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A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system

Adis Dzebo^{a,b,*}, Björn Nykvist^{a,1}^a Stockholm Environment Institute, Postbox 24218, 104 51 Stockholm, Sweden^b Utrecht University Copernicus Institute of Sustainable Development, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands

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ABSTRACT

Since the 70s, Sweden has gradually replaced oil with renewables to provide energy for heating, and today the country uses the highest total amount of renewable energy for heating of all EU Member States. However, there are signs of new tensions in the heat-energy system, and of lock-in of less sustainable practices. Using the multi-level perspective (MLP), this paper assesses to what degree the sociotechnical regime in Sweden's heat-energy system is stable and locked-in, and whether there are emerging tensions. We identify three key characteristics of the regime – interconnectedness, complementarity and saturation – that together risk creating tensions and lock-in of less sustainable practices. We conclude that the heat regime is facing an unstable future, with several challenges of growing importance.

1. Introduction

Sweden has successfully initiated a transition to a low-carbon energy system, reducing domestic greenhouse gas emissions by 24% from 1990 to 2014 and by more than 40% since the mid-1970s [1]. This paper focuses on energy for heat, where the share of fossil fuels is now below 5%. It is well known that Sweden has achieved this decarbonisation by removing oil and other fossil fuels for heating in both detached homes [2] and multi-dwellings [3] over the past 50 years. They were replaced by two interconnected supply-side heat systems that provide up to 75% of the energy demand for heating in buildings: district heating (DH) and electricity through resistive heating and heat pumps (HP), both of which are almost completely decarbonised. Oil, which dominated the heat system from its introduction in 1940s until 1970s, had a less than 3% share in 2012 [4]. Since 1990, energy use for electric heating has decreased by 25%, largely due to HP efficiency improvements [5]. Today, DH delivers more than 50% of the generated heat in the building stock, compared with about 6% across the EU [4,6]. Another 20–25% of the heat is from electricity, much of it through HP. Overall, Sweden has the highest share of renewable energy in the heat domain in the EU [7].

Several studies have examined the role of individual technologies in this transition, with DH. For example, Ericsson and Werner [3] and Di Lucia and Ericsson [8] have focused on the processes behind fuel switching from fossil to renewables. However, there are few system-

level, interdisciplinary analyses of how this set of technologies came to dominate the Swedish residential heat system. There are also few studies of the challenges faced by the new regime [9,10]. This paper draws on lessons from past successful socio-technical transitions in Sweden to examine the regime dynamics of the heat energy system and analyse the potential for technological lock-in. The experience of Sweden, a forerunner in such low-carbon systems, could provide useful insights for low-carbon transitions in other countries.

Our analysis follows a socio-technical perspective [11,12]. We apply a case study approach [13], following the multi-level perspective (MLP) [11,14,15] to organise and analyse the data. The MLP framework, described in Section 2.1, offers a useful tool to explore the dynamics between incumbent regimes – the technological configurations and rules and practices that dominate the socio-technical system – and niches, the spaces where novelty grows [11,12]. Through qualitative analysis we recognise levels of social structuration, in which niches at the lower level challenge incumbent regimes at a higher level. The top level is the landscape – the slowly developing set of exogenous variables and processes that influence regime-niche dynamics [11,16]. MLP contributes interdisciplinary analysis to otherwise dominant techno-economic perspectives on energy transitions [17,18] and has been widely applied in studies of low-carbon transitions in energy and transport [19,20], including the low-carbon transition in DH in Sweden [8]. It has also been used in case studies of grid system development [21], sustainable mobility [22] and the energy industry

* Corresponding author at: Stockholm Environment Institute, Postbox 24218, 104 51 Stockholm, Sweden.

E-mail addresses: adis.dzebo@sei-international.org (A. Dzebo), bjorn.nykvist@sei-international.org (B. Nykvist).¹ Stockholm Environment Institute, Linnégatan 87D, 115 23 Stockholm, Sweden.

[23,24], contributing to a broadening of analytical approaches [25,21,22].

While the Swedish heat system has undergone a transition and established better performance in terms of CO₂ emissions, it also involves less sustainable practices, such as waste incineration [26]. Thus, analysis of the Swedish heat system offers insights into successful low-carbon transitions as well as into the tensions that can arise in the transition to a new stable configuration [27]. This paper aims to contribute to the growing understanding of the longer-term stability and adaptation of new regimes in socio-technical transitions.

Our analysis starts by assessing the regime change processes that underpin Sweden's transition to a low-carbon heat energy system. Second, we investigate what happens after new regimes with improved environmental performance are established. Finally we ask what determines whether a new regime becomes incumbent and locks in new problems, or it continues to adapt, reinvent itself and improve its performance.

We found that the Swedish heat regime faces strong support from both policy and civil society. The heat regime is characterised by interconnectedness, complementarity and saturation. Through interconnectedness the regime has been able to usurp supply-oriented niches such as industrial waste heat, and complementarity between DH and HP has only strengthened the regime. However, recently, the market for the different technologies has shown signs of saturation and there are now increasing tensions between DH and HP.

Section 2 sets out our theoretical and methodological approach and explains how our analysis contributes to understanding of socio-technical regimes. Section 3 explains key historical factors that have shaped the Swedish heat energy domain. Section 4 presents empirical analysis of the composition of the historical and current regimes, as well as the niche developments that led to regime changes. Section 5 focuses on the most important challenges and adaptation needs in the regime today. Section 6 provides a brief summary and concluding thoughts.

2. Theory and method

2.1. The multi-level perspective

The MLP framework recognises three interconnected levels: the socio-technical regime – a semi-coherent set of rules and institutions that shapes the actions, interpretations and identities of social actors at the meso-level; niche innovations – radical novelties that deviate on one or more dimensions from existing regimes at the micro-level; and the socio-technical landscape – an exogenous macro-level environment beyond the direct influence of niche and regime actors [11]. The socio-technical regime forms the ‘deep structure’ that shapes the perceptions and actions of the incumbent actor groups who reproduce or change elements of socio-technical systems [28,30]. The MLP thus draws heavily on neo-institutional concepts of formal and informal institutions, with the latter containing cognitive and normative rules [31–34]. The links to institutional theory have only recently been recognised and discussed explicitly [35,28], however, and there is a lack of studies drawing explicitly on institutional theory [35].

In MLP, the term system refers to more tangible ‘measurable’ elements, such as artifacts, market shares, infrastructure, regulations, consumption patterns and public opinion, while the term regime is concerned in particular with underlying rules and institutions [30]. The strength of MLP has been to provide a heuristic framework for analysing how new technologies and new actors create societal transitions through innovation. As noted above, it has been used successfully in many case studies of socio-technical traditions over the past decade [19,20,22–24].

However, scholars applying the MLP framework to sustainability transitions tend to focus on ‘green’ niche-innovations and the role of new entrants [12]. This excludes important aspects of institutional

change, such as the role of existing regimes and incumbent actors, and how change can be driven from within. In that context, the objective of transition management is to steer bottom-up niche-to-regime processes of transformation towards a pre-defined goal or ‘vision’ [36]. While these studies consider the stability of existing regimes, they often conceptualise it in terms of lock-in, path dependence and inertia [26,29], with less attention to the mechanisms behind this inertia. Explanations such as vested interests, organisational capital, sunk costs, economies of scale, increasing returns with refinement of production lines and skills, stable and favourable regulations, cognitive routines, social norms and behavioural patterns do arise in the literature. Still, regimes are often conceptualised as monolithic and homogenous [30,37,28] – as barriers to be overcome by creating protected spaces where green niches can grow [38].

Socio-technical regimes are deeply institutionalised [28], in a manner that reflects socio-technical patterns, but we know that institutions do change, albeit slowly [31–33,39]. MLP theory itself includes an understanding that transitions can be induced in different ways [14]: through a build-up of niche momentum, through shocks or changes in the landscape that put pressure on the regime, or through a combination of the two. This means there are different transition pathways, in which regime stability and change is an important factor [14]. Yet since the introduction of MLP theory, there has been much less attention on existing regimes and incumbent actors [40,28]. This has recently prompted studies of the need to destabilise and the processes by which this can occur [23,24], as well as studies of regime adjustments [41]. Empirical cases with explicit focus on regime change are slowly emerging [20], but the actual strength and change process of regimes needs further empirical analysis [30]. That is a key objective of this paper.

In particular, we seek to understand how the low-carbon transition in Sweden's heat energy system has established a new regime, as well as the on-going dynamics of that regime. We shift the focus to less structured processes and to how the regime is contested. From that perspective, the purpose of transition strategies is less to identify and implement consensual transition pathways, but rather to understand and engage with the emergent and contentious character of such change processes.

Regimes imply rules, technologies and actor-networks as the main components that can enforce stability or, when they change, create instability [42]. Building on this, we explore how three elements of regimes – i) technology and infrastructure, ii) intangible components, such as actor configurations, and iii) formal and informal institutions – explain how DH and HP became the central elements of the current heat regime. We will explore which components led to the regime change and which are causing new cracks and tensions. Like recent work by Geels and colleagues [19], this approach focuses on critically exploring technological development alongside policy-making and the norms, cognitive elements and routines that result in stable or dynamic regime actor configurations.

2.2. Three analytical dimensions of regime change

Technologies that provide improved or new services have been shown to play a key role in driving a transition, even if they are relatively expensive in the early stages [35]. It is clear that technological development is critical to regime destabilisation [24]. However, what is less studied is what happens after the transition. Our analysis considers how tensions and inconsistencies at the regime level – for example, between two energy-supply sources, or between supply and demand – affect how actors engage and intervene in conflicts and make sense of the situation [43,44].

Second, looking at actor configurations, we are interested in agents and structures and their mutually constitutive nature [45]. We need to know which are the important actor groups and what interests they represent, as well as their relationship to governance. The precise

nature of historical relationships between actor groups and political organizations will affect the choices made and the nature of institutional rules and norms. Another relevant factor is the historical economic and political importance of the industries that different actors represent [46]. While incumbent actors tend to support continuity and innovators tend to be forces for sustainable change, this is not always the case. Actor groups will seek to influence governance and to inform and/or control the terms of debate about system change. Their ability to be influential, however, will depend on domestic political institutions and inferred power relations [46].

The third dimension of analysis involves formal and informal institutions, and the ways in which they change or provide opportunities for change, as a result of learning or through the deliberate actions of individuals or coalitions seeking advantage for themselves [47,48,39]. Conversely, institutions can constrain or resist change, sometimes allowing only incremental and path-dependent [35]. To understand this process, we study the historical development of institutional change [49,50]. We also study the types of policies and interventions [42] and the system levels at which they are applied [22].

2.3. Methodology

The work builds on three research reports from the PATHWAYS project that focus on the Swedish heat energy domain [51–53]. PATHWAYS aims to provide insights on ongoing and necessary transition pathways for key domains relevant to EU policy. The project combines three scientific approaches: integrated assessment modelling, MLP, and participative action research; this paper is based on our analysis of empirical case study material using the MLP framework.

The methodological approach is in-depth case study work focusing on process tracing [13]. Our data is mainly gathered through a literature review, complemented with policy analysis and a limited number of interviews to broaden the author's understanding of the literature [13]. The interviews involved researchers and policy actors, as well as technical experts in the field of Swedish heat energy. The empirical material was first analysed to identify the strongest qualitative and quantitative patterns at each level in the MLP framework [51–53], applying standard methods of similar empirical studies of socio-technical transitions in the past decade [20,22–24]. In a second step, we deepened our analysis, looking at each of the three dimensions of regime development described in Section 2.2 [19]. We then apply those same dimensions of analysis to ongoing processes, to explore how the regime may continue to change and what new stable regime configurations are emerging. Here we again use the MLP categories to examine the implications for the achievement of more ambitious long-term goals for energy efficiency.

3. Historical context: how the current socio-technical system emerged

The Swedish residential building heat system has two main elements: heat generation systems, and the building stock. An important factor in the make-up of heat generation systems is Sweden's history of abundant, cheap electricity from hydropower and, starting in the 1950s, nuclear power. This led to the use of large amounts of direct electricity for heating, mainly replacing oil. The heat system has since then moved to being based primarily on biomass, with virtually no oil (~5%) (Figs. 1–3).

The oil crisis in the 1970s was a shock [8] of the type of landscape factors highlighted by Geels that shape the regime dynamics [11]. It led to a broad change in political discourse towards gradually replacing oil – both its direct use in single- and multi-unit housing and in the central heat plants in the expanding DH system. Renewable energy policy during the 1970s and 1980s mainly focused on technology research, development and demonstration, but it had little impact on the Swedish energy balance [54]. In other words, the regime began reconfiguring

[29] with some technical regime change [11]. The overarching energy regime did not change, but started reinventing itself to be less oil-dependent in the heat domain.

The second landscape-level pressure was a rise in concerns over climate change, which led to the introduction of a carbon tax in 1991. Normative changes led to several energy taxes, and overall policy shifted taxation from labour to energy and emissions [59]. Energy taxes have a long history in Sweden and have also been central to the development of bioenergy [54]. The CO₂ tax has been flexible, and tariffs have been changed as new experience was gained [60,61]. It has been influential in lowering GHG emissions in Sweden. Market development for new niches, such as HP, took off during the 1990s, and the total share of renewable energy in the heat domain grew over time, to about 70% today (depending on yearly average temperature), the highest in the EU [4].

The nature of Sweden's residential building stock, meanwhile, favoured the development of district heating systems. The residential multi-dwelling housing system in Sweden is communal, both for rental and owner-occupied units. In the latter case, owners have a share in a whole building, rather than just owning their apartment. This communal approach has facilitated pooled heat networks over individual heating options. Swedes have historically taken a pragmatic approach to sharing, and this helped advance the energy transition. Of the roughly 4.5 million residential units in Sweden, 2.5 million are in multi-dwelling buildings [62]. Single-unit buildings (e.g. small detached houses) represent a heated area of 292 million m², compared with a total of 175 million m² for multi-dwelling buildings. About half the Swedish population lives in each category of housing, but single-dwelling buildings take up more space and thus require more heat per resident.

4. Results

4.1. Technology and infrastructure

DH in Sweden can only be described as a success story. From a cautious start in the 1950s, it grew from less than 5 TWh in 1960 to more than 50 TWh in 2010 (Fig. 4). The system was pioneered by engineers working for the municipal energy utilities, amid strong resistance from incumbent actors – mainly from heating oil vendors, plumbers and chimney sweeps. The process was encouraged by the opportunity to cogenerate heat and electricity through combined heat and power (CHP) systems [63]. DH supplies more than half of the total heat demand in Sweden. It dominates the Swedish multi-dwelling sector, with an 85% market share, compared with only 16% in single-dwellings [64].

A key technological explanatory factor for the success of the DH regime is its capability for reinvention. Fig. 4 shows the dynamic fuel supply changes of the DH system over time. Most noticeable is the entrance of biomass in the early 1980s, which crowded out coal and coke, and the entrance of waste incineration in the early 1990s. This transition was facilitated by the opportunity to initially use a mix of fuels, such as electrical energy as a temporary solution, which later led to a transition away from fossil fuels [65,24]. CHP constitutes 45% of the total supply to DH. Since heat and electricity demand often coincide in the Nordic countries (because colder months are also the darkest, and summers are not very hot), CHP plants have the largest electricity generation when the heat load is greatest [66], making CHP highly efficient: it captures 90% of the fuel energy, of which 50–70% is heat [24,7].

The DH system is vertically integrated with central production of hot water, and with its distribution in culvert systems and final consumption through heat exchangers and radiators. System characteristics and economies of scale mean that it is not cost effective to compete with parallel infrastructure, so DH creates a natural monopoly [5].

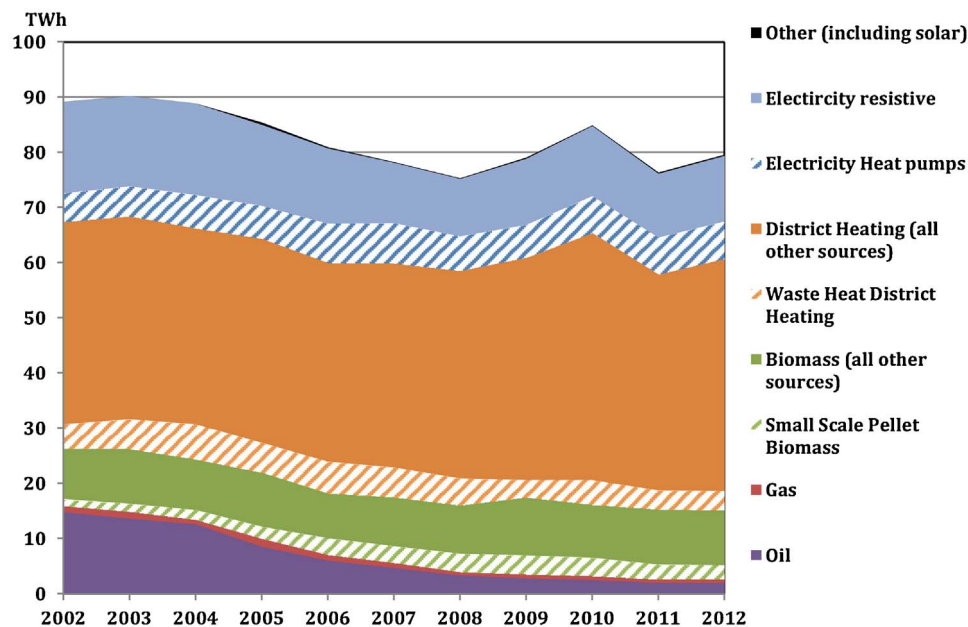


Fig. 1. Energy use for heating and hot water by energy carrier in Swedish housing domain. Source: [7,55,56].

Another strength of the DH regime is the potential to incorporate the industrial waste heat, a niche in the socio-technical system, through third-party access – new actors such as heavy industry that connect their waste heat to the local DH infrastructure. Sweden is a world leader in this area, with 4.9 TWh of waste heat supplied. A DH system that includes waste heat has a lower average price [70]. There is potential for further recovery of waste heat, estimated at 6.2–7.9 TWh [71].

DH providers are scattered around the country with a large diversity of energy supply [72]. Most operate at the local level; larger cities contain several operators with relatively small-scale networks. The main factors influencing price to consumers include the mix of fuels, customer density and heat demand. Higher customer density results in a more efficiently used grid and lower unit cost per customer. Price variations also depend on soil conditions, because capital costs depend

on the cost of burying pipes and restoring the soil [5].

Electricity, meanwhile, is the main source of heating in single-unit homes [65]. A large share of the inefficient heating systems that were traditionally used has been replaced by HP. HP systems vary in the heat source used (air, water and ground) and in 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 [73].

Sweden is the country with the largest number of installed HP systems per capita, along with Switzerland [73,74]. The Swedish HP market took off as a niche following the oil crisis in the late 1970s, and since the early 1980s more than one million HP have been sold by Swedish manufacturers. Important factors in this development include the low-carbon policy, and that Swedish citizens tend not to move very

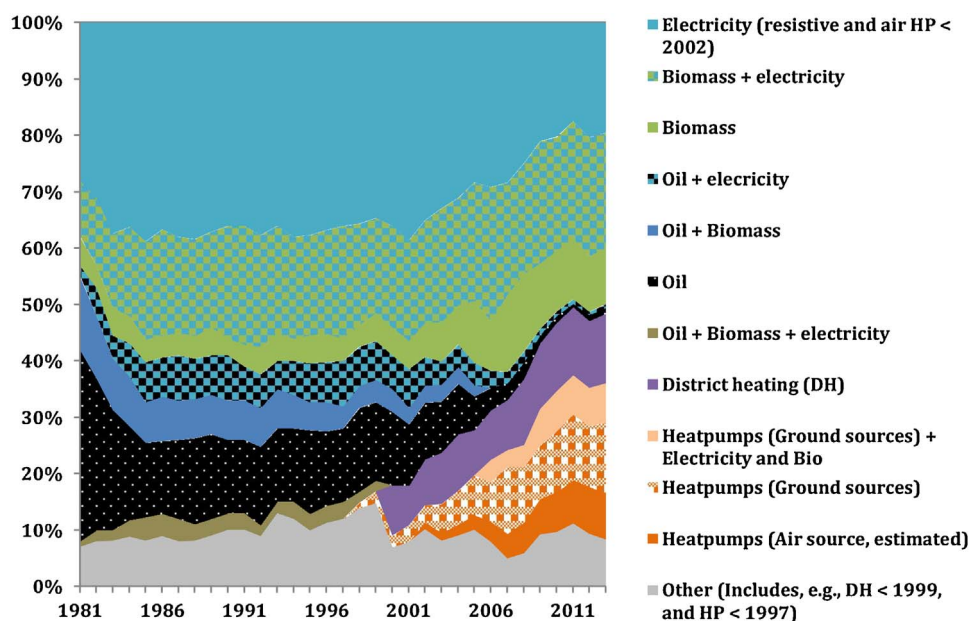


Fig. 2. Share of total heated area in single-dwellings for each heating technology. Even more combinations exist and are included in the other category that contains niche options until they emerge as individual categories in the statistics. Note that air heat pumps form a large proportion of the electricity segment. Source: [2,57].

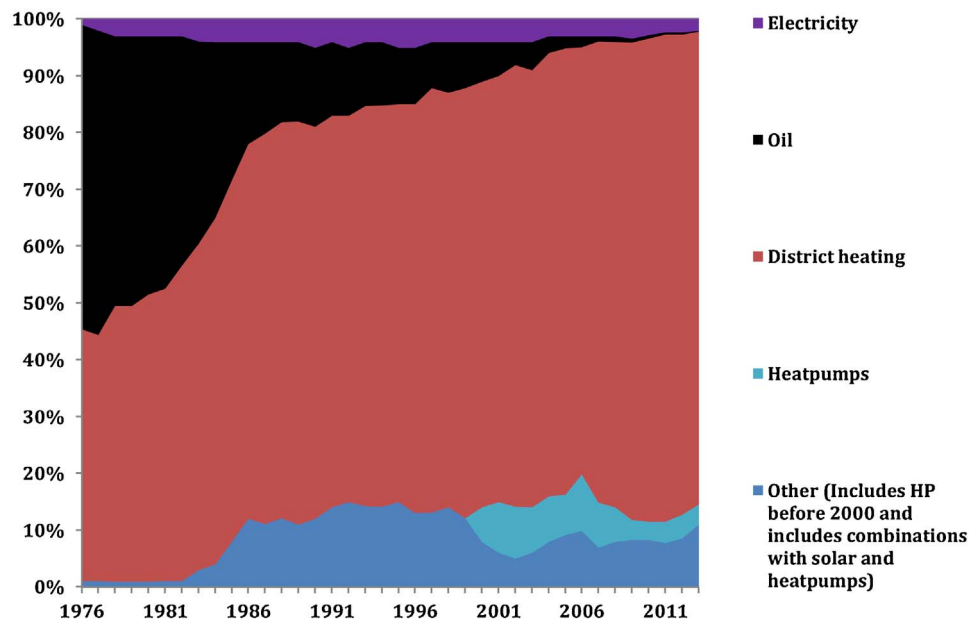


Fig. 3. Share of heated area in multi-dwellings.

Source: [58].

often, which encourages relatively expensive long-term investments. Since 2000, the market share of air–air HP has increased rapidly as they have become more efficient and require significantly lower capital investments [6].

HP significantly contributes to lowering energy consumption, with a total absorbed energy of 14 TWh in 2009 [74]. Although temperatures in 2001 and 2012 were similar, the amount of energy for heating and hot water used in Swedish single-family dwellings was 17% lower in 2012—a drop attributed mainly to HP [4,75].

Sweden has played a key role in the development and commercialization of HP, with a third of Europe's ground source heat pumps found in Sweden [76]. Policy incentives have encouraged HP research and testing. Early policy initiatives were poorly coordinated, but did

support technology development, entrepreneurial experimentation, knowledge development, and the involvement of important actors in networks and organizations [73]. The Swedish government has also provided subsidies for conversion from oil-fired boilers and direct electricity to HP [5]. These policies and programmes increased production and sales of HP, halving costs over the past three decades and making HP cost-competitive with fossil-fuel systems. The support has also boosted exports, which now account for about 50% of total Swedish HP systems production [77]. Technological development continues to improve the coefficient of performance (COP – the ratio of heat produced per kWh of electricity used), which has increased by 2% annually since 1995 [5]; looking ahead, it is also important to control loads so that expensive peaks, both from electricity and DH, can

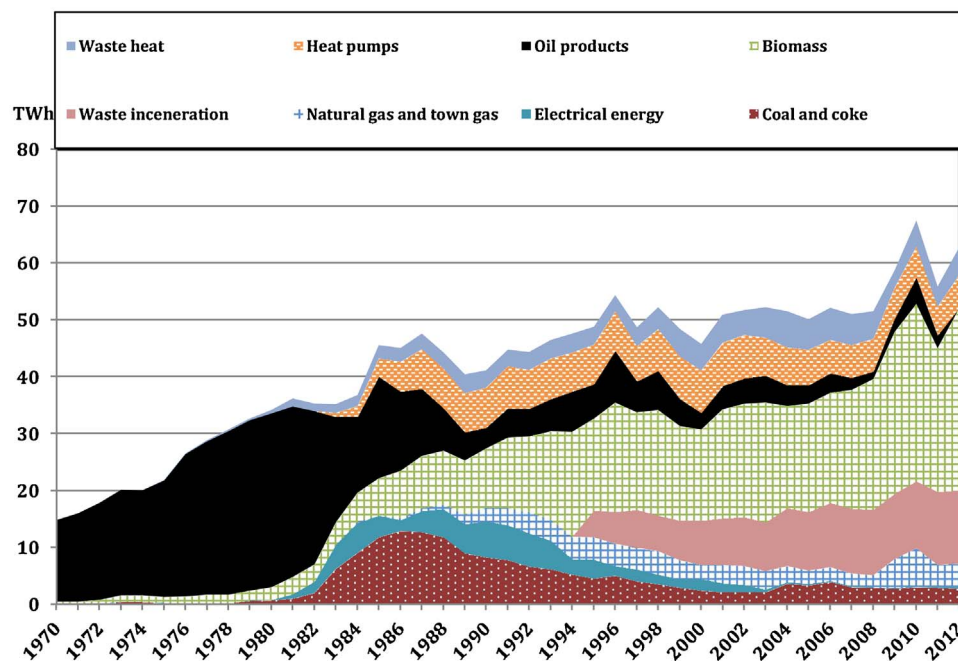


Fig. 4. Fuels in the DH system in Sweden in TWh.

Source: [86].

be avoided on cold days [74].

Historically, HP and DH have complemented each other in the transition to a low-carbon energy system, both by serving different housing sectors, and within the same system. For example, HP can be used to recover energy from the exhaust air in a DH-heated house. However, DH has recently experienced increased competition from HP due to the saturation of its traditional market segment [67].

Like others before us, we find the Swedish heat regime has a history of being dynamic, not monolithic [28]. New technology has been developed both within the regime and externally. The heat system in Sweden reflects a cultural preference for supply-side-dominated large-scale solutions and domestically sustained heat production. The fall of the oil regime was not a fall of the socio-technical DH regime. The oil regime in Sweden consisted mainly of technological components, not a complete set of socio-technical elements with actors tied to oil and supporting policy. The minor change processes (e.g. resistance from chimney workers and boiler technicians) was not a big factor. Hence, while the transition was a clear case of de-alignment/re-alignment [8] with regard to the fuel regime, the system as a whole reconfigured itself with some technological substitution [29], but fewer deep changes in institutions and structures. Large DH infrastructure and networks have continued to develop and benefit from ample natural resources (e.g. forest resources). This is a key explanation for the successful transition to a low-carbon system. On the other hand, the building stock is depreciating. The need for renovation and refurbishment is severe and in the coming years this can be expected to put even more pressure on the heat generation regime, as the demand for heat is expected to decrease [78].

4.2. Intangible regime components

Local heating markets are heterogeneous in terms of size, settlement density and production mix, and have strong connections to the electricity market, the forest sector and waste management. The major utilities, public and private, have played a central role in developing new heat and power generation technology. However, other actors, including municipal energy utilities and local governments, have been equally or more important for the increased use of renewable energy [68]. The early adopters of new technology thus include a range of different actors, but much of the demand has been in the DH systems [54,69].

In terms of policy and governance, support from the regulating authorities, the Swedish Energy Agency (SEA) and the Swedish National Board of Housing, Building and Planning (Boverket) has been crucial. The SEA implements EU energy directives as well as national regulation. It also mediates the negotiations between the DH companies and customers on conditions under the District Heating Act (2008:263) as well as negotiations between DH companies and those wishing to gain access to DH infrastructure as a third party. Boverket regulates energy consumption in the built environment and provides information on building energy use to through the (compulsory) Energy Performance Certificate.

In addition, municipalities are key actors through the Planning and Building Act (2010:900), which instructs all municipalities to have a 'comprehensive plan' for overall development planning. Thus, the municipalities control and develop DH infrastructure. However, through an increasingly liberalised economy and stronger private actors, their planning power has gradually decreased since the 1980s [79].

For DH, the key actors are the providers. The majority (98%) are organised through the Swedish District Heating Association (SDHA), with 140 members [9]. As the electricity and heating markets were deregulated in the mid-1990s, the market structure shifted away from communal ownership toward private ownership [24]. Buyers were large utilities, national and international, such as Vattenfall, E.ON and Fortum. In 2004 these operators accounted for 35% of the DH energy

supply [79].

In terms of fuel input, the forestry sector has been an important supplier of biomass for DH. Private owners dominate the industry and own 49% of Swedish forest land area, but the state is also a significant owner. The forestry sector was initially reluctant to engage in the development of a biomass market, fearing competition for the raw material [80]. Today, however, biomass is the main fuel in the DH systems and the industry has benefited from energy taxes that have generated a strong bioenergy market [54,8].

The second important fuel input for DH is waste incineration. In 2002, Sweden banned the use of landfills for waste, so municipalities began to pay DH companies to incinerate waste, leading to very low or even negative costs for waste fuel [81–86]. About half of all household waste is incinerated, contributing to the production of 12.6 TWh of heat and 1.8 TWh of electricity in 2010, or 20% of total DH and about 1% of total electricity [10]. Waste incineration capacity continues to grow, and by 2020 is expected to increase by a further 2 million tonnes. However, existing capacity already is greater than the domestically generated waste, leading Sweden to import waste from abroad for incineration. In 2010, 748,000 t of waste was imported as fuel for DH [10,23,87]. Waste incineration may be displacing the use of industrial waste heat in DH [81–86]. Moreover, a lock-in of waste incineration as a major fuel source for DH would conflict with the EU Waste Framework Directive (2008/98/EC), which defines disposal through incineration as the second least effective treatment of waste, after landfills.

In HP, meanwhile, early policy initiatives helped start a market. The number of actors increased as the market grew in the early 1980s, including manufacturers, retailers, driller and installation suppliers, research organizations, authorities, certifying bodies and test institutes [73]. However, as the price of oil fell in the mid-1980s, government subsidies were terminated, and the market collapsed, shrinking from 130 small and local manufacturers, retailers and installers, to only a few [73,88].

In the early 1990s, amid growing concerns about climate change and lobbying from advocacy groups, the HP market was again strengthened. A well-coordinated market transformation and technology procurement programme was launched, combined with test and certification programmes, policy incentives, subsidies and massive information-sharing activities. The focus was on knowledge development, networking and market formation, but also on quality control, credibility and legitimacy. Networking among actors encouraged important processes of learning [5]; activities through the International Energy Agency also fostered learning and spillover effects [89]. This led to the development of higher-quality technology and substantial market support, which boosted demand for HP in the mid-1990s; in the decade that followed, average growth was 35% per year [73]. The market continued to flourish in the 2000s [5,4], establishing HP as a key part of the heat energy regime.

The Swedish heat regime has been helped by the strong role of the public sector – municipalities and the national government – which has served as a force for continuity [46,68,69], both as regime actors and by providing the institutional structure of the regime itself. The government and municipalities are historically majority owners of electricity and DH companies, and the government, through formal institutions, regulates the heat energy system through legislation and policy. Thus, DH managed the transition without any problems. Municipal experimentation and government policy incentives and support also contributed to HP's rise from niche technology to a new part of the regime. However, as the HP actor configuration also consisted of new entrants, HP first experienced hype-disappointment cycles [19] before breaking into the regime. Likewise, waste incineration is building on the same set of strong actor configurations that supported the fuel switch from oil, but now with additional actors and technical systems connected to the heat system. As the role of institutional change processes in socio-technical regimes change depends on how embedded institutions and energy infrastructures are

[46], we find a risk that waste incineration will become an incumbent regime in itself, deeply entrenched in the system structure.

4.3. Formal and informal institutions

The policy landscape for heating in Sweden is currently steered by the Swedish draft ratification bill on the implementation of the EU Energy Efficiency Directive (2012/27/EU). The directive requires national governments to develop a strategy for energy efficiency in order to implement the 20/20/20 targets – i.e. 20% reduction in GHG levels, raising the share of renewable energy to 20%, and a 20% improvement in energy efficiency by 2020 relative to 1990 levels. Another important directive is the Waste Framework Directive (2008/98/EC), which regulates the waste cycle, and the EU Ecodesign Directive (2009/125/EC), which provides EU-wide rules for improving the environmental performance of energy-related products and is relevant to the energy performance of HP [90].

The Swedish government's own climate and energy policy targets for 2020 go further, aiming for a 40% reduction in greenhouse gas emissions, a 50% share of renewable energy, and 20% more efficient energy use [91]. Sweden also incentivises renewable energy production through a Tradable Green Certificate system (TGC) [92], aiming to contribute to 25 TWh of renewable electricity from 2002 until 2020 [93,94]. As a consequence, the TGC system favours electricity generation from mature technologies such as CHP and wind power, since their production costs are lower than for newer technologies such as solar and wave power [95].

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, in 2009, the European Parliament approved a new version of the directive (2010/31/EU), which states that all new houses by the end of 2020 should be “near-zero energy buildings”. Building efficiency standards in Sweden are complex, with different rules for different building types, three climate zones from north to south, and special rules for specific devices – but overall, they are not stringent about energy efficiency. For example, the current standard for central Sweden is 110 kWh/m²/year, twice the level of energy use envisioned by the EU directive [96]; indeed, the directive is roughly at the same level as the Swedish passive house standard, a maximum of 54 kWh/m²/year in purchased energy for heat and hot water.

With DH specifically, a key issue has been third-party access. Two national inquiries have been undertaken [99,100], which led to proposed changes in the District Heating Act to allow third-party access under certain circumstances [97,98]. It is expected that the regulations will not create effective competition on the supply side, because of high entry barriers for new actors [101]. Still, the increased focus on new industries and businesses beyond heavy industries, such as large server rooms adjacent to cities and shopping malls, has the potential to increase the use of waste heat [71]. Failure to agree on the price and large cultural differences between the private industries and (mostly) municipally owned DH companies have been cited as two barriers to further utilisation [102,99,100]. There is a lack of institutional and financial support from the government and municipalities, but the proposed regulations and the implementation of the EU Energy Efficiency Directive have generated some momentum.

Meanwhile, recent revisions of the building code have given an advantage to HP over DH, since a larger amount of energy for heating is permitted with HP [5]. HP is not only favoured in policy, but also in the public debate. After a long and steady upward trend for DH, property owners increasingly prefer alternative heat energy sources, even where DH is available. One reason for the shift is that many customers feel they are in a weak position vis-à-vis the DH supplier. By investing in an alternative heating system, property owners reduce the risk of future price increases, while being in control of their own energy [103].

Moreover, a study found that ground source HP systems are perceived to be better than DH, pellet boilers and resistance heaters in terms of GHG emissions, market value of the house, environmental friendliness, security of fuel supply and annual cost of heating [104].

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 reductions in energy use in buildings can be achieved either through efficiency upgrades (e.g. additional insulation and optimisation), or by installing HP combined with solar panels to reduce the amount of purchased energy. Calculations have shown that the cost of achieving this goal is significantly lower when using HP [103].

On the consumer side, demand for heating energy is high. Indoor temperatures in Sweden have remained constant in the past decades, averaging 21.2 °C (± 0.2°) in single-family homes and 22.3 °C (± 0.2°) in multi-dwelling buildings. This is significantly higher than in other European countries; in the UK, for instance, the average is less than 20 °C. Climatic and cultural difference explains the higher indoor temperatures. The National Board of Health and Welfare in Sweden recommends an indoor temperature of 20–23 °C [105], so the current indoor temperatures are right in that range. Nonetheless, optimising and reducing the average indoor temperature to the bottom of the range has the potential to yield significant savings. Mata and colleagues have estimated that reducing the average temperature in both types of dwellings to 20 °C would save 13.3 TWh per year in Sweden, the largest single savings potential in the housing sector [106].

For multi-dwelling buildings, indoor temperature is usually controlled centrally, which means people in individual apartments do not have full control of their heating. In order to reduce the indoor temperature, the entire owners' association must agree. However, thanks to repeated educational campaigns, larger numbers of households in single-family homes have adopted lower indoor temperatures. Single-dwelling households get direct feedback on their heating energy use, as they pay the costs directly to the energy supplier, while in multi-unit buildings, the heat is included in the rent or in other monthly fees [107].

Both formal and informal institutions have contributed to the development of HP and DH and the stabilisation of the new heat regime, through the policy landscape, public opinion and culture. However, there are also signs of resistance and constraints in the new regime configuration. Strong incentives are working against deeper reductions in energy demand. High indoor temperatures remain the norm, there has been limited development of passive houses, there is resistance to smart energy metering, and stricter energy standards have been slow to emerge, all suggesting new forms of lock-in [8–10]. Thus, the new regime is continuing on old paths of a supply-oriented heat system, with large centralised DH plants and locked-in infrastructure that supplies cheap heat and cheap, reliable electricity for HP.

5. Discussion

Put simply, MLP assumes that green niche-innovations can develop in an institutional environment that make them capable of competing with the dominant regime, while landscape developments put pressure on the regime. As a consequence, regimes may destabilise and give way to new socio-technical configurations [14]. However, the Swedish case illustrates how the dynamics behind the success of the two dominant supply-based systems – DH and HP – is characterised by (DH) and heavily influenced (HP) by adaptations of incumbent actor configurations and institutions. Technical progress, and process of changing markets, user practices, policies, governance and institutions, have all been centred on regime adaptation.

Our analysis shows that the system as a whole did not undergo deep changes on all analytical levels, but rather managed to transition through technological substitution and reconfigurations. For this reason, there were limited tensions in the past, but this is changing, and

external pressures and integral inconsistencies are becoming more prevalent in the Swedish heat regime [43]. The same rules and structures that were agents of change are now institutional barriers resisting further change [33,36]. We put emphasis on historical development (complementarity and interconnectedness) and current status (saturation) to explain this development.

HP and DH have historically *complemented* each other as systems. The two technologies have developed in parallel with (varying) help from incumbent regime actors. DH dominates the multi-dwelling sector and was part of the previous regime, while HP, prevalent in single-family homes, broke through from niche to regime with help from public incentives and policy. Both HP and DH have benefited from regimes in other systems, such as the forestry industry, which provided fuel input for both DH and for electricity generation. Both have also benefited from historically low energy prices in Sweden, meaning that the Swedish government could pursue the goal of domestically sustained heat production over energy efficiency measures.

The regime is also *interconnected*, in the sense that the niches identified in the Swedish heat energy domain are not in competition with the regime, trying to break through, but rather are linked in various ways with DH and HP. For example, waste heat is almost exclusively used as part of a DH system, and other forms of third-party access are similarly linked to DH. In the single-dwelling sector, HP built on the existing regime of using electricity for heat; the niche technology is just a more efficient alternative to direct electricity. In addition, one type of HP is mainly replaced with another (e.g. switching from ground source HP or air–air HP to air–water HP). Table 1 summarises the most important factors driving this process from oil to a low-carbon regime.

Notably, we found no momentum in demand-focused niches such as net metering and low-energy housing. A historical preference for collective ownership (e.g. in multi-dwelling buildings) has created a regime overwhelmingly dominated by the supply side. As a consequence of the lack of demand-side energy efficiency measures, the low-carbon transition has been hindered by the persistence of high indoor temperatures and slow implementation of EU directives on building energy efficiency.

Thus, while the Swedish case is a success story, we find that the regime dynamics are changing, and the focus on production and heat energy supply may become problematic. The HP market is becoming saturated in the single-dwelling sector; after 13 consecutive years of growth, in 2007, HP sales declined relative to the previous year, and declines also occurred in 2009 and 2011 [5]. This has led HP providers to seek to grow their business in larger cities and multi-dwelling buildings. Recent policy development and discontent with the monopolistic DH structure has made HP a competitive alternative to DH, and it is expected to take market share away from DH [67]. DH is also facing market saturation, and an expected decline in demand for heating due to building upgrades could create challenges for these businesses [108].

Warming temperatures due to climate change and the need to adopt new policies to comply with EU energy efficiency standards will create additional pressures on the regime alongside the renovation needs of

Table 2

Current regime dynamics, new stability and tensions, 1990 and onwards.

	Multi-dwelling housing	Single-dwelling housing
Landscape drivers and pressures	<ul style="list-style-type: none"> ● Climate change ● Energy efficiency ● Liberalised planning ● Low energy demand in new buildings 	<ul style="list-style-type: none"> ● Climate change ● Energy efficiency ● Liberalised planning ● Low energy demand in new buildings
Green niche development	<ul style="list-style-type: none"> ● Third party access ● Waste heat ● Solar heating ● Low energy buildings 	<ul style="list-style-type: none"> ● Solar heating ● Heat control systems
New regime stability and tensions	<ul style="list-style-type: none"> ● Market saturation ● Implementation of EU Directives ● Waste incineration problematic 	<ul style="list-style-type: none"> ● Improved efficiency of HP ● Market saturation

the existing building stock. At the same time, continued investment in new waste-burning CHP plants has led to a debate about over-capacity, lock-in of waste incineration, and dependency on waste imports [24]. The Swedish heat regime is thus experiencing increasing tensions, disagreements and competing interests [28] (see Table 2).

Reducing demand through more energy efficient but expensive building techniques, such as materials and heat control systems, will likely continue to meet resistance due to high investment costs (and relatively low energy costs). As electricity is already nearly fully decarbonised, and institutional barriers are strong, is not clear that future policy development will include the range of policy instruments and interventions needed to achieve deep reductions in demand [42] and thus meet the EU and national policy targets.

6. Conclusions

We assessed how the current low-carbon regime of the Swedish heat energy system was established and what determined whether the new regime became incumbent and established new problems, or whether it continued to improve its performance.

The Swedish heat regime has shown remarkable stability in terms of the long-term domination of DH and the breakthrough of HP. The regime has strong support from policy, and there is little opposition from civil society, despite Sweden's high energy consumption and the lack of strong demand-side measures. Incumbent firms dominate the regime, and the natural monopoly of the DH means that there are few alternatives once DH infrastructure is in place. The heat regime is characterised by three factors: interconnectedness, complementarity and saturation. Through interconnectedness, the regime has been able to usurp supply-oriented niches such as industrial waste heat, while and complementarity between DH and HP has only strengthened the regime. However, recently the market for the different technologies

Table 1

Development from oil to low-carbon regime in multi-dwelling and single-dwelling housing, 1970–1990.

	Multi-dwelling housing	Single-dwelling housing
Landscape drivers and pressures	<ul style="list-style-type: none"> ● Oil crisis ● Large-scale communal solutions favouring infrastructure-heavy solutions ● Municipalities as key actors for energy planning 	<ul style="list-style-type: none"> ● Cheap electricity from nuclear and hydro ● Oil crisis
Green niche development	<ul style="list-style-type: none"> ● Municipal experimentation ● Integration of local systems to larger DH systems 	<ul style="list-style-type: none"> ● Domestic R & D of HP technology ● Small-scale biomass (pellet boilers)
Resulting regime change from fossil fuels	<ul style="list-style-type: none"> ● Built out from DH infrastructure ● Sunk investments in DH infrastructure – pipes, plants (centralised power generation) ● Switch from oil to mix of fuels and technologies ● Municipalities become regime actors 	<ul style="list-style-type: none"> ● Oil replaced by HP technology

has shown signs of saturation, and there are now increasing tensions between DH and HP. The regime has become entangled, with increased competition between the two heat generation sources.

While the low-carbon transition has been successful in terms of reducing CO₂ emissions, there is also evidence of new lock-in and less sustainable practices. The regime is still locked in to supply-dominated heat production with an overarching objective of self-sustained production. There is little focus on reducing demand for heating as a sustainability practice. Waste incineration in CHP plants is growing despite overarching ambitions for recycling materials [8,23], and there is resistance from incumbent actors to more stringent energy efficiency standards for buildings that would align Sweden with its long-term goals and with EU Directives.

The heat energy system is more or less fully renewable, which means there is little necessity for supply-side actions. However, the need for renovation in the building stock, climate change, and the EU Directives on energy efficiency and energy performance of buildings will lead to less demand for heat energy, and thus put pressure on the regime.

This study highlights the importance of examining regime change dynamics, both to understand how successful changes occur, and to identify new challenges and emerging tensions. There is a need for more research that applies MLP but focuses on the governance of regime change, and not just on how to protect niches of innovation.

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