced heat pump in Denmark appeared on the market in 1974, developed by civil engineer Marc Fordsman, who had collaborated for some time with the electricity companies in Southern Jutland, which were pushing the development of heat pumps (Elnyt 1975).

While heat pumps fitted with the action program of electricity companies and the ministry, the grass roots movement, however, did not consider heat pumps a renewable energy technology because they needed fossil-based electricity to drive the pump (at the time dubbed 'black energy'[2]) and they preferred technologies that utilised the sun or wind directly (Beuse et al. 2000: 41). Moreover, it was argued that claims for the energy saving potential of heat pumps were not genuine; although heat pumps generate more heat energy than the electrical energy they consume, this does not compensate for the great loss of energy inherent in electricity production (this was before CHP was widespread in Denmark). An article in the magazine *Renewable Energy* (published by OVE) from 1981 summed up the argument by stating that 'the greater the number of heat pumps, the greater the energy consumption in the form of electricity' (Beuse 1981: 13).

Furthermore, incumbents such as the electricity companies and the Association of Danish Electricity Companies' Investigation Department (DEFU) supported heat pumps, which did not encourage grass roots' approval of the technology. Since the heat pump could easily be enrolled in the action program of the mainstream electricity system as an energy efficient electricity consumer, it represented a threat to the actor-world of OVE. The article mentioned above emphasised that these dominant actors:

> '…are heavily engaged in the development of heat pumps and are also represented in the steering committee that is to administrate the funding, which is set aside for heat pump development in the Ministry of Energy's Research programme… Who said you should let the fox guard the chicken?' (Beuse 1981: 13).

Thus, the heat pump did not represent the utopian promise in the way the 'true' alternative technologies did since it was endorsed by dominant interests and would reproduce existing societal structures. In the opponents' view, heat pumps 'promoted the need for the continued expansion of power plants and brought nuclear energy closer' (Willumsen 1993: 5).

1980s: The heat pump test station and opposing programs of action

In 1979, another international oil crisis stimulated greater attention on developing renewable energy technologies and, therefore, wind, sun and biomass received extensive funding. In addition, a comprehensive, ten-year long research programme into heat pumps was established in 1980, which resulted in the completion of over 76 heat pump projects (Poulsen 2011).

[2] In Danish, 'sort' (black) indicates the colour of fossil fuels and moreover signals something negative.

In 1981, a new law made it possible for households to receive a subsidy for 20% of the installation costs for a range of renewable energy technologies: solar heating, wind turbines, heat pumps, biogas plants, compost heating and hydro-power facilities. The Danish Energy Agency administered the subsidies and also funded the establishment of test stations for each new energy technology to standardise them so public funding was not wasted on poorly developed technologies and the heat pump test station was placed at the Technological Institute (TI) (Meyer 2000). The resulting inscriptions and standards that flowed from these calculation centres in the following years meant that the technologies – including heat pumps – were embodied in a range of immutable mobiles that strengthened their networks.

Heat pump program, concerns and anti-programs

However, the influential grass roots movement still hadn't warmed up to heat pumps and they continued to problematise their alliance with the electricity system macro-actor, making it increasingly difficult for heat pumps to gather allies. According to civil engineer, H. C. Aagaard, who started and ran the test station for heat pumps, the OVE/OOA-run 'Energy Offices' that received public funding to inform on all subsidy schemes, including heat pumps, clearly preferred sun, wind and biomass. The frustrations this created with proponents of heat pumps was evident in an article from the newspaper *Information,* reporting from a meeting of The Danish Society of Engineers in 1977. In the article, the marketing director of NESA, the largest electricity company in Denmark at the time, Jørgen Gullev, said, 'It is activists and watercress-eating Gold Coast socialists that together with OOA are dominating the picture' (Meyer 2000: 84).

However, the OOA and OVE were not the only actors with concerns about heat pumps. The Ministry of Environment and the water utilities authority were, for instance, concerned about ground source heat pumps and their possible contamination of the groundwater, which turned out to be an important actor in the development of heat pumps. The fear was that if a tube leaked, the fluids – which could contain e.g. antifreeze – would seep into the groundwater, polluting the main source of fresh water in Denmark. In 1981, a decree on ground source heat pumps came into effect, which stated that heat pumps should be placed at least 300 meters from public water supply plants. This decreased the number of households that could install a heat pump.

In Aagaard's view, the emerging concerns, protests and reluctance from several powerful actors resulted in the translation of the subsidy law to the advantage of sun, wind and biomass when the subsidy for heat pump installations was reduced in 1982 to 10% of installation costs, while subsidies for solar heat, wind turbines, biogas installations, compost heating facilities and hydropower facilities were raised to 30% of the installation costs. However, the establishment of the natural gas project played perhaps an even bigger role in the increasing political and regulatory disfavouring of heat pumps.

Natural gas – an emerging macro-actor

The first Danish Energy Minister, Poul Nielson, who took office in 1979, was a devoted proponent of natural gas as great gas reserves had been found in the North Sea. The minister secured huge investments in a national gas distribution network, which became one of the biggest and most expensive, state-financed construction projects in Denmark. Together with District Heating (DH) and Combined Heat and Power (CHP), the natural gas system was an

element in strong political ambitions to develop and strengthen collective heat supply systems in Denmark.

Meanwhile, in 1981, a new energy plan was presented, which continued the former plan by cutting down on oil imports and decoupling energy consumption from economic growth. However, the dissemination of natural gas did not proceed as expected, among other things due to increased focus on energy savings, and one of the means to secure the huge public investment in the natural gas project was to extend the gas network all the way to the individual household so that gas would be used in individual boilers (Meyer 2000). Moreover, in 1982, it became mandatory for households to connect to the collective systems in areas with district heating or natural gas. Furthermore, electricity, oil and coal taxes were raised considerably in the early 1980s to counter falling oil prices, while natural gas was not taxed (Nielsen 2006).

The fight between two emerging programs of action

Parallel to the rollout of the gas system, the emerging heat pump industry experienced a sudden decrease in sales. In the late 1970s and early 80s, sales had seemed very promising. In 1979, DKK 50m were made available for alternative energy subsidies, which – according to a newspaper article from October 1979 – were 'torn away in less than two months' (Rosenberg 1979). Applications for heat pumps topped the list of the six renewable energy installations available for subsidies with DKK 14.7m followed by straw burners (12.7m), wind turbines (10.3m), solar heat (5.6m), wood burning (5.5m) and biogas (0.1m).

However, demand for heat pump systems declined from around 2,000 units sold in 1982 to a few hundred in 1986. In the action plan 'The Heat Pump's Possibility in the Future' from May 1986, which was sent out to various stakeholders to secure their commitment to the program, Ole Willumsen from DEFU wrote: 'undeniably, the development does look quite disastrous" (Willumsen 1986: 1).

Willumsen blamed the inconsistent quality of heat pump installations, inadequate promotion of heat pumps, fluctuating subsidy schemes and volatile oil and electricity prices. A new decree of the subsidy law imposed in January 1985 had entirely removed the subsidy for 'smaller, electrically powered heat pump installations' (although it was reinstated again in 1988), whereas the other renewable energy installations continued to be subsidised. Nonetheless, the heat pump stakeholders considered the emerging natural gas network and the tax exemption, as well as the mandatory connection to collective systems one of the biggest barriers to the dissemination of heat pumps.

1990s: From independence from imported oil to global warming

Global warming becomes an issue: new alliance

The third official Danish energy plan was presented in 1990 and was greatly influenced by the emerging debate on global warming; aiming for a 20% reduction in CO_2 emissions compared to the 1988 level – at the time, one of the most ambitious national energy policy targets (Meyer 2000). However, this new sustainable political direction did not signal a break from the political headwind that heat pumps had experienced for almost a decade, and there was no ambitious proposal for them in the new plan – they had still not succeeded in being inscribed in policy. In addition, a ban on electric heating had come into effect in 1988 and

taxes on electricity had been further raised in 1989, which strengthened the association between electricity and an undesirable direction for the energy system.

Nonetheless, the new sustainability agenda presented an opportunity for heat pumps since renewable technologies were increasingly framed as a means of reducing CO_2 emissions, as opposed to just securing independence from oil or fighting centralised electricity system actors. In autumn 1990, Aagaard in the memorandum, 'The use of heat pumps as an element in energy planning', urged the heat pump manufacturers' organisation (AMHP) and the test station to adopt a stronger public profile (Aagaard 1990: 1). As the AHMP wrote in a press release, 'the heat pump as an advantageous heating form has been kept silent in the public debate for too long' (Winther 1990). Heat pumps, Aagaard argued, presented the possibility of 'environmentally-friendly and yield-increasing interoperation with, for example, wind power, solar cells, wave energy [etc.].' Moreover, he called for political attention to the fact that despite the significant amount of exporting to, e.g. Sweden, 'the home-market is far too small to maintain our leader position in the long run' (Aagaard 1990: 2).

Despite these attempts and growing resistance to the natural gas project, which increasingly gained debt and failed to keep black boxes closed, the expansion of natural gas and district heating continued, while domestic heat pump sales remained low. In 1993, a new decree stated that subsidies would no longer be granted to heat pumps in collective supply areas, whereas the other renewables continued to receive 30% as the Energy Agency had become aware of 'aggressive marketing' from heat pump manufacturers in these areas (EnergiNyt 1993).

However, natural gas companies' equally aggressive marketing and the introduction of green taxes in 1994, which increased taxes on electricity, but not on heating oil while natural gas remained tax-exempt, led the AHPM to write to the Energy Minister, Jann Sjursen. In their view, the new CO_2 tax was unfair because heat pumps would have less CO_2 emissions than natural gas with the implementation of the recent energy plan with its green development in electricity production (Andersen 1994). However, the minister argued that in the Energy Agency's assessment, this was not the case and that it was well known that connection to collective systems was a high political priority (Sjursen 1994). Thus, the CO_2 friendliness of heat pumps was controversial, and the Energy Agency took the opposite position than heat pump proponents; the change in focus from independence from oil to a reduction in CO_2 emissions actually weakened the heat pump.

The role of heat pumps in the energy system – emerging opportunities

Nonetheless, the Energy Agency believed they had assisted the heat pump since they in a new decree from 1993 raised the subsidy from 10% to 15% in areas *outside* collective supply and finally supported a quality assurance scheme for installers (VPO), which Aagaard and others had been trying to establish since the 1980s. Moreover, TI received funding from the Energy Agency to investigate whether integrating heat pumps in collective supply systems and with solar heat, micro-CHP and small wind turbines would be viable. However, the district heating and natural gas companies were reluctant to get involved in the project and there was little political interest in pursuing the project further.

In 1996, the fourth official energy plan was presented, which continued the focus on energy savings and the expansion and greening of collective systems. Wind power was becoming a macro-actor, being given a significant place in Danish energy policy. In the same year, the Electricity Saving Trust was established, which aimed to promote electricity savings in private households and the public sector. Despite Aagaard's continued efforts to build a strong relation to wind energy by emphasising how the growing share of wind energy would interoperate well with heat pumps (Aagaard 1999a), the Trust initiated a campaign against electric heating, which once again supported the link between electricity and 'black energy'.

2001 – 2007: The heat pump network is dismantled

In 2001, the change in government led to the abolition of the subsidy law for renewable energy and the decommissioning of the test stations. The new right-wing Prime Minister, Anders Fogh Rasmussen, wanted to break from the former Environmental Minister's ambitious and 'centralised environmental policies' as well as his so-called 'energy and environment mafia'. He closed a large number of government councils, boards and institutions, which he believed had developed into 'state authorised "arbiters of taste" that dictate what is right and wrong in various fields'. He promised that the new government would undertake 'a very extensive rationalisation' of the boards and the environmental field in general, including the Ministry of Environment (Rasmussen 2002). Apparently, one of these 'arbiters of taste' was Aagaard, who left the test station when its funding was ceased following the abolition of the subsidy law. From 1 January 2003, the test station was still located at TI, albeit in a different form and with a much lower budget, which was based on a voluntary user-financed system approval scheme, i.e. a positive list, under the charge of Claus S. Poulsen. Evidently, this policy led to a weakening of the already fragile heat pump network, which lost the strength that had after all been embodied in the inscriptions the test station had disseminated. Also, the other renewable energies suffered, although wind energy had become such a strong network that it did not suffer to the same extent (Karnøe in progress).

2008 – ?: New energy policy & smart grid framing

After several years of almost complete silence in relation to heat pumps, things started happening politically. In 2008, the Prime Minister publicly acknowledged that he 'had been wrong' and the government had been dragging its feet regarding its energy and environmental policy (Lehmann 2008). Instead the government's vision was that Denmark should become completely free of fossil fuels and that policy should increasingly support green growth. The same year, a two-year DKK 30m heat pump campaign was launched to 'promote the use of energy efficient heat pumps as replacements for worn-out oil burners' (Regeringen 2007: 4). Moreover, in 2009, a new ground source heat pump decree was issued allowing heat pumps only 50 meters away from public water supply plants, while in 2010, a one year subsidy scheme to replace oil burners with solar heat installations, district heating or heat pumps was launched. Thus, the translation of publics, politicians, regulations and calculations seemed within reach again.

Electricity means 'green'

Meanwhile, in 2010, the words 'intelligent energy system' and 'smart grid' began appearing in a number of policy documents and white papers, and a clear association between this modernised electricity system and heat pumps was being established which strengthened the heat pump network. Although heat pumps started to appear more in governmental policy

plans in 2007-2008, their role and meaning started to change around 2010. They shifted from being seen as separate units, to being seen as an integral and beneficial part of a collective system. They were no longer merely associated with a means of increasing energy efficiency, but had also become one of the dominant means of taking advantage of an increasing amount of intermittent wind energy, which threatened to destroy the stability of the energy system. Electricity was increasingly related to something 'green' and 'pure' based on its relation to wind energy, therefore enabling the same characterisation of heat pumps. The emerging association with the smart grid strengthened the heat pump's position and identity as green and as invaluable and flexible consumers of green electricity. Even the hereditary enemies of heat pumps such as OVE had been translated and had to accept them 'in their new form', although they still argued 'that the heat pump expansion only be increased in pace with the increase in renewable energy in electricity production' (OVE et al 2010: 65).

In 2010, the government's Climate Commission published its report, 'Green Energy – the road to a Danish energy system without fossil fuels', which emphasised that the energy system should become more intelligent and that heat pumps in combination with heat storage systems are some of the technologies required to exploit periods with maximal wind production (Klimakommissionen 2010: 9). Strikingly, as Claus Poulsen noted, 'the word "heat pump" is included 55 times in this report. Not too bad considering that heat pumps have historically struggled to even be characterised as renewable energy' (Poulsen 2011: 51). Clearly, the heat pump was being inscribed into technical reports and policy more than ever before.

The DEA played an important part in creating this new and significant role for heat pumps and in circulating immutable mobiles in which they were inscribed. In the background report to their annual meeting in 2009, they suggested the electrification of heating (heat pumps) and transport (electric cars) as 'new ways of utilising electricity' (Dansk Energi 2009: 26)), which was necessary if more national wind energy production was going to be utilised socio-economically sensibly (Nyborg & Røpke 2011). Then, in 2010, just before the publication of the Climate Commission's report, the DEA published another report, 'Smart Grid in Denmark', where the term 'smart grid' was firmly established for the first time in relation to the transition of the energy system (Energinet.dk & Dansk Energi 2010). In the smart grid, increasing electrification meant escalating peak loads, which could be solved with intelligent or flexible consumer behaviour. Notably, ground source and air-water heat pumps were presented as excellent flexible agents as the electricity companies could, e.g. turn them off externally in periods of peak demand without any comfort loss as the heat is retained in the central heating system or buffer tanks. Heat pumps had finally become part of an action program that was not opposed by renewable energy proponents – rather heat pumps were now seen as allies.

Many new projects and knowledge building on dissemination

As a result of the heat pump campaign in 2008, the new smart grid focus and the subsequent ambitious energy agreement from March 2012 led by a new centre-left government elected in 2011, a range of heat pump projects was initiated in the political system, energy sector and at universities. The first projects were explicitly concerned with users and barriers in relation to investment. A main finding was that homeowners experienced poor service and suboptimal installation. Accordingly, the Energy Agency financed a big project to address this issue

(Energitjenesten et al. 2012). These studies were followed by interest in the heat pumps' smart grid potential and, furthermore, the energy agreement from 2012 entailed the complete phasing out of individual oil burners, which had spurred an interest in exploring, e.g. alternative business models for selling heat pumps outside collective supply areas (see also Maagensen & Krøjgaard 2013). One suggestion was to allow district heating companies invest in heat pumps so the customer merely pays for the heat. This focus was also a result of the growing debate over the problems some homeowners had with obtaining a loan. Increasingly, pellet burners have also been discussed as an alternative to oil burners (Ea Energianalyse 2012, Dansk Energi et al. 2013).

Discussion: A history of failed translations and problematisations

The above account clearly illustrates that Denmark missed an opportunity. Table 1 shows that there were many green lights in the 1970s, and the prospects looked promising. The subsidy law and the work of the test station for heat pumps meant that up until 2001, 'the quality and effectiveness of heat pumps improved so much that the Danish heat pump manufacturers were at the absolute forefront in the field of individual heat pump systems' (Beuse et al. 2000, Aagaard 2003: 9). Thus, 'many of the Danish produced heat pumps matched many of the products from the big international corporations when they were being tested at the TI in the 1980s and 1990s' (Poulsen 2011: 50). Also, internationally, the Danish heat pump industry was 'renowned for being at the highest technological level on the European market' (Aagaard & Bünger 1997: 30). For instance, this was confirmed in 1997 when a ground source heat pump system produced by the Danish company Lodam Energy A/S won an international competition organised by the Dutch government. Today, however, Danish heat pump manufacturers are losing ground to an increasing number of imported brands. Only a few Danish manufacturers remain and their exports are decreasing (Rambøll 2011).

As shown in Figure 1, heat pumps quickly gained ground compared to wind power after the introduction of the subsidy law in 1981, but 20 years later they had clearly lost the race.

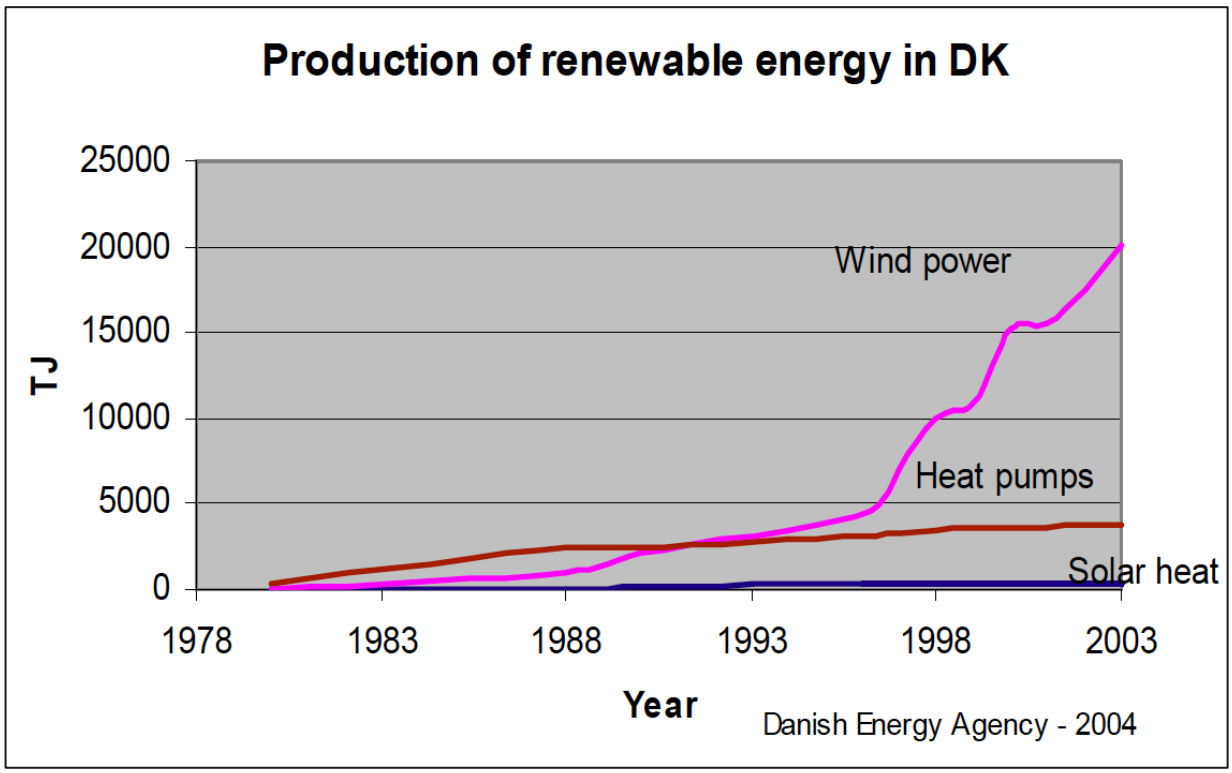

Figure 1: Production of renewable energy in DK. Source: Claus S. Poulsen

So, why was the opportunity not seized? Clearly, this is a story of continuous struggles to create a durable heat pump network and it provides examples of a range of failed translation attempts that illustrate why the heat pump was not realised decades ago. The failed translations are present in:

- Policy and regulation, where there was little success in inscribing the heat pump into subsidy law.
- Failure of the heat pump network to enrol installers through proper education.
- Failure to translate material entities such as heat emitter systems in houses that often fit much better with the oil burners' 'definition of the situation.'
- The success of competing action programs such as OVE. Undeniably, this actor-network had immense success in circulating interessement devices that continuously broke the links that heat pumps were trying to establish by, e.g., arguing that heat pumps were not a renewable energy.

In the following, we summarise and analyse the insights gained from 'following the actors' and the historical account. This is done in relation to the three arenas of policy and regulation, users and civil society and technology and design.

Policy and regulation – heat pumps disfavoured compared to other renewable energies

Clearly, Danish energy policy did not really support the heat pump. Firstly, the dissemination of collective systems and, notably, the natural gas project became a barrier to the development of renewable (heating) energy technologies in general[3]. Secondly, heat pumps were often disfavoured compared to the other renewable technologies, e.g. by receiving a lower subsidy when subsidies were raised for other renewable technologies, by being exempt from subsidies in collective supply areas when other renewables were not, while sometimes they received no subsidies at all as they were not acknowledged as a renewable technology. The lack of support also meant that heat pump representatives were excluded from the Energy Agency's advisory boards on renewables in the 1990s, where they could no longer be the 'spokesmen' of heat pump technology. Thirdly, energy taxes did not favour heat pumps and their manufacturers realised very early on that they should avoid being seen as competition to collective supply systems and, therefore, argued for dissemination in areas *outside* collective supply systems. However, the high taxation on electricity (also for heating) meant that it was comparatively more expensive to be a heat pump owner than it was to have another renewable heating installation.

Finally, the abolition of the subsidy law in 2001 and the disruption of the network and technological competence that had been built up by Aagaard over 23 years –as Danish heat pumps were winning international prizes – probably also influenced how the market looks today. The removal of the subsidy scheme meant there was no longer the same legitimate quality control or framework that supported heat pump efficacy and competent installers, and a range of possibly low quality heat pumps and unauthorised installations could penetrate the market – thus experiences with bad installations could start anew.

Users and civil society – a strong group of allies

Unlike the other renewable technologies, heat pumps did not have a loyal and inventive group of users with 'zest and pioneering spirit' (Beuse et al. 2000: 26) to promote and develop the technology and construct and circulate artefacts such as handbooks on how to produce wind turbines or display examples of home-made prototypes. OVE, for instance, organised study circles and open-house events, where people discussed opportunities for building their own wind-turbines, solar heating installations and small biogas-plants and demonstrated their self-built installations. These actor groups were powerful and their activities were a barrier to heat pump dissemination, e.g. by influencing political opinion through the steady supply of alternative calculations and by being critical of heat pumps when householders sought advice. This problematisation of heat pumps has been very persistent throughout time. As late as 2001, Hans B. Jespersen, an energy consultant at the energy office in Viborg, wrote an article in which he stated that 'the total energy consumption [in Denmark] is increasing slightly and there are several explanations for this. One explanation is heat pumps' (Jespersen 2001: 5). In the article, Jespersen criticised heat pump advertisements distributed by a utility company because they did not illuminate how extra components such as air-conditioning and air-recirculation features could increase consumption.

[3] This is one of the observations that would be interesting to explore in a comparative study of Sweden and Finland. Here the development of collective heat supply systems has been far more modest than in Denmark and the dissemination of heat pumps has conversely been quite a success.

In a reply to Jespersen's attack, Jørgen Gullev argued that if used properly, heat pumps did not result in increased consumption. In his view, the energy offices were just not 'geared to accept that in many respects, both for the customer and generally for the environment, there can be a good and energy-efficient solution based on electricity' (Gullev 2001: 20).

Technology and design – a complex technology with shifting meanings

The very specific technological design of the heat pump has also presented challenges to its dissemination[4]. Whereas an oil burner is a simple technology that builds mostly on mechanical technologies, a heat pump is more complex and includes several systems including a heat absorber, a refrigerant, an evaporator, a compressor, a condenser etc. Its installation requires much more precise dimensioning and necessitates the meeting of several heterogeneous crafts and skills, e.g. plumbers, HVACs, electricians, gardeners and well drillers; this demands much tighter project coordination and involves greater risk of poor installation. Although Aagaard worked very hard to enrol installers from the early 1980s and somewhat succeeded when the VPO scheme was established in 1994, the many poor installations in the 1980s gave the heat pump a bad reputation, which it struggled to shed.

The technical design of heat pumps represents another challenge as they supply a much lower flow temperature in radiators than oil burners – the latter requires much smaller radiators or heat emitter surfaces, which are literally inscribed in most of today's building stock. Furthermore, its specific technical design means that it imposes and depends on a wider network of other important actors over and above the installers; for example, ground water, water utilities, environmental groups, chemical and refrigeration industries, etc, which increases the networks that it interacts with and may lead to greater resistance.

Difficulty understanding how the heat pump works and where it receives renewable energy from may also explain why people have struggled to define it as a renewable energy since its birth in Denmark in the 1970s. However, early on, heat pump stakeholders attempted to frame heat pumps in relation to solar heat instead of electricity or electric heating. The sales director of the heat pump manufacturer Vølund A/S, H. Busch, for instance, wrote in an article in the VVS magazine from 1979: 'when one talks about solar heat, one normally talks about two different forms, namely 1) solar energy that is collected through solar panels, and 2) solar energy that is accumulated in the ground and collected by a heat pump installation via a tube in the ground' (Busch 1979: 26). Later, the Energy Agency adopted the view that an electrically-driven heat pump was not a renewable energy installation because of the electricity needed for the compressor. However, in 1999, both AMHP and Aagaard emphasised that heat pumps delivered twice as much renewable energy as all the wind turbines in Denmark and approximately twelve times the amount of renewable energy as active solar heating facilities (Aagaard 1999a). Thus, Aagaard constantly produced alternative calculations to re-frame heat pumps. Yet it was their relation to electricity that dominated the meaning ascribed to them.

[4] In Denmark, the image of heat pump installations as a complex technology differs from the image in Sweden and Finland. It would be interesting to explore the background for this difference in a comparative study.

The story about OVE and the controversy over whether a solution based on electricity is good or not also signifies how *the meaning* of a technology varies greatly depending on the system it becomes associated with. The fight to define the heat pump as a renewable energy and subsequent smart grid transformation demonstrates that the 'truth' about or meaningfulness of heat pumps was highly contested and contingent on how they were framed in relation to, e.g. the historically 'black' electricity system or recently to wind energy and their benefits for the smart grid.

Conclusions and perspectives

What can be learned from the historical account and the above analytical summary? Firstly, an important lesson is that since the heat pump program never succeeded in translating materials such as buildings or ideas, policy and skills into a durable network that could have existed today, all the effort that was made is more or less invisible and somewhat wasted. Even though many elements that could make up a network were circulated – 'facts', experiences, ideas, technologies etc. – they did not assemble into a macro-actor. None of the relations ever became black-boxed, but almost always remained problematised. Despite the numerous inscriptions and other interessement devices that flowed from the test centre in the form of yearly reports, letters, press releases, etc., they did not succeed in enrolling a large number of faithful or disciplined allies. The consequence, it seems, is that many of the challenges of the past keep being repeated when attempts are made to construct a new heat pump network.

Regarding the current attempt to disseminate heat pumps, it is interesting that most of the benefits, potentials, barriers and issues being discussed (and repeated) today have been highlighted by various actors several times in the past; for instance, how heat pumps could interoperate effectively with the growing share of wind energy and handle 'overflow-electricity', how getting a loan for a heat pump due to the specific loan ceiling of each property could present a problem, and how heat pumps could increase peak-demand problems. Already 40 years ago at an international electric utilities conference, Gullev, emphasised how heat pumps could 'very easily be oversold' by 'some less serious plumbers, electrical contractors and manufacturers' whose 'heat pump installations […] may not in their final form satisfy the high expectations' (Gullev 1974: 2). Needles to say, this is exactly what happened in the 1980s and continues today.

Probability of a fairy tale?

So what are the chances for a future heat pump fairy tale? As seen in Table 1, there are again many green lights, but can they be maintained? In an ANT perspective, this would require the translation of opposing programs of action and formation of stable networks and relations. Are there any signs that entities such as policy, users and materialities are being translated and a network is assembling? And is there resistance and anti-programs?

At first glance, it seems that the large number of interessement devices such as smart grid policy papers that have circulated in recent years have translated a range of actors such as the ground source heat pump decree. As argued by minister Martin Lidegaard, the oil burner phase out agreement the new education scheme for installers and the lower tax on electricity are also important steps in terms of policy and regulation.

Current resistances

However, other important human and non-human actors have not been translated such as heat emitter systems in houses or the building regulation, which is unsuitable for the heat pump's technological setup. According to such building regulations, a heating system should be dimensioned to ensure an indoor temperature of 20^0 C with an outdoor temperature of -7^0 C. Installers routinely follow this regulation, but in reality most people require a higher temperature inside, which renders the heat pump incapable of fulfilling the promised savings (Søren Rise, Tekniq, pers. comm.). Oil burners, on the other hand, which should also provide a temperature of 20^0 C, do not need to be dimensioned nearly as precisely because considerably higher flow temperature means it is much easier to increase the heat without efficiency losses. Furthermore, the building regulation's demand for individual room temperature control via thermostats leads to difficulties when installing air-air and exhaust air heat pumps in new buildings in Denmark.

Moreover, the lack of stability regarding heat pump policy is still a problem, which has hardly been reduced by the change of government in June 2015. For instance, although the tax on electricity was reduced by 42% for households registered as electrically heated and which consumed more than 4000 kWh per year in 2013, this reduction is only applicable until 2015 after which it will be re-evaluated in accordance with the net price index. Moreover, the sporadic subsidising of heat pumps such as the scheme in 2010/2011 is a short-sighted means of reducing the costs of heat pumps. The interview material suggests that such unstable initiatives may not only reduce installers' commitment to investing in education, but may also reduce householders' investment willingness since they do not know the direction of future development or whether they will be able to secure sufficient operational savings. Moreover, occasional subsidy schemes possibly make customers wait with an investment in the hope that a new subsidy scheme will be presented. Also, abrupt subsidy schemes probably create sudden booms in demand, for which the installers are unprepared. Finally, essentially, the energy taxation system still favours biomass, e.g. pellet burners, over electricity regarding heating.

Thus, ensuring a stable, long-term policy plan concerning subsidies and energy taxes would help ensure a strong network. Regarding subsidies, one suggestion is to subsidise the cost of insulation or improvement of the heat emitter system, e.g. larger radiators, when people buy a heat pump instead of subsidising the cost of the heat pump itself.

In the current situation, evidently there are additional anti-programs regarding, e.g. installers. As written earlier, heat pumps require explicit skills in terms of dimensioning and guidance for users, and the issue of poor installation still represents a significant problem today. As one householder put it, 'Many people are put off due to poor guidance. […] He [the neighbour] got a ground source heating installation in an old house that was badly insulated and which he couldn't insulate more. To sufficiently heat the house, he had to increase the flow temperature just to get to 60° C and then efficiency falls […]counselling today is very poor' (interview with heat pump owner, 2011).

However, although the Energy Agency has introduced a new voluntary education for installers of biomass ovens, PVs, solar heat and heat pumps, the TI considers this a poorer alternative to the already existing offers such as the VPO that was established in 1994. Furthermore, as

energy consultant for the trade and employers' association for craftsmen, Carsten Helmer, said to the media: 'One scheme replaces another and what should you choose as an installer? As the market is at the moment, installers can virtually educate themselves from now on until they are retired without earning a dime' (Andersen 2014). So far, the Energy Agency has refused to make such education obligatory to make sure that the many offers are actually used.

Regarding the users of heat pumps, it seems like this heterogeneous group of actors are not so easily translated. The lessons learned from the activities of OVE and the other civil society groups demonstrate a general point about the role of users in the transition of the energy system, a stance which the eFlex (Nyborg & Røpke 2013, Nyborg 2015) and DREAM (Svanborg & Aarup 2014) projects have also supported. Users do not necessarily fit into the passive consumer role so often assigned to them by system designers; nor can they be understood as one homogenous group with anticipated, compliant action programs. Just as these past civil society groups were unwilling to enrol in the electricity companies and government's nuclear power program, of which they viewed heat pumps as being a part, not all homeowners today are willing to be translated by the minister to become enrolled in the smart grid program by, e.g. investing in a heat pump. As discussed previously (Nyborg & Røpke 2011), the ideas about who the users are, which are inscribed in new smart grid systems, are often rather simple. However, the lesson from the users is that many of them have different rationales to those expected from a system builder's action program, and some have a strong desire to interact with the system. Such findings indicate that a 'one size fits all' design and rollout of heat pumps may be unfruitful and call for homeowners to be used as a resource and for a more systematic exploration of the potential of user involvement in the development of the heat pump and its interaction with other systems, as well as practices, in the home.

We would argue that better support systems *after* the acquisition of the heat pump are needed. Our research suggests that users like to share their experiences with the daily operation of the heat pump. Such dynamics could be supported through better user-user interaction or peer-to-peer advice. In relation to this, we would like to point to experiences with user-run internet forums, which may support some of the most inventive users in 'providing top end technical assistance to other users that facilitate market creation of these technologies' (Hyysalo et al. 2013a: 46). Such initiatives may support the users' ability to create inscriptions and other devices that can help in the translation process and expand the network. In addition, a grass roots level promotion programme has been suggested (Sugden 2013) as well as open-homes events, where experienced heat pump users – local experts – open their homes to potential users (Heiskanen et al. 2014a). Such events and physical demonstrations were also widespread in Denmark in the 1970s regarding the development of sun, wind and biomass technologies and helped strengthen their networks.

The shape-shifting heat pump and the smart grid – a too monogamous love affair?

The meaning ascribed to heat pumps in the current development of the smart grid has strengthened the heat pump. However, there may be a risk of adhering exclusively to one specific agenda or energy system pathway. Just as the energy offices and OVE resisted heat pumps because they could not foresee the huge amount of wind energy that would become part of the electricity system, it is impossible for us to foresee the exact pathway the energy

system will take in the future or whether the electrification/smart grid pathway will be in line with the imagined scale (Lunde et al. in progress).

If the definition of the heat pump is so intimately linked to the energy system to which it is a part, there is perhaps a danger in it being linked too firmly to its ability to elicit flexible electricity consumption from individual households. What is the competition, for instance, from individual pellet burners? Or from natural gas and district heating systems where heat pumps function only as a supplement? Indeed, whether flexible electricity consumption from households really presents any real flexibility advantage in the bigger picture is being increasingly debated, and some argue that the heat pump should rather play a central role as large units in district heating systems (Mathiesen et al. 2011). However, the heat pump *is* currently being linked to broader discourses and systems. In relation to the oil burner phase-out agreement, the Energy Agency is, e.g. currently investigating the potential of natural gas/heat pump hybrid systems. The idea is that while the heat pump is generally fuelled by electricity, during rare peak events, e.g. during very cold weather, the central water system of the house is heated by a gas burner. Hybrid systems are actually well suited to a smart grid context because they significantly reduce the problem of electricity peak demand. Therefore, there may be an alternative and more hybrid path for heat pumps than that which has dominated the Danish view, i.e.- a heat pump replacing the entire heating system of a house in one go. Hence, we should remain open to the potential and implications of the heat pump in case the dominant vision is not realised.

Finally, we call for greater attention to the heat pump's interaction with changing everyday life practices and to the possible negative energy implications. This issue was only briefly discussed in the paper and remains under-investigated. A Danish study of air-air heat pumps has, for instance, pointed to how heat pumps 'potentially contribute to long-term changes in comfort behaviour and practices, which may undermine the energy saving potential' (Christensen et al. 2011: 1963). Thus, considerations about whether heat pumps are an unconditionally sustainable solution and which issues require attention if heat pumps are to be a normal and unquestioned heating form in Denmark are also needed.

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