PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

Grant Agreement number 603942

Deliverable D2.2: ‘Analysis of stability and tensions in incumbent socio-technical regimes’

Country report 3: Regime analysis of the Swedish heating system

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28 May, 2015

Executive summary

This report assesses the degree of lock-in and path dependence of the socio-technical regimes in the Swedish heat domain and possible cracks and tensions. The Swedish heat domain is dominated by its supply-oriented elements, namely district heating and electricity, mainly through heat pumps. On the demand side, the housing regime is characterised by single- and multi-dwelling properties.

District heating in Sweden dominates with more that 50% of the heat production. Moreover, Sweden is a world leader in using waste heat with 4.9 TWh of energy produced coming from industrial excess heat pumped into the district heating networks. The strength of district heating is its capability to constantly reinvent itself. Sweden is also a world leader in heat pump system, with more than one million heat pumps sold.

The reason for the overall successful development of the heat generation regime can be found in the long term and continuous support for energy technology innovation and the early decision to go for district heating already in the 19650s. The government-supported policy programmes and their effect on increased production and sales and have enabled cost reductions over time. Thus, the Swedish example is a historical case study. However, today there are signs of saturation in market development, which has led to increased competition between district heating and heat pumps. Moreover, the expansion of combined heat and power plants is increasing demand for waste for incineration. Today, the capacity is greater than the domestically-generated garbage. However, notwithstanding the recent development, there are few signs indicating that there will be any disruptions in the heat generation regime in the long-term.

Regarding the housing regime, the Swedish tradition of large-scale systems serves as a stabilising pressure for the regime in the sense that individuals living in multi-dwellings have little control of their heating bill due to a collective heat control system, which is regulated on the meso-level by landlords/caretakers of the properties. This leaves little incentive for individuals to lower their heat consumption. However, there are also interesting patterns of energy use and demand from consumers in that Sweden has rather high indoor-temperatures, a lagging implementation of EU directives on more stringent energy requirements in buildings, and a reluctance to use demand management instruments such as net metering.

In summary, the socio-technical regime of the Swedish heat domain is very supply-side oriented with few demand-based pressures, as the heat production is more or less fully renewable. Tables below summarise the findings of this report.

Heat Generation - Supply

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	- Energy (oil) independence - Societal values on climate change and sustainable development - Natural monopoly of DH	- Climate change (warmer temperatures equals lower demand) - EU policy directives (energy efficiency and waste)
Industry	STRONG - Sunk investments in DH infrastructure – pipes, plants (centralised power generation) - Natural monopoly of DH - High investment costs for HPs - High level of renewable energy in system and low amount of CO_2 in electricity generation - Interconnectedness between HP and DH - Strong trade associations - Large forestry sector means easy access to biofuels for DH	MODERATE - Stagnation and saturation in the heat domain - Increased competition between DH and HP - Waste incineration lock-in - Increased import of waste - TPA for DH
Consumers/ households	STRONG - Sweden has a high demand for heating - Generally low interest in heating from consumers and households - Natural monopoly of DH - High investment costs for HP	WEAK/NON-EXISTING - No tensions. Very stable regime dynamics from consumer side
Policy/gover-nance	MODERATE - Public sector own the majority of DH companies - Historically strong policy support for HP - TGC premiers DH (through CHP) over other less developed renewable energy sources	MODERATE - New legislation for TPA might threaten DH dominance. - Current political attention on nuclear energy might affect electricity prices and future HP sales.
Public debate and opinion	STRONG - Strong support of carbon-tax - Strong support of renewable energy - 70-80% of heat is renewable, which leads to little contention in the public opinion towards the current regime.	MODERATE - Negative opinion about long-term dependence on waste import and waste incineration
Pressure from civil society and academia	STONG - Sweden is a world leader in both DH and HP, which have a strong support from academia through research programmes – supported by the government together with the trade associations – which are contributing to the lock-in of the regime	- NON-EXISTING
Overall assessment	STRONG - The heat domain is more or less fully renewable. DH and HP have in the past decades formed the new regime and the stabilizing forces are strong	MODERATE - Most interesting cracks and tensions are with the new interactions between DH and HP, and for the processes opening up DH for competition.

Building stock - Demand

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	- Collective societal values explain culture of leaving limited control over heat to residents.	- Very limited
Industry	STRONG - 70-80% of heat is renewable, limited pressure on industry to further change practices - Low interest from industry towards low-energy buildings and passive houses	NON-EXISTING
Consumers/ households	STRONG - Single-dwellings – Residents rarely move, which encourages large investments in e.g. HP. - Multi-dwellings – Heat is usually incorporated in the rent and, thus, is not usually controversial or something on which users have capacity to act - Stable culture of high indoor temperatures.	WEAK - Smart-meters could decrease the demand for heating, but very few signs that this put any substantial pressure on the regime
Policy/gover-nance	MODERATE - Very few polices and governance arrangement that influence heat consumption. Some information campaigns on energy savings. - Some norms from health policy makers on indoor temperature makes lower indoor temperature in multi-dwelling hosing difficult to implement.	MODERATE - Policy on additional energy efficiency measures, such as lower limitations on energy use /m2 in buildings and stronger regulation on passive houses, might contribute to destabilise the regime. - The building code gives preference to HP over DH and other heating systems
Public debate and opinion	STONG - 70-80% of heat is renewable, which leads to little contention. - Little interest in demand-side actions for heat reduction	MODERATE - Public opinion against the higher costs (due to the natural monopoly) for connecting a building to the DH infrastructure. - Flagship constructions (such as the New Karolinska Hospital) opting for HP over DH. - Some debate on energy efficiency measures, through Energy Performance Contracting
Pressure from civil society and academia	WEAK - Few campaigns from NGOs on reduced heat use.	NON-EXISTING
Overall assessment	MODERATE/STRONG - General low interest in heat demand side from many actors as system has high share of renewables, and the regime is stable. Stabilising forces that limit low energy buildings, maintains regime stability with regard to high heat demand focus.	WEAK - Very limited cracks and tensions in the buildings regime due to high degree of renewable energy. Some tensions on renovation of housing and energy efficiency, else the tensions that exist are rather related to the implementation of the two dominating supply technologies DH and HP.

Content

1. Introduction

This report assesses the degree of lock-in and path dependence of the socio-technical regimes in the Swedish heat domain and possible cracks and tensions. A socio-technical regime consists of the cognitive, normative and regulative institutions (Scott, 1995) that shape the actions, interpretations, and identities of the actors that reproduce elements of the socio-technical system. In this report, we will focus on heat generation and the building stock. The heat generation, or supply-side, regime level is dominated by two interconnected heat systems accounting for up to 75% of the energy demand in Sweden, district heating (DH) and electricity, mainly throug heat pumps (HP). Heating with oil has declined by 90% from 1990, while DH has increased by 50%, and electric heating decreased by 25%, which is largely explained by the increased use of HPs (SEA 2015). Today, almost 50% of the generated heat in properties is delivered by DH, compared with EUs 10%. Electricity delivers 20-25% of the heat, where HPs play a significant role. The housing regime, or demand-side, consists of – for the purpose of this study – of the residential building stock, i.e., single-house dwellings and multi-dwellings. Sweden stands out as a frontrunner on a European level, which has already undergone significant decarbonisation over the past six decades.

The goal of this research is to explore how the current regime has become path dependent and therefore, despite its general high environmental performance, contributes to some lock-in in of technologies that hamper further improvements. Our initial assessment is that the supply side system consists of two main regimes, DH and HP. These two technologies and their supporting actors and institutions dominate the heating sector. Traditionally, small-scale biomass has also played an important role in the Swedish heat, and currently has an opportunity to re-invent itself by harnessing niche developments in advanced small-scale pellet biomass (see report D2.1).

The Swedish case will in other words be a regime analysis that should be understood primarily as dominated by the actors and structures on the supply-side. The key theme here is combustion of waste that is turning into path dependence along a development trajectory in which materials are not recycled but burnt in municipal combined heat and power (CHP) plants. This practice is locked-in as municipalities, in practice, pay the DH companies for incineration of waste. In this report our focus is to explore more in-depth how DH and HP became the central elements of the current heat regime, to provide lessons for other countries aiming for a similar transition. However, there are also interesting patterns of energy use and demand from consumers in that Sweden has rather high indoor-temperatures, a lagging implementation of EU directives on more stringent energy requirements in buildings, and a reluctance to use demand management instruments such as net metering (as described in the D2.1. report).

1.1 The Socio-technical regime of the Swedish heat domain

Figure 1 highlight the integrated socio-technical regime(s) embedded in the larger socio-technical system of the Swedish heat domain, including green niche-innovations, and stabilising and de-stabilsing landscape developments.

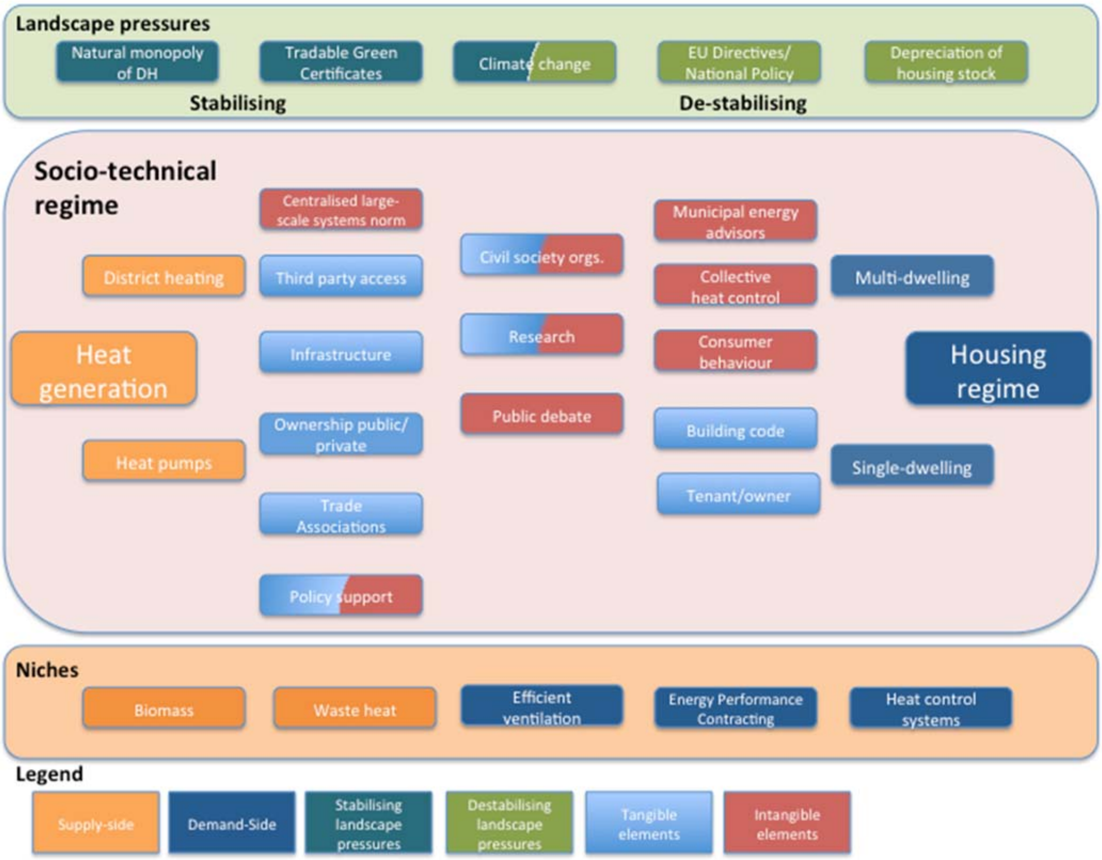

Figure 1 Socio-technical regime of the Swedish heat domain

The socio-technical heating regime in Sweden can be sub-divided into two central system elements: heat generation and the building stock part of the housing regime. Heat generation accounts for the heating technologies and energy resources in place. The existing building stock part of the system focuses largely on the heat demand in single- and multi-dwelling buildings. Although the two regime-elements are interdependent, they can be seen as separate within the larger socio-technical system of the Swedish heat domain. Although the regimes and actors are related within this system, it is useful to analytically distinguish them because they refer to different dimensions of reality and methods. In this report, we will distinguish between relatively 'tangible' or 'objective' elements that can often be measured quantitatively (e.g. technical performance, price, market demand); and more 'intangible' and 'qualitative' elements, referring to beliefs, motivations, strategies, alliances, goals and norms that underlie concrete actions. Their characteristics are elaborated below.

2. Overall system trends and longitudinal development

The Swedish heat domain is dominated by its supply-oriented elements, namely DH, biomass and electricity. Since the oil crisis in the 1970s, the Swedish policy has been to gradually replace oil use, both direct use in single and multi-dwelling housing, and in the central heat plants in expanding the DH system. The DH system has moved from being fully dominated by oil in 1970 to being based primarily (>two thirds) on biomass, with virtually no oil (~ 5%) (Figure 1). Renewable energy policy during the 1970s and 1980s was mainly focused on strong efforts in technology research, development and demonstration. This supply-led attempt to transform the energy system had little impact on the Swedish energy balance. Market development instead took off during the 1990s when taxes and subsidies created favourable economic conditions for new investments and fuel switching. The total amount of renewable energy in the heat domain is currently around 70% (depending on yearly average temperature), which is highest in the EU (SEA 2013a).

The policy landscape for heating in Sweden is currently steered by the EU Energy Efficiency Directive (2012/27/EU), which requires national governments to develop a strategy for energy efficiency in order to implement the so called 20/20/20 targets - i.e. 20% reduction in greenhouse gas (GHG) levels, raising the share of energy consumption produced by renewable energy to 20% and a 20% improvement in energy efficiency by 2020; and the Swedish draft ratification bill on the implementation of the EU Energy Efficiency Directive. The directive also states that energy efficiency in existing buildings needs to be improved and that co-generation of heat and electricity in CHP plants should be promoted. 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. Moreover, the EU Ecodesign directive (2009/125/EC) – together with Swedish Energy Agency's (SEA) energy labelling – provides consistent EU-wide rules for improving the environmental performance of energy-related products, and has an influence on the energy performance of HPs (Karlsson et al. 2013). Alongside the EU directives, the Swedish government's climate and energy policy targets by 2020 go even further with 40% reduction targets in greenhouse gas emissions; at least 50% renewable energy; 20% more efficient energy use; and at least 10% renewable energy in the transport sector (Swedish Government, 2009).

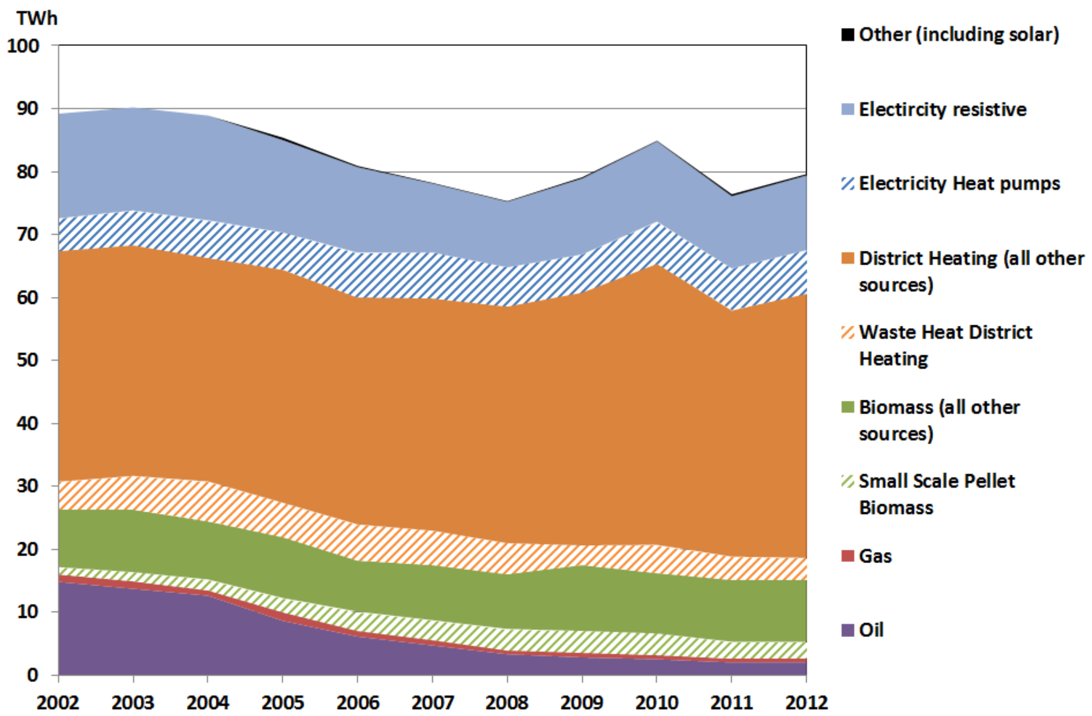

Figure 2 Energy use for heating and hot water by energy carrier in Swedish housing domain

From the policy perspective, the Swedish carbon tax in 1991 was introduced as a feasible policy measure to mitigate climate change. Successful implementation of CO_2 and energy taxes can be further ascribed to the policy of shifting taxation from labor to energy and emissions developed in late 1990s and early 2000s (Naturvårdsverket, 2004). The tax has delivered substantial revenues to government (currently on the order of 20 billion SEK annually) and also induced a changed behaviour in the desired direction. The carbon 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). Energy taxes have a long history in Sweden and have been central to the development of bioenergy. High oil taxes led to the increased use of coal, electricity and biomass during the 1980s. The carbon tax (250 SEK/t or 28 euro/t CO_2) that was introduced in 1991 made biomass relatively less expensive than coal and oil for heating. The carbon tax has increased in steps, reaching 530 SEK/t CO_2 (59 €/t CO_2) in 2001 and 1080 SEK/t CO_2 (116 €/t CO_2) in 2014 (Carlén 2014).

Another policy incentive towards more renewable energy production is the tradable green certificate system (TGC), a legally binding market-based support system intended to increase the production of renewable electricity in a cost effective manner (Swedish Government, 2005b). In Sweden, the certificate system aims to contribute to 25 TWh of renewable electricity from 2002 until 2020. In 2012, the TGC system expanded to include Norway to increase the opportunities for cost efficient development of renewables. From 2002 until 2011, renewable electricity production increased by over 13 TWh, mainly through new bio-power and wind power (SEA, 2013c). The TGC system has been addressed in Unger and Ahlgren (2005), where the effects of introducing a common TGC market for the Nordic countries has been studied. They suggest a large TGC quota in the short run to promote wind power, and in the long-term support for wind technology progress. TGC is a stabilsing mechanism because the system favors electricity generation from mature technologies like CHP, since their production costs are lower than for new technologies such as wind and wave power (Wang 2006).

The Swedish energy policy for buildings is aimed at phasing out oil and resistive electric heating, increasing energy efficiency, and the use of renewable energy resources (Swedish Government 2005a). The share of fossil fuels in the heating system has been on a significant downward trend for the past 20 years and is more or less phased out today (Figure 2). The heating market interacts with the growing electricity market through electric heating, HPs, and heat exchangers as well as through cogeneration of heat and power. Combined heat and power (CHP) production improves the total conversion efficiency but relies on an available heat sink such as a DH system. The use of biomass for energy increased substantially during the 1990s, specifically wood fuels for district-heating which increased from 13 PJ in 1990 to 65 PJ in 2001. A system with high CO_2 taxes, for fuels for heating but no taxes on fuels for electricity production created strong incentives for fuel switching in DH, albeit not for biomass-based cogeneration (Nilsson et al. 2004).

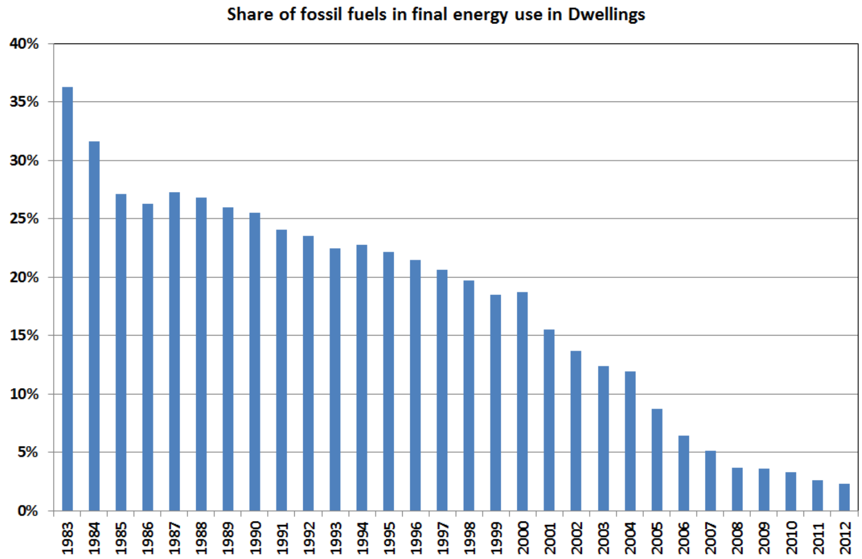

Figure 3 The share of fossil fuels in the Swedish heating system

The residential building stock in Sweden is characterised by single- and multi-dwelling properties. The multi-dwelling housing ownership system in Sweden is communal both for social/rental housing properties and private properties. In the latter case, owners have a share in a whole building rather than owning a separate apartment. This communal system has facilitated pooled heat networks (e.g. DH) over individual heating options. A pragmatic approach to sharing has historically been strong in Sweden and this has in several ways facilitated the energy transition. The building stock has a relatively large amount of multi-dwelling buildings, representing 2,5 of 4,5 million dwellings in Sweden. The main reason for the large number of multi-dwelling is the Swedish million programme; an ambitious housing programme consisting of a million new dwellings built between 1965 to 1974. However, the building stock is becoming depreciated. The need for renovation and refurbishment is severe and the coming years this can be expected to put even more pressure on the heat generation regime, as the demand for heat will decrease (Formas 2012).

Single dwelling buildings (e.g. small detached houses, with one or a few households) represent 292 million m^2 heated area, which compares to a total of 175 million m^2 for multi-dwelling buildings. About half the Swedish population lives in each category, but single dwelling buildings is hence much less densely populated and requires more heat. Single house dwellings are mainly heated through electricity, and to a growing extent by HPs. However, 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 has remained an important fuel for heating in Sweden and has been so since the 1970s (Boverket 2008; SEA 2013b).

The Swedish National Board of Housing, Building and Planning (Boverket) is a key actor that regulates the building stock through the Energy Performance Certificate and the Building Regulations. This includes limiting energy used in new buildings to no more than 90 kWh/m^2 (Boverket, 2011). However, the lack of strict regulation is a barrier for the development of low energy buildings. The buildings code and legislation do not promote low energy housing. The current average levels at 110 kWh/m^2/yr allows twice as high energy use as needed to fulfil the Energy Performance of Buildings Directive (2010/31/EU; 2002/91/EC) (SEA 2010), which in turn is roughly the same level as the Swedish passive house standard at <54 kWh/m^2/yr bought energy for heating and hot water purposes.

3. External landscape developments

3.1 Stabilising landscape pressures

A number of landscape developments are contributing to the stabilisation of the heat regime in Sweden. On the supply side the historically most important factors are energy independence and external oil-price fluctuations (driving efforts to use domestic biomass and electric phasing out oil), growing recognition of climate change (low emission policies following shifting values). The high share of electricity use in the heat domain is also connected to the external landscape change of nuclear innovation in mid 20 century. This spurred a large nuclear program in Sweden in the 50s through 70s, and still influence the debate. Energy independence preceded the focus on sustainable development in the heat sector but both goes back in time, and is connected to underlying societal values of independence and neutrality in foreign policy and a high affinity to nature and long tradition of nature conservation. Lastly, from a cognitive perspective, the Swedish tradition of large-scale systems serves as a stabilising pressure for the housing regime in the sense that individuals living in multi-dwellings have little control of their heating bill due to a collective heat control system, which is regulated on the meso-level by landlords/caretakers of the properties. This leaves little incentive for individuals to lower their heat consumption. Another example is that this culture is connected to the large-scale build out of multi-dwelling housing in the 70s that was paired with DH infrastructure. The historical and expanding DH infrastructure that today offers a natural monopoly that stabilise the DH regime is thus rooted in these societal values.

3.2 De-stabilising landscape pressures

The exogenous landscape developments that put pressure on the socio-technical regime include future climate change (warmer weather) and energy efficiency driven by the EU policy directives.

Climate change serves both as a stabilising process, through the gradual shift in values described above, and a de-stabilising pressure on the regime. In its destabilising sense, climate change will lead to warmer winters in Sweden and thus further decrease the demand for heat. Heat demand is expected to decline due to energy efficiency and lower energy consumption in buildings. Similarly, the EU policy directives push Sweden toward a higher focus on energy efficiency in the heat domain. The effect is similar as with climate change, a destabilizing pressure in that less heat supply is needed.

4. Developments in the heat generation regime

4.1. Tangible system elements of heat generation

4.1.1. District heating

DH is a large and infrastructure-intensive system in Sweden, covering almost 18 000 km. There are more than 200 DH companies around Sweden, providing more than 50 000 GWh in 2010 (Figure 4). In 2010 the turnover was 33 billion SEK (3,64 billion €).

A DH system consists of a network of underground pipes carrying steam or hot water from a centralized heating facility or heat source to individual buildings. The first municipal system in Sweden was introduced in 1948. The system was pioneered by engineers working for the municipal energy companies amidst strong resistance from incumbent actors, mainly the oil business, and the trade association for plumbers and chimneysweepers. The process was encouraged by the opportunity to cogenerate heat and electricity simultaneously, so called Combined Heat and Power (CHP) (SDHA 2009). From a cautious start on a rather small scale in the 1950s, in the 1960s and 1970s, following the first oil crisis, DH system developments took off and grew exponentially from <5 TWH in 1960 to 35 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). Today, 42% of the heating is generated through biofuels, followed by waste incineration 18%, flue gas condensation 9%, and waste heat 7% (see Figure 5).

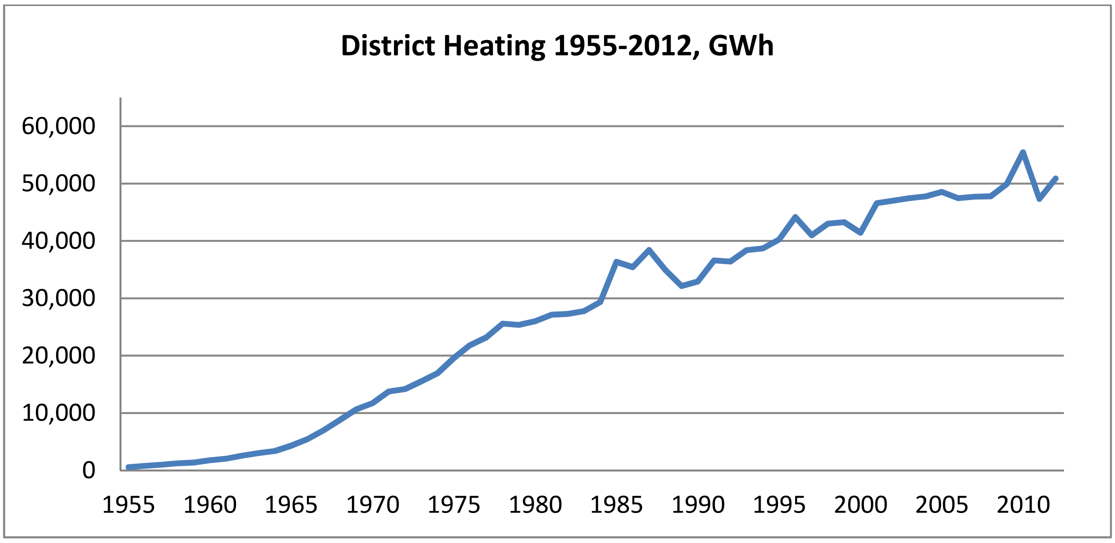

Figure 4 Development of District Heating over time in GWh. (Source: The Swedish District Heating Association)

The strength of the DH regime is its capability to constantly reinvent itself. Figure 5 shows the dynamic fuel supply changes of the DH system over time, from almost 100% oil-based to today's fuel mix which includes biomass, HPs, waste heat, electrical energy, natural gas and oil. Today, the DH system is, through CHP, in many respects also integrated into the electricity market. In 2011, CHP constituted 45% of the total supply to DH. CHP is highly efficient and captures 90% of the fuel energy (compared to 50% for coal powered plants). Energy produced from CHP plants consists of 50-70% heat, while the rest is electricity (Magnusson, 2012; SEA, 2013a).

Since heat and electricity demand often coincide in the Nordic countries, CHP plants also have the largest electricity generation when the heat load is greatest (Amiri and Mosfegh 2010).

The nature of the DH system with hot water production with associated culvert system of distribution need to be considered as vertically integrated units. The business of distribution of hot water for DH thus has such system characteristics and economies of scale that it is not cost effective to compete with parallel culvert as this would lead to inherently higher infrastructure costs. Therefore, DH systems can be seen as a natural monopoly. This is a strong stabilising mechanism for the heat generation regime. In turn, the fact that the DH distributor has a relatively high control of the distribution network, means that the system output can essentially be viewed as a monopoly (Swedish Energy Market Inspectorate 2012).

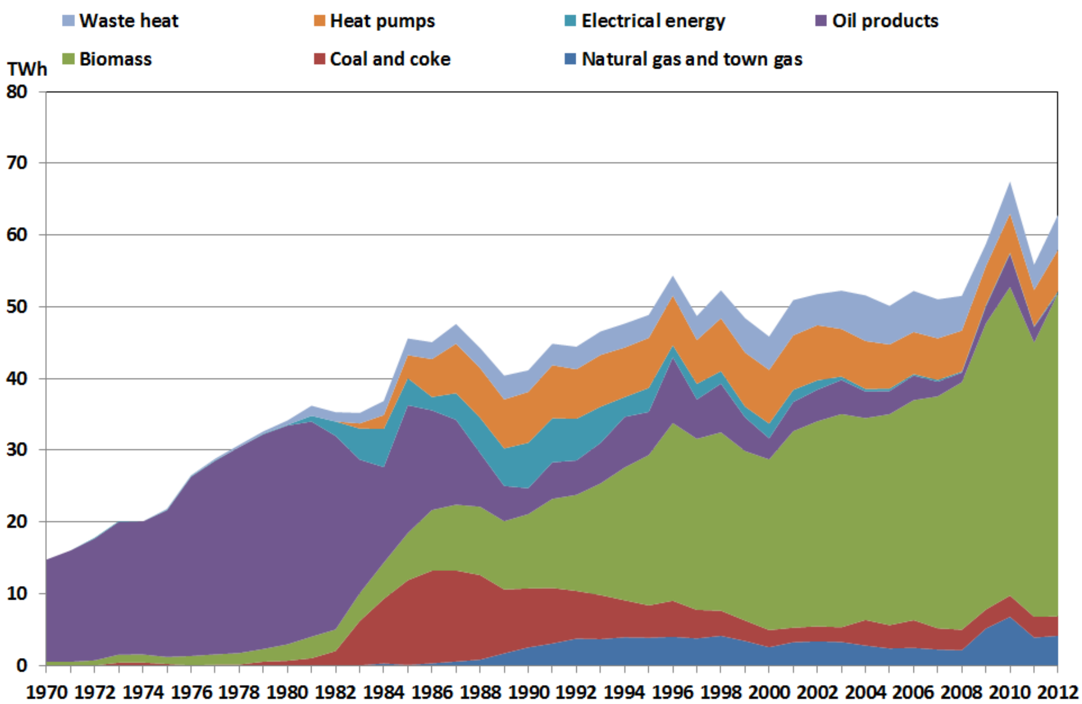

Figure 5 Fuels in the DH system in Sweden in TWh (Source: SEA 2013a).

According to the Swedish District Heating Association (SDHA), electricity production from Swedish CHP plants can increase to 20 TWh/year, from today's level of 9,2 TWh/year or 6,1% of the total electricity generation (SEA 2015). Cogeneration is still at a modest level in Sweden compared to other European countries. Comparatively, the CHP in Finland is 34% of electricity and in Denmark the proportion is 43% and the EU average is around 10% (Amiri and Mosfegh 2010).

Another strength of the DH system is its ability to incorporate industrial waste heat in its system, in order to optimize the use of resources and to reduce environmental impact. Sweden is a world leader with its 4.9 TWh of energy produced through waste heat. 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).

It has been shown that the DH systems that include waste heat have a lower average price (Arnell et al. 2013). However, further potential for recovery of waste heat is still possible. A study calculated the potential for Sweden to be between 6,2 and 7,9 TWh, 30-60% above today's levels (Cronholm et al. 2009).

More than 85% of all multi-dwelling buildings have DH and is the largest customer in terms of volume delivered heat. In addition, DH is supplied to industries for processes, and to premises. In total 93% of apartment blocks, 82% of office areas, and 16% of single family homes get their energy from DH. Individual houses represents about 70% of the total number of delivery points but only a small part of the total volume delivered.[1]

The price is mainly influenced by local conditions and varies between municipalities. The most important factors are fuel prices and the structure of the DH network and infrastructure, i.e. distances between houses, length of pipelines etc. In terms of price development, an important price factor has been the 1996 deregulation of the energy market. As a consequence of this, the principle of cost-based pricing that had previously governed municipal energy companies was lifted in order not to distort competition with private electricity companies. Municipal energy companies were instead required to operate in a business-like fashion (Westin and Lagergren 2002). Partly due to these new circumstances and partly due to financial problems, a considerable number of municipalities decided to sell their energy companies, including DH systems, during the 1990s and early 2000s. The buyers were large national and international energy companies such as Vattenfall, E.ON and Fortum. In 2004 these companies together accounted for 39% of the DH supplied in terms of energy (DiLuzia & Ericsson 2014), leading to price increases by as much as 50% (Avgiftsgruppen, 2009). Following this, there has been another 30% increase over a 10-year period (Figure 6).

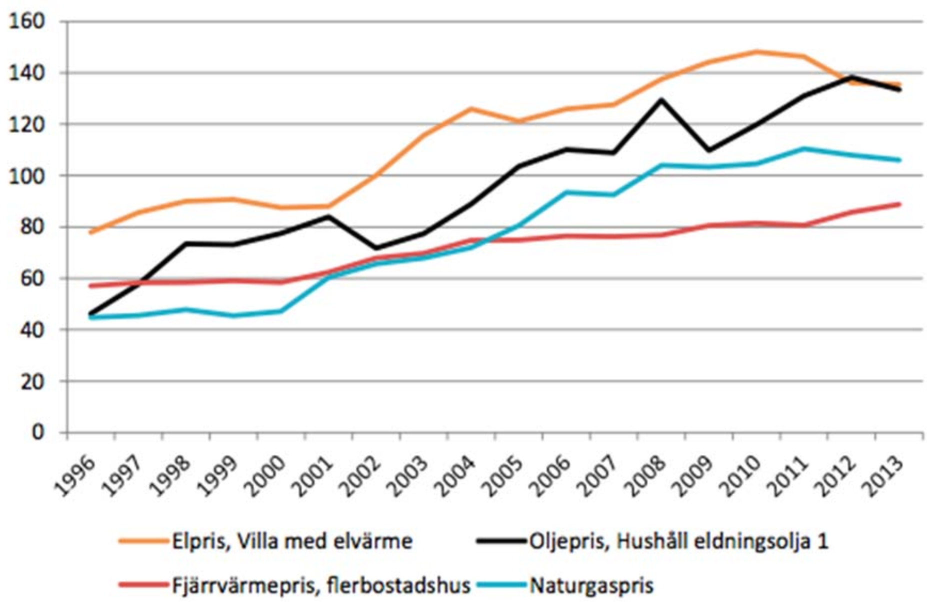

Figure 6 Energy prices development in residential and service sector 1996-2013, in Öre/kWh (yellow: Electricity, black: Oil, red: DH in multi-dwellings, blue: Natural gas) (Source: SEA 2015)

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

The DH companies are scattered around the country and have different prerequisites for their operations. They are characterised by a large diversity of production-mix solutions (Knutsson et al., 2006). Most are operating at a local level, and even in the larger cities there are several operators working with relatively small-scale infrastructure networks. These conditions affect the costs to varying degrees and depending on the company's pricing philosophy. Main factors include mix of fuels, customer density and heat demand. A high customer density and a larger demand allows the grids to be used more efficiently, resulting in a lower unit cost per customer. Another factor that may underlie price variations between DH companies are soil conditions where the pipes are buried. The cost of burying the pipes and then restore the soil varies greatly and can give great impact on DH price especially in the newly expanded areas. Other factors that come into play is that companies have different capital costs due to depreciation methods and the age of the capital stock (Swedish Energy Market Inspectorate 2012).

4.1.2. Heat pumps

An important factor explaining the historical and current energy patterns in the Swedish heat 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 led to large amounts of direct electricity for heating. Today a large share of this inefficient heating is replaced by HPs – an energy system where Sweden is today a world leader. HPs are usually characterized by their heat sources (air, water and ground) and by the mediums between which they transfer heat (air-air, air-water, water-air, water-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 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 7). An important factor for this development is the Swedish low-carbon policy, which started in the early 1990s following the introduction of the carbon tax. The housing sector is among the best performers and the total amount of fossil primary fuels in this sector is now only 4% (SEA 2014a). Additional important factor for the success of HPs is that people in Sweden do not tend to move frequently, which encourages relatively expensive long-term investments (TPA Forum 2012).

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). The Swedish government is also providing subsidies for conversion from oil-fired boiler and direct electricity to HPs (SEA 2015). 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. However, it is difficult to explain this high uptake in Sweden since for example Finland, with similar culture, climate, geology, and infrastructure has only a relatively small number of HPs. One explanation to the

Swedish success could be that much of the research and testing were undertaken in Sweden (Bayer et al. 2012).

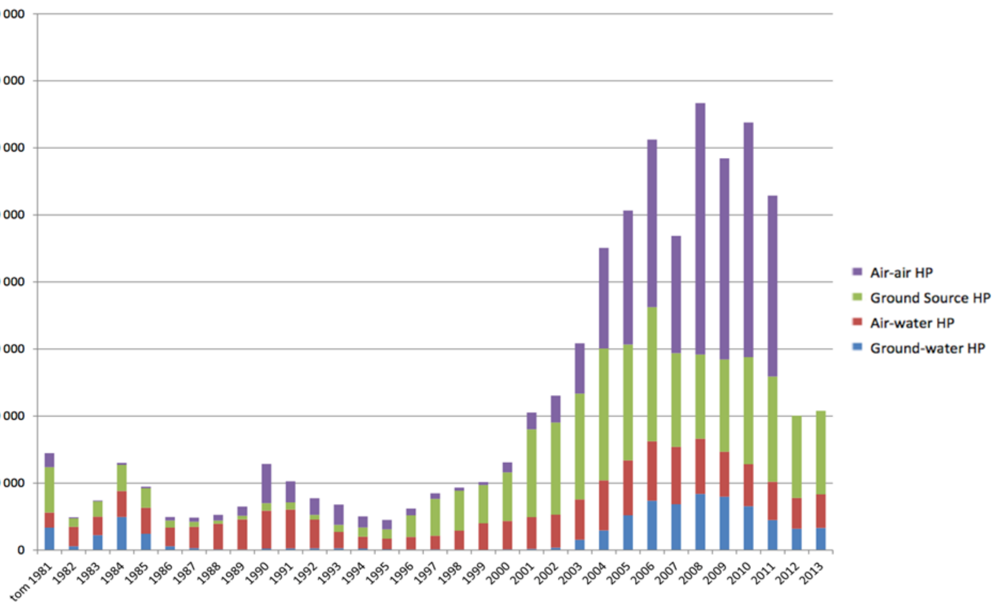

Figure 7 Heat pump sales in Sweden 1981-2013 (Source: SVEP). Air-air data missing for 2012-2013

The reason for the overall successful HP development can be found in the long term and continuous support for energy technology innovation in HPs. The government-supported policy programmes and their effect on increased production and sales of HPs have enabled cost reductions 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 fuelled heating systems. Today, HPs are cost-competitive. Important drivers of cost reduction have been economies of scale, not only for HPs as such, but also for borehole drilling, and continuous technology improvements (Kiss et al. 2012).

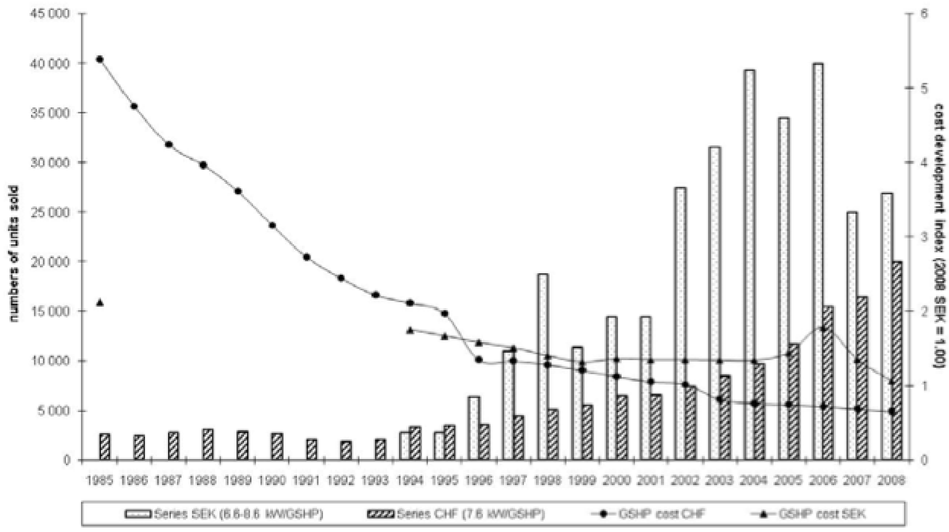

Figure 8 Number and cost of heat pumps installed in Sweden and Switzerland (Source: Kiss et al. 2012)

The demand for HPs decreased significantly in the mid 1980s as the price of oil fell and as government subsidies for domestic HPs were terminated. As a result, 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 consequences not only on the sales of new HPs but also on the maintenance of the installed ones (Kiss et al. 2012; Törnell, 2007). However, the research programmes continued in the 1980s, and the existing 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 (Kiss et al. 2012).

HPs 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 SEA, the purchased energy for heating and hot water in Swedish single-family households has decreased with 17% (from 25 500 kWh to 21 400 kWh) between 2001 and 2012[2], which is mainly attributed to HPs (SEA 2012b). 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. One explanation for this might be that HPs have been shown to add value to properties (Boverket, 2008; SEA, 2012b). Focusing on ground source HPs (GSHP) in residential heating systems, Mahapatra et al. (2010) found, in a Swedish survey, that they are perceived to be better than DH, pellet boilers and resistance heaters regarding GHG emissions, market value of the house, environmental benignity, security of fuel supply and annual cost of heating. Until the mid 2000s, GSHP dominated market sales, constituting on average 45% of HPs sold each year with annual growth rates between 1993 and 2006 exceeding 30%. Moreover, not only the number of GSHPs in Europe is highest in Sweden, but also the emission savings with almost 36% in 2008 are the highest (Bayer et al. 2012). However, since 2000, the market share of air-air HPs has increased rapidly, and in 2008 they consisted of more than 60% of total sales. The reason for this development is might be that the air-air HPs have become more efficient and require much lower capital investment (SEA 2015). Exports have also represented a significant share of the sales, in the mid 2000s approximately 40-50% of the total Swedish production was for export (SVEP 2009).

The future of HPs lies in the technological development that goes on constantly improving the coefficient of performance (COP)[3], and opportunities to control loads so expensive peaks, both from electricity and DH, can be avoided on cold days. Recently, however, the growth rate in HP sales has been decreasing, 2007 being the first year in thirteen years for which sales declined compared to the previous year. This scenario was repeated even in 2009 and 2011 (Figure 8) (SEA 2015), which is indicative of market saturation.

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[2] These two years were approximately equally warm.
[3] If the HP has a COP 3 it means that 1 kWh of thermal electricity generates 3 kWh of heat.

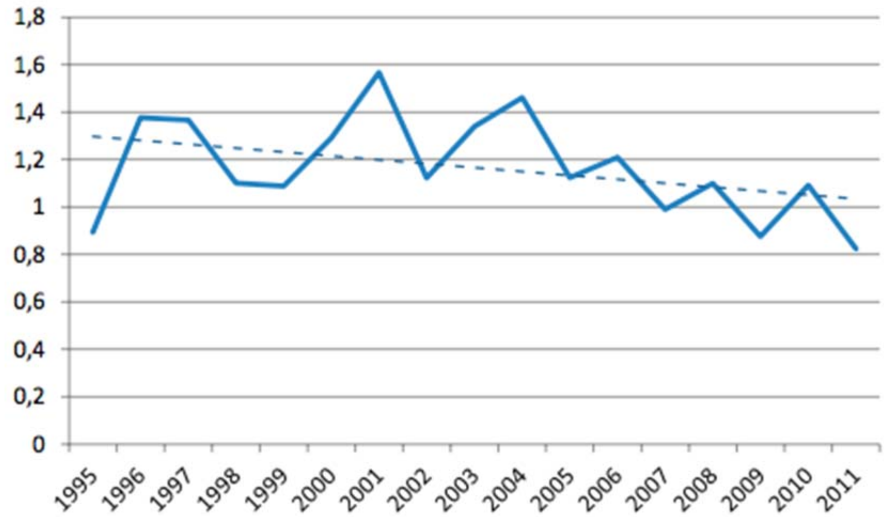

Figure 9 Annual sales growth rate of the heat pump market in Sweden 1995-2011. (Source: SEA 2015)

4.2. Intangible regime elements of heat generation

4.2.1. District heating

The key actors in Swedish DH are the providers. Until the beginning of the 1980s, the majority of DH operations were under municipal administration. In connection with the deregulation of the electricity and DH market in the mid-90s, the market structure changed and communal ownership of DH operations decreased (Magnusson, 2012). The majority of the providers are organised through the Swedish District Heating Association (SDHA), which represents 98% of the providers.

Sweden has had an early focus on developing new heat and electricity-generating technology and the major utilities have played a central role in this work. However, other entities, including both municipal energy companies and local governments, have been equally or more important for the increased use of renewable energy. For example, political support and capability to handle siting and physical planning at the local level has been important for energy development. The early adopters include a range of different actors, but much of the demand has been in the DH systems (Nilsson et al. 2004).

With regards to fuel input, the ability of the forest industry to handle harvesting of forestry residues and associated logistics has been important for the supply of biofuels for DH (Nilsson et al. 2004). Private owners hold 49% of Swedish forests, limited companies 40%, the state 3%, and the church, municipalities, etc., own the remaining 8%. However, it should be noted that the state owns about one-third through a limited company. The ties between the forest industry and the power industry are traditionally strong. The forest industry was initially reluctant, and to some extent still is today, to engage in the development of a biofuel market, fearing competition for the raw material. Historically, forest industry's support for nuclear power has been strong since turning to biomass instead of nuclear power could lead to increased electricity prices. Both the forest and the pulp and paper industry are energy-intensive and control much of the biomass flow both as producers and users of wood and by-products. Consequently, they are important players on the energy market and have a strong interest in low fuel and electricity costs. However, the industry appears to have developed a more positive attitude towards biomass for energy generation since 1990. It accounts for a large part of the wood fuels market through own use and through subsidiary fuel companies. The forest industry has also benefited from, for example, taxes that have generated a bioenergy market, e.g. the CO_2 tax and the energy tax, whereas industry is largely exempt, or receives significant discount, from these taxes (Nilsson et al. 2004).

Although some DH companies became involved in wood fuel production, most of them procured wood fuels through external wood fuel companies. These were, and many still are, subsidiaries of forest industry companies, which have traditionally been key actors on the Swedish wood fuel market since they control much of the biomass flow as users and producers of wood and its by-products. Several DH companies also started to import wood fuels during the early 1990s. Large DH plants along the coast, in particular, were able to diversify their wood fuel supply through imports. Imports primarily comprised various fuels from the Baltic countries, pellets from Canada, and production waste from Germany and the Netherlands (Di Luzia & Ericsson, 2014).

Next to biofuels, waste incineration is a significant fuel input to DH. One of the main reasons for the high amount of waste incineration in DH is a 2002 ban on landfill waste, which 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 (SEA 2014b; Ganslandt 2011; SEA 2008a; Rydstrand 2005; Jönsson et al. 2007). Waste incineration contributed to a production of 12.6 TWh of heat and 1.8 TWh of electricity in 2010 (Avfall Sverige 2009). This means that about 20% of DH and about 1% of the electricity produced by energy recovery from waste in 2010. About half of all household waste goes to energy recovery and that means that DH has an important role in municipal waste. Of the approximately 5 million tonnes of waste in DH households accounted for approximately 2 million and other waste, mainly industrial waste, approximately 3 million tonnes. Capacity expansion for waste incineration is underway and by 2020 capacity is expected to increase with a further 2 million tonnes. But today, the capacity is greater than the domestically-generated garbage. In 2010, 748,000 tonnes of imported waste was for incineration in Sweden. Future projections indicate a strong increase of waste import, up to 30% (Avfall Sverige 2009; Pädam et al. 2013).

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. However, 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 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 (MoEEC, 2014; Swedish Energy Market Inspectorate, 2013). However, it is expected that the recent changes are not enough to encourage more waste heat in the DH systems as the regulations will not create effective competition on the supply side because of high entry barriers for new actors and the large-scale nature of the DH production facilities, leading to a lack of business opportunity (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). Currently, there is a lack of institutional and financial support from the government and municipalities. However, the change with TPA and the implementation of the EU energy efficiency directive has generated some momentum. The process of arranging a contract between the waste heat provider and the DH company from idea to actual delivery 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 the TGC system. 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, which creates an untapped potential for reducing national and global CO_2-emissions (Arnell et al. 2013).

As the multi-dwelling market of DH has become saturated, DH has expanded towards investments in the single-dwelling sector (Sköldberg et al. 2011). These investments are different from the traditional, large-scale ventures. Instead of attaching one large customer to the existing network, small house DH attachments necessitate expansion of the existing distribution network, which in turn calls for increased production quantities. Also, engagement in the small house DH segment makes customer service important. Even though private homeowners consume smaller quantities of heat per annum, compared to large and professional customers, their need for support and information is sometimes larger, as they are more in control of their heat consumption. Private homeowners have other demands than their multi-dwelling counterparts. In Sweden, large companies are more efficient than small ones when it comes to supplying small house with DH. Network density and network length per customer impact the efficiency of small house DH the most. Thus, large Swedish DH companies, facing market saturation, are more ready to invest in the segment of small house DH than small companies. In doing so, they expand sales long-term, albeit at a lower margin (Lygnerud and Peltola-Ojala 2010).

Demand for heating from the Swedish consumers is high. But paradoxically the consumer interest is low. As previously stated, DH is the most common form of heating for apartment buildings. Competition with other systems is limited as customers have no real choice of other forms of heating. This applies above all to multi-dwellings in the central parts of large cities, where the ability to install a pellet boiler or a HP may be limited for several reasons. For single-dwellings and apartment buildings, outside dense areas, there are less practical obstacles to change from e.g. DH to pellet boiler or heat pump. However, the limited competition resulting from DH's position as the dominant form of heating is an obstacle even here. A customer who chooses DH generally makes a relatively large initial long-term investment. The customer is then tied to one supplier with only a short-term price contract. This means that the DH supplying company will have a strong position vis-à-vis the customers. A supplier may initially offer a low price and once the customer has invested in DH so the supplier can increase the variable energy cost because it is not profitable for the customer to switch form of heating. Should a customer wish to change the form of heating before the system's equipment is worn out, there are often significant costs. Replacement costs are limited in the case of DH due to the natural monopoly of the system, and a change may be expensive. The practical and economic change barriers to existing DH customers give the supplier scope to raise prices. The ability to raise prices is limited if the provider intends to win new customers and not price discriminate between new and existing customers. However, if the supplier already has a sufficiently large customer base he may choose to increase the price and thus increase the margin on the existing customers at the price of not getting new customers (Swedish Energy Markets Inspectorate 2012).

From a policy perspective, DH development 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 was initiated with the need for replacement of oil as a ocnsequence of the first oil crisis. Lastly, the fourth phase of DH came about through climate change discourse and the need for 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). Moreover, in terms of policy and governance support from the two regulating municipalities SEA and Boverket has been crucial. The SEA controls and implements EU energy directives as well as the national directives. Together with the Swedish Energy Markets Inspectorate, the SEA is also the host of the District Heating Council with the task of being a mediator in the negotiations between the DH companies and customers as regulated in the District Heating Act (2008:263). This council also facilitates negotiations between DH companies and those wishing to gain access to the DH infrastructure through TPA. Boverket is the Agency that regulates energy consumption in the built environment. Through the (compulsory) Energy Performance Certificate, it provides information on building energy use to owners, renters, or buyers of a house. Boverket influence also through the building code, 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. The municipalities' planning power has, however, been considerable weakened since a 1987 change in this legislation and a generally liberalised economy, with stronger private actors, (Blücher, 2006).

As already mentioned, the CO_2-tax has been influential in lowering the GHG emissions in Sweden. Although, heavy industry has paid a much lower tax than other sectors, currently 25% of the carbon tax and no energy tax. In addition, no energy or carbon taxes are levied on fuels for electricity production. The taxes do apply, however, to heat production and heat produced in combined heat and power (CHP) plants. Biomass is exempt from energy taxes and the tax system explains much of the increase in biomass use during the 1990s. Owing to the tax system, biomass has been highly competitive in district-heating but not so in industry (Naturvårdsverket 2004). In 2014, the carbon tax generated 23,3 billion SEK (€2,5 billion).

Relating to the role of TGC for the heat production, several studies have addressed the issue of policy instruments affecting the energy sector in Sweden. Bergek and

Jacobsson (2010) concluded that while the TGC system has been efficient in promoting early increases in renewable energy, it does not drive longer term learning and technological change and it has led to significant rents to already profitable solutions for established actors. A study on TGC and on the EU's emission trading system (ETS) showed that the two trading schemes significantly increase the profitability of investments in new CHP plants in the Swedish DH sector. It was also shown that investments in such plants would lead to great increase in power generation and decrease in CO_2 emissions (Knutsson et al 2006).

The public debate and opinion on energy in Sweden leans towards strong support for mitigation measures. However, for heat, there is concern on waste import-lock-in and long-term implications of waste incineration. The fear is that increased waste incineration and the expansion of CHP plants will lock-in the heat system to less productive technologies and waste dependence.

In terms of the role of research and development in maintaining regime stability Sweden has had a long experinece of research regarding DH systems. This reseaerch became institutionalised 2006, when the SEA together with the Swedish District Heating Association, initiatied a multidisciplinary research program aimed at solving problems and promoting future competitiveness for DH and cooling is jointly funded. The 'Fjärrsyn' programme[4], which is currently in its second funding phase, is being organised in three areas: 'system development', 'effects and adaptation to new policy and world changes', and 'collaboration for sustainable development' (Fjärrsyn, 2013).

4.2.2. Heat pumps

As the HP market grew in the 1980s the number of actors increased; relevant actors included 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 HP technology. Another important actor is the Swedish Heat Pump Association (SVEP), which represents the majority of manufacturers, retailers and other companies associated to HPs. Furthermore, the International Energy Agency's (IEA) Heat Pump Centre, based in the Swedish city Borås is another sign of the succesful development of HPs in Sweden.

Boverket is also a key actor through its Energy Performance Certificate, and the 'Planning and Building Act' (2010:900). Installation of geothermal HPs must be reported to the municipality environmental and construction committee or the planning office before installation. In some cases, licenses are also required to install the bedrock or water HPs, in accordance with the environmental code. If installation will be carried out will depend on factors such as how densely populated the area is, how many HPs that are already installed, and if drilling is planned to take place within a water protection area. Various obstacles for installations can be lack of space,

[4] http://www.svenskfjarrvarme.se/Fjarrsyn/

infrastructural obstacles under the ground in the form of tunnels, sewage systems, DH pipes, or other culverts. Moreover, in areas with DH systems available it is rarely profitable to convert to HPs. Another obstacle has also been that some municipalities can deny geothermal HPs, reasoning that the geothermal heat is less environmentally friendly than DH. This is, however, sensitive in cases where the municipality is the DH provider and can end up in a conflict of interest (SEA 2015).

In general, HPs and DH are not primarily competitors but complement each other in the heat generation regime. In many cases, combining the two technologies in different ways, for example by adding in a HP to recover energy from the exhaust air in a DH heated house, or by producing heat for DH system with HP to take advantage of low temperature heat from e.g waste water or geothermal heat. Moreover, inside the cities there are usually limited opportunities to drill geothermal wells due to lack of space making DH more suitable than HP. In areas with sparse heating demand and in rural areas it is not always economically justifiable to draw up a DH network.

However, as already mentioned, HPs have recently been facing increased competition from DH due to the saturation of its traditional market segment. This has motivated DH companies to engage more actively in the HP dominated single-dwellings sector (Sköldberg et al. 2011). Conversely, the HP market is becoming saturated in the single-dwelling sector; the expansion is looking towards larger cities and multi-dwellings. This development has made HPs a competitive alternative to DH (Sköldberg at al. 2011), and created conflicts with the DH providers who are arguing that DH is at a legislative disadvantage to HP (Jarlfelt 2014). HPs are expected to take market shares from DH, but according to SEA (2012a) eventually a balance will occur between the two heating systems. The saturation has also led manufacturers towards looking for new markets in Europe (TPA Forum 2012).

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. In the early 1990s, as a result of increasing concerns about environmental pollution as well as strong lobbying from the HP 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 International Energy Agency research may have also played an important role for international learning and spillovers. 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, and in the decade that followed (1996 to

2006) the number of installations of HPs increased at an average rate of 35% per year (Kiss et al. 2012). 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 HPs 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).

5. Developments in the housing regime

5.1 Tangible system elements for the housing regime

Whilst the supply side of the domestic heating system fulfils the function of heating homes, on the demand side the main function can be seen as maintaining a given level of thermal comfort. The main technical elements relate to thermal specifications (e.g. insulation and ventilation) and thus relate mainly to the building envelope, energy input and the behaviour of property owners and tenants (Figure 10). The Swedish residential housing regime consists of single-dwellings and multi-dwellings. There are various forms of ownership. For single-dwellings, the main form is direct ownership[5]. For multi-dwellings, these are either rented or collectively owned through associations. In total, there are 2,5 million multi-dwellings and 2 million single-dwellings in Sweden. In terms of temporal development, the building stock has remained relatively constant except for privately owned multi-dwellings, which have increased with 35% over 20 years (Figure 10).

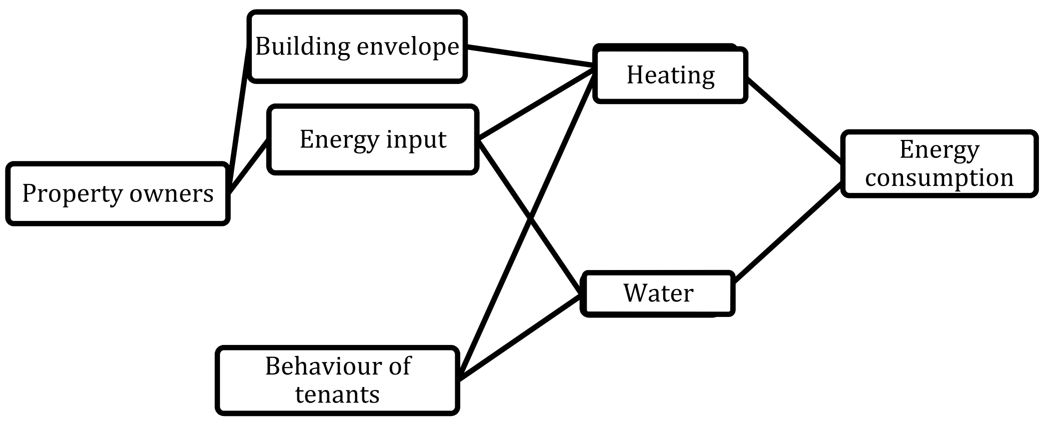

Figure 10 What and who affects the energy consumption for heat and water

[5] Marked as 'S-D Ownership – single' in Figure 11

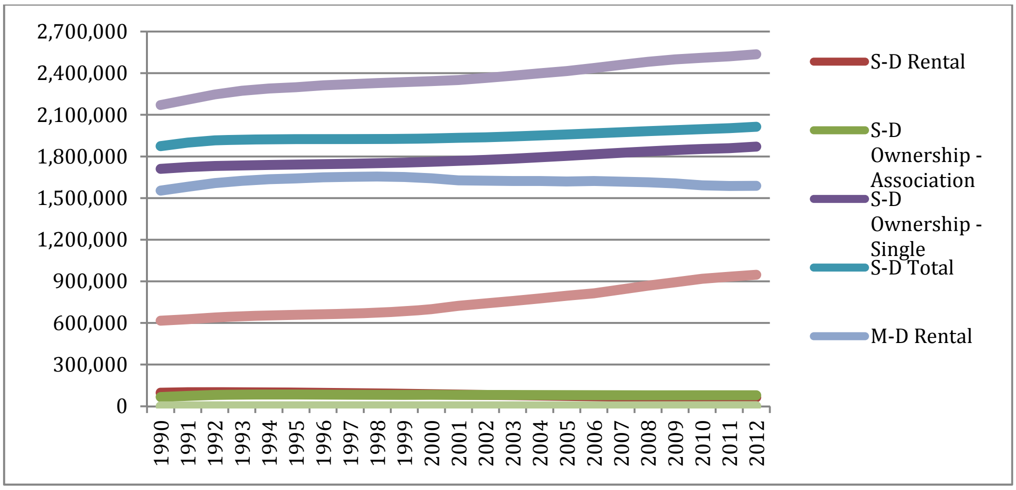

Figure 11 The Swedish building stock, number of dwellings – single-dwellings (S-D) and multi-dwellings (M-D) (Source: Statistics Sweden www.scb.se)

The key actors in the Swedish housing regime are individual building contractors, ownership and rental associations, the Swedish homeowners association, and the municipalities commissioning new public housing, the SEA and Boverket.

5.2 Intangible system elements for the housing regime

Energy for heating, cooling, operation and lighting in buildings represents almost 40% of Sweden's total energy. In the multi-dwelling unit sector tangible opportunities exist to save energy if energy efficiency improvements are included in future renovations. Many of the buildings constructed before 1975 will need to be renovated before 2050. For single-dwellings, there are many more owners than in multi-dwellings, which means more decision-makers. House owners also have fewer resources and less information at their disposal to take a systematic approach to energy efficiency compared to professional owners (IVA, 2012a).

Regarding the multi-dwelling segment, it is important to consider that multi-dwellings from the so-called "Million Programme", from 1965 to 1975 are in great need of renovation (SABO 2009). An estimated three times more apartments will be renovated by 2050 than what will be built, which means that approximately 600 000 to 700 000 new apartments will be built and about 1.5-2 million apartments renovated. The efficiency measures alone can not bear all the renovation costs, which requires other reasons to renovate (IVA 2012b). In connection with the necessary renovations carried out, an explicit focus on increasing the energy efficiency of these properties is thus needed. The energy savings that can be made are dependant on the condition of the property. However, it is unclear who should pay for the needed renovations is in the current situation. Notwithstanding this, future renovations in DHs largest market segment risks eroding the growth potential for DH (Lygnerud 2011) and can potentially act destabilizing for the heat generation regime.

The low-energy passive housing is a niche in the housing regime. It is achieved by the aggregated effect of applying a number of well-known technologies, including including extra thick layers of insulation, low U-value windows, and airtight building techniques that enables efficient ventilation techniques using heat regeneration. The progress on passive house and low energy buildings is rather limited. The first set of passive houses in Sweden was constructed in 2001, over 10 years after first demonstrations in early adopter countries, such as Denmark (Janson 2010). Since late 2000 there has been some progress, albeit from a very low level (Figure 12), and the past 10 years have very much been an early experimentation phase. 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 0.04%.

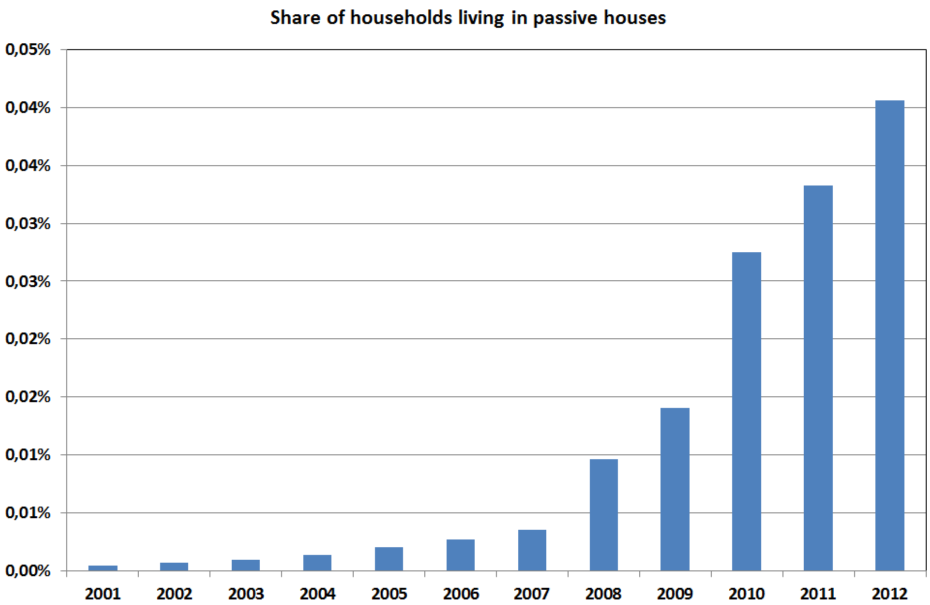

Figure 12 Share of households living in passive houses or apartments. (Data source, Svensson, 2012).

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 the building process and suppliers to use new materials and components used in low energy houses. This 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 the few entrepreneurs specialised in these technologies. Regime actors such as larger buildings contractors are strongly opposing stricter building standards.

On the consumer side, 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. This is significantly higher than other European countries, e.g., the UK with averages below 20 ºC. Climatic and cultural difference explains the higher indoor temperatures and there are also problems with too cold indoor climate. Studies in the UK have found that indoor related deaths increase for each degree below 20ºC 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 23ºC (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 20ºC 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.). For multi-dwellings, however, indoor temperature is usually controlled centrally, which means that individual apartments do not have full control of their own indoor heating. In other words, for a multi-dwelling to lower temperature, the whole association must jointly agree terms.

Households living in single-dwellings have to a greater extent adopted a lower indoor temperature than households living in apartments. Since the oil crisis in the middle of the 1970s there have been repeated information campaigns addressing house-owners about the importance of lowering indoor temperature in order to decrease energy use. Households living in detached houses have a direct feedback on their energy use for heating as they pay their heating costs directly to the energy supplier, while households living in dwellings in multi-occupancy blocks normally have their heating included in a monthly rent (Lindén et al. 2006).

Another consumer/household-focused niche intervention is individual metering and billing (IMB) of heat and water. Calculated savings potential is approximated to 10-20% reductions for heat and 15-30% for hot water (Svensson 2012; Boverket 2008). 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 housing is for heat demand to be included in rent, creating the same situation as for indoor temperature above where the building management company is the agent rather than the tenant. Moreover, 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 residents (Boverket 2008). This has however been opposed by the main incumbent actors, including 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).

In summary, the housing regime has a very stable development with regard to consumer preferences of indoor temperature, the technologies use, and policymaking. There are few threats to the current configuration of rather high in-door temperatures, and few destabilizing pressures attributable to consumers. A potential regime-destabiliser may come from the EU Directive on Energy Performance of Buildings (2010/31/EU), which specifies that states shall encourage the introduction of intelligent metering systems. However, protests from the incumbent actors, i.e. the rental and ownership associations, as well as the construction industry, in Sweden 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).

Regarding policy and governance of energy use in buildings, the key piece of legislation is the buildings code and its requirements on energy efficiency, which is supported by the EU Directive (2002/91/EC) on the Energy Performance of Buildings. As part of efforts to achieve climate targets the European Parliament agreed in 2009 a new version of the directive (2010/31/EU) which states that all the houses from the end of 2020 should be "near-zero energy buildings". The Directive also specifies that the low amount of energy that needs to be supplied building should largely consist of energy from renewable sources and from sources on site or nearby the building. The directive comes into force in 2020 for new buildings and 2018 for public buildings. It is recommended, however, that 30% of all new buildings should consist of near-zero energy buildings from the year 2015. The Directive requires regulations on both maximum permitted energy input and maximum installed effect (SEA 2015).

In Sweden, the previous target was a 50% reduction in energy use in building by 2050. However, new suggested standards are still under evaluation with the latest review of these being assessed, to be presented in June 2015. 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 (SEA 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 on-going, governance processes are primarily concerned with implementation of EU directives. There are hence only incremental changes in energy efficiency requirements, toward implementing the directive.

There has, however, been some recent revisions of the building code, which has given to certain extent an advantage to HPs over alternative heat systems, such as DH and pellets, since larger amount of energy for heating is permitted with HP. As the regulation 'border' is drawn by the house walls, the assessment criteria becomes slightly skewed seen from a system perspective. For example, if a HP is placed within the DH system (ie outside the building), its part of the energy supplied to the house is accounted for. But if the pump is located inside the house only the electricity supplied to the HP is counted as energy input, and not the savings from the HP. When the system boundary is drawn at the house waste heat, for example, is counted as purchased energy. Also, releasing free heat from the chimney instead of using it for heating is a waste of energy and is not taken into account (SEA 2015).

Reduction in energy use in homes is included as part of the 20% target for energy efficiency improvements by 2020. Today's building regulations are based on energy purchased for the property and not on how much energy the building needs for heating and operation. This means that the (previous) target of 50% reduction in energy use in buildings can be achieved either through various measures in the houses, for example, additional insulation and optimization, to reduce the building's need of energy purchased or by installing HPs and solar panels to reduce the amount of purchased energy. Calculations from the ÅF Consulting Group show that the cost of achieving this goal is significantly lower when using HPs (Byman and Jernelius 2012). ÅF's report estimates that it can be up to 2,5 times[6] more expensive to halve

[6] Assuming the energy efficiency measures in buildings are implemented in conjunction with other renovation of the property and to an interest rate for discounting purposes of 2 per cent is used.

the energy consumption of buildings with energy efficiency measures in the building envelope, compared with installing HPs. At the same time the increased use of HPs puts greater demands on the production and transmission capacity in the grids which is also a factor to consider (SEA 2015).

HPs are not only being preferred in policy, but also in the public debate and opinion. After a long and steady upward trend for DH, we can begin to see a trend where more and more property owners are buying their own energy production, even where DH is available. The most common alternative is the GSHP. One reason for the shift in trend is that many customers feel they are in a weak position vis-à-vis the DH supplier as there is no opportunity to influence or bargain on the price. Confidence is low for the the suppliers that have a monopoly on the market. By investing in alternative energy systems, property owners reduce the risk of future price increases whilst being in control of their own energy (Byman and Jernelius 2012). Moreover, a few flagship projects, mainly the New Karolinska hospital in Stockolm[7], has opted for HPs over DH, which has created a debat around the monopolisation of DH.

Another recent trend in the public opinion debate has been focusing on the role of Energy Performance Contracting (EPC) in reducing energy use in the building stock, mainly the public sector. 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 few academic studies on its effect 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, 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).

Conversely, there is very little pressure from civil society to increase the reduction of energy use in buildings. A few vociferous NGOs have argued for a 50% reduction already by 2030 rather than 2050 (Naturskyddsföreningen 2008), but in general there is little opposition from civil society on the current housing regime.

6. Summary – stability, cracks and tensions in the Swedish heat domain

Existing dominant systems and regimes are stabilised in many ways on different dimensions, e.g. stabilising landscape developments and undeveloped niche innovations. This stabilisation helps explain why transitions often come about slowly, and why green niche-innovations face many barriers. Nevertheless, tensions and cracks may arise with systems and regimes, which create windows of opportunity for transitions. On the one hand, regimes have internal coherence, shared rules, and similarity, but on the other hand they may contain variety, disagreement on specific

[7] http://www.energi-miljo.se/artikelem/lagrad-energi-kyler-och-varmer-karolinska/

issues, contentious debate, and internal conflicts. Such a conceptualization would make the strength, homogeneity and internal alignment of regimes an empirical question rather than an assumption.

The stability of existing regimes may weaken if problems and stresses appear within the socio-technical system, leading to cracks and tensions between the actors involved. These problems and stresses may arise from external pressures, e.g. from exogenous landscape developments or from 'below', i.e. consumers, social movements, NGOs or academia drawing attention to negative externalities, and/or internal problems.

In this report, we have assessed two separate, but inter-connected, regimes, the heat generation regime and the housing regime. We have analysed the tangible and intangible aspects of the socio-technical system in order to assess the degree of stability and path dependence of the regimes; specifically by evaluating the stabilising forces that contribute to regime lock-in and the cracks, tensions and problems that have the potential to destabilise the regime and make way for alternatives. The work is summarised in table 1 and table 2.

6.1 Heat generation regime

The Swedish heat generation regime has shown remarkable stability in terms of the long-term domination of DH. In the regime's establishment, DH is facing market saturation and there are several policy challenges from both future energy efficiency measures and climate change, which will both lead to less demand for heating. DH is almost exclusively in multi-dwellings but the market is becoming saturated leaving little room for expansion. The system is experiencing difficulties through stagnation and competition from other sources, such as HPs, particularly in the one- and two-dwelling buildings sector. However, notwithstanding the recent development, there are few signs indicating that HPs might disrupt the DH dominance in the long-term.

The strong development of DH was made possible by strong public support during its early phases. However, much has changed since and a gradual transition towards more liberalised planning and energy systems has led to a weakened planning monopoly for municipalities and more liberal political and economic ideas are being implemented. The issue of TPA has led to two national inquiries (SOU, 2005, 2011), and finally to proposed changes in the District Heating Act (2008:263) that will allow TPA under certain circumstances (MoEEC, 2014; Swedish Energy Market Inspectorate, 2013). Regarding the future development of DH, although the market is becoming saturated, new waste-burning CHP plants are still being built. This has led to a debate about overcapacity, 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). Conversely, The EU directives and the government's climate bill will decrease heat demand through efficiency measures, as well as demand for less waste, which powers a large part of Swedish CHP plants, and thus risks destabilising the regime.

But there are also strong stabilising forces strenghtening the regime. TGC and the Carbon-tax are beneficial to both DH and cogeneration through CHP plants. Moreover, the pressure from HPs has so far mainly complemented DH by increasing its share in single-dwellings rather than multi-dwelings and strenghtened the current regime rather than being in direct competition. This is somewhat starting to change and there is more direct competition, which may destabilise the regime in the long-run. Additionally, the legislation and policy premiering HPs over DH might also destabilise the regime.

On the other hand, an indication of future regime stability can be found in a Danish study, which analysed the role of DH in a future 100% renewable energy system. It found that the best solution to complement DH is with HP (Lund et al., 2010; 2014). 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, 2012a; Johansson et al., 2011) and solar thermal energy combined with DH.

Lastly, and perhaps surprisingly, is that there is very little opposition from civil society and academia towards the current regime.

Table 1 Heat Generation - Supply

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	- Energy (oil) independence - Societal values on climate change and sustainable development - Natural monopoly of DH	- Climate change (warmer temperatures equals lower demand) - EU policy directives (energy efficiency and waste)
Industry	STRONG - Sunk investments in DH infrastructure – pipes, plants (centralised power generation) - Natural monopoly of DH - High investment costs for HPs - High level of renewable energy in system and low amount of CO_2 in electricity generation - Interconnectedness between HP and DH - Strong trade associations - Large forestry sector means easy access to biofuels for DH	MODERATE - Stagnation and saturation in the heat domain - Increased competition between DH and HP - Waste incineration lock-in - Increased import of waste - TPA for DH
Consumers/ households	STRONG - Sweden has a high demand for heating - Generally low interest in heating from consumers and households - Natural monopoly of DH - High investment costs for HP	WEAK/NON-EXISTING - No tensions. Very stable regime dynamics from consumer side
Policy/gover-nance	MODERATE - Public sector own the majority of DH companies - Historically strong policy support for HP - TGC premiers DH (through CHP) over other less developed	MODERATE - New legislation for TPA might threaten DH dominance. - Current political attention on nuclear energy might affect electricity prices and future HP sales.

	renewable energy sources	
Public debate and opinion	STRONG - Strong support of carbon-tax - Strong support of renewable energy - 70-80% of heat is renewable, which leads to little contention in the public opinion towards the current regime.	MODERATE - Negative opinion about long-term dependence on waste import and waste incineration
Pressure from civil society and academia	STONG - Sweden is a world leader in both DH and HP, which have a strong support from academia through research programmes – supported by the government together with the trade associations – which are contributing to the lock-in of the regime	- NON-EXISTING
Overall assessment	STRONG - The heat domain is more or less fully renewable. DH and HP have in the past decades formed the new regime and the stabilizing forces are strong	MODERATE - Most interesting cracks and tensions are with the new interactions between DH and HP, and for the processes opening up DH for competition.

6.2 Housing regime

The housing regime is characterised by two main findings. First, the lack of interest on low energy buildings by the incumbent actors; and second, by the renovation need of the housing stock, mainly the million programme multi-dwellings.

The first point can be mainly attributed to the heat generation regime and the fact that the heat domain is more or less fully renewable, which means there is little necessity for the industry to act. In general, there is much more focus on the supply side than on the demand side. Even on the consumption side, there are few incentives. IMB, for example, is included in the rent for multi-dwellings and indoor temperatures are difficult to lower because of the collective heat control, which give residents little individual control. Moreover, there is little opposition from both public debate and opinion and the civil society on stronger action on energy efficiency and low energy buildings.

Regarding the second point, the renovation need and the EU Directives on energy efficiency and energy performance of buildings will put pressure on the regime in the future. Furthermore, the changes in the building code, which give preference to HP over DH and other supply sources, might create cracks and tensions on both the building regime, as well as the heat generation and the electricity regime.

Table 2 - Building stock - Demand

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	- Collective societal values explain culture of leaving limited control over heat to residents.	- Very limited
Industry	STRONG - 70-80% of heat is renewable, limited pressure on industry to further change practices - Low interest from industry towards low-energy buildings and passive houses	NON-EXISTING
Consumers/ households	STRONG - Single-dwellings – Residents rarely move, which encourages large investments in e.g. HP. - Multi-dwellings – Heat is usually incorporated in the rent and, thus, is not usually controversial or something on which users have capacity to act - Stable culture of high indoor temperatures.	WEAK - Smart-meters could decrease the demand for heating, but very few signs that this put any substantial pressure on the regime
Policy/gover-nance	MODERATE - Very few polices and governance arrangement that influence heat consumption. Some information campaigns on energy savings. - Some norms from health policy makers on indoor temperature makes lower indoor temperature in multi-dwelling hosing difficult to implement.	MODERATE - Policy on additional energy efficiency measures, such as lower limitations on energy use /m2 in buildings and stronger regulation on passive houses, might contribute to destabilise the regime. - The building code gives preference to HP over DH and other heating systems
Public debate and opinion	STONG - 70-80% of heat is renewable, which leads to little contention. - Little interest in demand-side actions for heat reduction	MODERATE - Public opinion against the higher costs (due to the natural monopoly) for connecting a building to the DH infrastructure. - Flagship constructions (such as the New Karolinska Hospital) opting for HP over DH. - Some debate on energy efficiency measures, through Energy Performance Contracting
Pressure from civil society and academia	WEAK - Few campaigns from NGOs on reduced heat use.	NON-EXISTING
Overall assessment	MODERATE/STRONG - General low interest in heat demand side from many actors as system has high share of renewables, and the regime is stable. Stabilising forces that limit low energy buildings, maintains regime stability with regard to high heat demand focus.	WEAK - Very limited cracks and tensions in the buildings regime due to high degree of renewable energy. Some tensions on renovation of housing and energy efficiency, else the tensions that exist are rather related to the implementation of the two dominating supply technologies DH and HP.

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