Factors for enhancing the market development of energy efficient heat pumps – scaling up through European policy instruments

Carlos Lopes
Swedish Energy Agency
Box 310
631 04 Eskilstuna
Sweden
carlos.lopes@energimyndigheten.se

Caroline Haglund Stignor
RISE – Research Institutes of Sweden
Box 857
501 15 Borås
Sweden
caroline.haglundstignor@ri.se

Emma Olsson
Swedish Energy Agency
Box 310
631 04 Eskilstuna
Sweden
emma.olsson@energimyndigheten.se

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Abstract

Heat pumps have largely contributed to the almost phase out of fossil fuels for space and water heating in detached houses in Sweden, and for reducing greenhouse gas emissions by more than 90 % since 1990. Ground source heat pumps are now a typical heating solution and equip a quarter of the houses, which is the highest penetration in the world.

The paper focuses on the factors behind this development. Special attention is given to the continuous research, development and dissemination policy programmes since the 70's. Also, taxes and subsidies are studied, as well as public product testing, information and advice, which have been essential to create consumer acceptance and trust for a new technology. Both the collaboration and the competition between manufacturers are analysed, as well as the training of installers they organise. The replicability of these factors in other situations is also discussed.

The paper analyses also the possibilities for enhancing the coordination between policy instruments at EU and at Member State level. The paper discusses implementation at national level, namely the interaction between standardisation and the verification of requirements under ecodesign and energy labelling implementing measures.

Lastly, the paper explores the perspectives for increasing the market penetration of heat pumps. One crucial factor is the capacity for demand-side flexibility, which can be promoted through ecodesign and labelling implementing measures, and through the buildings smart-readiness indicator.

The paper is based on the experience of the Swedish Energy Agency in its different roles: funding research and innovation, carrying out information and promotion activities, coordinating tests, negotiating requirements at EU level, and as market surveillance authority.

Introduction

Heat pumps have now lived up to the expectations of the visions established in early 70's. This is despite the changes of the drivers in energy policy: increasing energy independence and developing nuclear electricity as an answer to the oil crisis; mitigating CO_2 emissions; setting energy efficiency as a policy objective, and now an increasing focus on controlling power demand to allow an energy system with a growing part of renewable variable electricity production.

In particular, heat pumps have largely contributed to the almost phase out of fossil fuels for space and water heating in single- and two-dwellings buildings in Sweden and for reducing greenhouse gas emissions by more than 90 % since 1990. Today heat pumps range from small exhaust air heat pumps from 1 kW, to heat pumps used in district heating plants with 260 MW (Värtaverket in Stockholm).

The factors that have led to the development of the heat pump technology and their market penetration are analysed in this paper. These include: inherent characteristics of the energy system; broad energy policy; research, development and dissemination; regulations; public product testing; information and advice aiming at creating consumer acceptance. Finally, besides public policy, the collaboration and the competition between manufacturers are described, as well as

the training of installers they organise. This is summarised in Figure 1.

The paper deals with heat pumps for hydronic systems used in single- and two-dwelling buildings. The focus is on ground source heat pumps, where Sweden has a unique position in terms of manufacturing industry and market penetration. Sweden is the largest market in the European Union with 28 % of the market and 35 % of the stock in 2016 (EHPA, 2019).

The paper attempts to describe what we consider is a successful case study of market transformation: a complex innovative technology, with its inherent problems including in its installation, that becomes common, competitive and affordable. Ground source heat pumps are now a typical heating solution and equip a quarter of all houses.

Heat pumps and the phase out of fossil fuels in the heating sector

Final energy consumption in single- and two dwelling buildings has decreased by ca 30 % in the last 30 years, while the heated floor area has increased by almost 20 %. The total energy consumption in these buildings has been reduced from about 170 kWh/m² in 1983 to 105 kWh/m² in 2016 (Swedish Energy Agency, 2019). Fossil fuels, which accounted for 40 % of the consumption in 1983 were almost phased out by 2010 and CO_2 emissions were reduced by more than 90 %.

Almost all oil boilers have been replaced. District heating has increased 225 % in single and two-dwelling houses but still only accounts for 17 % of the final energy use for heating. Oil has also been phased out from district heating, being replaced by biomass including urban waste, and by heat pumps.

Despite a large increase of the area heated by electricity, and that heat pumps have replaced a large number of oil boilers, electricity consumption remained in 2018 at the level of 1983, after an increase in the late 90's (Swedish Energy Agency, 2015 and 2019). There are two reasons for this electricity efficiency improvement. First, the use of air-to-air heat pumps (room air conditioners used in heating mode) in houses with resistance based electric radiators and therefore without hydronic system. Secondly, the cases where heat pumps have replaced electric boilers connected to a hydronic system.

Market and stock of heat pumps in Sweden – Ground source heat pumps as the most common solution

The market for heat pumps including air-to-air heat pumps is described in Figure 3 below, while Figure 4 describes the penetration of ground source (brine-to-water), air-to-water and

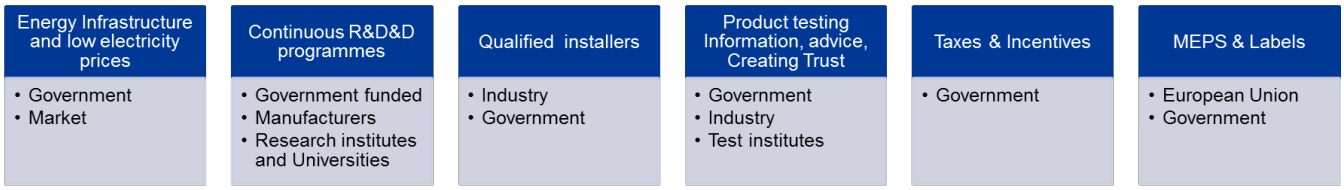

Figure 1. Factors that led to the development of heat pumps in Sweden and actors behind the factors.

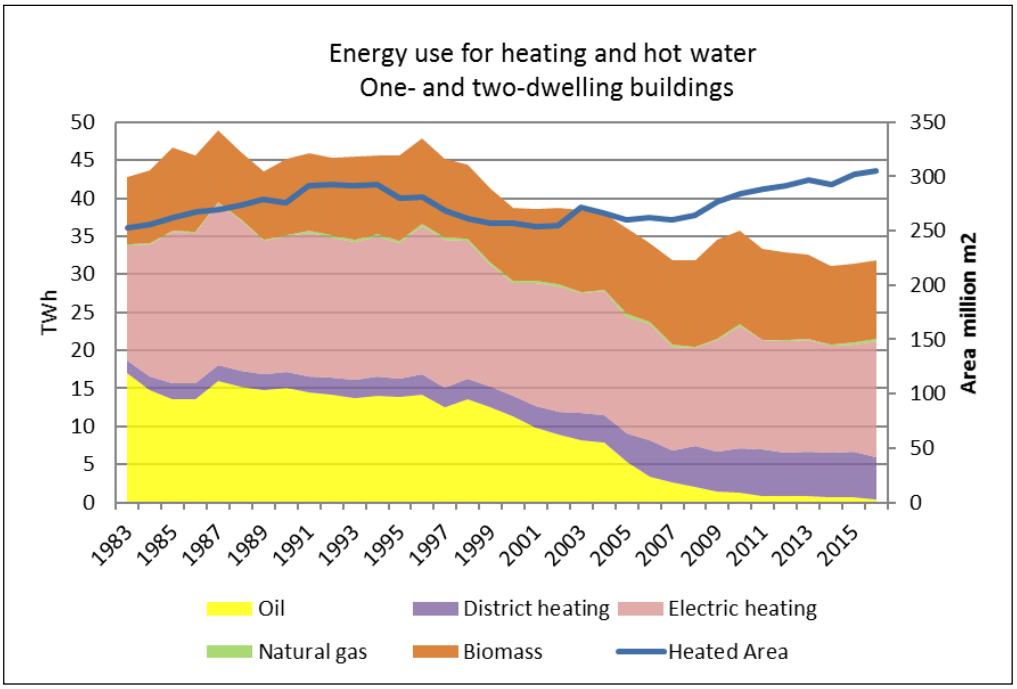

Figure 2. Final energy consumption for heating (including cooling) and hot water in single and two-dwelling buildings vs total heated area (Swedish Energy Agency, 2019).

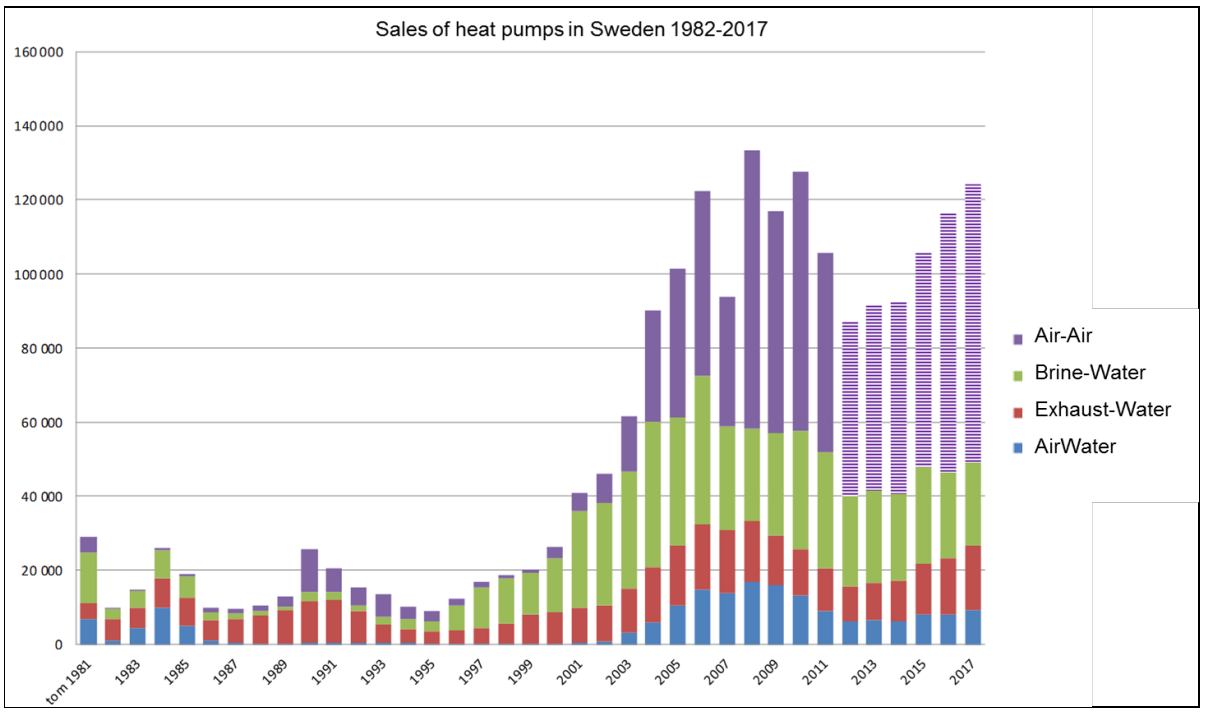

Figure 3. Sales of Heat pumps in Sweden 1981-2017 (source: SKVP – Swedish Refrigeration and Heat Pump Association) – (from 2012, sales of air-air heat pumps are estimated).

exhaust air-to-water heat pumps in single and two-dwellings buildings with hydronic systems.

Air-to-air heat pumps (lilac in Figure 3) have saved energy in buildings without hydronic systems by replacing some of the resistance heating by heat generated by the heat pump. These heat pumps are actually room air conditioners operated in heating mode. From 2004, tests on heat pumps were organised by the Swedish Consumer Agency and continued from 2006 by the Swedish Energy Agency and performed at RISE – Research Institutes of Sweden (former SP). The results were published by the Swedish Energy Agency and were used by consumer and professional magazines. These tests have stimulated manufacturers to enhance the development of their products and importers to require products to be adapted to the Nordic climate conditions, for example with suitable defrost functions (Sandvall and Lopes, 2015). Air-to-air heat pumps can now operate at temperatures as low as -20 °C or even lower. However, unlike other types of heat pumps, the impressive technology development that they have experienced cannot be significantly attributed to the R&D efforts in Sweden and there is no manufacturing industry in Sweden for these products. We shall not focus in this paper on the sales of these air-to-air heat pumps (lilac in Figure 3).

HEAT PUMPS FOR HYDRONIC HEATING SYSTEMS IN ONE AND TWO DWELLING BUILDINGS

Heat pumps for hydronic systems equip 37 % of single- and two-dwellings houses. Ground source heat pumps (in green in Figure 3 and yellow in Figure 4) are the most common heating solution and equip 23 % of the buildings. Air source and exhaust air source heat pumps (in red and blue in Figure 3, and blue in Figure 4) equip 14 % of the buildings.

Exhaust air source heat pumps (in red in Figure 3) have been common since the mid-eighties in new buildings. However, as the requirements in the building regulations have become more stringent, they have become more difficult to meet using exhaust air heat pumps. For new well insulated houses below 200 m^2 this type of heat pump can be a cost-efficient solution, and further efficiency development may still make them an option. On the other side, the use of double flow ventilation units with heat recovery make exhaust air heat pumps less interesting. Even if the market for new buildings may be limited, there is still a relevant market for the replacement for these heat pumps in existing buildings.

The sales of (outdoor) **air source heat pumps** (in blue in Figure 3) have increased significantly from 2003 to 2009, mainly due to their energy efficiency improvement at low outdoor temperatures. It is expectable that the energy efficiency of this type of heat pumps will further improve as a result of ecodesign and energy labelling requirements (see below). Ecodesign requirements have removed the less efficient products from the market while energy labelling is expected to stimulate more efficient products. We believe that the requirement of disclosing the product's performance in a cold climate (Helsinki) will also lead to the development of products designed for this climate, especially if this information is required to be shown on the label.

Ground source heat pumps equip a quarter of the single and two-dwelling buildings, making it the most common heating system in Sweden (see Figure 4). While this type of heat pumps, often called "geothermal heat pump", is often considered a very advanced, innovative and expensive solution, in Sweden it has become a fully technically mature option and commercially competitive. It is more energy efficient and more silent than other types of heat pumps. Furthermore, it is more adapted to the cold and in particular to the artic climate as the heat source has a more stable temperature than the outdoor air. Sweden

has now the highest penetration per capita in the world and it is even the largest market and stock in absolute terms in Europe (EHPA, 2019) (IEA – Heat Pump Technologies, 2019). In the next chapter, we analyse the factors that have contributed to this development.

Energy infrastructure and prices

A number of factors related to the energy infrastructures and the energy prices have been very favourable for the development of heat pumps, especially for replacing oil boilers:

- The availability of hydroelectricity, with a large storage capacity, acting as a valuable complement to address peak demands;
- An electricity-to-oil price ratio about 1–2, the lowest in OECD, partly due to the decision of reducing oil dependence by setting high fuel taxes. Conversely, electricity-to-oil/gas ratio in other countries has been on the order of 3–4 (see Figure 6), making heat pumps a less attractive investment (Nilsson, 2005);
- Competition with district heating, which may appear a paradox, but a common competitor can contribute to unite the manufacturers and make them cooperate (Jonasson, 2018);
- The perception that electricity is clean and an indigenous resource, while heating oil is seen as polluting, with high CO_2 emissions and negative for the national energy independence;
- Gas infrastructure is very limited, only available in parts of the west coast.

Another important factor is that the ground in most parts of Sweden is suitable for drilling and suitable for continuous heat extraction at a borehole density required by the normal distances between houses in Sweden.

Conversely, it can be questioned if the increase of nuclear electricity production in the 70's and 80's, has been positive for the development of heat pumps. The abundancy of electricity initially led to a large penetration of houses using direct electric resistance heating, i.e. with no hydronic system. The low marginal price of electricity and the high cost of installing a hydronic distribution system lead to a lock-in effect and a low level of replacement of this inefficient heating solution. From the late 90'ies, those "systems" have been complemented by air-to-air heat pumps. Furthermore, the abundancy of electricity and the low electricity-to-oil ratio led in the late 90'ies and the 00'ies to the installation of electric boilers, including as replacement of oil boilers, obviously a highly non-rational use of energy, namely for users that became vulnerable to changes in electricity prices.

Research, development and dissemination

The first Energy and Research Programme was created as an answer to the oil crisis and an Energy Savings Programme was established aimed at reducing oil consumption. Heat pumps were identified as one promising technology option, with the ground (surface, soil or bedrock) or open water (sea or lake) as the heat source.

Since the vision in the 70's, there has continuously been research, development or dissemination programmes that have promoted the development of heat pumps, directly or indirectly. These include Energy Savings Programme, Sol 85, Klimat 21,

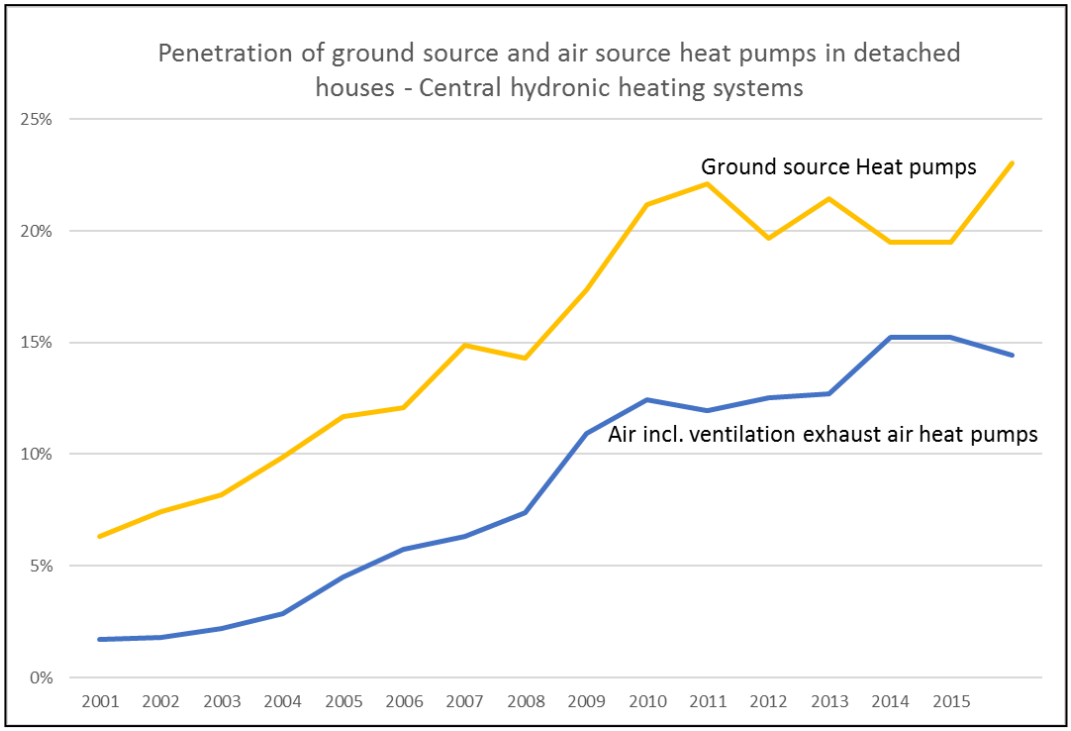

Figure 4. Penetration of Ground- and Air Source Heat Pumps in one and two-dwellings buildings 2001–2016 (source: Energy in Sweden – Swedish Energy Agency).

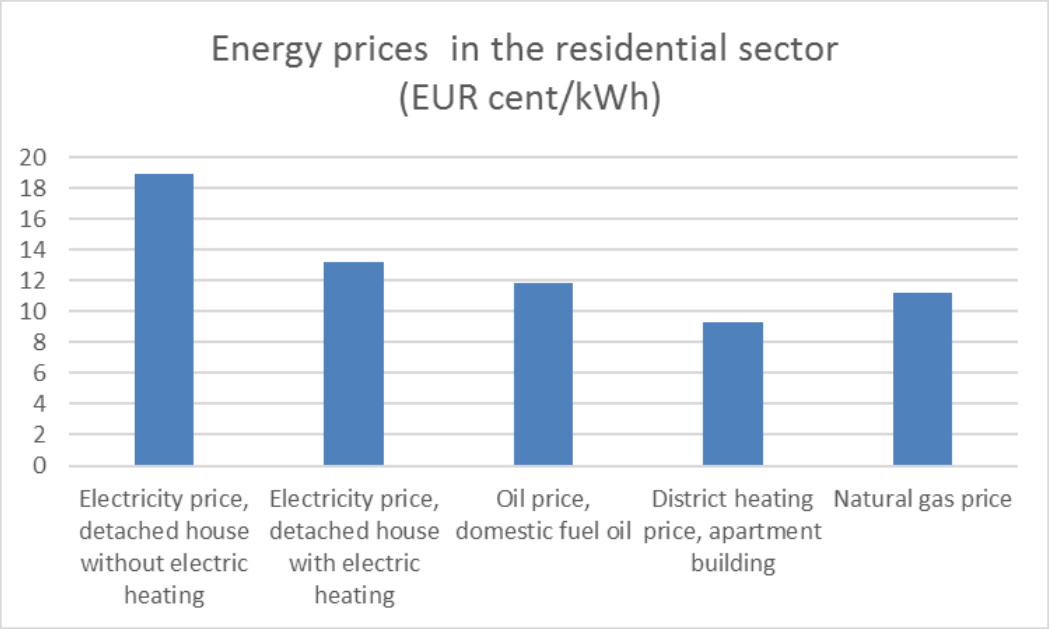

Figure 5. Energy prices in the residential sector in 2017 (source: Swedish Energy Agency, 2019).

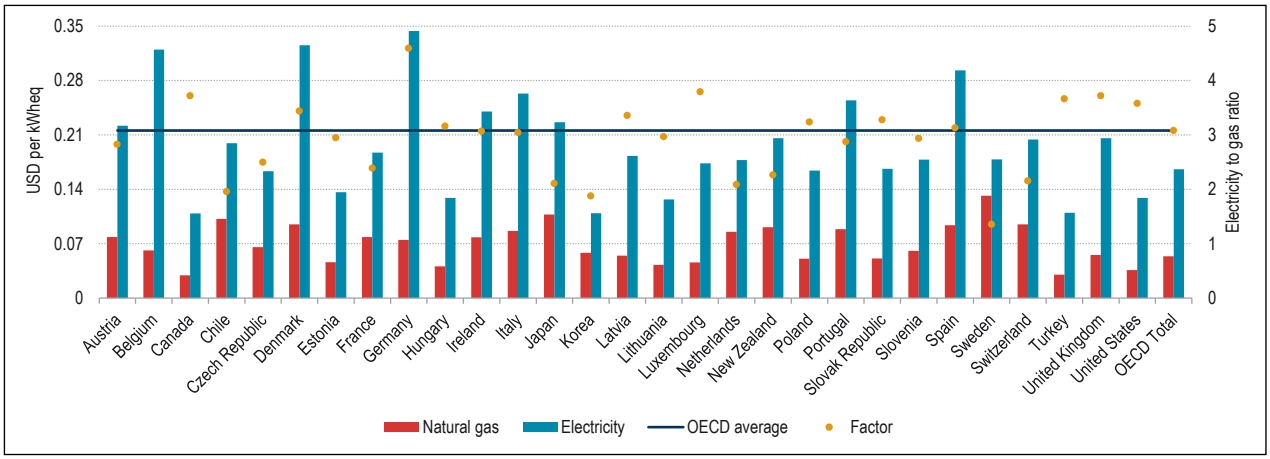

Figure 6. 2017 household prices for natural gas and electricity in OECD countries and "electricity to gas ratio" (factor in the diagram). Source: IEA Energy Balances and Statistics 2017.

Effsys 1, Effsys 2, Effsys Plus and Effsys Expand. The current programme is called Termo, where a more holistic approach has been adopted for the whole heating sector, instead of a specific programme focusing on refrigeration and heat pump technology. Heat pumps have nevertheless a large role in this programme, notably in their combination with district heating, as well as in providing demand-side flexibility and storage, which are important components of the programme. Two initiatives are described below due to their importance to the development of heat pumps.

The Sol-85 and Vattenfall's "solar project". Heat pumps were regarded as an essential part of a solar heated house and during 1979–1985 the "Sol-85" programme was the main sponsor of RD&D on heat pump technology. Concurrently, Vattenfall became a pioneer with a demonstration programme, the "Solar project", with the aim of developing and spreading heat pump technology. Vattenfall installed, tested and evaluated 433 heat pumps, mostly under 25 kW, and the results were used to produce an extensive training material. The Building Research Council also coordinated an education programme, starting in 1983, to meet the need for improved knowledge among mainly installers (Swedish Energy Agency, 2009).

Technology procurement market transformation programme. The technology procurement that ran between 1993 and 1995 is recognised as the main responsible for the breakthrough of ground source heat pumps for single-family houses (Nilsson, 2005). The objective of this initiative led by NUTEK (the precursor of the Swedish Energy Agency) was to support the development and market introduction of more efficient, reliable and less expensive ground source heat pumps. This was necessary after a period of decline and a bad reputation due to reliability problems of installed heat pumps. A group of potential buyers drafted, together with experts and NUTEK, a list of performance criteria and the buyer group committed to buying 2,000 units

of the winning product. Sixteen manufacturers were invited to develop a product 30 % more efficient and 30 %, easy to install and using refrigerants with low ozone depletion factor (Swedish Energy Agency, 2009). Six manufacturers met the criteria and two heat pumps were announced as winners. The programme was complemented with information campaigns including a customer hot-line. This time, the ground-source heat pumps for single- and two-dwelling houses would capture an increasing and eventually the largest share of the market. This is mainly due to ground-source heat pumps being manufactured in Sweden and for Swedish conditions. In 1998 an investment subsidy was introduced for conversion from electric and oil boilers to other means of residential heating, such as heat pumps.

International collaboration has always been part of the R&D policy. Sweden is one of the 16 member countries of IEA's Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP). The Swedish Energy Agency and the Business Association SKVP are represented in the Executive Committee. This membership gives Swedish researchers and industry an excellent opportunity to participate in international collaboration projects, so called Annexes. In addition, since 2004 RISE (former SP) is the host for Heat Pump Centre – the communication centre and programme office for HPT TCP. This gives Sweden and the heat pump sector an additional link to the IEA and its technology network which stimulates a bidirectional flow of information.

Economic, administrative, information & advice

PHASE OUT OF HEATING OIL THROUGH HIGH TAXES

Energy taxes have been one of the main instruments to phase out oil from the heating sector, bringing the electricity-to-oil price ratio very low, the lowest in the OECD. Today the tax on heating oil, including VAT is 5.3 cEUR/kWh (3.3 of which is for the CO_2 tax) while tax on electricity is 4.1 cEUR/kWh (2.9 in Northern Sweden).

These high taxes on oil, combined with the low electricity price have led to no oil boilers being replaced by like-for-like boilers, and in addition, earlier replacements of oil boilers occurred. The taxes also led to further development of district heating networks. Heat pumps became the main alternative in areas not covered by district heating, which is the most common situation in areas with detached houses. Even in areas covered by district heating, heat pumps have increased their penetration. This puts a pressure on the district heating companies as the fixed costs have to be distributed by less customers, increasing the prices and thus giving a further advantage to heat pumps.

During the years when most oil boilers were replaced by ground source heat pumps, the normal time for a full return of investment of the ground source heat pump, compared to oil heating, often ranged between 7–10 years according to the prospects from the manufacturers.

SUBVENTIONS – A LIMITED IMPACT

In the end of 90'ies and 00'ies, tax credits (an amount of 3,000 EUR) were available for the replacement of oil boilers, if these were substituted by district heating, biomass boilers or heat pumps. However, these are considered to have had a limited impact on the acceleration of the replacement (Nilsson, 2005).

Today, there are no specific subsidy related to the installation of heat pumps. However, it is possible to get a tax reduction of 30 % of the cost for the labour work related to the installation of a heat pump. For the installation of a new ground source heat pump it is assumed by the Swedish Tax Authority that the cost labour work is 35 % (30 % for an air source heat pump) of the total cost of the heat pump including installation.

The total investment cost for purchase and installation of a ground source heat pump and borehole today range from 10,000 EUR for the smallest models around 5 kW and more for larger ones (Haglund Stignor et al., 2018).

INFORMATION, ADVICE AND TESTING – CREATING CONSUMER TRUST

Tests on appliances have been performed by Swedish authorities since the 1940s. The main purpose was consumer protection and the consumer agency had its own consumer journal until 2000'ies where tests results were published. Tests of heat pumps became a very important activity from 2006. The aim of these tests was to:

- Provide information on the performance in order to guide consumers in their purchasing choices;
- Deliver information for training municipal energy advisers, who are providing direct advice to consumers. This included the choice of products, their sizing and their installation and use;
- Stimulate competition between manufacturers, including innovative solutions. Aspects other than energy performance were also tested such as noise and performance of different refrigerants;
- Expose low-performing products.

These tests and the information associated have been very important to create trust in a new technology, which is usually a barrier for its acceptance. The tests of heat pumps are still the most visited pages of the Swedish Energy Agency's website. Furthermore, the results of these tests have provided valuable inputs for the formulation of ecodesign and energy labelling requirements, and for investigating unclarities in the test methods (Sandvall and Lopes, 2015). Since ecodesign requirements and energy labelling have been adopted, the need for these tests targeted at general consumer information has decreased.

An active role of manufacturers and installers

Manufacturers have been able to work together and to create the knowledge necessary to introduce a new technology. They have also been able to create consumer trust despite the quality and installation problems encountered. The main business association in Sweden for heat pumping technologies, both for heating and cooling, is "SKVP Svenska Kyl- och Värmepumpsföreningen" (*Swedish Refrigeration and Heat Pump Association*).

COMPETITION AND COLLABORATION BETWEEN MANUFACTURERS

A factor that is recognised to have been positive for the development of heat pumps is the existence of both collaboration *and* competition between manufacturers (Jonasson, 2018). The collaboration has traditionally occurred within the trade organisation. Manufacturers built a common front to face the

main competitor, the district heating sector. Another example of collaboration was for influencing the ecodesign and energy labelling process (see below). Manufacturers joined forces to follow the preparatory study and influence the assumptions that initially were putting heat pumps at disadvantage.

Competition between manufacturers is at the same time considered to have contributed to create a relevant technical expertise and to stimulate innovation. It also created the possibility for becoming a Swedish export industry and attracting foreign investment.

Another reason behind that the heat pump sector in Sweden was well prepared to influence the development of and handle the introduction of the ecodesign and energy labelling regulations was the long-time engagement in international standardisation work. Since 2003 there has been a Swedish technical committee for standardisation of heat pump testing for performance rating. This committee, associated to the national standard institute, SIS, has been a mirror committee to a similar committee at CEN level. The Swedish committee has been led by representatives from the national research and test institute, RISE (former SP) and all the larger heat pump manufacturers have participated as members of the committee. Members from this committee have participated actively in the expert groups at CEN level. The existence of and participation in this committee made it possible for RISE as well as the manufacturers to obtain and exchange knowledge of existing and new test standards, which is the base for the ecodesign and energy labelling regulations, since these are used for declaring as well as verifying performance data in market surveillance activities.

THE IMPORTANCE OF INSTALLERS

Ground source heat pumps require correct sizing, installation and control regimes, if the installation is to provide the rated performance and consumer satisfaction in terms of comfort, bills and control. Sweden has managed to achieve skilled and efficient installers of heat pumps as well as drilling services that allow the supply of these systems at competitive prices (Jonasson, 2018). This is the result of: training programmes provided by manufacturers as a requirement to install their own products; training programmes organised by the trade organisation; and the scheme for the certification of installers, which was adopted in Sweden before it became an obligation under the Renewables Energy Directive (2009/28/EC).

DEALING WITH CONSUMER DISPUTES

As any new technology, heat pumps were in the beginning prone to failures, generating many claims. A very interesting solution that the trade organisation implemented is the way they chose to deal with the disputes. Inspired by the "National Board for Consumer Disputes" (a public authority functioning roughly like a court), the trade organisation created their own "Board for consumer disputes for Heat Pumps". This Board was created to manage and arbitrate conflicts between consumers and manufacturers.

Ecodesign and energy labelling

Ecodesign and energy labelling requirements for space and combinations heaters for hydronic heating systems were negotiated at EU-level between 2006–2013 and came into force in 2015 (regulations (EU) 811/2013 and (EU) 813/2013). The regulations apply to heat pumps and boilers (electric, gas- or oil-fired) for space and water heating. The types of heat pumps in the scope of the regulations are ground source (brine), air-source and exhaust air source.

When the process started, heat pumps were in large disadvantage compared to oil and gas boilers due to technical issues such as assumed temperatures of hydronic heating systems and other parameters in the calculation models that were used to determine the performance parameters, such as energy efficiency, that would be regulated. At that time, the European Heat Pump Association (EHPA) formed a group for Norms and Standards in order to formulate and coordinate comments on the regulations. The Swedish heat pump industry was well represented in that group and contributed with experience from a well-developed heat pump market. Dialogue and information meetings were also arranged by the Swedish Energy Agency, which were attended by both industry and standardisation experts.

The Swedish Energy Agency had already over many years regularly organized comparative tests, performed by RISE (former SP), of different types of heat pumps. Experiences from these tests made it possible to make relevant independent assessments of the proposed requirements, including threshold levels, during the development of the regulations. For example, it could be seen that all eight ground source heat pumps that had been tested during 2012 would very likely (the differences in the measurement and calculation methods require some assumptions) pass the ecodesign requirements and obtain a A++ or above (Lindqvist *et al* 2014).

For the 15 air-to-water heat pumps that had been tested between 2006 and 2012 the situation was different: six of them would, according to the calculations performed, pass tier 2 of the ecodesign requirements that came into force in September 2017, i.e. more than ten years after that some of the products tested were placed on the market. The products that passed would obtain an A+ (Haglund Stignor *et al.* 2014. As a comparison, the most efficient gas condensing boiler (for which lower ecodesign requirements apply) would obtain an A.

There is an ongoing review process regarding possible revision of these regulations and during this revision, it has been concluded that the impact of the regulations has been very good from a European point of view (Kemna et al., 2019). They have stimulated technology development when it comes to variable capacity control, and thereby more energy efficient products, and have strongly phased down the use of non-condensing boilers. However, we believe that from a Swedish perspective, the effects of the regulations could have been more significant. One reason for this is that the heat pump market was relatively mature even before the regulations went into force. One important reason is that the performance declared on the labels is in many cases not relevant for how the heat pumps are used in Sweden in a cold climate. We have therefore formulated some suggestions to improve the regulations on ecodesign and energy labelling.

SUGGESTIONS TO IMPROVE ECODESIGN AND LABELLING OF HEAT PUMPS

An objective with the ecodesign and labelling regulations for space and combination heaters is, not only to compare products of the same type, but to compare and choose between products that provide the same service. That is, to be able to compare heat pumps (ground source, air, exhaust air) with

boilers (electric, gas or oil-fired). A challenge when setting these requirements is to stimulate competition and continuous improvement of heat pumps, while at the same time ensuring a fair comparison with products such as boilers. A less efficient heat pump is still a more energy efficient options than a good boiler. Too strict requirements on heat pumps could put them in disadvantage compared to boilers, especially in climates with lower heating demands.

The possibility of regulating products with more than one functionality should also be explored. Even broader than comparing product types (eg heat pumps with boilers) and promoting good products, regulations should encourage efficient system solutions. A heat pump is a part of a system for providing space heating, space cooling, ventilation and domestic hot water. Products are available where these functionalities are combined, with possible benefits from a system and control perspective. Today, these products have to comply to the applicable regulations for each function, which can make the requirements difficult to meet. The appropriateness of setting specific requirements to products with several functionalities should therefore be analysed.

Energy labelling is the main tool to show that heat pumps are more efficient than other space heaters. In the current label, heat pumps populate classes A+ to A+++. Gas- and oil-fired boilers are in class A–B. In order to accommodate different technologies and fuels (and the corresponding political and industrial interests), the scale is not linear, i.e. some steps between classes are much larger than others. An undesirable result of the label is that fossil fuelled boilers are allowed to be classified as high as A. As a consequence, the label does not reflect the huge difference in energy efficiency between heat pumps and these boilers.

In addition, the label should allow differentiation between heat pumps of the same type (e.g. within air source heat pumps and within ground source heat pumps). Today the classes for heat pumps are too few and too wide. Products with as much as 25 % difference in efficiency can be in the same class, which does not stimulate competition between heat pumps. Also, the incentive of achieving a higher class might not be enough to motivate improvement when the step to the next limit is too big.

As of 26 September 2019, the top class of A+++ is available for labelling of heat pumps. The requirement to reach the highest class is a seasonal efficiency above 150 %. Already in 2016, the average efficiency for ground source heat pumps was 158 % and for air source heat pumps 145 % (Kemna et al., 2018).

Besides enabling the differentiation between different types of heat pumps and within each type, the label needs to give room to promote more efficient solutions such as combinations with e.g. solar panels. In this respect, the label has failed to give credit to the best products and packages. We consider therefore that a rescaling is crucial and urgent.

We consider that all space heaters products should continue to have a common scale as they provide the same function. To provide a relevant distinction for products with such a wide spread in efficiency only seven classes in total (A-G) may be challenging. It requires a careful design of energy classes and limits and other ways of distinguishing the products may be needed. At least, we consider that to display the efficiency on the label is necessary as a way of providing a reward to manufacturers for each small step of efficiency improvement they undertake. We also consider that the efficiency for the cold climate should be displayed on the label. This would ensure that a consumer chooses a heat pump that is suited for the climate zone in which it will be used and that the efficiency displayed corresponds to this climate zone. Note that in the current label, the energy class is only shown for the average climate.

Conclusions

The development of heat pumps in Sweden is a case study on how market transformation can be achieved in the long term as a result of a vision, perseverance and continuity in adopting a mix of policies, even if not always coordinated. Also, it shows the importance of creating consumer trust in a new technology, and the importance of involving research institutes, test laboratories, manufacturers and installers. It further shows that the capacity of industry stakeholders to collaborate is essential.

One of the main challenges ahead is the role of heat pumps in an energy system with an increased penetration of variable (renewable) energy sources. Although heat pumps reduce electricity peaks when used for replacing resistance-based heating, the peaks in power demand from heat pumps tend to be coincident with the electricity system peak, in particular in average and cold climates where electricity heating already is, or will become, significant. In order to meet the challenge of an increasing role of heat pumps in a renewable electricity system, the first step is to improve the efficiency of heat pump products and systems, especially at low outdoor temperatures.

Secondly, heat pumps should allow demand-side flexibility. This implies that heat pumps have the following "smart" characteristics: i) the ability to adapt to the heating demand of the building and its users and ii) the ability to interact with the electricity system, such as to adapt to real time electricity prices or to different load management signals. Beside these advanced control capabilities, thermal energy storage is crucial and should be further investigated and promoted. This will be further encouraged by the "Smart Readiness Indicator" introduced by the newly revised Energy performance in Buildings Directive (Directive (EU) 2018/844). This indicator will indicate the buildings' capacity to adapt to the needs of the user, optimise its operation and interact with the grid. Also, heat pumps will have a large role when integrated in larger urban systems, with extensive storage capabilities and interactions with cooling, ventilation and other processes.

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