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Exploring transition pathways to sustainable, low carbon societies

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Country report 3: The Swedish heat system

Adis Dzebo and Björn Nykvist
Stockholm Environment Institute

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Executive Summary

Our Swedish heat energy domain case is one of few examples in the PATHWAYS project that shows radical system change over time where new niches have broken through and established themselves as new regimes. This development has been achieved with a combination of niche innovations and changes in old regimes. Importantly, the critical change of fuel in the District Heating (DH) regime was instrumental for the low carbon development of the system. This was a PATHWAY A change, resulting from concerted policy action that empowered new innovations, and spurred the de-alignment of existing technology solutions in the old oil-dominated regime. That is, change in the DH system has been rather narrow in a sub-set of system dimensions, most importantly switching fuels with minor adjustments in boiler technology, and some incorporation of innovations developed in niches. But clearly, change in the system has been aligned and symbiotic within the existing regime. Likewise, while Heat Pump (HP) was originally a niche application, the reason behind its success has deep connections to other characteristics of our heat regime. It was aligned with the electricity regime (Air-to air HP), and, in the case of water radiator systems, aligned with that existing infrastructure in houses (ground source HP). Again, the incumbent regimes cannot be argued to have become substantially undermined and the dominating transition pathway pattern is one of symbiotic adoption of niche-innovations. But it is important to note that the net outcome has nonetheless been a rapid de-carbonization of the heat energy system. Despite the old regime's reliance on fossil fuels, the past regime orientation was favourable to the transition. Reducing dependence on oil imports, securing supply, and early political commitments to tackle climate change was synergistic and oriented the regime toward solving the larger low carbon problem (Table 1). Finally, the success was inherently dependent on the high share of renewable energy in the power system and gradual phase-out of fossil fuels in the DH system.

In contrast to this, several of the niche innovations characterised as PATHWAY B type that require more significant system change along several dimensions meet heavy opposition unless they become aligned with existing regimes (Table 1). This clearly shows how inherently inert the Swedish heat domain system is, and that the way forward – based on the experiences of one of the few successful national cases in Europe – is that governance interventions need to consider system change, focusing on landscape pressures and regime dynamics, not only on niche innovations.

The current Swedish heat regime faces strong support from both policy and the civil society and is largely oriented toward solving environmental problems. Future goals of energy efficiency and material re-use rather than waste incineration are, however, new challenges where the current HP and DH dominated regimes are to

some degree less well aligned to new environmental concerns and both regimes are part of the supply focused heat energy system in Sweden (Table 2).

Niche-innovation	**Internal momentum**	**Strong or weak alignment with broader regime characteristics and developments**	**Likelihood of imminent breakthrough (and/or future potential)**	**Pathway A or B (or mixed)**
Heat Pumps	Moderate	Well aligned, following "Transformation pathway" of symbiotic niche.-innovation and "De-alignment and Re-alignment"	Broken through, final phase four	Pathway A
District heating	Low	Perfectly aligned, is the regime, and developed in harmony with expanding society and need for energy	Phase four	Pathway B originally, but pathway A in terms of low carbon developments past 20-30 years
Waste heat recovery	Low	Perfectly aligned with the DH regime, again a transformation pathway of symbiotic niche-innovation	Phase two	Pathway A
Individual metering and billing	Very Low	Very limited alignment with regime and low niche protection.	Phase one, predevelopment	Primarily pathway A (Behavioural change, yes, but no fundamental change in several types of variables, no new technology needed)
Small-scale biomass	Low	Well aligned, technological substitution, but with few or none system changes	Phase two	Pathway A
Low energy housing	Very Low	Very high resistance from the regime	Phase one	Pathway B

Table 1: Breakthrough analysis of niche-innovations in the Heat domain in Sweden

	Lock-in, stabilizing forces	**Cracks, tensions, problems in regime**	**Orientation towards environmental problems**	**Main socio-technical regime problems**
Regime DH	Strong, natural monopoly	Moderate	Both High (GHG emissions reductions) and Weak (Waste incineration lock-in)	Overcapacity limits focus on Heat energy efficiency
Regime HP	Moderate (rather fluid between different types of HP solutions)	Low	High	None.

Table 2: Assessment of regime trends in the Heat domain in Sweden

1. Introduction

This report contributes to deliverable D2.3 and assesses the present feasibility of transitions by focusing on two tasks:

1. Is the analyses of recent developments in green niche-innovations (D2.1) and regime (in)stability (D2.2) suggesting that a transition is beginning to take place? If so, does this transition look more like pathway A or pathway B?
2. If niche-innovations are *not* about to break through more widely, then make an assessment of dominant system/regime trends in your domain/country (based on D2.2): a) are these trends continuing as Business as Usual, with limited regime change to address environmental problems, or, b) are existing regime actors implementing incremental changes to address environmental problems.

To assess if a transition is beginning to take place, we will draw on our earlier assessments of momentum in D2.1, but make the discussion on transition phases and alignment with the regime more explicit. We provide summaries of each niche and make an assessment of whether niche-innovations have entered the breakthrough phase. We also reflect on what type of pathways (A or B) the niche is associated with. Finally, to discuss the alignment with the regime, we also make some remarks on the development based on literature on different pathways typologies (Geels and Schot 2007) and patterns of niche protection (Smith and Raven, 2012).

Since the Swedish case shows quite some success, where niches have been established as new regimes or have transformed regimes in the past, we provide a common discussion at the end on the more mature phases of past and ongoing transitions. Focusing on this lead towards a discussion of what type of transition pathways and the steering of these that have been represented in the successful heat energy transition in Sweden.

In summary, this report will show that the transformation in the Swedish heat energy domain is both due to niche breakthrough through the establishment of new technology and actors around the Heat Pump (HP) niche but also significant regime adaptation that can be described mainly as following a transition pathway (Geels and Schot 2007) where the process of niche protection is mostly "fit and conform" (Smith and Raven 2012). This is the case both because the already established regime of District Heating (DH) was instrumental in transitioning from high oil dependence to a more or less fully renewable low carbon system, and because the HP niche is well aligned with the electricity for heat regime. The regimes developed and adopted symbiotic niche-innovation under landscape pressures, most prominently the oil crisis and a changing discourse on climate change. We conclude with some reflections on the Swedish case for the steering of transitions in systems with particularly strong inertia due to long-lived infrastructure.

The rest of the report is structured as follows. In section 2 we revisit our 6 niches from report 2.1 and develop more refined descriptions of what stage of transition each niche is in. Section 3 discusses the degree of regime adaptation and reorientation and, finally, Section 4 draws conclusions on what type of transition pathway (A or B) has been most important for explaining the success in Sweden. We also reflect on this given the literature on transition pathways.

2. Assessment of breakthrough for each niche

2.1 Heat pumps

2.1.1. Internal momentum

HPs are reliable, efficient and affordable, and can add to comfort and building quality by providing heating, cooling and sanitary hot water. According to the Swedish Heat Pump Association (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).

The current momentum for HPs is moderate. The HP market is becoming saturated in the Swedish small housing market, and the expansion is looking towards larger cities and multi-dwelling buildings, where DH is dominant. Heat pumps are expected to take market shares from DH, but according to SEA (2012), a balance will eventually occur between the two heating systems. The saturation in the single-dwellings has also led manufacturers to look for new markets in Europe and globally (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 belongs to Pathway A.

2.1.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

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. Until the mid-2000s, ground source heat pumps (GSHP) 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-air HPs has increased rapidly, and in 2008 they consisted of more than 60% of total sales. The reason for this development 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).

b) Changes in policy and institutional frameworks

An important factor for the successful development of HPs is the Swedish low-carbon policy, which started in the early 1990s following the introduction of the carbon tax. Concerns about environmental pollution alongside strong lobbying from advocacy coalitions, 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. The Swedish Energy Agency (SEA) and the Swedish National Board of Housing, Building and Planning Boverket has had a big role in supporting this development. 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 successful development of HPs in Sweden.

c) Changes in public discourse and support

Mahapatra and Gustavsson (2009) study on GSHPs in residential heating systems found that HPs 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. Another study from the ÅF Consulting Group ÅF's report estimated that it can be up to 2,5 times[1] more expensive to halve the energy consumption of buildings with energy efficiency measures in the building envelope, compared with installing HPs (Byman and Jernelius 2012).

Studies such as these have led to HPs being preferred in policy and in the public debate and opinion. The trend is that more and more property owners are buying their own energy production, even where alternatives such as DH are available. 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 in the suppliers who have a monopoly on the market. By

[1] 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.

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). This development has also been helped by a few flagship projects, mainly the New Karolinska hospital in Stockholm[2], which has opted for HPs over DH.

2.1.3. Is the niche-innovation about to breakthrough?

HPs have made a successful transition from being a niche to becoming a part of the regime. The niche has broken through but not replaced the existing regime. Instead, it placed itself alongside DH as complementary and is, to an extent, also integrated into the existing DH regime. HP is simply a modification or and improvement of the previous dominant source in the single-dwelling housing regime, direct electricity in resistive radiators. HP are stabilised in the new system and are, thus, in phase four development stage. This process is in line with the "transformation pathway" of Geels and Schot (2007). But the transformation also has some elements of De-Alignment and re-alignment (ibid), as there has been a flora of variants of HP technologies developed. HPs are now in a phase of market saturation where some options, such as air-to-air HP, are being established as the dominating HP technology, in particular for new houses.

2.2 District Heating

2.2.1. Internal momentum

DH is a large system in Sweden and the dominant heat energy source in the regime. Today, almost 50% of the generated heat in properties is delivered by DH. A comparative number for the EU is 10%. 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 single-dwelling sector. The successful development of DH was made possible by the strong public support during its early phases and until the deregulation of the market 1950-1990. 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 politic economic ideas are being implemented. Today, the market is becoming saturated, but the new waste-burning Combined Heat and Power (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 by 2020 (Avfall Sverige 2009). Additionally, the unregulated pricing in natural monopolies is leading to higher prices (Magnusson 2013). The proposed changes for third party access (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.

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

In terms of pathways, DH belongs to Pathway B, meaning a broader regime transformation. From the 1960s 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.

2.2.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

The nature of the DH system with hot water production with associated culvert system of distribution need to be considered as vertically integrated units, meaning that DH companies are controlling the supply chain. The business of distribution of hot water for DH 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.

In terms of price development, an important price factor has been the 1996 deregulation of the energy market. As a consequence, 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 (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. In 2010, the DH turnover was 33 billion SEK (3,64 billion €).

b) Changes in policy and institutional frameworks

DH system development took off and grew exponentially from 10 TWH in 1973 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). This process was supported through public funding, as most energy companies were municipal. 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).

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.

c) Changes in public discourse and support

The DH system in Sweden is relatively uncontroversial and recognizes wide support. 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. Moreover, there has 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).

2.2.3. Is the niche-innovation about to breakthrough?

DH has been the dominant heat energy source since the 1970s and is thus part of the regime. 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.

The process from niche to regime started with the need for new electricity generation through cogeneration of heat and electricity in CHP plants. The second phase is related to the million programme. But DH was also formed by a process of novel installations and joining existing small-scale neighbourhood systems. The infrastructure grew in the expanding Swedish housing sector and thus to some extent never represented a niche overtaking an existing regime. The third phase was initiated with the need for replacement of oil as a consequence 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. In terms of sustainability transition pathways the final two phases are most crucial and the fuel switching in the DH system can be describe as following a "transformation pathway" (Geels and Schot, 2007) where niche innovations symbiotic with the regime are adopted but with limited fundamental change of the regime. The system remained the same, but biofuels technology, an already well established parallel regime in small scale housing were refined and adopted in the DH system. Today, the natural monopoly of DH infrastructure is a strong stabilising mechanism for the heat generation regime. DH is the most significant part of the heat energy regime and is, thus, in phase four.

2.3. Waste heat recovery

2.3.1. Internal momentum

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. A lack of business opportunity is an important barrier 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. Currently, there is a lack of institutional and financial support from the government and municipalities, albeit a recent change in legislation for increase third party access (TPA) and the implementation of the EU energy efficiency directive has started a change process.

Even though waste heat gathers new actors to 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. Together with rather slow development in new projects the overall momentum is now low.

2.3.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

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). A successful initiative is very dependent on the financial aspects, particularly for the industry, which generally have higher required rates of return than public DH companies. In terms of contract agreements, most initiatives are bilateral agreements between the industry and the DH companies. In Sweden, 90% of the waste heat comes from the energy-intensive industries. However, less is known of the potential in, for instance, the food industry or 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/).

b) Changes in policy and institutional frameworks

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). 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 (Naturvårdsverket 2005). The public investment support initiatives are no longer available.

Another barrier for increased use of waste heat is the increasing application of biomass-fired 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). This example highlights both the maturity and diversity of the heat regime as well as its interconnections to the electricity regime.

Many DH providers have been reluctant in allowing network access to other parties. This has led the Swedish government to finalise a bill that regulates Third Party Access (TPA) to the DH networks, leading to changes in the District Heating Act (2008:263) that will allow TPA under certain circumstances (MoEEC, 2014). 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).

c) Changes in public discourse and support

In general, the public debate around waste heat is positive and receives support from both the public and the media. It is seen as a sustainable way to ever further decrease the environmental impact from the heat energy regime.

2.3.3. Is the niche-innovation about to breakthrough?

Waste heat as a niche-innovation is fully dependant on DH. However, as Sweden is a world leader in this area, it could be argued that waste heat has been a success, which can be further increased. 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. Waste heat is also discussed as an important component in the Swedish implementation of the EU energy efficiency directive.

However, currently there is a lack of institutional and financial support from the government and municipalities. Waste heat is in an early market niche (phase two) with growth potential. Notwithstanding, there is no possibility to replace DH (or any other existing technology) and it will not bring any broader regime transformations. Instead this is a concrete example of how a series of adoptions of symbiotic niche-innovations in to the DH regime in line with a "Transformation pathway" according to Geels and Schot (2007).

2.4. Individual metering and billing (IMB)

2.4.1. Internal momentum

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 and so is its momentum. 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 multi-dwelling 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, i.e. DH, 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).

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.

2.4.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

IMB is 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).

b) Changes in policy and institutional frameworks

The 2008 Swedish Energy Efficiency Inquiry (SOU 2008:110) and Boverket 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. However, strong protests from opponents 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).

c) Changes in public discourse and support
Suppliers of products and services for IMB 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. 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). The opposing actors are, however, not opponents of IMB. They are rather opposing legislation and compulsory installations of IMB systems.

Another issue working against IMB is the culture of high indoor temperatures in Sweden, which are is significantly higher than other European countries. 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 in the middle of this range. Nonetheless lowering indoor temperature represents the largest single savings potential in the buildings sector (Mata et al. 2013).

2.4.3. Is the niche-innovation about to breakthrough?
IMB is still in the predevelopment phase where various options are competing and actors are either opposing or not interested. The current regime is strongly focused on heat production and supply and not so much on demand-side initiatives/niches such as IMB. For this reason it is not expected that IMB will reach even the second phase as an early market niche. In terms of the possible pathways typology, despite IMB requiring behavioral change we think this is more represent of incremental change in existing structure of Pathway A type. There is no fundamental change in several variables and - using Geels and Schot's terminology (2007) - the system is not even transforming but in a "reproduction process" with very low niche protection.

2.5. Small-scale biomass – Pellet boiler systems

2.5.1. Internal momentum
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 bandwagon effects, and few controversies. Some hype decline due to short-term polices in past

10 years, but still with a stable market share. Additional growth is in clear competition with heat-pumps to replace direct heating from electricity.

2.5.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

Small-scale biomass is since long an important option for heating for single dwelling buildings. 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; SEA 2013). As such, small-scale biomass use is an established fuel option and historical regime but with low total market share today. However, pellet boiler technology, today the dominant biomass energy source, is somewhat more expensive than the more dominant HPs. And this is notwithstanding the unfavourable fact that pellet fuel is being exempted from energy and CO_2-taxes that are applied to electrically driven HPs.

b) Changes in policy and institutional frameworks

Modern 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 DH. Development of small-scale burners came first later and was not led 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 DH plants with co-generation of electricity and heat converted their oil boilers to pellet use. 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 national standards were in place and sales reached 10000 units annually by 2001 (Mahapatra and Gustavsson 2008).

The rapid expansion and peak in number of units delivered in 2005-2006 is explained by a temporal investment support from the government 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. The resulting jerkiness in the market as a result of these polices has been heavily criticized by the Swedish Heating Boilers and Burners Association (SBBA) association of manufactures.

c) Changes in public discourse and support

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 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.

2.5.3. Is the niche-innovation about to breakthrough?

Pellet boiler technology successfully passed the first stage of predevelopment with help from research and development for more large-scale biomass technologies. It is worth noting that it benefitted strongly from the existing DH dominated regime as pellet fuel is used in certain DH systems in Sweden. The technology substituted traditional boiler system (using a range of different fuels) but there were very limited fundamental change to the regime and from a system perspective very similar to existing wood fuel boilers. Rather than a "Technology substitution" typology, the transition pathway is again characterised as Pathway A, and an "transformation pathway" according to Geels and Shot (2007). Pellet boilers are currently remaining in phase two as an early market niche. In terms of future development the momentum is low and the system is beyond its main competitor HPs. Moreover, the already higher economic and non-economic costs of appliance could be amplified if energy taxation is added, and even more important, the strong development of air-air HPs, which require lower investments than pellet boilers. All indicates that pellet boiler system will not reach the next phase and become an integral part of the regime.

2.6. Low energy housing

2.6.1. Internal momentum

Low-energy housing belongs 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 on energy efficiency (2012/27/EU) and the energy performance of buildings (2010/31/EU), 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 discernible 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.

2.6.2. Alignment with the broader regime and landscape developments

a) Finance and business interest

The first passive houses in Sweden were constructed in 2001, over 10 years after demonstrations in, e.g., Denmark. Since late 2000 there is more progress but the past 10 years have mainly been an early experimentation phase (Janson 2010). About 400 new dwellings in passive houses or low energy houses are now built annually and the cumulative share of the stock in Sweden is about 0,05% (Svensson 2012).

There is limited published information on price developments. Contractors and suppliers are still learning for each project built. The key barriers that make low-energy housing more expensive than existing standards are lack of knowledge of construction techniques and the lack of developed relationships with new suppliers, rather than the added cost of building materials per se. There is some evidence that costs are coming down, and that passive house projects are only marginally more expensive (Nordling and Carlsson 2009). There is also some network development and 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.

b) Changes in policy and institutional frameworks

During 2005-2010 the SEA 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. Several conferences have been organised as part of dialogue initiatives between private and public actors. The SEA has 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, public landlords, and universities (Nordling and Carlsson 2009).

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).

Perhaps a change might come through the directive on energy performance in buildings (2010/31/EU) which states that all the houses from the end of 2020 should be "near-zero energy buildings" might give this niche a push in the right direction. 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. 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. A true passive house should arguably rather be a zero net energy consumer and the niche and regime is clearly not aligned with high resistance from the supply focused regime.

c) Changes in public discourse and support
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. 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.

However, 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.

2.6.3. Is the niche-innovation about to breakthrough?

The momentum for low-energy housing is low and in terms of niche development, it is still in the first predevelopment phase where new actors are struggling against a building stock regime that is very conservative. Moreover, the implementation of the EU Directives in Sweden is lagging. However, both the buildings which are in need of renovations, and the long-term demand from EU policies indicate a need for change, which might benefit the niche. In terms of the pathway typology, low energy housing is the clearest case of a future Pathway B in the Swedish study.

2.7. Summary of momentum, regime alignment and breakthrough potential

Niche-innovation	**Internal momentum**	**Strong or weak alignment with broader regime characteristics and developments**	**Likelihood of imminent breakthrough (and/or future potential)**	**Pathway A or B (or mixed)**
Heat Pumps	Moderate	Well aligned, following "Transformation pathway" of symbiotic niche.-innovation and "De-alignment and Re-alignment"	Broken through, final phase four	Pathway A
District heating	Low	Perfectly aligned, is the regime, and developed in harmony with expanding society and need for energy	Phase four	Pathway B originally, but pathway A in terms of low carbon developments past 20-30 years
Waste heat recovery	Low	Perfectly aligned with the DH regime, again a transformation pathway of symbiotic niche-innovation	Phase two	Pathway A
Individual metering and billing	Very Low	Very limited alignment with regime and low niche protection.	Phase one, predevelopment	Primarily pathway A (Behavioural change, yes, but no fundamental change in several types of variables, no new technology needed)
Small-scale biomass	Low	Well aligned, technological substitution, but with few or none system changes	Phase two	Pathway A
Low energy housing	Very Low	Very high resistance from the regime	Phase one	Pathway B

Table 1: Breakthrough analysis of niche-innovations in the Heat domain in Sweden

	Lock-in, stabilizing forces	**Cracks, tensions, problems in regime**	**Orientation towards environmental problems**	**Main socio-technical regime problems**
Regime DH	Strong, natural monopoly	Moderate	Both High (GHG emissions reductions) and Weak (Waste incineration lock-in)	Overcapacity limits focus on Heat energy efficiency
Regime HP	Moderate (rather fluid between different types of HP solutions)	Low	High	None.

Table 2: Assessment of regime trends in the Heat domain in Sweden

3. Assessment of regime reorientation

3.1. Business as usual, but mostly a good business

Sweden has successfully initiated a transition to a low carbon energy system and domestic emissions have decreased by more than 40% from the mid-1970s and by 9% from 1990 to 2006 (Ministry of Environment 2008). The single most important change over the past 50 years has been the decline of oil as a fuel for heating. Oil dominated the heat system from its introduction in 1940s until 1970s but has since then declined to a less than 3% share in 2012 (Swedish Energy Market Inspectorate 2012). More recently DH has increased by 50%, and electric heating decreased by 25% since 1990, which is largely explained by the increased use of the more efficient HPs in the past decades (SEA 2015). Today, more than 50% of the generated heat in the building stock is delivered by DH, compared with EUs 10%. Electricity delivers 20-25% of the heat, where HPs play a significant role. The total amount of renewable energy in the heat domain in Sweden is highest in the EU (SEA 2013).

The Swedish socio-technical heat system has undergone a transition and established better performance in terms of CO_2-emissions. The regime has shown remarkable stability in terms of the long-term domination of DH, predominantly in the multi-dwelling segment. The stabilising landscape developments include cheap electricity, the oil crisis, municipalities as key actors and the preference for large-scale solutions. The transition to a low carbon energy system in Sweden was initiated in the 1970s and has successfully been implemented. The two dominant systems DH and HPs have – through technical and market changes, user practices, policy, infrastructure, and governing institutions – transitioned from being niches to form today's stable heat energy regime. We can thus conclude that the trends at large continue as business as usual, but, what is important, in an inherently already established low-carbon system.

3.2. Current system dynamics

The regime is characterised by complementarity and interconnectedness. HPs and DH have historically complemented each other as systems and the niches identified in the Swedish heat energy domain are not in competition with the regime, trying to break through, but are in various ways linked with DH and HP. For example, waste heat is almost exclusively utilised in connection to a DH system. Similarly, other forms of TPA, such as industrial waste heat initiatives and interconnections between various DH networks, are linked to DH. In the single-dwelling segment, HP is a niche that was strongly linked to the existing regime through direct electricity. HPs are merely a more efficient way to utilise electricity. Moreover, one type of HP is most often replaced with another (e.g. switching from GSHP to air-air HP).

But there is also evidence of new lock-in and less sustainable practices such as waste incineration. Recently, the regime dynamics have somewhat changed and the focus on self-sustained production might become problematic. Future demand for heating is bound to decrease and there are pressures from both the landscape and niche levels. Potential landscape pressures include climate change (in terms of higher temperatures), and measures on energy efficiency such as renovation of the existing building stock and the development of the low-energy housing niche. This would be a much more destabilising pathway for the current regime than the historical development that has been mostly along Pathway A and characterised by symbiotic niche-innovations gradually adopted and transforming the regime.

There are clear signs of market saturation in the regime. The HP market is becoming saturated in the single-dwelling sector. The growth rate in sales has been decreasing with 2007 being the first year in thirteen where sales declined compared to the previous year. This scenario was repeated in 2009 and 2011 (SEA 2015). The expansion has instead reached towards larger cities and multi-dwellings. This development has made HPs a competitive alternative to DH, where they are expected to take market shares from DH (Sköldberg at al. 2011).

The Swedish heat system thus not only offer insights on past successful low carbon transitions, but it is also a case suitable to understand continuous regime change where the transition to a new stable configuration leads to tensions over new issues.

In a historical context the key moment was the sea change in fuel choice and technologies adopted in the DH regime following the first oil crisis (Figure 1). In 1970, the system was almost 100% oil, the landscape change was then sudden and an explosion of niche-innovations applicable and symbiotic with the regime were adopted in the expanding Swedish DH system. By mid 1990s no less than 8 different major energy sources and were used. However, the past 20 years since then have seen a stabilized dynamics where the system today is again dominated by a few options, notably waste incineration and biomass. The dynamics is a clear example of de-alignment and re-alignment (Geels and Schot, 2007) and similar patterns of de-alignment can be seen in the single house domain (figure 2) but in this case market share of biomass is more stable and there are signs of saturation of the main technologies in a new system with many options.

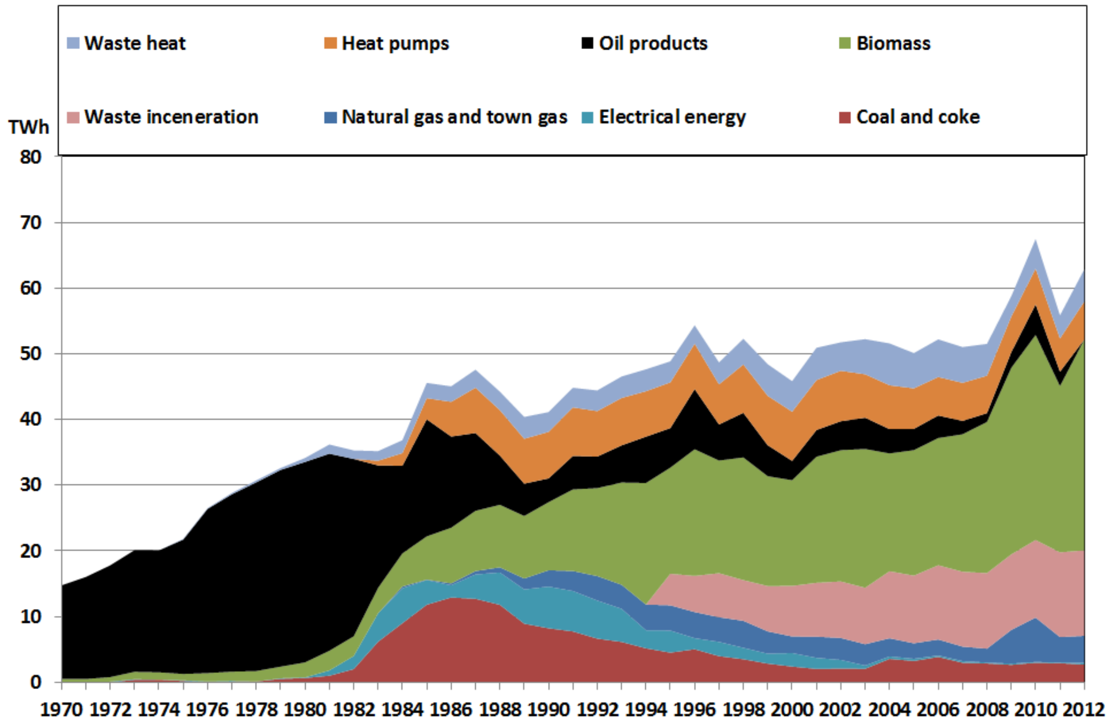

Figure 1 Fuels in the DH system in Sweden in TWh (Source: SEA 2013a).

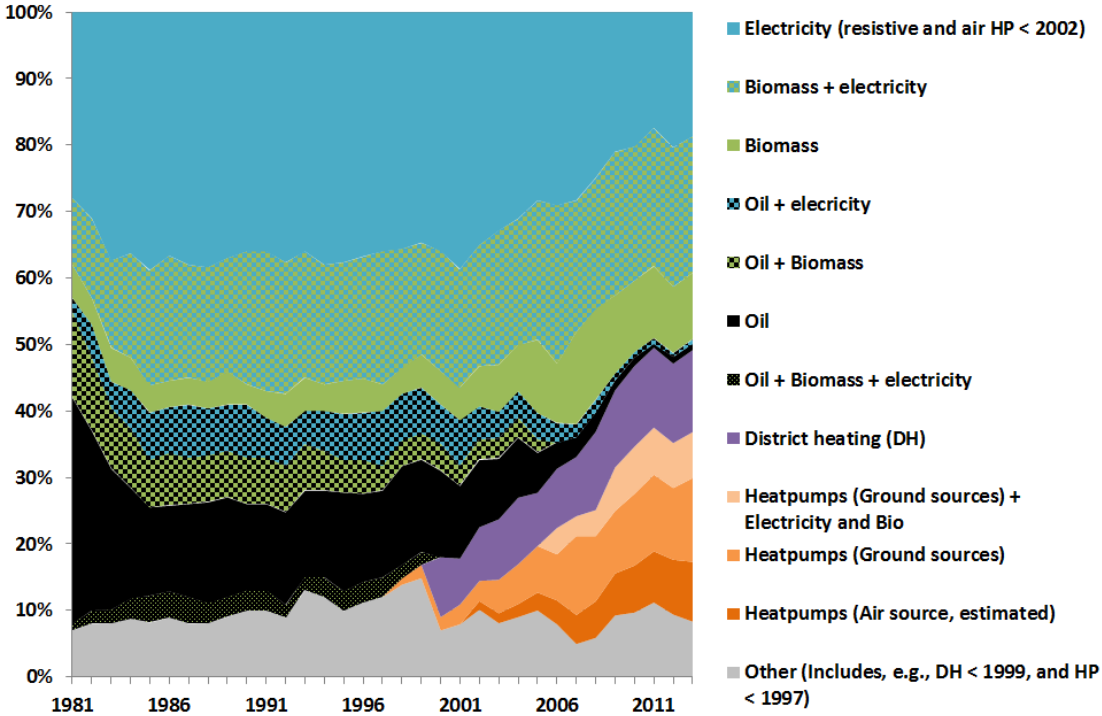

Figure 2 Share of single houses heating technologies. Even more combinations exists and are included in the other category that contain niche options until they emerg as individual categories in the statistics. Note that Electricity includes a large proportion for Air heat-pumps (Source: SEA 2013a, own calculations).

Hence, the Swedish case at the macro-level be described as having undergone a de-alignment, but each individual successful niche innovation has been in more or less synergy with the existing regimes. In the terminology of Geels and Shot (2007) a "transformation pathway" with mainly stretch and mainly displaying patterns of empowerment to fit and conform (Smith and Raven, 2012), and the system as a whole has followed and is following pathway A.

4. Conclusion

Our Swedish heat energy domain case is one of few examples in the project that shows radical system change over time. This has been achieved with combination of niche innovations and regime changes. But, importantly, the critical change of fuel in the DH regime was not PATHWAY B and clearly highly influenced results of concerted policy action empowering new innovations and spurring the de-alignment of existing technology solutions in the regime. Change was rather narrow in a sub-set of system dimensions. Innovations were developed in niches but clearly aligned and symbiotic within the existing regime. DH infrastructure and niche-innovations like biomass or waste heat in DH were empowered following the pattern of "fit and conform" (Smith and Raven, 2012). Likewise, while HP was originally a niche application, the reason behind its success has deep connections to other characteristics of our heat regime. It was aligned with the electricity regime (Air-to air HP), and, in the case of water radiator systems, aligned with that existing infrastructure in houses (ground source HP). Again, the incumbent regimes cannot be argued to have become substantially undermined as in "stretch and transform" (Smith and Raven, 2012) and the dominating transition pathway pattern is one of symbiotic adoption of niche-innovations (Geels and Schot, 2007). But it is important to note that the net outcome has nonetheless been a rapid de-carbonization of the heat energy system. And the success is inherently dependent on the high share of renewable energy in the power system and gradual phase-out of fossil fuels in the DH system.

In contrast to this, several of the niche innovations characterised as PATHWAY B type that require more significant system change along several dimensions meet heavy opposition unless they becomes aligned with existing regimes. This clearly shows how inherently inert the Swedish heat domain system is, and that the way forward, based on the experiences of one of the few successful national cases in Europe, is that governance interventions need to consider system change, focusing on landscape pressures and regime dynamics, not only niche innovations. If the energy and/or climate discourse suddenly shifts toward stronger requirements on the demand side, this would be potentially very disruptive for the Swedish heat regime.

The Swedish heat regime faces strong support from both policy and the civil society. For example, the natural monopoly of the DH means that there are few alternatives once DH infrastructure is in place and this sub system is naturally dominated by incumbent firms and municipal actors.

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