Swedish heat energy system – new tensions and lock-ins after a successful transition

Sweden has successfully begun 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. In terms of energy for heating, the share of fossil fuels is now below 5%. This has been achieved by removing oil and other fossil fuels for heating in both detached homes and blocks of flats over the past 50 years.

Fossil fuel energy has been replaced by both district heating and electricity through resistive heating and heat pumps, which provide up to 75% of the energy demand for heating in buildings. Today, district heating delivers more than 50% of the heat in the building stock, compared with about 6% across the EU. Another 20 to 25% of the heat is generated from electricity, much of it through heat pumps. Overall, Sweden has the highest share of renewable energy for heating in the EU, and its experience could provide useful insights for low-carbon transitions in other countries.

Key findings

- The Swedish heat energy system has been remarkably stable in recent decades, despite Sweden's high energy consumption, owing to the dominance of district heating and the breakthrough of heat pump technology. The system also has strong support from government.
- When district heating infrastructure is built, the district heating firms define how the infrastructure in the system develops, which limits options to develop alternative infrastructure. This means that district heating can be seen as a natural monopoly.
- While in terms of reducing CO_2 emissions Sweden's efforts to transition to a low-carbon economy have been largely successful, the heat energy system is still locked in to supply-dominated heat production with the overarching objective of self-sustained production. There is little focus on reducing demand for heating as a sustainability practice.
- The practice of incinerating waste to generate heat in district heating plants is increasing, despite overarching ambitions to recycle it instead. There is also resistance from the dominant actors in the district heating domain to more stringent energy efficiency standards for buildings that would align Sweden with its long-term goals and with EU directives.
- The need to renovate Sweden's building stock, rising temperatures following climate change, and tightening EU directives on energy efficiency and energy performance of buildings, will lead to less demand for heat energy. The heat system will face challenges unless it adapts to these pressures.

Historical context: how the heat energy system emerged and changed

Sweden has historically had abundant, cheap electricity from hydropower and nuclear power, which led to the direct use of large amounts of electricity for heating. The oil crisis in the 1970s led to a broad change in political discourse towards gradually replacing the direct use of oil, both in single-dwellings and apartment buildings. In contrast, 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.

A second system shock resulted from growing concern over climate change, which led to the introduction of a carbon tax in 1991. Several energy taxes followed, shifting overall taxation policy from labour to energy and emissions. These taxes have been influential in both lowering Swedish greenhouse gas emissions as well as shifting the discourse towards renewable energy. As a consequence, market development for new innovations, such as heat pumps, took off and the total share of renewable energy in the heat domain grew over time to about 70% today (depending on yearly average temperature), which is the highest percentage in the EU.

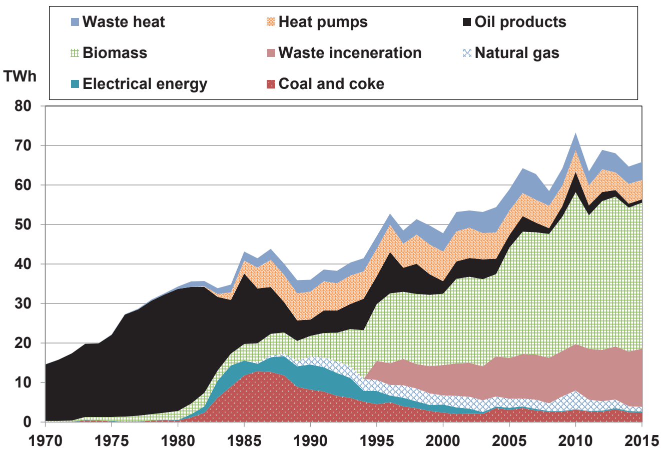

Figure 1: Fuels in the district heating system in Sweden in TWh.

At the same time, the nature of Sweden's residential building stock favoured the development of district heating systems. The prevalence of residential apartment buildings, both rental and owner-occupied, 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 apartment buildings. Detached houses represent a heated area of 292 million m^2, compared with a total of 175 million m^2 for multi-dwelling buildings. The Swedish population is split roughly 50/50 between each of these categories of housing, but single-dwelling buildings take up more space and thus require more heat per resident.

Technology and infrastructure

District heating 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. The process was encouraged by the opportunity to cogenerate heat and electricity through combined heat and power (CHP) systems, which today constitute 45% of the total supply. District heating supplies more than half of the total heat demand in Sweden, dominating the Swedish multi-dwelling sector, with an 85% market share, compared with only 16% in single-dwellings.

A key technological feature for district heating is its capability for reinvention. Figure 1 shows the dynamic fuel supply changes 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. District heating is vertically integrated with central production of hot water. System characteristics and economies of scale mean that it is not cost effective to compete with parallel infrastructure, so district heating creates a natural monopoly.

District heating incorporates industrial waste heat through access to third party actors, which has led to new heavy industries that connect their waste heat to the local infrastructure. Sweden is a world leader in this area, with 4.9 TWh of waste heat supplied. But there is more potential, estimated at 6.2–7.9 TWh.

Electricity, meanwhile, is the main source of heating in single-dwelling houses. A large share of the inefficient heating systems that were traditionally used has been replaced by heat pumps. Heat pump 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).

Sweden and Switzerland are the two countries with the largest number of installed heat pumps per capita. The Swedish market took off following the oil crisis in the late 1970s, and since the early 1980s more than one million heat pumps have been sold by Swedish manufacturers. Heat pumps significantly contribute to lowering energy consumption, with a total absorbed energy of 14 TWh in 2009. The Swedish government has played a key role in the development and commercialization of heat pumps by supporting technology and knowledge development, entrepreneurialism, and involving key actors in networks and organisations. It has also provided subsidies for conversion from oil-fired boilers and direct electricity.

Actors in the heat energy system

The Swedish heat system has been helped by the strong role of the public sector – municipalities and the national government – which has served as a force for continuity, both as actors and by providing the institutional structure of the system itself. 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. Boverket regulates energy consumption in the built environment and provides information on building energy use to through the Energy Performance Certificate. In addition, municipalities are key actors through the Planning and Building Act, which instructs all municipalities to have a "comprehensive plan" for overall development. Thus, the municipalities control and develop district heating infrastructure.

For district heating, the key actors are the providers. As the electricity and heating markets were deregulated in the mid-1990s, the market structure shifted away from communal ownership toward private ownership. Buyers were large utilities, national and international, such as Vattenfall, E.ON and Fortum. In 2004 these operators accounted for 35% of the energy supply for district heating.

For heat pumps, 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. Amid growing concerns about climate change and lobbying from advocacy groups, the market was further strengthened in the 1990s with substantial market growth at 35% per year. The market continued to flourish in the 2000s, establishing heat pumps as a key part of the heat energy system.

In terms of fuel input, the forestry sector has been an important supplier of biomass for district heating. Biomass is the main fuel for district heating and the industry has benefited from energy taxes that have generated a strong bioenergy market. The second important fuel input is waste incineration. About half of all household waste is incinerated, contributing to the production of 14.7 TWh of heat, which composes 22% of he total heat production, and 2.3 TWh of electricity in 2015, which is about 1.5% of total electricity production. 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 2015, 1.6 million tonnes of waste was imported as fuel for district heating.

Formal and informal institutions

The EU Energy Efficiency Directive (2012/27/EU) requires national governments to develop a strategy for energy efficiency in order to implement 20% reduction in greenhouse gas emissions, to raise the share of renewable energy to 20%, and reach 20% improvement in energy efficiency by 2020 relative to 1990 levels. The Government of Sweden'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. Sweden also incentivizes renewable energy production through a Tradable Green Certificate system, aiming to contribute to 25 TWh of

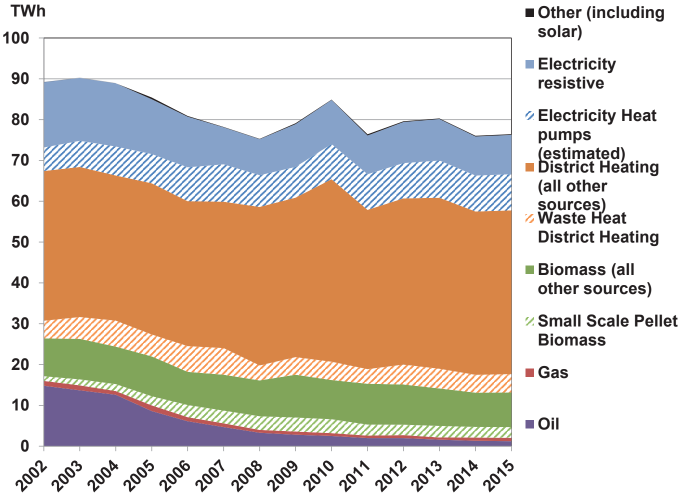

Figure 2: Energy use for heating and hot water by energy carrier in Swedish housing domain.

renewable electricity from 2012 until 2020. As a consequence, the Tradable Green Certificate system favours electricity generation from mature technologies such as combined heat and power and wind power, since their production costs are lower than for newer technologies such as solar and wave power.

In terms of the built environment, the key piece of legislation is the buildings code and its requirements on energy efficiency, which is supported by the EU Directive on the Energy Performance of Buildings (2010/31/EU). It states that all new houses by the end of 2020 should be "near-zero energy buildings". Conversely, 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/m^2/year, twice the level of energy use envisioned by the EU directive.

In order to increase industrial waste heat in district heating, two national inquiries have been undertaken. These led to proposed changes in the District Heating Act to allow third parties to access the district heating infrastructure under certain circumstances. A strong emphasis has been put on new industries and businesses beyond heavy industries, such as large server rooms adjacent to cities and shopping malls. Notwithstanding, it is expected that the regulations will not create effective competition on the supply side, because of high entry barriers for new actors. There are also other reasons, such as failure to agree on the price and large cultural differences between the private industries and municipally owned companies.

Recent revisions of the building code have given an advantage to heat pumps over district heating, since a larger amount of energy for heating is permitted with heat pumps installed. 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. Calculations have shown that the cost of achieving the energy efficiency goal is significantly lower when using heat pumps.

On the consumer side, demand for heat energy is high. Indoor temperatures in Sweden have remained constant in the past decades, averaging 21.2°C in single-dwellings and 22.3°C in multi-dwellings. This is significantly higher than in other European countries. In UK, for instance, the average temperature is below 20ºC. Reducing average indoor temperature has the potential to yield significant savings. If the average temperature in Sweden was reduced to 20ºC, it could save 13.3 TWh per year, which constitutes the largest single savings potential in the housing sector.

A successful transition and then what? Key characteristics of the new heat energy system

The Swedish heat energy system illustrates how the success of two dominant supply-based systems is characterized and heavily influenced by technological development. Shifts in how actors and institutions interact, and by changes in markets, user practices, policies, governance and institutions all also have an impact. Three characteristics that explain these changes and future challenges are presented below.

Complementarity

District heating and heat pumps have historically complemented each other as systems. The two technologies have devel-

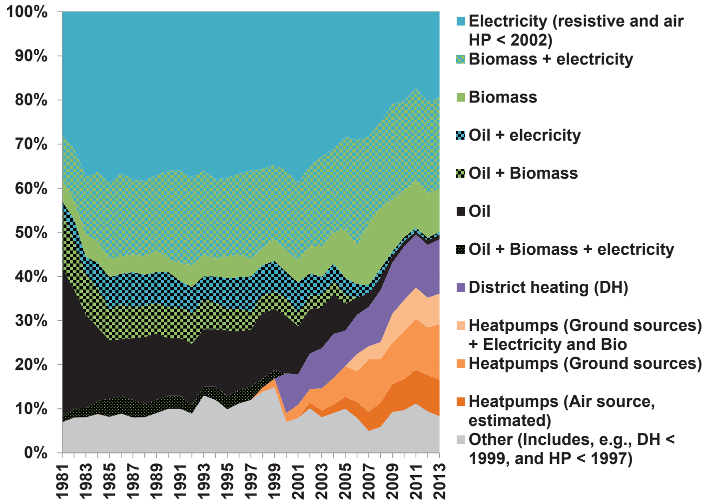

Figure3: Share of total heated area in single-dwellings for each heating technology.

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.

oped in parallel (with varying help from different actors in the system), district heating being dominant in apartment buildings, while heat pumps are more prevalent in single-dwelling homes. Both technologies have benefited from other sectors, such as the forestry industry, which has provided fuel for both heating and electricity. 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 above energy efficiency measures. The two sources can also be used within the same system. For example, heat pumps can be used to recover energy from the exhaust air in a building with district heating.

Interconnections

The system of supply-dominated technologies is interconnected. For example, waste heat is almost exclusively used as part of a district heating system, and other forms of access to third parties are similarly linked to district heating. In the single-dwelling sector, heat pumps built on the existing application of using electricity for heat; the niche technology is just a more efficient alternative to direct electricity. And usually, one type of heat pump is mainly replaced with another (e.g. switching from ground source or air-air heat pumps).

The heat system in Sweden reflects a cultural preference for supply-side-dominated large-scale solutions and domestically sustained heat production. There is no momentum for demand-reducing technologies such as net metering and low-energy housing. As a consequence, the transition to an energy efficient system has been hindered by the persistence of high indoor temperatures and slow implementation of EU directives on building energy efficiency. Conversely, the need for renovation and refurbishment in the building stock 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.

Saturation

Notwithstanding the successful transition, the system dynamics are changing and the focus on production and heat energy supply is becoming increasingly problematic as the markets are saturating. After 13 consecutive years of growth, in 2007 sales of heat pumps declined relative to the previous year,

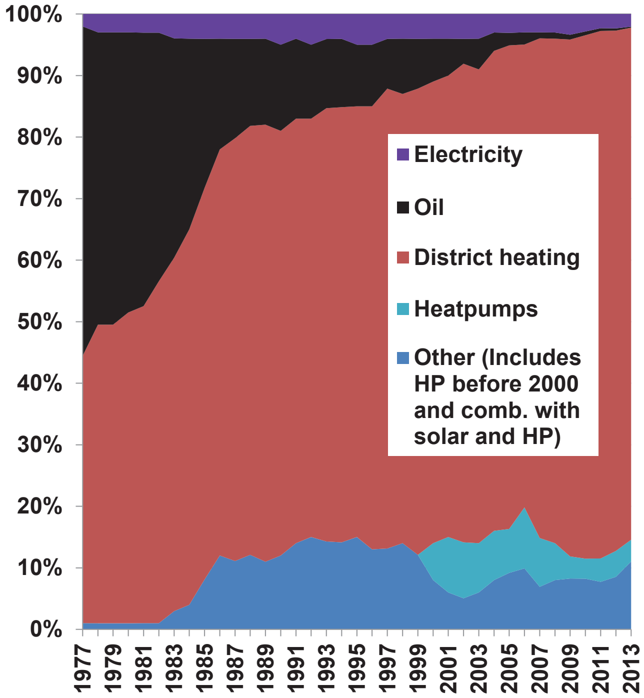

Figure 4: Share of heated area in apartment buildings.

and declines also occurred in 2009 and 2011. This has led heat pump actors to seek to grow their business in larger cities and apartment buildings. Recent policy development and discontent with the monopolistic structure of district heating has made heat pumps a competitive alternative. Conversely, district heating is also facing market saturation and decline in demand due to building upgrades and renovations of multi-dwellings. Warming temperatures and the need to adopt new policies to comply with EU energy efficiency standards will create additional pressures on the system.

At the same time, continued investment in new waste-burning combined heat and power plants has led to a debate about over-capacity, lock-in of waste incineration, and dependency on waste imports. The Swedish heat regime is thus experiencing increasing tensions, disagreements and competing interests among regime actors. A lock-in of waste incineration as a major fuel source 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 addition, waste incineration may be disrupting the potential of industrial waste heat in district heating systems.

Conclusion

Despite the low-carbon transition the system as a whole did not undergo deep changes. Tensions between the main actors have been limited, and they have maintained their dominance. However, this is changing: external pressures and integral inconsistencies are becoming more prevalent in the Swedish heat energy system.

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. Thus, the new system is continuing on an old path of a supply-oriented production, with a large centralized system with locked-in infrastructure that supplies cheap heat and electricity.

Reducing demand through more energy efficient but expensive building techniques, such as materials and heat control systems, will likely continue to meet resistance from the main actors in the system. As electricity is already nearly fully decarbonised, and institutional barriers are strong, it is not clear that future policy development will include the range of instruments and interventions needed to achieve deep reductions in demand and thus meet the EU and national policy targets.

This policy brief is based on Dzebo, A. and Nykvist, B. (2017) A new regime and then what? Cracks and tensions in the socio-technical regime of the Swedish heat energy system. Energy Research & Social Science. 29 https://doi.org/10.1016/j.erss.2017.05.018

Policy recommendations

- The supply-side heat generation system in Sweden is not sustainable in the long-term. There is a need to find alternative options. Demand-reducing technologies, such as net-metering, low energy housing and lower temperatures should be considered as alternatives to continued increased heat production.
- Factors such as climate change, depreciation of the housing stock and policy will lead to an increased focus on energy efficiency measures that decrease the demand for heating in both single-dwellings and particularly in apartment buildings. The government, municipalities and energy producers should coordinate better to reduce the impacts from the potential shocks to the heat system.
- The potential to increase third party access to the district heating network is high. There is a need to reduce barriers in order to increase the use of industrial waste heat both from heavy industry and from new alternatives in larger cities such as shopping malls and server rooms.

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2017

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