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Country report 3: Green niche-innovations in the Swedish heat system

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Executive summary

The development of the Swedish heat domain from 1950s until today can be described as a success story reaching a very low level of carbon emissions. From a system fully dominated by coal and oil, the heat domain is today dominated by renewable energy. The main energy carriers in the Swedish heat domain are district heating, biomass and electricity. Electricity is in turn dominated by low carbon primary energy in the form of hydro and nuclear power. The total amount of renewable energy in the heat domain is between 60-70% (depending on yearly average temperature), which is highest in the European Union.

In this report, we have assessed and described the most interesting elements in the development of the Swedish heat domain from a niche innovations perspective. First, a long list of potential cases was generated; from this list we have selected a primary set of 6 niches. In addition, we have also made initial analysis of one additional niche and reflected on interesting options and development for two more. Our primary set of niches is as following: Small scale biomass; District heating; Heat pumps; Low energy housing; Waste heat recovery; and Heating control systems. In addition, we have included initial analysis of: Efficient mechanical HVAC systems and heat recovery; Retrofitting; and Energy Performance Contracting (EPC).

The policy landscape for heating in Sweden is currently steered by the EU Energy Efficiency Directive (2012/27/EU), and the Swedish draft ratification bill on the implementation of the EU Energy Efficiency Directive. But the focus on renewable energy and sustainable development in the heat sector goes further back in time. First to the oil-crises in the 70s which prompted a move away from dependence on foreign oil, and two decades later to the introduction of the Swedish CO_2 tax in 1991 as a feasible policy measure to mitigate climate change. In terms of important actors, the main two public actors today include the Swedish Energy Agency (SEA) and the National Board of Housing, Building and Planning (Boverket). The agencies have helped shape the heat regime with numerous reports, policy documents, investment programs, information campaigns and major investments in research and development of several niches as discussed below.

This report shows that Sweden has made a transition from a heavily fossil fuel dependent heat system to a close-to fully renewable system. This has been an incremental change encouraged by early innovators, strong public support, the two oil crises and an ambitious climate and energy policy. Indirect factors have also played an important role. For example, the multi-dwelling housing ownership system in Sweden is communal both for social housing properties and private properties, where owners have a share in a whole building rather than owning a separate apartment. This has facilitated large-systems (e.g., district heating) over individual and diverse ones and has in several ways facilitated the energy transition.

Today, the Swedish heat domain is characterised by three general factors. First, the heat regime is showing signs of *saturation*. All energy inputs and their associated niche- – innovations indicate declining growth and among the main actors there is little belief in substantial growth of any particular technology. Second, the Swedish heat domain is *interconnected.* Several niches are linked in and dependent on each other. Third, niches are characterised by their *complementarity*.

However, the Swedish heat domain is also characterised by its focus on hard technological innovations. Niche innovations, which aim for deeper changes in institutions and transformations in societal involvement appear to lag compared to the other niches.

1. Introduction

The Swedish heat domestic domain is dominated by district heating, biomass and electricity (Figure 1a). Since the oil crisis in the 1970s the Swedish policy have been to gradually replace oil use, both direct use in single and multi-dwelling housing, and in the expanding district heating system. The district heating system has moved from fully dominated by oil in 1970 to be based primarily (two thirds) on biomass, with virtually no oil (~ 5%). The total amount of renewable energy in the heat domain is between 60-70% (depending on yearly average temperature), which is highest in the EU (SEA 2013). The second most important factor explaining the historical and current energy patterns in Swedish heating domain is the historically cheap electricity that abundant hydro and nuclear power have generated. Favourable conditions for hydropower and the political decision to go for nuclear power in the 1950s lead to large amount of direct electricity for heating. Today a large share of this inefficient form of electricity used is replaced by heat pumps – a niche where Sweden is today a world leader. A third important factor is the low-carbon development, which started in the early 1990s following a carbon tax introduction. Since 1990, Sweden has decreased its emissions annually by 0.5% on average. Average 2008-11 emissions were 12.6% lower than the 1990 level. The housing sector is among the best performers and the total amount of fossil primary fuels in this sector is now only 4%.

In this background report we have aimed at describing the most interesting elements of these developments from a niche innovations perspective, while also enabling interesting comparative research with the other domain case studies of Germany and the UK.

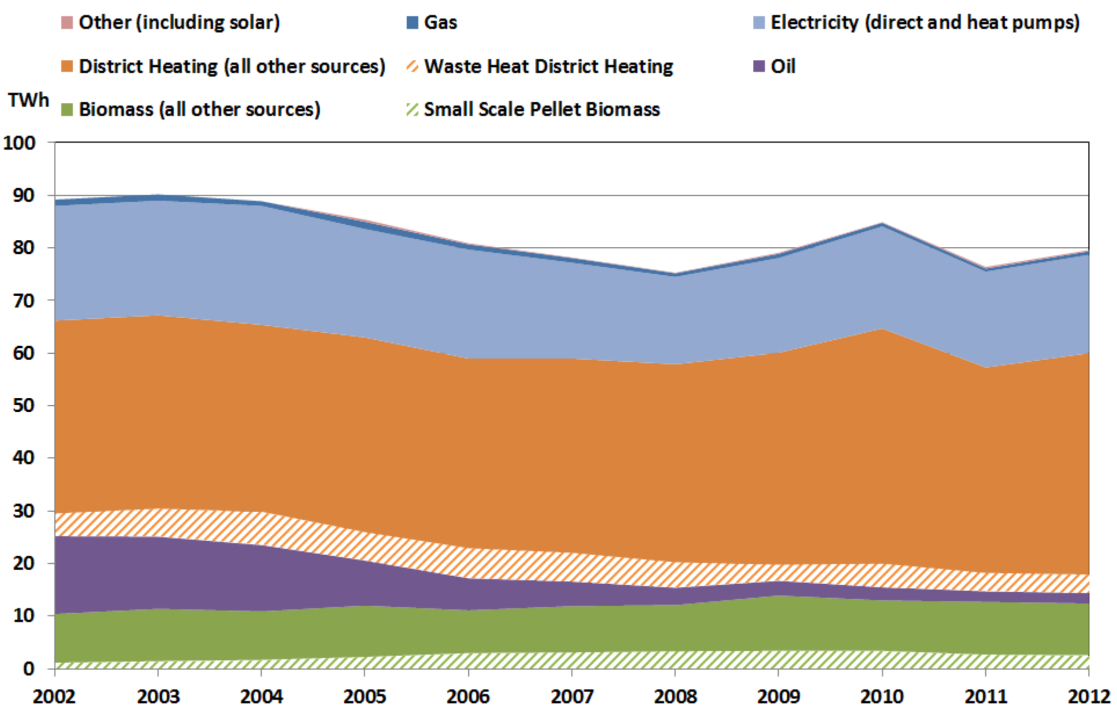

Figure 1a. Energy use for heating and hot water by energy carrier in Swedish housing domain. Separate data for small-scale pellet share in biomass and waste heat reuse in district heating are also given in striped segments to illustrate development of key technologies discussed in this report.

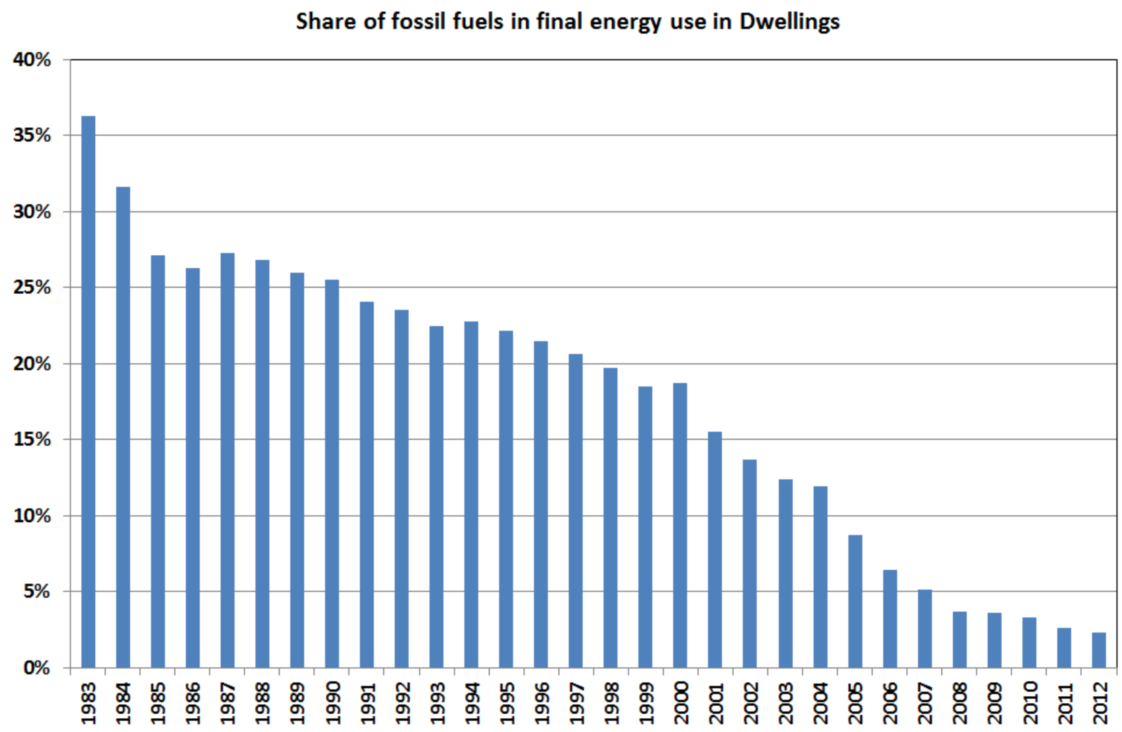

Figure 2b. Share of fossil fuels in the Swedish housing domain. This longer dataset includes all primary energy (i.e., not heating only) but shows clearly the transformation of the sector.

1.1 Initial sketch of socio-technical system

In order to identify the most relevant niche innovations a system description of key actors, technologies, and institutions was created based on an internal expert workshop and literature reviews (Figure 2). A more detailed actor mapping was also conducted outlining the key industrial, policy, and civil society actors in the domain. The system map was later used to help identify the most important niche innovations relevant in Sweden (see section 2) and figure 2 show these as green boxes.

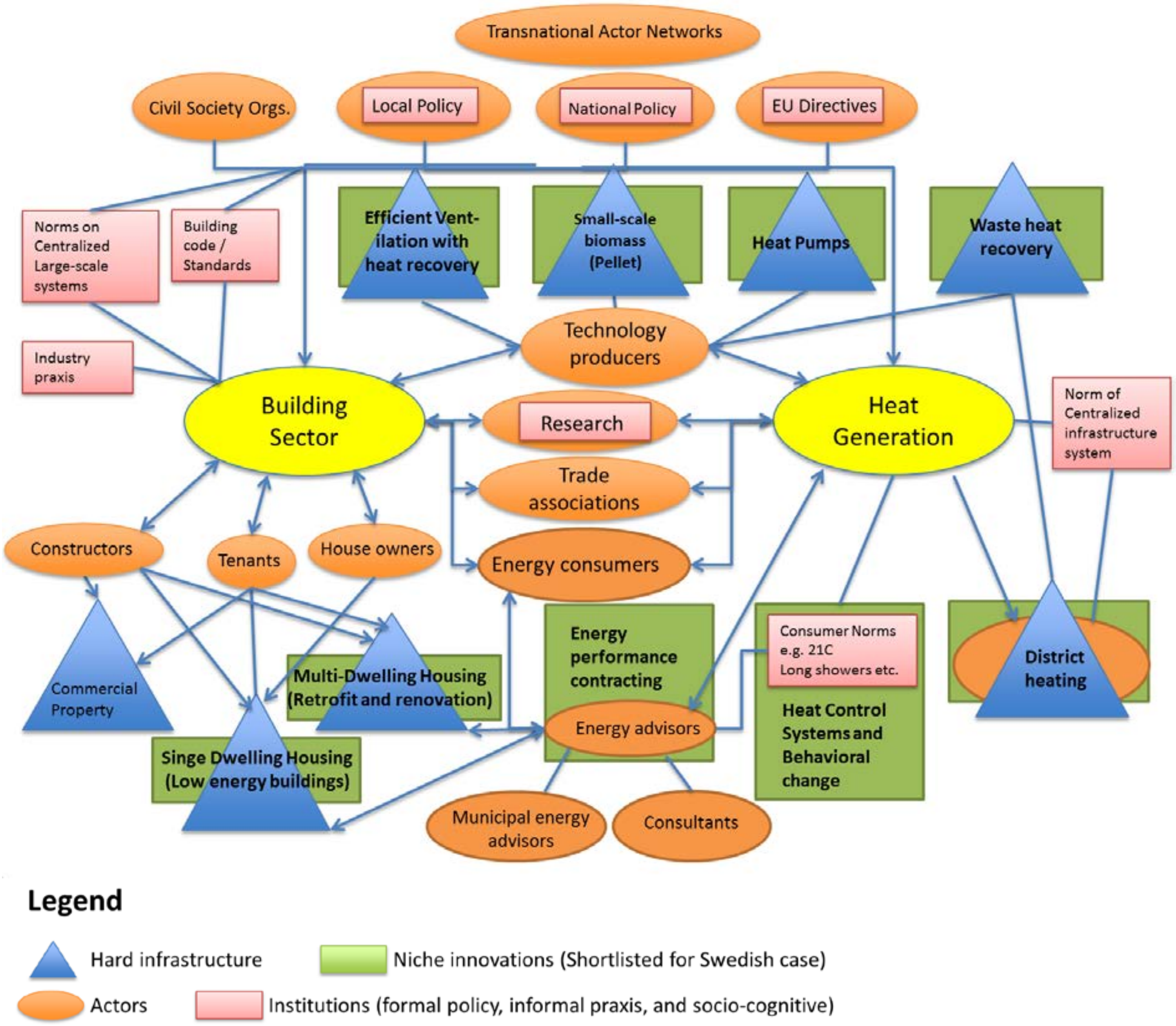

Figure 3: Sketch of the selected niches and their position in a Socio-Technical Heat System in Sweden

1.2 Main characteristics and developments

In Sweden heat generation and energy used in the building sector is dominated by large-scale systems such as district heating and electricity. The building stock has a relative large amount of multi-housing dwellings, representing 2,5 of 4,5 million dwellings in Sweden. Single house dwellings use also to a large degree these energy carriers, mainly through electrically powered heat pumps.

The policy landscape for heating in Sweden is currently steered by the EU Energy Efficiency Directive (2012/27/EU), and the Swedish draft ratification bill on the implementation of the EU Energy Efficiency Directive. But the focus on sustainable development in the heat sector goes further back in time, to the introduction of the Swedish CO_2 tax in 1991 as a feasible policy measure to mitigate climate change. The tax has delivered substantial revenues to government and also induced a changed behaviour in the desired direction. The CO_2 tax has been flexible and tariffs have been changed as new experience was gained (Bohlin 1998). According to the Ministry of Environment, Swedish emissions decreased by 9% from 1990 to 2006 and by more than 40% from the mid-1970s to 2008 (MoE 2008). Another important policy document that has shaped energy policy is the climate bill ‘An integrated climate and energy policy’ from 2009.

In terms of important actors, the main two public actors include the Swedish Energy Agency (SEA) and the National Board of Housing, Building and Planning (Boverket). The agencies have helped shape the heat regime with numerous reports, policy documents, investment programs, information campaigns and major investments in research and development of several niches as discussed below. Other important actors include the municipalities, mainly through their monopoly on planning and building, the trade associations, energy producers, property owners and tenants (Figure 2).

2. Case selection

2.1 Long list of potential green niche innovations

A long list of potential cases was generated together with the initial system description through an internal expert workshop, literature reviews, and comparisons with lists provided by other partners in the PATHWAYS project. An initial assessment was made of the characteristics of each niche innovation as either Pathway A or B. This initial analysis of type of pathway focused on assessing the *speed* of development in combination with type of actors and institutions that drive and explain the developments (*depth/scope*). The following technologies were considered: Waste water heat recovery, Small scale biomass heating systems. combined heat and power (CHP), District heating, Heat pumps, Insulation of water pipes, exterior walls, roofs etc, Low energy loss windows, Heating control systems, Lower indoor temperature, Lower size of dwellings p.capita, Waste heat recovery, and Energy performance contracting.

2.2 Selection of 6 niche innovations

Discussions between the three heating cases (Sweden, Germany, UK) and WP2 leadership led to a joint assessment of most important niche innovations to be short listed in order to enable good opportunities for comparative research. Therefore, several of the chosen innovations have in Sweden surpassed early niche development and are clearly part of the regime.

The analysis in the Swedish case is thus more historical – discussing developments further back than past 10 years at focus in our niche analysis – than forward looking as the transition to a renewable heating domain is almost completed. As will be shown in this report (Section 3), several markets (e.g., for small scale biomass, heat pumps, district heating etc.) are showing signs of saturation. This is, however, mainly related to the energy production side. Several niches related to energy efficiency and behavioural change are not very well developed in Sweden, and the ambition with the Swedish short list is to both have niche innovations that are interesting from a historical and comparative perspective, and some outlooks on niche-innovations in the earlier stages of development.

Our primary set thus consists of the following 6 niche innovations:

- Small scale biomass – Pellet fuel use in single housing
- District heating
- Heat pumps
- Low energy housing – Passive houses
- Waste heat recovery – Use of industry waste heat in the District Heating system
- Heating control systems – Smart meters and behaviour change through individual metering and billing

In addition to these, we have made initial analysis of one additional niche (Efficient mechanical HVAC systems) and reflected on interesting options for two more that are connected with the developments in the primary set of 6 niche innovations.

- Efficient mechanical HVAC systems, and heat recovery (part of low energy housing)
- Retrofitting – Low energy housing renovation

- Energy performance contracting (technical consultants making retrofits, part of retrofit niche innovations)

We provide some information on these, focusing on ventilation, as they are of high relevance in Sweden, but due to the restriction in time and length of the report, we have focused our efforts on the 6 primarily niche innovations above.

3. Analysis of the momentum of 6 niche-innovations

In sub-section below follows the niche descriptions for the Swedish case. Each section ends with a brief reflection on the categorisation of respective niche as pathway A or B. The analysis of the selected niches is done through an extensive literature review and a limited number of interviews with key actors.

3.1 Small Scale biomass case: The introduction of pellet fuel in single dwelling

3.1.1 The particular (technological or social) innovation

Small-scale biomass is since long an important option for heating for single dwelling buildings. Single dwelling buildings, with a total of 292 million m^2 heated area here refers to small detached houses, with one or a few households, in contrast to multi-dwelling buildings, a total of 175 million m^2. About half the Swedish population lives in each category, but single dwelling buildings is much less densely populated and requires more heat. Around 10 TWh energy in this category of housing comes from biomass (Figure 3). As a country with ample forest resources, wood biomass was until the 19th century the fuel that dominated the housing sector (Fiedler 2006). Despite introduction of modern energy sources, small scale biomass remained an important fuel for heating in Sweden and has been so since the 1970s (Boverket 2008; Energimyndigheten 2013). As such, small-scale biomass use is an established fuel option. However, the specific development of pellet fuel and the associated boilers, burners and stoves as a more efficient option for small scale biomass heating systems in single dwellings buildings is a more recent and important niche innovation (Mahapatra, Gustavsson, and Madlener 2007).

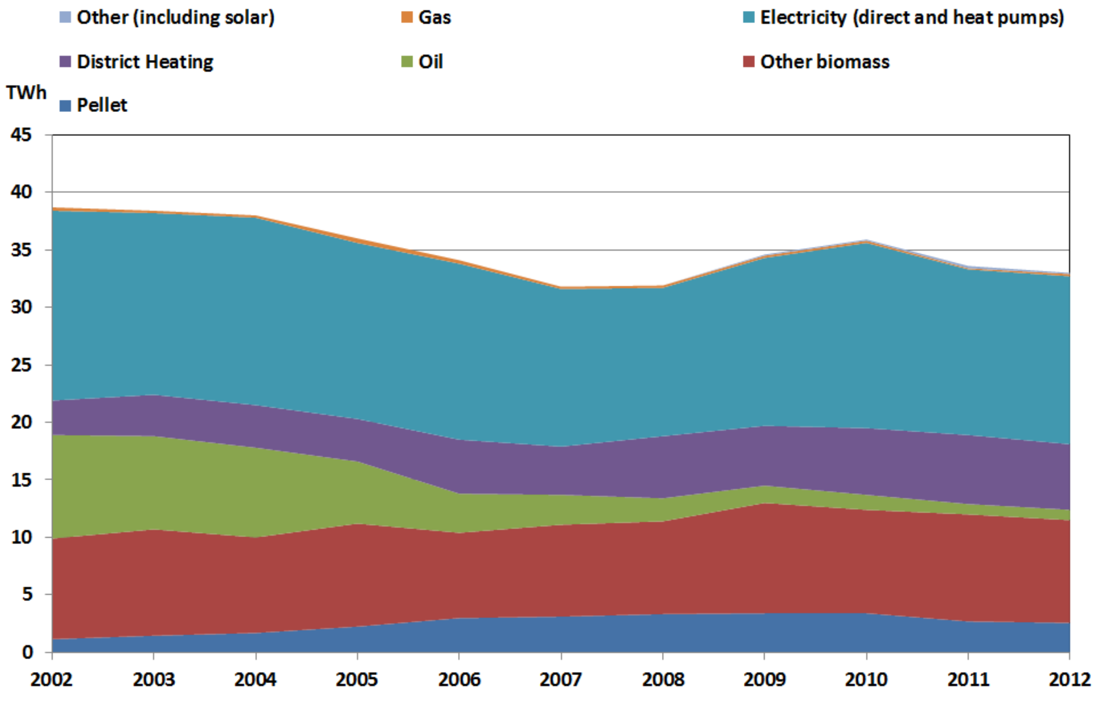

Figure 4. Total use of energy for heating and hot water single dwelling houses.

In terms of energy supplied the pellet market share of about 3 TWh represent some 8% of the energy used in single dwelling houses. The market for pellet fuel has grown strongly in the past 10-15 years, but plateaued around 2007-2008 (Figure 4, Figure 5. The exact reasons are complex and requires further study, but as will be briefly explain in this short description of the niche-development, short-changed regulations and some market maturity is likely to have contributed to lack of continued growth.

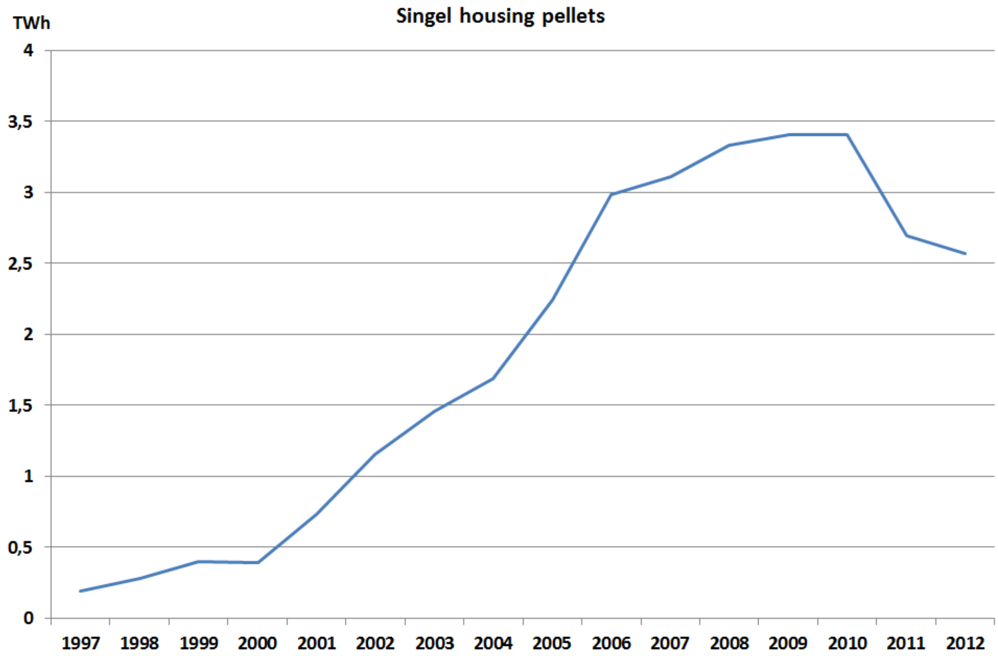

Figure 5. Pellet fuel used in single housing.

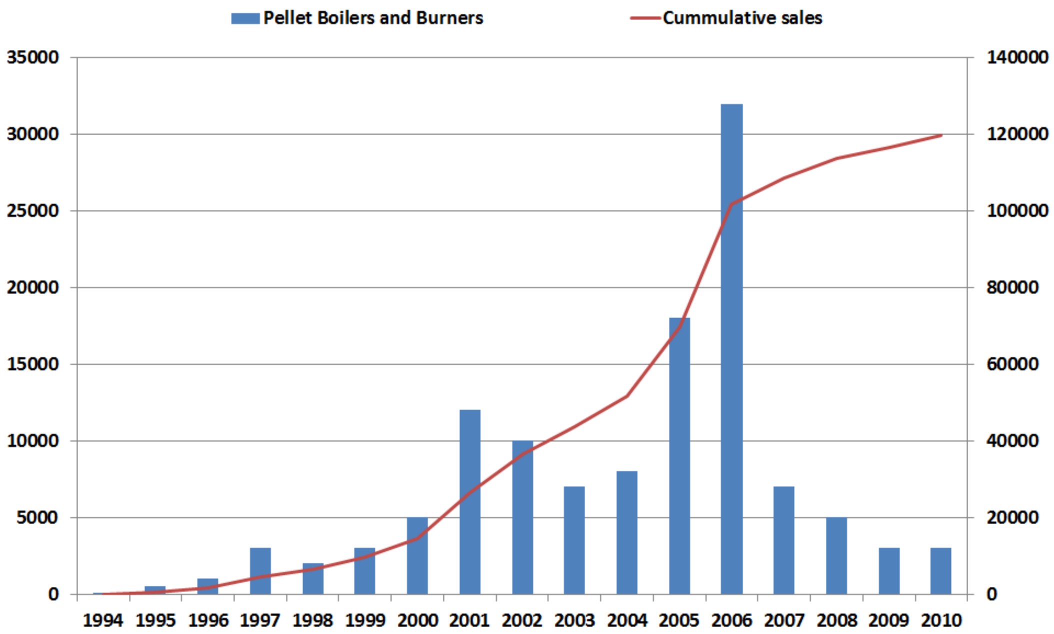

Figure 6. Pellet stoves sold in Sweden

Wood pellet production technology was developed in USA in the 1930s (Mahapatra, Gustavsson, and Madlener 2007) and the market for boilers and burners is today international and with numerous manufacturers. The biggest markets for small scale wood pellet in Europe (Audigane 2012) are Italy, Austria, Belgium, Netherlands, and Germany, some of the Nordic countries, i.e., Sweden and Denmark, and certain parts of north America, and there are signs of the pellet fuel market becoming internationalized (Olsson 2012). In Sweden, overall cost for the pellet technology is somewhat higher per MWh heat than for heat-pumps, despite pellet fuel being exempted from energy and CO_2 taxes that apply to the electricity driving heat pumps (Regeringskansliet 2014).

3.1.2 Actors, social network, strategies/actions

Wood pellet technology in Sweden was first driven by the oil crisis in the 1970s and went through early experiments in the 1980s. This included building the first large scale pellet production factories and the first large scale heat plants combusting pellet for district heating (Mahapatra, Gustavsson, and Madlener 2007). Development of small-scale burners came first later and was not lead by the same actors. Early small-scale pellet boilers and burners were instead developed and installed by entrepreneurs in the heating sector and individual enthusiasts (ibid). Following the introduction of the Swedish CO_2 tax, more large scale district heating plants with co-generation of electricity and heat converted their oil boilers to pellet use, notably the Hässelby plant in Stockholm, belonging to Sweden's largest district heating system. With higher volumes of pellet produced, more cost-efficient production was established, compensating for otherwise increasing costs of biomass for pellet. Combined with the introduction of the CO_2 tax this meant that the number of professional actors producing small scale equipment increased in the 1990s and by late 1990s standards were in place (ibid) and sales reached 10000 units annually by 2001 (Mahapatra and Gustavsson 2008).

The actor configuration has been fairly stable since the early developments in 1990s. The Associations of Pellet Produced (PIR) formed in mid 1980s[1] and have had roughly the same members of members the past 10 years. The burner and boiler sector expanded in the 1990s from 8 small manufactures in 1994, to 26 in 2004 (Mahapatra, Gustavsson, and Madlener 2007), and the market has since matured and consolidated to only 10 Swedish manufactures[2]. The manufacturers are represented in the Swedish Heating Boilers and Burners Association (SBBA) since the mid 1960s, an important actor also on the international arena.

Taking a historical perspective, the most important actors for the relative success of small-scale pellet heating appear to be the large-scale district heating actors that established a demand for pellet, the Swedish government for introducing the CO_2 tax. In other words, what enabled in the transition was chiefly changes at the landscape level, e.g., the CO_2 tax, and the price of oil and electricity. These developments spurred innovation and experimentation with pellet at both large plants and small scale.

Few actors could be said to oppose the development of small-scale biomass in Sweden. The technology has rather been enabled by the possibility to easily retrofit or otherwise adopt existing regime actors mid-to large scale district heating and co-generation plants for pellet fuel. The technological barrier was also relatively low for small users with existing boilers for wood fuel or oil, as the burners in these can often be replaced. Despite some quality problems with both larger plants and small-scale burners there were few technical or institutional barriers to overcome. A significant proportion of single dwellings in Sweden have hydronic heat distribution systems and chimneys needed for the technology, and since the technology contain few complex parts it was easy of new actors and existing heat entrepreneurs to experiment with pellet burners and boilers.

However, after some significant market expansion, there are signs of the remaining single-dwelling not being as easy to convert. A study from 2008 found that the perception of pellet boilers is that they are both less convenient to use (they require higher maintenance than other options) and with higher running costs than district heating and heat pumps (Mahapatra

[1] http://www.pelletsforbundet.se/
[2] http://www.sbba.se/medlemsforetag-och-produkter

and Gustavsson 2008). The main advantage is lower investment cost if the water-based heat distribution system exists in the house, and if district heating is not an option. But as district heating has expanded and most single houses with oil boilers have now been phased out, there are fewer houses that meet the criteria of both an easy install and relative cost efficiency and convenience over other options.
The biggest non-economic barrier to higher penetration of small-scale biomass remains a lower convenience for consumer in terms of the higher maintenance requirements of wood fuel or pellet burners. The technology has matured and simplified, so there is some level of information challenge disputing some misconceptions (Mahapatra, Gustavsson, and Madlener 2007), but the pellet still remains less convenient and requires a certain degree of enthusiast interest[3]

3.1.3 Institutions/governance

There are two significant types of policy instruments that have favoured and significantly influenced the development of small-scale pellet use in Sweden. Firstly, the CO_2 tax introduced in 1991 was instrumental in developing a market for pellet fuel among large scale users, and also spurred entrepreneurs to develop small-scale solutions. This policy is largely the result of the aligned long term policy goal and visions in Sweden of becoming both less dependent on oil imports (since the 1970s) and the later commitment to mitigated climate change. Secondly, the rapid expansion and peak in number of units delivered in 2005-2006 is explained by a temporal investment support for switching from oil to renewable fuels. This support however had both pros and cons. It introduced a wave of sales during a brief period when consumers were eligible for the support, but as the budget was fixed, and the incentive popular, it soon disappeared. And the resulting jerkiness in the market as a result of these polices has been heavily criticized by the SBBA association of manufactures[4]

3.1.4 Summary

Pellet technology as a specific small scale technology should be regarded as a regime development where the established bio-fuel regime is changing to be based on another technology and hence pathway A in Sweden. No deeper behavioural change or significant sets of new actors were necessary for the transition as the technology was developed by existing heat energy actors and entrepreneurs. The momentum is currently low, with a stable market share achieved. Core barriers for further adoption are user friendliness and cost-relativity to heat-pumps and district heating. There is a very stable actor configuration and no expected band-waggon effects, and few controversies. Some hype decline due to short-term polices in past 10 years, but a stable market share. Additional growth is in competition with heat-pumps to replace direct heating form electricity.

3.2 District Heating in Sweden: Successful transition from niche to a regime

3.2.1 The particular (technological or social) innovation

The first municipal district heating (DH) system in Sweden was introduced in 1948. The system was pioneered by engineers working for the municipal energy companies amidst

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[3] Personal communication Olle Olsson, Stockholm Environment Institute, expert in Wood Fuel Markets in Northern Europe.
[4] http://www.sbba.se/sbba-tycker Remissvar "Konsekvensanalys av åtgärder och styrmedel för minskade utsläpp från småskalig vedeldning", 2007-08-22; ”Konsekvenser av tillfälliga stöd”, 2007-06-08

strong resistance from incumbent actors, mainly the oil business, the trade association for plumbers and for chimney sweepers. The process was encouraged by the opportunity to produce heat and electricity simultaneously, so called Combined Heat and Power (CHP). Today, almost 50% of the generated heat in properties is delivered by DH. A comparative number for EU is 10, which makes it a real success story (SDHA 2009).
From a cautious start on a rather small scale, in the 70s, following the first oil crisis, DH system development took off and grew exponentially from 10 TWH in 1973 to35 TWH in 1985. The strategy was to reduce the national oil dependence, which decreased from constituting 90% of DH fuel in 1980 to 14% in 1988 (SDHA 2009). Another reason for this development was the Swedish million programme, an ambitious housing programme consisting of a million new dwellings built between 1965 to 1974, most of which were connected to the DH system. From the 1990s and onwards, the main reason for further DH development has been the Swedish climate and energy policy. The Swedish heating market generates yearly 100 TWH, of which 50% is provided through DH (Figure 6). Thus, rather than being a niche, DH in Sweden has become part of the larger heating regime. However, the system is constantly reinventing itself. Figure 11 shows the dynamic fuel supply changes of the DH system over time. And with regards for future DH developments, the discussions for a future DH system are based around district cooling, use of solar power, and smart thermal grids (see e.g. Lund et al., 2014; Johansson et al., 2011; Cronholm et al., 2009). Today, the DH system is in many respects integrated into the electricity market through the use of CHP), which in 2011 constituted 45% of the total DH plants. CHP is highly efficient and captures 90% of the fuel energy, compared to 50% for coal powered plants. Heat from CHP forms 50-70% heat, while the rest is electricity (Magnusson, 2012; SEA, 2013).

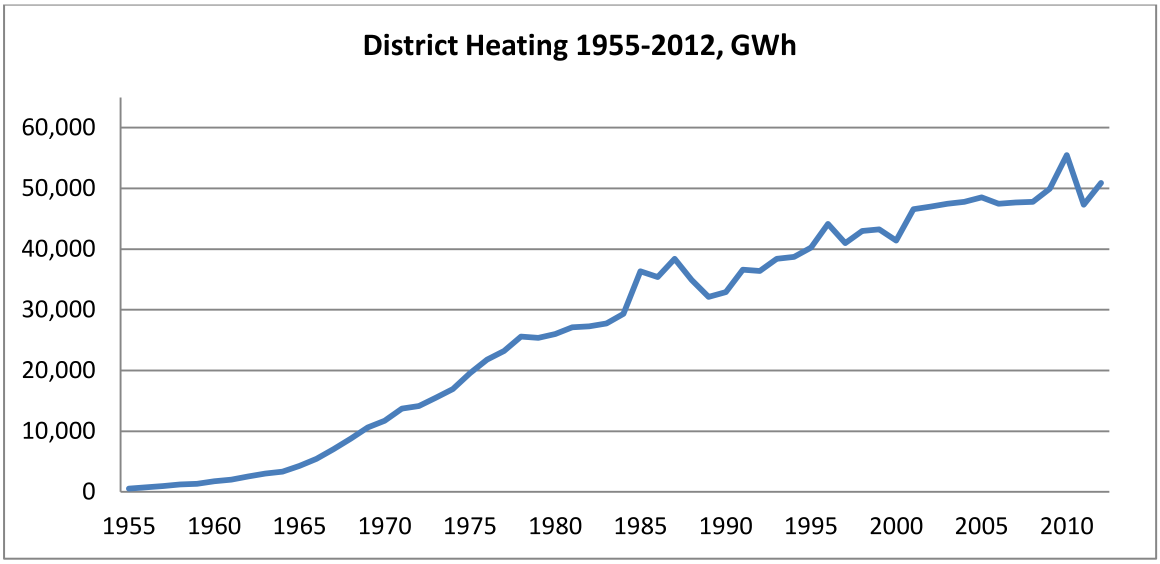

Figure 7. Development of District Heating over time. (Source: The Swedish District Heating Association)

The Swedish DH system today covers almost 18000 km. Originally, it was mainly powered by coal, but with the introduction of a carbon tax in the 90s, the industry initiated a transition towards biofuels. Today, 42% of the heating is generated through biofuels, followed by waste 18%, flue gas condensation 9%, and waste heat 7% (see Figure 11). In terms of price development, there has been a 30% increase over a 10-year period. The price is mainly influenced by local conditions and varies between municipalities. The most important factors are fuel prices and the composition of the local DH network, i.e. distances between houses, length of pipelines etc. Another important factor has been the 1996 deregulation of the energy market, which has lead to DH price increases of as much as 50% (Avgiftsgruppen, 2009). In total 93% of apartment blocks, 82% of office areas 16% of single family homes get their energy from DH[5].

3.2.2 Actors, social network, strategies/actions

The key actors in Swedish DH are the providers. Before the deregulation of the Swedish electricity market most providers were municipal. However, after the deregulation many energy companies were sold off. Today, approximately 30% of the energy companies are privately owned (Magnusson, 2012). The majority of the providers are organised through the Swedish District Heating Association (SDHA), which represents 98% of the DH and district cooling providers. Other important actors include the two regulating municipalities the Swedish Energy Agency (SEA) and the Swedish National Board of Housing, Building and Planning. The SEA controls and implements EU energy directives as well as the national directives. It is also the host of the District Heating Council, which holds the task of being a mediation role in the negotiations between the DH companies and customers on conditions under the District Heating Act (2008:263). The Council also mediates negotiations between district heating companies and those wishing to gain access to district heating pipes. The National Board of Housing is the Agency that regulates energy consumption in the built environment. Through the (compulsory) Energy Performance Certificate the Board provides information on building energy use to owners, renters or buyers of a house, but also to the public. Lastly, the municipalities are key actors through the Planning and Building Act (2010:900), which instructs all municipalities to have a 'Comprehensive Plan' for its development. Through the plan, the municipalities have the possibility to control and develop the DH infrastructure. Although, the municipalities' planning power has been considerable weakened since a 1987 change in legislation and has, together with a liberalised economy with stronger private actors, weakened their power (Blücher, 2006).

DH in Sweden has, as already mentioned, successfully managed to transform from a niche to an established regime. The development of DH can be described with four different phases. It started first with the need for new electricity generation. The second phase is related to the million programme. The third phase is the replacement of oil as a reason for the first oil crisis. Lastly, the fourth phase of DH is climate change and the reduction of GHG emissions. This constantly growing development has been helped and informed by the Swedish government and the local municipalities (Werner, 1989). The lack of competition from other heating sources such as natural gas has also contributed to the development (Werner and Sköldberg, 2007).

The DH system in Sweden is relatively uncontroversial and recognizes wide support. There has, however, been some problems relating to the monopolization of the DH infrastructure. Currently, it is very difficult for third party actors (TPA) to get access to DH pipelines (SOU, 2011). In terms of competition from alternative energy sources individual heat pumps seem to be the best alternative to district heating. They have been found to be at the same level as district heating in terms of fuel efficiency, CO_2 emissions and cost. With regard to cost, heat pumps are more or less equal to DH. However, it is highly dependent on the distance to existing district heating grids." (Lund et al., 2010). DH is dominant in the multi-unit residential sector, but in one and two-dwelling buildings alternative heat sources such as electricity (including heat pumps) and biomass are much more popular (SEA, 2013).

Research development of the Swedish DH system is supported by the SEA and the Swedish District Heating Association, who are jointly funding a multidisciplinary research program

[5] Swedish District Heating Association http://www.svenskfjarrvarme.se/Om-oss/

aimed at solving problems and promoting future competitiveness for district heating and cooling. The 'Fjärrsyn' programme, currently in its second funding phase, is organised in three areas: system development, effects and adaptation to new policy and surrounding world changes, and collaboration for sustainable development (Fjärrsyn, 2013).

3.2.3 Institutions/governance

The EU directives that affect DH include the Energy Efficiency Directive (2012/27/EU), which requires national governments to develop a national strategy for energy efficiency in order to implement the so called 20/20/20 targets, i.e. 20% reduction in GHG levels, raising the share of energy consumption produced by renewable energy to 20% and a 20% improvement in energy efficiency by 2020. Another important directive is the Waste Framework Directive (2008/98/EC), which regulates the waste cycle, which powers a substantial part of the DH plants. On the national level, the Swedish DH system is regulated with the District Heating Act (2008:263) and is controlled through the Swedish Energy Markets Inspectorate and the Swedish Energy Agency (SEA). The Swedish National Board of Housing, Building and Planning is another key actor through its Energy Performance Certificate, and the Building Regulations, which state that no building can use more than 90 KWh/mw^2 (Boverket, 2011). Additionally, an electricity certificate system has been put in place since 2003 to promote the growth of renewable energy in Sweden. Until 2012, the certificate system has subsidized the CHP production (SEA, 2014).
Notwithstanding the regime's establishment, DH is facing stagnation and there are several policy challenges. Magnusson (2012) distinguish three particular issues for the Swedish DH: energy efficiency and new efficient buildings, competition and saturated markets, and climate change. The energy efficiency directive alongside new efficient building standards decreases the demand for heat. The energy use was approximately 20% lower in 2008 than in 1998. The DH is almost exclusive in multi-dwelling buildings and the market is becoming saturated leaving little room for expansion. In one- or two-dwelling buildings, DH is facing strong competition from heat pumps, which are preferred. Lastly, climate change will lead to warmer winters in Sweden and thus further decrease the demand for heat. Another outstanding challenge is the TPA. Two national inquiries, in 2005 and 2011, have considered the issue of TPA (SOU, 2005, 2011). This has led to proposed changes in the District Heating Act (2008:263) – active from August 1st 2014 – that will allow TPA under certain circumstances (MoEEC, 2014; Swedish Energy Market Inspectorate, 2013).

3.2.4 Summary

DH is a large system in Sweden. In 2010 the turnover was 33 billion SEK (3,64 billion €). However, the momentum for DH seems to be low and the system is experiencing difficulties through stagnation and competition from other sources, such as heat pumps, particularly in the one- and two-dwelling buildings sector. The strong development of DH was made possible by the strong public support during its early phases. However, much has changes since and a gradual transition towards more liberalised planning and energy systems has led to a weakened planning monopoly for municipalities and more liberal politic economic ideas are being implemented. Today, the market is becoming saturated, but the new waste-burning CHP plants are still being built. This has led to a debate about overcapacity and waste lock-in and waste import dependency from other countries. Future projections indicate a strong increase of waste import. A recent report predicts 30% waste incineration increase in the near future (Avfall Sverige 2009). Additionally, the unregulated pricing in natural monopolies is leading to higher prices (Magnusson, 2013). The proposed changes for TPA have been criticised for not being strong enough and to perpetuate the monopoly rather than increase competition. Moreover, increased energy efficiency in buildings is reducing the demand for DH.

Analysing the role of DH in a future 100% renewable energy system, a Danish study found that the best solution to complement DH is with heat pumps (Lund et al., 2010). Other alternatives for a future DH system include further development of combined CHP systems in the remaining DH plants (Åberg and Henning, 2011), the development of district cooling systems (SEA, 2013; Johansson et al., 2011) and solar thermal energy combined with DH. Lastly, opportunities to exploit the waste heat from big industries and connect these to the DH system, is currently becoming a niche of its own.

In terms of pathways, DH belongs to Pathway B, meaning a broader regime transformation. From the 60s and onwards, DH transformed the energy production for heat and water in large apartment buildings and became part of a broader regime in terms of new actors and technological and societal changes.

3.3 Heat pumps: A successful niche innovation in Sweden

3.3.1 The particular (technological or social) innovation

Heat pumps (HP) are usually characterized by their heat sources (air, water and ground) and/or by the mediums between which they transfer heat (air-to-air, air-to-water, water- to-air, water-to-water). The most common types are exhaust air HP, air source HP, water HP and ground source HP, and they are generally electrically-powered or gas-fuelled (Kiss et al. 2012).

The heat pump systems contribution to lower energy consumption is significant. In Sweden, total absorbed energy from HPs was 14 TWh in 2009, of which 9 TWh was renewable energy (SEA 2012a). According to the Swedish Energy Agency, the purchased energy for heating and hot water in Swedish single-family households has decreased with 17% (from 25500 kWh to 21400 kWh) between 2001 and 2012[6], which is mainly attributed to HPs (SEA 2012b). Sweden is the country with the highest number of installed HPs per capita (Ruud 2010). Along with Switzerland, Sweden has been essential to the development and commercialization of HPs in Europe. In both countries, numerous policy incentives have lined the path of technology and market development. Early policy initiatives were poorly coordinated but supported technology development, entrepreneurial experimentation, knowledge development, and the involvement of important actors in networks and organisations (Kiss et al. 2012). Sweden is a good example of the major potential of geothermal technologies for the growing European market. One third of the European ground source HPs are found in Sweden, with 320,687 GSHPs reported in 2008. It is difficult to explain this high take-up in Sweden since for example Finland, with similar culture, climate, geology, and infrastructure has only a relatively small number of systems. One explanation to the Swedish success could be that much of the research and testing were undertaken in Sweden (Bayer et al. 2012).

The Swedish HP market took off following the oil crisis in the late 1970s with more than one million HPs sold by Swedish manufacturers since the early 1980s (Figure 8). However, in the mid 1980s the price of oil fell and in Sweden and the government subsidies for domestic HPs were terminated. As a result, the demand decreased significantly and the market collapsed. In 1984 there were about 130 manufacturers, retailers and installers in Sweden, most of which were small and working locally. In 1986 only a few companies were left. This had severe

[6] These two years were approximately equally warm.

consequences not only on the sales of new heat pumps but also on the maintenance of the installed HPs (Kiss et al. 2012; Törnell, 2007). The market turned again in the 2000s through renewed support for HPs. In Sweden, market development was, again, supported through subsidies. However, uncertainties regarding the duration and magnitude of these subsidies undermined manufacturers' long-term investments in technology development. As a result, between 2000 and 2003, 26% of the ground source heat pumps installed in Sweden were reported to have some problems such as leaking connections and electrical complications, early-stage break-down of the HPs, and sub-optimal heat production (Snaar, 2005).
As of 2010, approximately 98% of the HPs sold serve the residential market, with most of the sales being small HPs (<20kW) for single-family houses, which have been shown to add value to properties (Boverket, 2008; SEA, 2012b). Until the mid 2000s, ground source HPs dominated market sales, constituting on average 45% of HPs sold each year with annual growth rates between 1993 and 2006 exceeding 30%. However, since 2000, the market share of air-to-air HPs has increased rapidly, and in 2008 they consisted of more than 60% of total sales. Exports have also represented a significant share of sales, in the mid 2000s approximately 40-50% of total Swedish production was exported (SVEP, 2009).

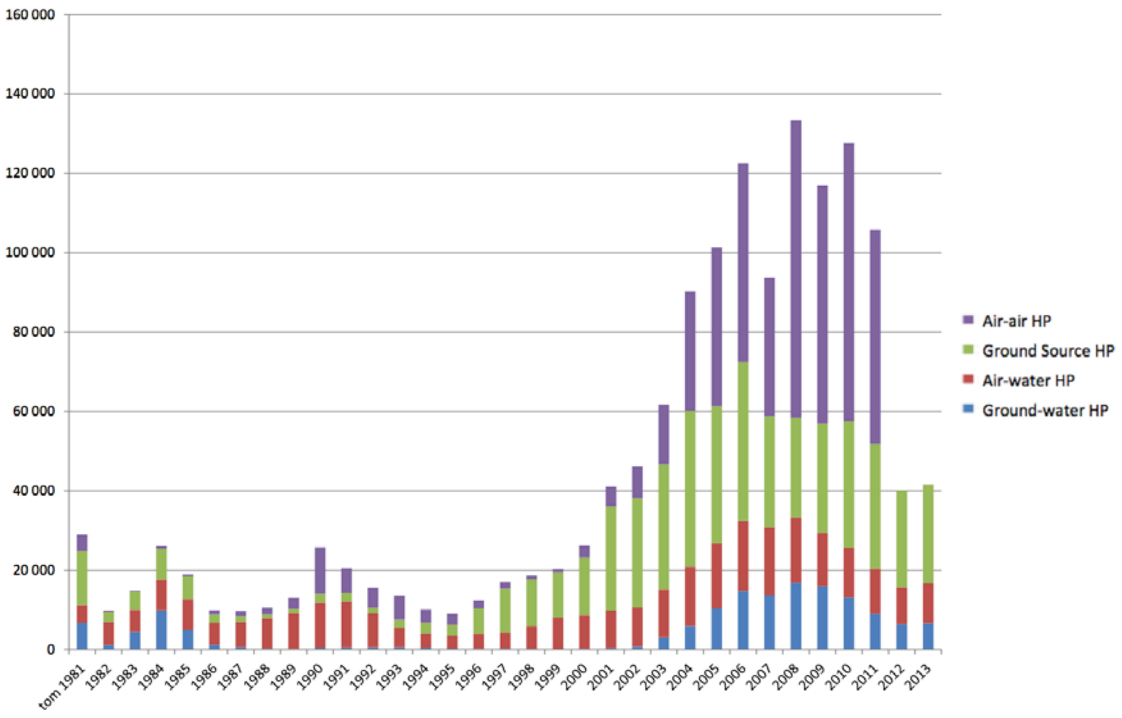

Figure 8. Heat pump sales in Sweden 1981-2013 (Source: SVEP 2013). Air-air data missing for 2012-2013

Various policy programmes and their effect on increased production and sales of HPs have enabled cost reductions for heat pumps over time. During the past three decades, costs have been reduced by more than a factor two (Figure 9). In the early 1980s, the total cost was almost twice as high as for fossil fuel heating systems. The consumer prices decreased slightly between 1985 and 1995; despite several drivers of cost reduction. The prices then remained fairly stable until the mid 2000s. Today, HPs are cost-competitive. Important drivers of cost reduction have been economies of scale, not only for heat pumps as such, but also for borehole drilling, and continuous technology improvements. According to Kiss et al. (2012), reasons for this includes a limited competition of contractors and fragmented and uncertain subsidies. Another reason discussed by the same authors is the high production cost of heat pump components in Sweden as they are all domestically manufactured.

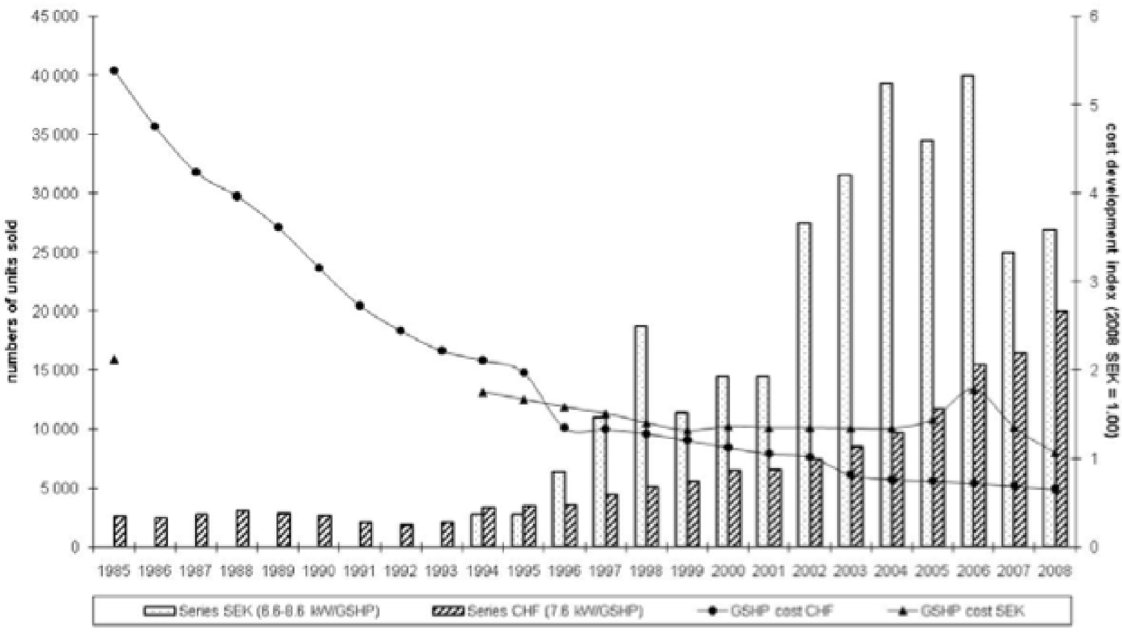

Figure 9. Number and cost of heat pumps installed in Sweden and Switzerland (Source: Kiss et al. 2012)

3.3.2 Actors, social network, strategies/actions

As the HP market grew in the 1980s the number of actors increased; relevant actors included heat pump manufacturers, retailers, driller and installation suppliers, research organizations, authorities, certifying bodies and test institutes. Research and development programmes were complemented with subsidies, favourable loans for investments, trainings and information campaigns (Kiss et al. 2012). From the governmental level, the Swedish Energy Agency (SEA) has had a big role in supporting this development, mainly through its financial support for the 4-year Effsys and Effsys2 research programs on ‘Refrigeration and Heat Pump Technology’. Another important actor is the Swedish Heat Pump Association (SVEP), which represents the majority of manufacturers, retailers and other companies associated to HPs. Another indication for the successful for Swedish heat pump development is the International Energy Agency’s (IEA) Heat Pump Centre, which is based in the Swedish city Borås. Lastly, the Swedish National Board of Housing, Building and Planning is another key actor through its Energy Performance Certificate, and the Building Regulations, typically limiting energy used in buildings to no more than 90 kWh/m^2 (Boverket, 2011).

It cannot be said that there are actors opposing heat pump innovation. However, with the saturated small housing market in Sweden, heat pump have started an expansion toward bigger cities and are competing with district heating (DH) systems. This development has made heat pumps a competitive alternative to district heating (Sköldberg at al. 2011), and created conflicts with the DH providers who are arguing that DH is at a legislative disadvantage to heat pumps (Jarlfelt 2014).

3.3.3 Institutions/governance

The institutional support for heat pumps has since 1970s been aiming at a strategy to improve energy efficiency, support energy security, reduce environmental degradation and combat climate change (IEA, 2008). The main EU directive that affect HPs include the Energy Efficiency Directive (2012/27/EU), which requires national governments to develop a national strategy for energy efficiency in order to implement the so called 20/20/20 targets, i.e. 20% reduction in GHG levels, raising the share of energy consumption produced by renewable energy to 20% and a 20% improvement in energy efficiency by 2020. Moreover, the EU Ecodesign directive (2009/125/EC), which provides consistent EU-wide rules for improving the environmental performance of energy-related products, and the SEA energy labelling are influencing the energy performance of HPs (Karlsson et al. 2013).
Over time, numerous policy incentives have lined the path of HP technology and market development in Sweden. Whilst the early policy initiatives were poorly coordinated, they supported technology development, knowledge development, the involvement of important actors, and market formation. The market collapse in the mid 1980s could have resulted in a total failure – but did not. The research programmes, continuing in the 1980s, and the set of stakeholders and networks formed in the early years – including public and private funded researchers, authorities and institutions – provided an important platform for further development.
In the early 1990s, as a result of increasing concerns about environmental pollution as well as strong lobbying from the advocacy coalition, Sweden decided to strengthen the HP market. A well-coordinated market transformation and technology procurement programme was launched in combination with test and certification programmes, subsidies and massive information activities. Strategic, coordinated and flexible policy incentives for the development of HPs were introduced. The focus was on knowledge development, networking, and market formation, but also on quality control, credibility and legitimacy. Particularly networking between actors encouraged important processes of learning. International networking through IEA research may have also played an important role for international learning and spill overs. Not only did this incentive provide high quality technology and substantial market support but also essential interactions among actors. In all, 25% of the procurement budget was earmarked for the evaluation of heat pump installations through a test and certification programme. A further 50% of the procurement budget was allocated to information activities, including information campaigns, brochures and articles. The programme boosted demand for HPs with sales doubling between 1995 and 1996. Furthermore, between 1996 and 2006 the number of installations of heat pumps increased at an average of 35% per year (Kiss et al. 2012).

3.3.4 Summary

HPs are reliable, efficient and affordable, and can add to comfort and building quality by providing heating, cooling and sanitary hot water. According to SVEP, the pathway changed from the late 70s, when HPs were viewed with scepticism, to a path of success through directed policy and financial support and strong research. Two main reasons for this have been the long-term investments in research and governmental subsidies. Additional important factors have been the low price for electricity in Sweden and the fact that people in Sweden do not move frequently, which encourages the relatively expensive long-term investments, such as heat pumps (TPA Forum 2012).
As the HP market is becoming saturated in the Swedish small housing market, the expansion is looking towards larger cities and multi dwelling buildings. Heat pumps are expected to

take market shares from DH, but according to SEA (2012) eventually a balance will occur between the two heating systems. However, the saturation has also led manufacturers towards looking for new markets in Europe (TPA Forum 2012).
In terms of Pathway A or B, HPs in Sweden were initially following Pathway B as they transformed the heating system in single-family households. The niche innovation included new entrants, technological changes, and massive institutional support. However, at the same time HPs do not require wider societal changes or technological transformations. Therefore, more recently as HPs gradually became part of the wider regime, the technology niche rather belong to the Pathway A.

3.4 Low energy housing: Slow development of passive houses

3.4.1 The particular (technological or social) innovation

Low energy houses is achieved by the aggregated effect of applying a number of well known technologies including extra thick layers of insulation, low U-value windows, and air tight building techniques with regenerating heat from ventilation. However, progress on passive house and low energy buildings that fulfil the intention of the Energy Performance of Buildings Directive (2010/31/EU; 2002/91/EC) is rather limited. The first passive houses in Sweden were constructed in 2001, over 10 years after demonstrations in, e.g., Denmark (Janson 2010). Since late 2000 there is more progress (Figure 10) and the past 10 years has very much been an early experimentation phase (ibid, p 350-351).
About 400 new dwellings in passive houses or low energy houses are now built annually (Svensson 2012), and the cumulative share of the stock in Sweden is about 0,05%. The standards in Sweden and EU vary slightly, and figure 10 show the development of all types of low energy and passive houses.

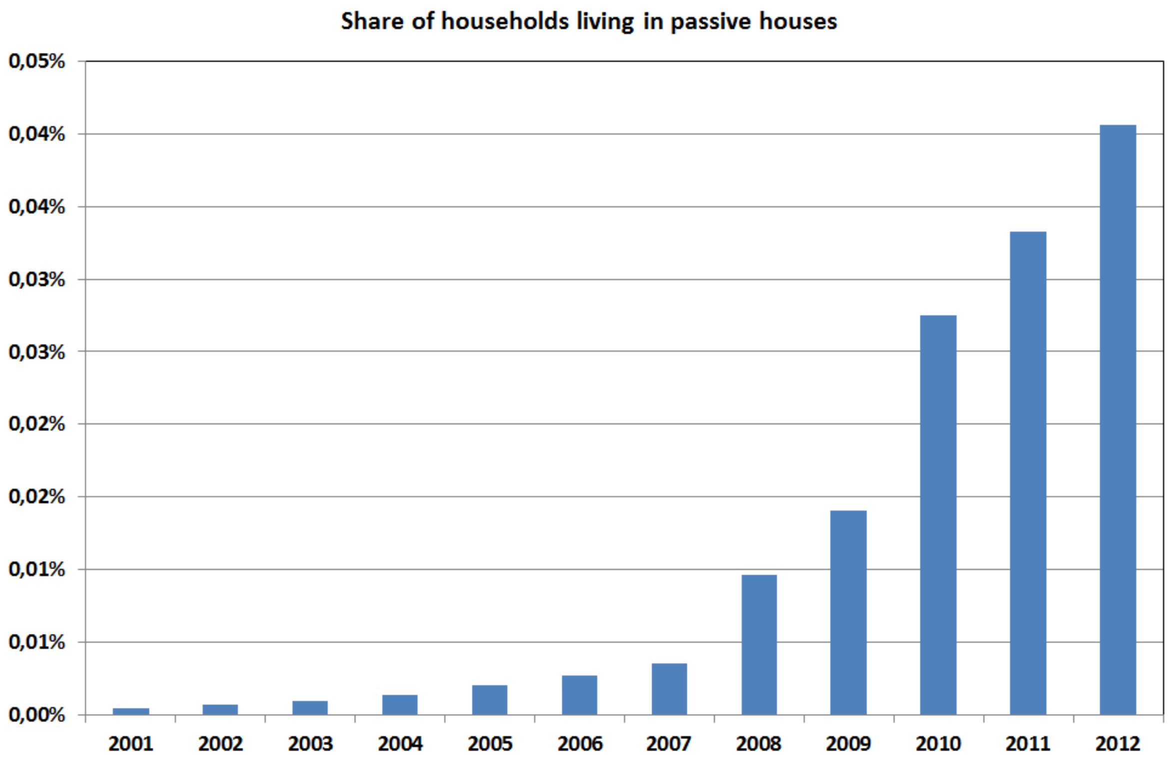

Figure 10. Share of households living in passive houses or apartments. (Data source, Svensson, 2012). Better data will be available summer 2014, personal communication Carlos Andreasson, Passivhus Sverige)

Since passive houses are still at an experimental stage there is limited published information on price developments. Contractors and suppliers are still learning for each project built. There is some evidence that costs are coming down, and that passive house projects are only marginally more expensive (Nordling and Carlsson 2009). But the key barriers that make projects more expensive are rather lack of knowledge of construction techniques and need to do develop relationships with new suppliers, than the added cost of building materials per se. Problems with lack of component and suppliers are however gradually being solved (Janson 2010).

3.4.2 Actors, social network, strategies/actions

The key actors in the Swedish low energy building niche are individual building contractors, the municipalities commissioning new public housing, the energy agency (Energimyndigheten) and housing authority (Boverket). During 2005-2010 the energy agency supported passive and low energy housing with a total of EUR 1 million and the research and development program was led by the Swedish Environmental Research Institute (IVL), an independent research organization.[7] Several conferences have been organised (e.g., ”Passivhus i Norden” Conference in Göteborg 2009) as part of dialogues initiatives between private and public actors. The energy agency have also supported a centre for Energy and resource efficiency in buildings (CERBOF), and there are several concrete buildings project among the built passive houses supported by collaborations between authorities, contractors, and public landlords, e.g., municipalities such as Gothenburg, and universities (Nordling and Carlsson 2009)

There are some networks of actors: The construction industry's organisation for research and development (SBUF) with approximately 3,000 affiliated companies in Sweden support some limited funding for research and development[8]. Experience and learning is shared through the “BeBo”-network contractors of energy efficient buildings funded by the energy agency)[9]. Finally, there are networks of contractors building passive houses[10]. That the latter only formed in 2010 is a clear sign of the relative recent and weak formation of actors in this niche innovation. The constellation and size of the networks appear to have grown over time, but the social networks are still small and clearly concentrated around temporary collaborations between the key actors of municipalities, individual contractors, and the relevant national agencies

The most important barrier toward more passive houses is the lack of strict regulation on low energy buildings. To voluntary engage in construction of low energy buildings is still not common. Constructors are not in the forefront as they have no incentives to push for more costly options in the construction phase, even if more energy efficiency means lower costs in the long run (Plåt Cardell 2009). Secondary barriers are lack of knowledge of building process and suppliers to use for new materials and components used in low energy houses. The lack of experience in turn increases cost. Visions for low-energy houses in Sweden are not clearly articulated or visible in society and the key actors supporting a future with growing shares of passive houses are researchers and entrepreneurs specialised in these technologies. Regime actors such as larger buildings contractors are strongly opposing stricter building standards.

[7] http://www3.ivl.se/AnsokningarPassivhusprojekt.htm
[8] http://www.sbuf.se/
[9] http://www.bebostad.se/om-bebo/
[10] http://www.nollhus.se/

3.4.3 Institutions/governance

The key piece of legislation is the buildings code and its requirements on energy efficiency. In 2013 this legislation also implementing the directive (Regeringskansliet 2014), but the new suggested standards are still under evaluation with the latest review of these are being assessed until 2015 (Regeringskansliet 2014, Näringsdep uppdrag boverket). Meanwhile the buildings code and legislation do not promote low energy housing. The current standards at 110 kWh/m2/yr allows twice as high energy use as needed to fulfil the directive (Energimyndigheten 2010), which in turn is roughly the same level as the Swedish passive house standard at <54 kWh/m2/yr bought energy for heating and hot water purposes. There are no signs of new kinds of instruments supporting passive houses specifically and the ongoing, governance process are primarily concerned with implementation of EU directives. There are hence no changes in worldviews on low-energy and passive houses and only incremental change in energy efficiency requirements, toward implementing the directive

3.4.4 Summary

Low-energy housing belong to pathway B in Sweden. The housing sector with large contractors and construction companies is very conservative and changes only gradually. Adopting low-energy housing technologies requires far reaching institutional change, and there is very limited progress in Sweden. The momentum is thus low, the core drivers are the EU directives, and key barriers include the unwillingness of contractors to develop knowledge of building techniques that are more expensive and not currently demanded by public and private actors procuring new housing projects. There are no discernable increases in investments or projects, no socio-cognitive band-waggon effects, limited political and institutional support. Developments of the niche innovation are rather hindered as concrete sharpening of building regulation implementing the directive is lagging behind.

3.5 Waste heat recovery

3.5.1 The particular (technological or social) innovation

The opportunity to capitalize on industrial waste heat is seen by many as a resource efficient way to contribute to reduction of greenhouse emissions. Sweden is currently a world leader in this development. In 2011, around 70 initiatives between DH companies and the industry account for nearly 5TWh, or 6%, of the delivered heat to the districh heating (DH) networks in Sweden (Figure 11) (SOU 2011; Arnell et al.2012; Cronholm et al. 2009). After several internal efficiency processes, further potential for recovery of waste heat is still possible is desirable for the energy sector, the industry sector and society at large both in order to optimize the use of resource and to reduce environmental impact. A study calculated the waste heat potential for Sweden to be between 6,2 and 7,9 TWh (Cronholm et al. 2009), 30-60% above today's levels.

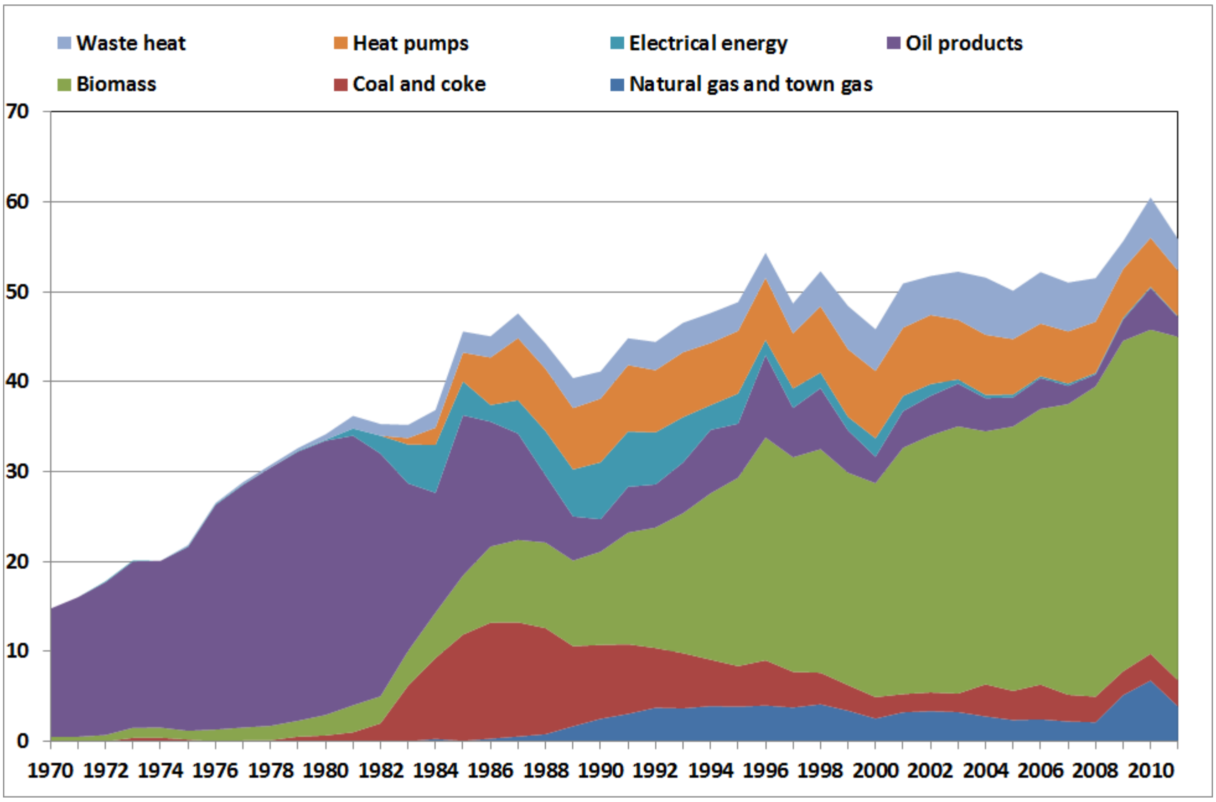

Figure 11. Fuels in the DH system in Sweden (Source: SEA 2013).

Waste heat is divided in primary waste heat, i.e. heat with sufficiently high temperature for direct use in the DH system, and secondary heat, i.e. low-tempered heat that needs to be heated before direct use (Arnell et al. 2012). There is no unifying definition of industrial waste heat. But the European Standard (EN 15316-4 5:2007) defines as following: 'industrial waste heat is heat that is a by-product, which is unavoidable in the production of industrial production. Heat of high quality that can be used for electricity generation is not counted as industrial waste heat'. However, the Swedish Energy Agency (SEA) argues that it is problematic to apply a uniform definition of 'waste heat'. (SEA, 2008a) because it is difficult to determine when an industrial process is optimized and any residual heat can be characterized as 'waste' has to question about what is considered as industrial waste assessed in each case (Krook-Riekkola & Söderholm 2013).
Utilised waste heat is hard to calculate as it is not reported in international energy statistics. The only bodies that report these heat streams are national district heating associations gathering own national statistics. An overview for 2008 gives following numbers: 0.3 TWh in France, 4.9 TWh in Sweden, 0.8 TWh in Denmark, 0.9 TWh in Germany, and 0.03 TWh in Italy. These volumes add up to 6.9 TWh for the whole EU27. But this is probably an underestimation, since the situation in many other countries is unknown. This accounts for only 3% of the available industrial excess heat in Europe that is recycled into DH systems. The reasons for the Swedish dominance in using waste heat lies in its well-developed DH network, which includes even smaller cities, and also the relatively large heavy industry in the country (Lund & Werner, 2012; Persson & Werner 2012).
Regarding price development for waste heat, it is difficult to give exact numbers as contracts are individually negotiated and differ. However, in general the price of the DH systems that includes waste heat has a lower average price (Arnell et al. 2012).

3.5.2 Actors, social network, strategies/actions

There is no government actor leading or supporting increased use of waste heat. In 2008, the SEA recommended an independent centre of excellence for bigger inclusion of waste heat (SEA 2008b), but it has not yet materialised. The most relevant actors include the Swedish District Heating Association and the SEA, who jointly fund the research program 'Fjärrsyn', focusing its research on DH as well as waste heat.

In terms of contract agreements, most initiatives are bilateral agreements between the industry and the DH companies. Waste heat, or industrial excess heat, is normally recycled from five typical energy intensive industrial sub-sectors (chemical/petrochemical; iron and steel; non-ferrous metals; non-metallic minerals; and pulp and paper production) and oil refineries (Lund & Werner 2012). In Sweden, 90% of the waste heat comes from the energy-intensive industries. However, less is known of the potential in other categories of industry such as food industry and large shopping malls. A study that analysed ca 600 potential waste heat sources found that more than 70% of the sources were non energy-intensive (Cronholm et al. 2009). Another recent waste heat source are large server rooms. For example, in Stockholm, a large IT company Bahnhof has joined with the city's DH provider Fortum Värme to provide its waste heat to the DH network. Fortum Värme has started a program 'Open DH' in order to link up other server rooms to its network (http://oppenfjarrvarme.fortum.se/). The process from idea to actual delivery of the waste heat usually takes between 5-10 years, involving a range of complicated aspects (SEA 2008b). A successful initiative is very dependent on the economic aspects, particularly for the industry, which generally have higher required rates of return than public DH companies. Another barrier for increased use of waste heat is the increasing application of biomass-fired Combined Heat and Power (CHP) systems, which are crowding out waste heat and are endorsed through an electric certificate system, put in place to promote the growth of renewable energy in Sweden. Moreover, a 2002 ban on landfill waste resulted in a sharp increase of waste incineration. This means that, in practice municipalities pay the DH companies for incineration of waste, leading to very low or even negative costs for the companies. Consequently, this helps to displace potential waste heat (SEA 2014; Ganslandt 2011; SEA 2008a; Rydstrand 2005; Jönsson et al. 2007). Thus, in DH systems where waste incineration makes up a significant proportion, the reduced heat demand for power generation can be an obstacle to increased waste heat utilization.

In terms of visions and expectations of the main actors, it has been shown that the most common problem is that partners in a waste heat project have difficulties on agreeing on a price (SOU 2005). Moreover, there are large cultural differences between the private industry and municipally owned DH companies, particularly in the decision-making process. The lengthy democratic process in a municipality can, from the industry – where decisions and actions swiftly follow the cost-benefit analysis – be interpreted as a lack of interest. This is seen as a significant trust barrier (SEPA 2005). However, Thollander et al. (2010) note a specific case where a generation change within an industry's board of directors, which led to a younger more environmentally conscious board. This change was described as a key to success in that particular case.

3.5.3 Institutions/governance

According to Jönsson et al. (2007), public support for investment has been an important driver for waste heat initiatives. A report from the Swedish Environmental Protection Agency investigated publicly supported initiatives and the conclusion was that these initiatives would not have been finalised without the given support (SEPA 2005). The public investment support initiatives are no longer available. However, waste heat is discussed as an important component in the Swedish implementation of the EU energy efficiency directive. For example, the Swedish government recently proposed compulsory cost-benefit analysis for 1) every new CHP plant with a total effect above 20 MW; and 2) every new industrial plant with a total effect above 20 MW and is generating waste heat, or an upgrade of an existing industrial plant (Swedish Government 2014). Moreover, the Swedish government recently finalised a bill that regulates Third Party Access (TPA) to the DH networks. This has led to proposed changes in the District Heating Act (2008:263) – active from August 1st 2014 – that will allow TPA under certain circumstances (MoEEC, 2014).

However, it is expected that the new changes such as TPA will do little for additional waste heat in the DH networks. The Swedish Energy Market Inspectorate – the regulator of Swedish DH – argues that most waste heat deals depend on profitability for both parts and that the bill will have limited impact. This notion is also supported by the Swedish District Heating Association (Swedish Energy Market Inspectorate, 2013; SDHA 2011). Instead, Krook-Riekkola and Söderholm (2013) argue that if there is a potential profit, then it is in both parties' interest to initiate an agreement. In such cases, the role of the government and the governmental actors consist mainly of 1) generating valuable information on the technical and economic potential for utilization of waste heat; and 2) reduce the transaction costs for the parties involved to enter into a voluntary, market-based agreement. Moreover, the authors argue that the municipal energy plans and their focus on the mapping of energy flows offers an opportunity to identify new waste heat sources.

3.5.4 Summary

Sweden is world leading in utilising industrial waste heat as an input source in its DH systems. There is an additional 30-60% potential increase meaning that waste heat can decrease both primary energy and CO_2-emissions. In order to increase waste heat use, the core developments of various waste heat-related actors and initiatives are twofold. First, Third Party Access (TPA) and the proposed changes in the district-heating act. However, it is expected that the recent changes are not enough to encourage more waste heat in the DH systems as the regulations will create effective competition on the supply side because of high entry barriers for new actors and the large nature of the DH production facilities (PWC 2011). Second, the increased focus on new industries and businesses beyond heavy industries, such as city adjacent large server rooms and shopping malls have the potential to increase the use of waste heat. Here the momentum is different and there is potential for increased waste heat use. To utilize this heat requires a great deal of creativity and new forms of business and system solutions (Cronholm et al. 2009).

A lack of business opportunity is an important factor in utilising additional waste heat. However, economy is not always the sole determining factor if waste heat will be used or not. Other factors such as contract terms, risk management, commitment and political decisions are of importance as well. Notwithstanding, the financial factor of any deal is an important aspect, as well as how policy instruments will affect the long-term profitability of investments. Currently, there is a lack of institutional and financial support from the government and municipalities, albeit the change with TPA access and the implementation of the EU energy efficiency directive has started a change process.

Another obstacle is the well-established system of green certificates for biomass-fired CHP plants, where the producers of electricity will receive compensation for electricity created on renewable resources. The use of waste heat can in many cases be less profitable than biomass-fired power plants since the above-mentioned certificates financially support renewable plants and not residual heating. In those cases where certificates discourage

industrial waste heat the result is a sub-optimal use of biomass and thus creates an untapped potential for reducing national and global CO_2-emissions (Arnell et al. 2013).
Even though waste heat gathers new actors in an energy system, it falls under Pathway A as it is merely an add-on to an established energy technology, and the new actors are dependent on the existing ones. Waste heat has no possibility to replace DH (or any other existing technology) and it will not bring any broader regime transformations.

3.6 Individual metering and billing – Niche innovations and behavioural change

3.6.1 The particular (technological or social) innovation

Heating and hot water in buildings amount to 61 TWh, which is nearly 15% of total energy use in Sweden. For apartment buildings, the average consumption is 159 kWh/m2 per year. Reducing the indoor energy consumption in apartment buildings is an important part of achieving energy efficiency, and individual metering and billing (IMB) for heat and water is put forward as a possible option as it raise awareness of consumption. Experience in other countries has pointed to potential savings of 10-30%. For Sweden the potential is 10 - 20% reductions for heat and 15 - 30% for hot water (Svensson 2012; Boverket 2008).

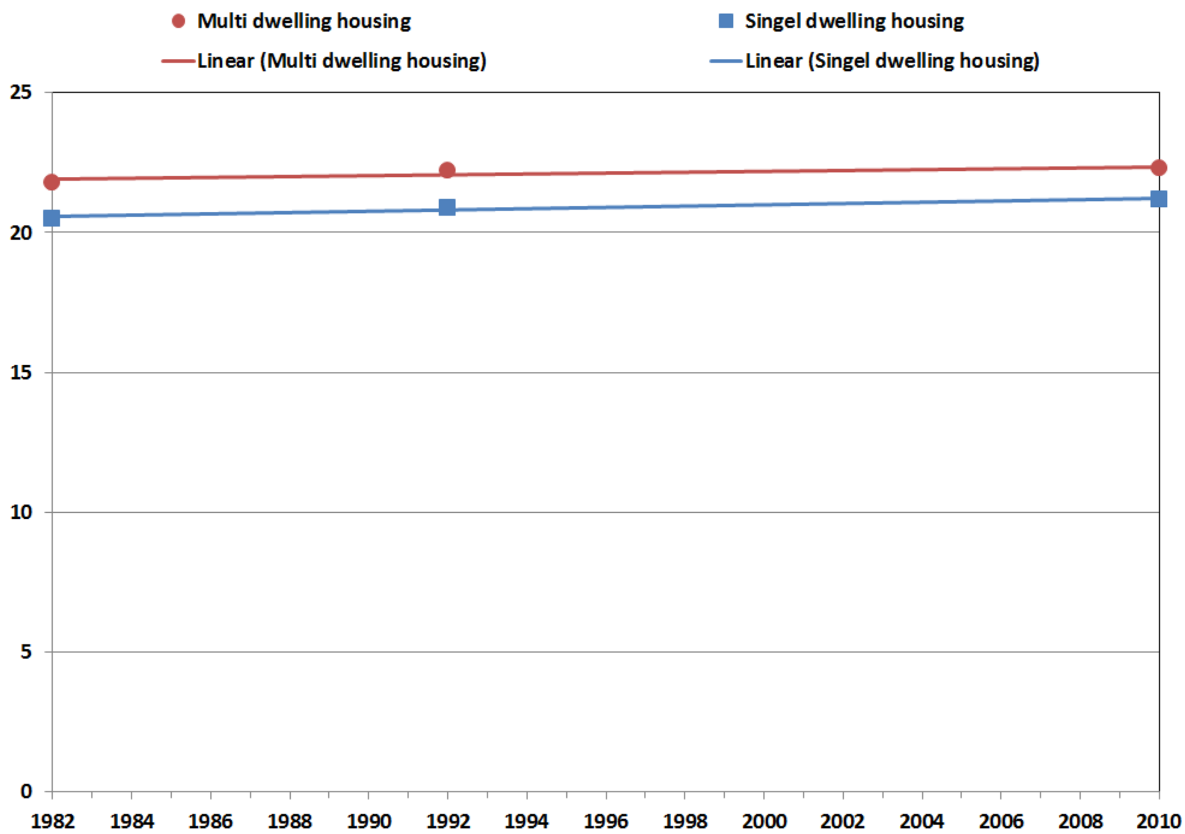

Figure 12. Indoor temperature in Sweden. Source ELIB (1993) Boverket (2010)

Indoor temperatures in Sweden have remained constant the past decades with single dwellings averaging 21,2 ± 0,2 º C and multi dwelling averaging 22,3 ± 0,2 ºC (Figure 12). This is significantly higher than other European countries, e.g., the UK with averages below 20 ºC, with some savings potentials (however, Sweden has a much higher building energy efficiency, and lower energy use per m^2). Climatic and cultural difference explains the higher indoor temperatures and in there are also problems with too cold indoor climate. Studies in the UK have found that indoor related deaths increase for each degree below 20 º C and such problems are surprisingly worse in countries with milder outdoor temperatures but lower indoor temperatures, such as UK (Wilkinson 2001). The National Board of Health and Welfare in Sweden recommend an indoor temperature should be between 20 and 23 ºC (Socialstyrelsen 2005:15) and the current indoor climate is thus right in the middle of this range. Nonetheless the savings potential to optimise and reduce the average indoor temperature to the lower endpoint in this range is significant. Mata et al. (2013) have assessed that reducing the average in both types of dwellings to 20 ºC would yield a saving of 13.3 TWh/y in Sweden, the largest single savings potential in the housing sector and a potential on the same order as upgrading ventilation systems with heat recovery or replacing both windows and facades of buildings to state of the art (ibid).

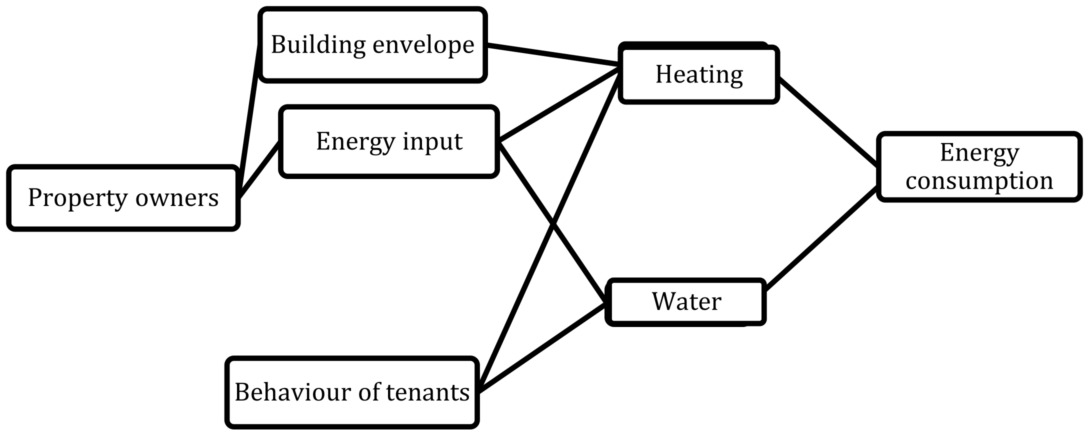

Figure 13. What and who affects the energy consumption for heat and water

The rationale for heat and water efficiency measures through IMB is reduced costs for both the landlord and the tenant (Figure 13). The same systems are in place or discussed for electricity. However, in Sweden there were less than 29 000 apartments (1,2%) that used some form of IMB for heat and water in 2008, albeit with an increasing rate. The standard practice in Swedish multi-dwelling hosing is for heat demand to be included in rent. IMB of heating is rather problematic because energy consumption is so dependent on the building envelope and operating systems; and hence of measures of the property owner, the residents can only affect the smaller part. In addition there are weaknesses in measurement methods between apartments. IMB of water is less problematic since consumption is largely determined by the residents (Boverket 2008). For a standard apartment the consumption ratio between heat and water is 75% heat and 25% water (Boverket, 2001).

IMB is thus a relatively new phenomenon in Sweden and it is only in the 1990s that the IMB start receiving some attention. This stands in contrast to other European countries, such as Germany where IMB has existed since the interwar years and is legislated since 1981. In Denmark, IMB has long been used and is legislated since 1997 for new buildings and since 1999 for existing buildings. Switzerland is another country where IMB is extensively applied (Boverket 2008).
There are no official data for costs of implementing IMB, but according to the Swedish Property Federation, costs for the property owners to install an IMB system would be 10 000 SEK (~1100 €) per apartment, excluding maintenance costs (Bostadsrätterna et al. 2014).

3.6.2 Actors, social network, strategies/actions

The IMB systems in Sweden have been mainly spurred by the EU Energy Efficiency Directive (2012/27/EU). The agencies driving it forward are the Swedish Energy Agency (SEA) and the Swedish National Board of Housing, Building and Planning (Berndtsson 2003; 2005; Boverket 2008; Boverket 2013). Other important actors for the niche development include suppliers of products and services for IMB, and can be roughly divided into four groups: 1) heat meter producers; 2) energy suppliers; 3) information transfer and management; and 4) property maintenance. There are two small interest groups of suppliers promoting instalments of IMB systems, but with no apparent visibility in the debate. From a non-public sector, the two SEA coordinated groups for dwellings and facilities BoBo and BeLok, including members from the public and private sector, have investigated the potential of IMB (Svensson, 2012).
The main opposing actors of IMB include the Swedish Association of Public Housing Companies, the Swedish trade association for property constructors (Fastighetsägarna), the Swedish Construction Federation, and the advocacy organization housing associations (Bostadsrätterna). However, the opposing actors are not by definition opponents of IMB. They are rather opposing legislation and compulsory installations of IMB systems. The opposing actors, together with the Swedish union of tenants, have prepared a report with general recommendations in order to facilitate property owners and tenants to sign agreement for IMB (SABO et al. 2011).
Concerns regarding IMB have also been raised from a gender perspective. Energy conservation affects the timing and types of household chores with resulting increased workload for women. A behavioural change in energy use increased the workload for women as they washed clothes and dishes at night and weekends when the energy price was lower (Carlsson-Kanyama and Lindén 2007).

3.6.3 Institutions/governance

From the EU-level, the directive 2010/31/EU on the energy performance of buildings aims to promote the energy performance of buildings and building units. Article 8.2 of the directive specifies '[m]ember States shall encourage the introduction of intelligent metering systems whenever a building is constructed or undergoes major renovation'. In Sweden, the 2008 Swedish Energy Efficiency Inquiry (SOU 2008:110) and the Swedish National Board of Housing, Building and Planning commissioned a report investigating the potential for IMB in apartment buildings. The report concluded that there was a reduction potential of 10-20% for heating and 15-30% for warm water (Boverket 2008). The report and its conclusions landed in a proposal for a new act on the energy measurement in buildings. The new act would require IMB for all new buildings and in many cases when retrofitting existing buildings.

As already mentioned, several actors have opposed the draft legislation, including the Swedish Association of Public Housing Companies, the Swedish trade association for property constructors, and the Swedish Construction Federation. The arguments were mainly based around: that IMB would not lead to any significant decrease in heat use; that the implementation of IMB would demand large investments for property owners, in the order of 25 billion SEK (2,74 billion €); the administrative burden would be particularly hard for smaller property owners; skewed heat consumption between tenants would mean that some would pay more at the expense of others; and that the economies of scale would disappear, which means that any incentive for energy efficiency measures for property owners would diminish (Eliasson 2013; Bostadsrätterna et al. 2014). At the same time, two agencies, the

Swedish Energy Agency and the National Board of Housing, Building and Planning published a joint report on divided incentives for energy efficiency between property owners and tenants. The report argued that whilst IMB has the advantage for both property owners and tenants in the sense that they both get better knowledge of the apartment's specific use of heat and water, the property owner would lose the incentive to decrease the overall energy consumption in the building as all profits would go to the tenant. Moreover, the thermostatic valves in apartment buildings are often fixed, which would cause difficulties for tenants to regulate their heat (Boverket 2013).

The protests led to a change in legislation and the new act instructs IMB in every newly built or retrofitted apartment's use of heating, cooling and domestic hot water, *when it is cost effective* to install metering at apartment level (Swedish Government 2014).

3.6.4 Summary

IMB systems have the potential to decrease indoor energy consumption in apartment buildings and are in many European countries widely applied. In Sweden, however, the use of IMB systems is low, indoor temperatures are relatively high, and there is strong opposition from incumbent actors for compulsory actions or legislation. The new entrants are few and not very well organised. The Swedish rental system, where heat and water is included in most dwellings is another factor that works against the increase of IMBs. This creates financial disincentives for property owners to install IMB systems. Another issue is the central heating systems, e.g. district heating, which are common in Swedish apartment buildings and make individual heat measuring difficult. In terms of opportunities for IMB, a separate system for water would have better opportunities as measuring water use requires less efforts and resources. On the other hand, savings in energy for only water would be significantly lower (Boverket 2013).

From a political and institutional perspective, there is support from both EU and the Swedish government. But so far, no financial support has been offered or even discussed. The future for IMB heating systems is uncertain as the opposition against legislation is strong and the proponents are weak. But on the other hand IMB for electricity is much more advanced and receives strong institutional and public support and might offer hope for a change in the mind-sets of the current opponents (Swedish Energy Markets Inspectorate 2010). In summary, the momentum can be assessed as low for the niche innovation.

In terms of pathways, IMB belongs to Pathway A, as it mainly focuses on substitution of technical components rather that a broader regime transformation. On the other hand, a change in underlying norms and behaviours of consumers to accept reduced indoor temperature could be argued as part of Pathways B, requiring deeper changes in institutions, and combined this represented wider changes in several dimensions. In the end, this will depend on the development course of this particular niche innovation.

3.7 Additional niche innovations: Efficient mechanical HVAC systems, renovations and energy performance contracting

Efficient mechanical heat ventilation and air condition (HVAC) systems include a range of different solutions for more energy efficient ventilation. In Sweden the most important technologies are different forms of mechanical ventilation with or without heat recovery. These can be either in the form of simpler mechanical systems regulating exhaust air or both exhaust and intake (Swedish denoted F and FT systems respectively), or more advance systems for heat recovery (HRV) with either heat exchanges or heat pumps (denoted FTX for heat exchanges and FTP for heat pumps). In Sweden, with low out-door temperatures,

advance heat recovery ventilation is highly efficient, particularly in the north, and the energy savings in single housing is on the order of 3-6 kWh per year.
Following the oil crisis in the 1970s and regulations making HRV mandatory on new buildings in the late 1980s, HRV systems have been widely adopted in Sweden, both in single and multi-dwelling housing. Among buildings built between 1986 and 1995 over 60% uses HRV systems. The policy forcing adoption of HRV systems was however removed in 1994 and in the newer building stock the share is lower at 40% (Boverket 2010). This illustrates well that regulations and buildings-standards is a key determinant of technology adoption and developments of niche-innovations in the Swedish Heat domain (Nässén et al 2008).

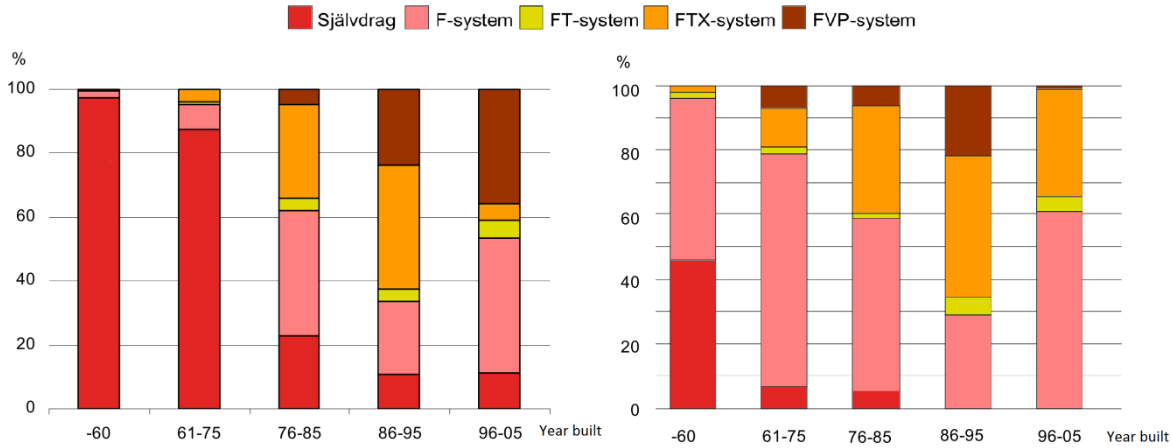

Figure 14. Type of ventilations systems in Swedish housing sector. Red bar “Självdrag” denotes no mechanical ventilation. For F, FT, FTX, and FVP, see text above Based on Boverket (2010)

Adoption of HRV is not yet assessed as a niche-innovation of its own in this background report. The different HRV technologies are a key aspect of low-energy housing and retrofitting of multi-dwelling housing and also interlinked to recent interesting actor developments in the Swedish heat domain that could be studied later on in PATHWAYS project. This includes the growing trend of using consultants on Energy Performance Contracting (EPC) to reduce energy use in existing multi-dwelling housing, often with the help of HRV systems.
EPC means that an external actor, e.g. engineering consultant, is paid for refurbishments and retrofits made only after energy and thus cost savings are gained for the house owners. The approach is common on several states in the USA, and the practice is growing in Sweden. However, there are yet very academic few studies in the housing sector, and the technique is also uncommon in energy intensive industry despite obvious savings potentials (Thollander et al. 2013.
Notwithstanding, according to one EPC-consulting firm (Axelsson and Persson 2013), the overall savings in publicly owned properties in Sweden would be 3,7 billion SEK (400 million €). The same firm argues that by using the EPC model, the city of Stockholm would, at a cost of 2.3 billion SEK (250 million €), retrofit all public properties. A measure that would eventually pay for itself and provide at least 287 million SEK (31,2 million €) in lower expenditure in energy every year, corresponding to 373 GWh (Axelsson and Persson 2013).
Regarding retrofitting of multi-dwelling housing, especially the large building stock from the million programme built in late 60s and early 70s, is an active debate that links several technologies such as HRV and low U-value windows and facades, but the cost effectiveness is not straight forward. The National Board of Housing, Building and Planning have assessed that and energy efficiency improvements that push energy use below current political targets

means earlier refurbishments then otherwise scheduled renovations, which is very costly (Boverket 2013). Since the housing sector is largely based on renewable energy, the discourse tend to be on cost savings and life cycle analysis of total emission, potentially leading lower ambitions in terms of retrofitting. However, all these developments are inherently linked to understanding the regime developments in the Swedish heat domain, and thus more analysis will be conducted later in the project to unpack these aspects of the transition in the Swedish housing sector.

4. Conclusion: Transition in the heat domain

Why did the transition in the heat domain go so well for Sweden? As shown in this report, Sweden has made a transition from a heavily fossil fuel dependent heat system to a close-to fully renewable system. This has been an incremental change encouraged by early innovators, strong public support, the two oil crises and an ambitious climate and energy policy. But also indirect factors have played an important role for example for DH. The multi-dwelling housing ownership system in Sweden is communal for rental flats but also for flats in private properties, where flat “owners” have a share in a building rather than owning a separate apartment. This has facilitated large-systems over individual and diverse solutions. Thus, sharing as pragmatism has historically been strong in Sweden.

We make three general conclusions of the developments of niche innovation in the Swedish domain. First, in terms of heat generation (see figure 2) the heat regime is showing signs of *saturation*. All energy inputs and their associated niche – innovations (small biofuel, district heating, heat pumps) indicate declining growth and there is little belief from the main actors for further growth. Moreover, ambitions in the energy efficiency domain indicate that the future demand for heat will decrease. Notwithstanding, additional CHP plants are being built and the risk for overcapacity is serious. However, while there is competition between small-scale biomass and heat pumps, neither shows signs of taking significant market shares from each other. Furthermore, there is no serious competition between heat pumps and district heating. Heat pumps are leading in small dwellings and district heating is almost exclusive in large dwellings apart from fine-grained DH in larger cities. Second, the Swedish heat domain is *interconnected.* Several niches are linked in and dependent on each other. For example, waste heat is almost exclusively linked to district heating and certain heat pump systems work best with ventilation systems. Many houses, small and large alike, use combinations of different technologies, often adding heat pumps to existing solutions. Furthermore, low energy housing and retrofitting is per se dependent on other technologies and niches-innovations. Third, there is *complementarity* between the niches. As already mentioned, the two main heat sources, district heating and heat pumps, are not mutually exclusive, but rather complementing each other. When a district heating system is built and houses have switched, the difference in infrastructure is effectively dividing the market in two segments with different logics, but each source has its own advantage and district heating is not universally cost efficient.

4.1 Overall assessment of the momentum (high, medium, low) in the heat domain

The momentum of the heat domain in Sweden needs to be described as two-fold. For heat generation (right hand side of heating systems shown in figure 2), as already mentioned, the domain is to a large extent renewable and the general feeling among actors is that the ‘problem’ is solved. The transition in the heat domain thus showed **high momentum the past** decades in terms of heat generation. There is little room for further development of existing energy sources and the momentum is low. Table 2 summaries the assessments of momentum in each niche innovation, and the key drivers behind this momentum.

Niche innovation	Relative ranking	Momentum	Drivers of momentum
Heat pumps	1	Moderate	Mainly driven by techno-economic factors. The most cost competitive option when DH is not available and often used combined with other heating technologies. Few socio-cognitive changes needed, and not thus not a driver. Policy (e.g., R&D support) has been important historically.
District Heating	2	Moderate	Mainly driven by policy and governance and socio-cognitive e.g., culture of large scale system solutions developed by state and municipalities. Today techno-economic factor more important; DH is the most cost-competitive option in Sweden.
Waste heat recovery	3	Moderate	Techno-economic factors dominates, but policy/governance a driver to some degree.
Small Scale biomass	4	Low	Complex. Socio-cognitive driver is historically key in terms small biomass being a technology in single house dwellings, but recently the cognitive aspects is more of a barrier (user (un)friendly technology). Key driver over time probably techno-economic factors.
Low energy housing	5	Low	Socio-cognitive dominates. Techno-economic is not perceived as driver, and governance/policy is lagging.
Individual metering and billing	6	Very low	Socio-cognitive dominates. Techno-economic is even a barrier as some researchers suggest solution is even increasing demand. Governance/policy is not driving either, rather resisting this development.

Table 1. Niche innovations sorted by relative momentum.

A heat source that is insufficiently explored in the Swedish heat domain is solar heating. A common view is that Sweden does not receive enough sunlight. But, the amount of sunlight received by the solar energy over Stockholm on an annual basis in fact equals to that in central Germany. In 2012, the department of environmental management in the city of Stockholm released a report arguing that investments on solar heat and solar power in the city were competitive with existing sources (Miljöförvaltningen 2012). Notwithstanding, we could not find sufficient data to include solar heating as an important niche of its own. For the building sector (left hand side of heating system shown in figure 2), on the other hand, there are clear opportunities for energy efficiency. Low energy buildings, behavioural change through IMB, as well as further use of waste heat, are niches where there is large potential. However, the **momentum is low in the buildings part of the domain** and there is a need for more institutional support.

4.2 Overall assessment of the pathways

The heat domain in Sweden is to a large extent fuelled by renewable energy sources and several of the niches discussed in this report are now part of the wider regime. Initially, however, both heat pumps and district heating belonged to Pathway B and caused a broad regime transformation, going from fossil fuel dominated heat sector to a renewable one. Today and in the recent past (at focus in task 2.1 of WP2) development of these energy sources, belong to Pathway A as technologies are rather improved than substituted. Also small-scale bio fuel belongs to Pathway A, as the niche-innovation only substitute fuel and makes minor changes to an already existing set of technologies on small scale use of wood fuels in the single-dwelling housing sector.

Niche innovation	Momentum Past	Momentum Current	Pathway [A/B]	Explanation to pathway assessment
Small Scale biomass	Medium	Low	A	Stable market share, gradual replacement of traditional biofuel in small scale applications
District Heating	High	Low	B historically but currently A	Broad regime transformation completed and new regime with stable market share today
Heat pumps	Very high	Moderate	A	Long development in different phases. Radical technology but no wider societal changes needed for transformation
Low energy housing	Very low	Low	B	Far reaching institutional change needed, high resistance from incumbent actors.
Waste heat recovery	Low	Moderate	A	Slow but steady development within DH domain. Difficult to assess momentum.
Individual metering and billing	Low	Very low	A/B	Both A and B? Substitution rather than regime transformation, but do require deep behavioural and institutional change.

Table 2 Momentum, Pathway and explanation to pathway assessment

Regarding the of niche innovations that are dependent on changed behaviour, new market solutions and application of technologies, such as individual metering and billing, and low energy housing, these belong to Pathway B. These innovations aim for deeper changes in institutions and transformations in societal involvement. In the Swedish case study, the developments of these appear to lag compared to the other niches.

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