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Cygnets or ugly duckling – what makes the difference? A tale of heat-pump market developments in Sweden

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Abstract

Who can pick a winner? Since 1974, various types of targeted support have at different times been directed at the development of the heat pump market in Sweden – which in the following decades oscillated violently between soaring sales and collapse. Eventually, however, small heat pumps for space heating of residential buildings have in recent years securely established themselves as a mature and competitive technology within the Swedish energy system. This presentation portrays the events and actors that defined the formation and transformation processes of the heat pump market segment in Sweden, extracting pieces of experience that contribute to our improved understanding of how combinations of policy instruments, their application and termination, can affect whether a technology is perceived and received by the market as a handsome swan-to-be or no more than a simple duckling.

Despite failing policies and markets, and despite continuously changing drivers in national energy policy, this technology has now lived up to the expectations of its proponents of the 1970s. One part of the explanation is found in the unique composition of the Swedish electricity supply and energy mix. Another is the perseverance of important key actors. A third part lies within the learning process that has taken place on the policy-making arena, and among manufacturers, installers, etc. Observations are made concerning the prospects for managing technical change.

The evolution may be seen as an uncoordinated transition management process over 25-30 years. A coordinated effort might have produced better results, but it is not clear whether it could have been sustained over such a long time period in changing organisational and political contexts.

A number of evaluations of policy instruments used in efforts to manage heat pump development have been performed along the way. These provide important information about the course of transpired events. But it is noted that such documents are permeated by the context in which they were written. Their assumptions and results need to be read and interpreted accordingly.

Introduction

Technical change in energy systems is an area that attracts increasing interest. An underlying reason is that the development of ecologically sustainable energy systems requires technical change. It is sometimes argued that the ambitious energy R&D efforts of the past 20-30 years have not impacted particularly on the development of the energy system (Näringsdepartementet 2003). Nevertheless, ground-source heat pumps for residential space heating are one example of a new technology, or at least a new application, which has developed from idea to reality over the past 30 years. These are now firmly established as a competitive option on the Swedish market for heating systems.

This study is inspired by the literature on technical change and the role of government in this process. During the period covered here, the literature on technical change and innovation systems has evolved. Inspired by the works of Schumpeter (1934) and the Vannevar Bush report “Sci-

ence the Endless Frontier” in 1945, innovation was long seen as a linear process where the role of government was to supply basic funding for R&D. However, the role of governments was soon extended to support demonstration programmes and to sponsor market development, even if the motives and scope of the market support differed substantially between countries. As innovation has grown to be one of the most important growth factors in the economy and one of the most hoped for solutions to many environmental and societal problems, the role of government has also grown and become much more complex focusing on innovation systems (Freeman 1995).

The theoretical framework explaining how governments can influence the direction of technical innovation has moved from a more or less linear view to a view best described by the term transition management or strategic niche-market management, see Kemp and Loorbach (2003) or Kemp et al. (1998)¹. This is a wider view than the linear approach and the role of government is to act as a manager of strategic niche markets, modulating the market by for example taxes, legislation and early deployment support together with traditional RD&D funding. The overall concept, which is based on voluntary agreements and soft compliance, is for governments to modulate technical change in a desired direction. Transition management can be seen as a reframing of new and existing programs into a comprehensive and coordinated policy framework.

It should be noted that different energy technologies have very different technical and economic characteristics and belong in different organisational and institutional settings concerning actors involved, financing, regulations, etc. Other factors, e.g. the broader energy infrastructure and system setting, may also be influential for the introduction and diffusion of new technologies. Hence, although it is difficult from a specific case as presented here, it is our ambition to make observations that have a bearing on the general discussion on technical change, evaluation, and the role of government.

There has been a growing interest in policy evaluation in recent years. The motivation behind an evaluation can be the wish to change policy or remove a specific policy instrument, to improve policy through learning from experience at home or abroad, or to show that the government is spending the tax-payers money wisely. It is not our aim here to evaluate relevant policies, or earlier evaluations made in Sweden, but rather to reflect on the role and scope of evaluations in a broad context and with a long time perspective. Several programs to support heat pumps in Sweden have been criticised and deemed as failures, but nevertheless, looking over the whole period, a relatively mature technology and a stable market has developed. We believe that these programs and policy instruments, regardless of how they, in isolation, were received at the time of their completion, also need to be considered from a distance, as parts of the entire chain of transition managing efforts (coordinated or not) of which they have become part. This paper illustrates that such a ho-

listic evaluative approach may now be possible to take in the case of Sweden’s heat pump market.

Objective and structure of the paper: Our overall objective in this study is to reconstruct and analyse the development of heat pumps and the heat pump market in Sweden in the context of overall energy policy and the specific government efforts directed at heat pumps. Our focus is on heat pumps for residential space and water heating and a brief note is made on technology and terminology in order to avoid misunderstandings. Some basic characteristics of the Swedish energy system and energy policy development are presented to provide the broader context. Government R&D support, market support and the market development is described chronologically in terms of different development phases. In the discussion we reflect on some key issues that emerge from the history of heat pumps in Sweden.

Technology and terminology

In this presentation, and in accordance with common Swedish vernacular, a heat pump – unless otherwise indicated – is to be understood as a system of connected technical components used for residential heating, particularly of small, detached houses. A heat pump absorbs energy in a (relatively cool) reservoir or heat source, transferring it to the (warmer) recipient, i.e. the indoor living space. The reverse process of air conditioning, using indoor air as a heat reservoir, is also possible. However, devices constructed for such a purpose are not included by our definition of a heat pump; unless the equipment is in fact also used the other way around – for heating. In order to sustain the transfer of heat from reservoir to recipient, a heat pump consumes electricity, and the ratio of delivered thermal power to feed-in electric power is called the coefficient of performance, or COP.

The COP varies with the temperature difference between the heat source and the delivered heat. A small difference yields a higher COP. A typical COP value for a ground-source heat pump in Swedish conditions is 3, i.e. three kWh of heat are delivered for each kWh of electricity consumed.² Hence, if electric resistance heating (which has a COP that equals unity) is replaced with a heat pump, we make a considerable energy saving. On the other hand, if heating fuel is saved in exchange for increased marginal electricity production, the energy saving depends on detailed assumptions concerning conversion efficiencies and distribution losses. Seen in economic terms, the relative electricity and fuel prices are important for the decision to install a heat pump. In Sweden, the electricity-to-oil price ratio has been about 1-2, partly due to high fuel taxes, whereas the electricity-to-oil/gas ratio in other countries has been on the order of 3-4, making heat pumps a less attractive investment.

In general terms, a heat pump consists of three separate, functional parts. These are (i) the collector, (ii) the compressor circuit and (iii) the distribution component. Note that in contrast to the terminology used here, the words “heat pump” may often, especially in technical contexts, refer merely to the compressor circuit, rather than to the entire

1. This is not to be confused with the theoretical framework describing the economy-wide implications of innovation, see e.g. Rosenberg (1982) and Lundvall (1992).

2. NB. This paper adheres to the Swedish tradition of using the kWh as the base unit not only for electric energy, but for thermal energy and for the heat content of fuels as well.

system of heating equipment. This circumstance may, unfortunately, constitute a reason for terminological confusion. Within the context of this paper, however, we hope hereby to have mitigated such ambiguities.

Heat pumps need to be specified in terms of heat sources and distribution media. Natural reservoirs for commercially available heat pumps include outdoor air, surface soil, (sea-, lake- or river-) water and bedrock. For small heat pumps, ventilation exhaust air is a factitious but widely used heat source. In contrast to the variety of available collector environments, the distribution medium is, for all practical purposes, either water (as in a hydronic radiator circuit) or air (as from a fan convector). For any given heat pump application, heat source and distribution medium may be selected and combined to suit the geographical and building-specific conditions at hand. In Sweden, four kinds of systems have been especially important, although to various degrees at different stages in the examined period. These systems are (i) air-to-water heat pumps, (ii) exhaust ventilation-air heat pumps, (ii) double-air heat pumps, and (iv) ground-source heat pumps (see Table 1). Ground-source heat pumps may, in turn, be subdivided into several different categories. Not only can they use different distribution technologies. They may also differ in the design of the collector component, which, first of all, can operate on an open circuit (i.e. a once-through system) or a closed circuit. Furthermore, a closed collector circuit can be directly or indirectly (via heat exchangers) connected to the compressor circuit. Most ground-source heat pumps are closed-circuit, indirect ones (STEM 2004).

In general, the primary purpose of a residential heat pump is to supply base-load heating. For economic reasons, heat pumps in Sweden are rarely dimensioned to cover peak-load demand (this is not necessarily true for other countries). This means that supplementary heating technologies need to complement heat-pump installations. Guidelines from the Swedish Energy Agency recommend dimensioning heat-pump capacity to cover no more than 50 to 60% of the maximum thermal power needed. Thus, the pump will provide between 80% and 90% of the annual energy demand for heating (STEM 2004). Supplementary heat may be supplied through individual oil, coal, biomass or electricity systems – or even (in theory) through a connection to district heating (STEM 2004, Laurén 2001, Fagerström 1992). Most common in new installations is some form of electric heating. In contrast, one may note other, contradictory (and ear-

lier), comments on the dimensioning of heat pumps (Oldin 1987, 53):

“Heat pumps that are complemented with electric or district heating during times of peak demand (winter) can **never** be justified. One must either install a heat pump that covers the entire annual demand, or, during the coldest months of the year, complement it with, for example, an oil-fired boiler.” *[Original bold-faced emphasis.]*

This kind of comment does not take into account the limitations and requirements of household economics, but has to be understood in a larger, systemic context. From a practical household perspective, such a heat-pump installation is not considered feasible, especially not in retrofit installations. In newly built houses that are designed with heat pump system solutions in mind, however, the peak-load, non-heat-pump component can be minimised through a flattened duration curve – and a ventilation-air heat pump may contribute the main share of base-load heating, in some cases even complemented by ground-source equipment. But supplementary heating (most often electric) will in most cases still be installed as a peak-load booster.

Overview

As background – and incentive – for the study presented here, we look upon the technology and market developments in Sweden of residential heat pumps in the past thirty years. Having gone through dramatic and turbulent changes in terms of sales figures as well as in public confidence, heat-pump technology now appears to have securely established itself as a commercially viable and technically mature option for those who invest in residential heating equipment. It is estimated that sales of heat pumps reached over 66 000 units in 2004 (up from nearly 50 000 units in 2003, not including about 20 000 convenience/air-conditioning heat pumps for which sales data are not disclosed) and that the total number installed now has been estimated to exceed 500 000 units (Ny Teknik, 2004). A statistical survey put the number of heat pumps in single family houses at 244 000³, but cautions that this is an underestimate since house owners are reluctant to report heat pumps due to property tax reasons (SCB 2004). There are three established Swedish manufacturers that dominate the market, IVT, NIBE, and Thermia. What started, at the height of the first oil and energy crisis of the

Table 1. Heat pump systems of specific significance during the period of heat pump development in Sweden.

RESERVOIR DISTRIBUTION	Outdoor air	Ventilated indoor air	Soil, bedrock or water
Hydronic circuit	air-to-water heat pumps	exhaust ventilation-air heat pumps	ground-source-to-water heat pumps
Indoor air (e.g. fan convectors)	double-air (or convenience) heat pumps		(ground-source-to-air heat pumps)

3. Of which 114 000 air-source and 130 000 ground-source (including soil, rock and water reservoirs).

early 1970s, as a vision among technicians and political and social planners, has finally eventuated after decades wrought with numerous government-supported programmes and various kinds of policy instruments.

In continental Europe, specifically Germany, visions and programs similar to Swedish ones were seen in the early years of the examined period, but there the concept of residential heat pumps never recovered from the setbacks in the early 1980s (see Keller 2004). Why did the development continue in Sweden? Was it just coincidence that a winning technology concept was picked right from the start? Which factors can explain the apparent success of heat pumps in Sweden and what lessons can be learned for policy and policy evaluations?

In order to discuss these questions, we portray the development chronologically. As a way of organising the presentation, the heat-pump development in Sweden may be seen to have gone through the following phases:

1. The visionary overture of the 1970s.
2. The prelude of support and expansion of the late 1970s and early 1980s.
3. The crash-and-crisis phase of the mid 1980s.
4. The reversible-pump interlude of the late 1980s and early 1990s.
5. The renewed focus on energy efficiency measures and support of the 1990s.
6. The establishment of a mature market of the new century.

The development takes place in a broader context where the development phases overlap a sequence of changing energy paradigms:

- 1970s: Oil was used as the main fuel in district heating systems and in boilers for space and water heating in most buildings. Reducing oil dependence was a key energy policy objective. On the electricity stage, a moratorium on further large-scale hydro developments had shifted attention towards the establishment of nuclear power in Sweden.
- Early 1980s: In the wake of public opposition to nuclear power, as manifested in the referendum of 1980, and still disfavoured regarding oil as a major energy source, the political and research agendas placed increased strategic importance in exploring the feasibility of renewable, “solar”, sources of energy. “Solar heat” included not only primary solar radiation, but also biomass (used as fuel) or heat stored in soil and water (retrieved by using heat pumps).
- Late 1980s to early 1990s: Saving electricity became a key energy policy objective as the plans for phasing out nuclear power were taking shape: “In Sweden, we have a large number of small [residential] houses with electric resistance heating. This is obviously not a rational use of electricity. Heat pumps are required to achieve rational

use of electric energy [for residential heating].” (Andersson and Setterwall 1995: 186)

- Mid 1990s to early 2000s: The electricity market reform took effect in 1996, fundamentally changing the role of electricity companies from a monopoly situation to competition down to the household retail level. Sustainability and climate benign technology is high on the agenda, and nuclear phase-out is progressing, but slowly.

The six heat-pump development phases mentioned above may also be seen in the light of varying political orientations of Swedish governments, which, in the period examined here, have often tended to be based on a minority of the parliamentary representation. This has affected Swedish energy-policy making. As established political parties or alliances have found themselves troubled, particularly within this area, by internal disagreement and opposition, any long-term energy agreements have required negotiation across traditional bloc boundaries. Still, short-term energy policy decisions and budgets have had to be consolidated within the coalition or support parties of the government in office. As a consequence, the period has been characterised by a generally turbulent and polarised energy-policy debate. These conditions may help explain the constant restructurings and shifts that occurred in the field of actors, as well as in the usage and design of policy instruments, during the 1980s and 1990s.

Energy in Sweden and the Policy Setting

The structure of the Swedish energy system and the broad strokes of energy policy since 1973 provide the overall setting in which the development of residential heat pumps unfolded. Primary energy use in Sweden is high (about 62 MWh per capita⁴ in 2000) and the electricity consumption is more than twice the EU average (15.7 MWh per capita in 2000). Important reasons for this are industrial structure and climatic conditions. The energy supply has undergone structural changes since the 1970s. Natural gas, for instance, was introduced in 1986. The use of oil, which accounted for about 80% of primary energy supply in the early 1970s, dropped by about one-third between 1970 and 1985, and has remained relatively constant since then. The oil consumption was partly substituted by the use of electricity from the large expansion of nuclear power during 1973-1985. Nuclear power accounts for about half of the electricity production in Sweden, and hydropower accounts for almost the other half.

For climatic reasons, space heating is important in Sweden. In 1970, about 80% of the energy use for space and water heating in single family houses in Sweden was accounted for by oil in district heating and individual boilers, and about 10-15% was fire wood (STEM 2000). These buildings were typically equipped with hydronic heat distribution systems. The total energy use in single family houses has been relatively constant at 50 TWh since 1970 whereas the specific energy use (kWh/m²) was reduced by about 50% between 1970 (320 kWh/m²) and 1986 (170 kWh/m²). The refurbish-

4. Primary energy supply includes conversion losses in nuclear power. Hydropower is counted as electricity and not calculated at a thermal equivalent.

ment of old houses, addition of new houses with better thermal performance, and the switch to electric heating with much lower conversion losses at the point of end-use explains much of this improvement. New houses in the 1970s and 1980s were typically equipped with direct electric resistance heating. By 1990, approximately 40% of the heating was electric and oil accounted for only 30%.

Since 1975, Sweden's energy policy objectives have been to secure energy supply through an increase of domestic, and preferably renewable, sources of energy under conditions that do not jeopardise Sweden's international competitiveness. The driving forces have changed over time – from reducing dependence on oil to phasing out nuclear power and, more prominently in the past decade, to limit the impact on health, the environment and the climate.

Until the late 1960s, electrification in Sweden relied heavily on the expansion of hydropower. Attention then turned to nuclear power, partly because of increasing controversy concerning the exploitation of the remaining rivers. Between 1973 and 1985, 12 reactors were built. The expansion of nuclear power coincided with the oil crises. Reducing oil dependence through changing the fuel mix became an important policy objective. Nuclear, coal, peat and renewables were the supply alternatives. Energy efficiency was also a key strategy to reduce oil consumption. Public resistance to the nuclear option grew during the 1970s. In 1980, Sweden held a referendum that led to the parliamentary decision that nuclear power should be phased out by 2010. The 1970s marked the start of a long and intense debate over the future course of energy system development in Sweden. In the late 1980s and throughout the 1990s, many decisions have been revoked, mainly motivated by the perceived negative impacts on industrial competitiveness that could result from higher electricity prices. The political decision to phase out nuclear power still stands, but the fixed closing date of 2010 was abandoned through the 1997 Energy Bill. The first reactor to be decommissioned, Barsebäck 1, was shut down in 1999 and the closure of Barsebäck 2 is scheduled for May 2005.

During the 1990s, sustainable development, climate change mitigation and deregulation emerged as important principles for energy policy. In 1991, a multi-party political agreement on the future energy system was settled. Since then, the energy policy objectives have been to secure energy and electricity availability in the short- and long-term, competitive energy supply, and change over time to a more sustainable energy system based on increased use of renewables and energy efficiency. Three major programmes – an energy efficiency programme, funding for technology RD&D, and investment studies – were to influence the transformation of the Swedish energy system. The energy agreement was reconfirmed in 1997. Climate change has emerged as an important aspect of the energy policies during the 1990s. In 2002, the Kyoto Protocol was ratified by Sweden together with the rest of the EU, and the Swedish Parliament decided on a climate strategy that had been developed over several years.

Energy market liberalisation was also an important factor for energy policy in the 1990s. Inspired by reforms in the United Kingdom and Norway, and by Sweden's accession to the EU in 1995, the reform of the Swedish electricity market

took place in 1996. Transmission and distribution were separated from production and trade, and the entire electricity market was opened for competition, causing a wave of acquisitions and mergers.

A heat pump chronology

The heat pump development for residential applications in Sweden should be viewed in the context of overall energy policy and the changing structural conditions brought about by the expansion of electric heating, typically direct electric resistance heating, of single family houses. The story begins in 1973.

PHASE 1: VISIONS (1973-1978)

The oil crisis in 1973 initiated the planning of the first Energy Research Programme (1975-1978) and prompted the government to institute an Energy Savings Programme in 1974 aimed at reducing oil consumption (Figure 3). Since electricity production was dominated by hydropower and the planned expansion of nuclear power, oil was mainly consumed in the transport sector and for heating in industry and buildings. The Energy Research Programme was characterised by a screening of various options, e.g. for energy efficiency and fuel switching, mainly for the purpose of reducing oil consumption. Heat pumps were identified as one promising technology option. There was essentially no market for residential heat pumps at this time.

A symposium organised by the Building Research Council and the State Power Board (now Vattenfall) in 1974 marks the start of modern heat pump development in Sweden. The basic technology had been known and tested since the 19th century, the interest and development in the United States and Japan was known, but the potential role and benefits of heat pumps in the Swedish energy system was not clear (Lindeberg 1984). The major R&D needs identified were to explore the applications and potential for heat pumps in residential heating (Fikri 1975). Prior to the symposium there was also an inventory of the knowledge base in Sweden which identified Chalmers and the Royal Institute of Technology as suitable environments for a strategic build-up of knowledge.

It is noteworthy that using the ground (surface soil or bedrock) or open (sea-, lake-, or river-) water as the heat source for small heat pumps was identified at this early stage as the most interesting option for Swedish climatic conditions. The main reason was that the temperature of outdoor air (a less complicated alternative heat source to use, in terms of then available technology) in the winter frequently falls well below 0 °C, creating conditions in which heat pumps do not perform well. Thus, a winner concept had been picked. Connecting a collector and compressor circuit to the heat distribution system of a small house, typically a hydronic system, may at this time have seemed like a relatively simple technical problem.

PHASE 2: SUPPORT AND EXPANSION (1978-1984)

In 1979, the Government initiated the Energi-85 programme aimed at gathering knowledge and experience for the purpose of assessing future possible energy systems (Efn 1985, Olofsdotter-Jönsson 1984). As a part of this, the

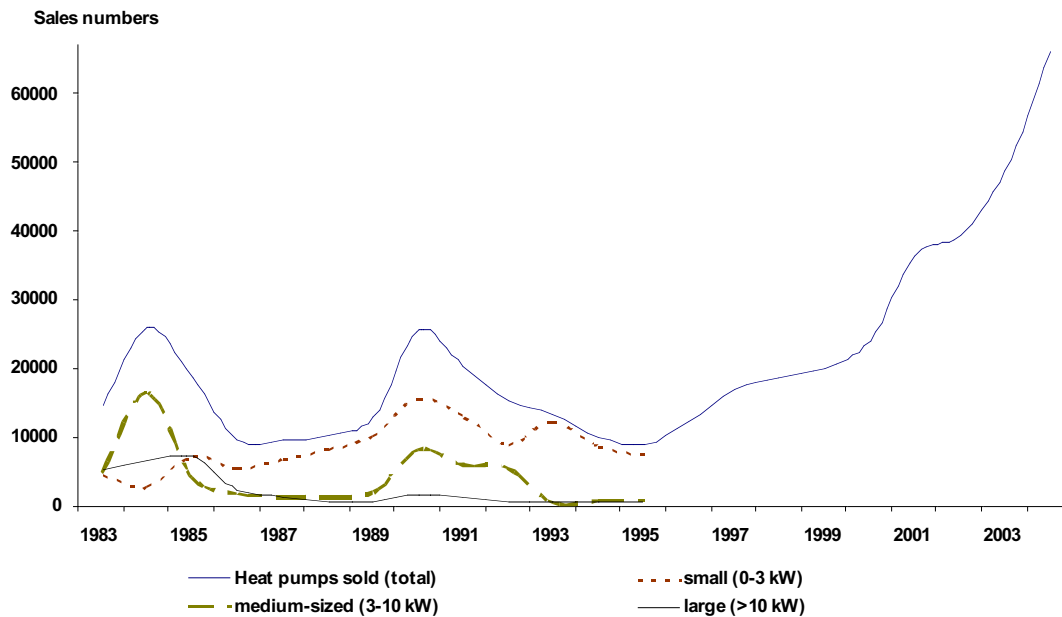


Figure 1. Heat pump sales in Sweden, 1983-2004. Source: data provided by SVEP (the Swedish Heat Pump Association) 2005.

Building Research Council conducted the Sol-85 programme, the focus of which was RD&D on solar based heating systems. Heat pumps were regarded as an essential part of a solar heated house and during 1979-1985 this programme was the main sponsor of RD&D on heat pump technology. Concurrently, Vattenfall ran a similar programme, the "Solar" programme, also exploring solar heating and heat pumps (Vattenfall 1989). Vattenfall installed, tested and evaluated 304 small heat pumps (< 25 kW) between 1982 and 1984. The Sol-85 programme was directed towards RD&D whereas the Vattenfall programme was mainly a demonstration programme. The Building Research Council also coordinated an education programme, starting in 1983, to meet the need for improved knowledge among mainly installers.

The framework of the energy-savings programme under which private installations of heat pumps would later be supported had been established in 1974, but its initial phase did not include heat pumps. Starting in 1978, however, heat-pump installations were explicitly eligible for favourable loan conditions and direct investment grants. The balance between loans and grants shifted during the lifetime of the programme (until 1983) but the combined support was relatively constant, corresponding to 10-15% of the total investment (Engebeck and Zingmark 1987). Although the support was relatively modest, it gave a signal to house owners that heat pumps were a preferable and viable option for heating. This market support stimulated the first wave of investments in heat pumps. The installed units were of different sizes, including large units for district heating systems (Figure 1). The change in Government in late 1982, from a house-owner friendly centre-right coalition to a Social democrat government led to a reassessment of the support programs. Partly motivated by the slump in the construction industry, efforts were redirected from the energy savings programmes to the refurbishing programmes that started in

1984, supporting the renovation of buildings. The final year of support for heat pump investments, announced as such, was motivated by concern for employment and capacity utilisation in the heat pump industry, in addition to energy savings. After 1984, there was no longer any financial support for owners of single family houses.

During this period the oil price increased drastically, so that the electricity-to-oil price ratio, including taxes, decreased from 3.1 in 1978 to 1.3 in 1984, i.e. electricity was only 25-30% more expensive than oil per unit of energy. Relative prices, in combination with the financial support (and a building code that required heat recovery on exhaust air in some ventilation systems) fuelled the rapid increase in sales (Figure 1). The units installed included many different types (Figure 2) but a popular system for single-family houses was the air-to-water heat pump. The boom attracted many new entrants to the market and towards the end of the period there were about 70 suppliers, most of them very small. The existence of some fundamental technical problems, as seen in the Sol-85 and the "Solar" programmes, together with a large number of unqualified suppliers, resulted in the malfunctioning of many heat pumps.

PHASE 3: CRASH AND CRISIS (1984-1989)

After the Sol-85 programme ended in 1985, heat pump RD&D was redirected from field tests and demonstrations towards more research on strategic components such as CFC replacements, engine-driven heat pumps, and advanced concepts. Vattenfall turned its attention to electricity efficiency improvements in general through the Uppdrag-2000 project (Josefsson 1990) which was charged with examining the potential for electricity savings as the political pressure for planning a phase out of nuclear power was building up. The Building Research Council together with STEV, the newly founded energy administration (1983-1991), continued to support academic R&D on heat pumps during this

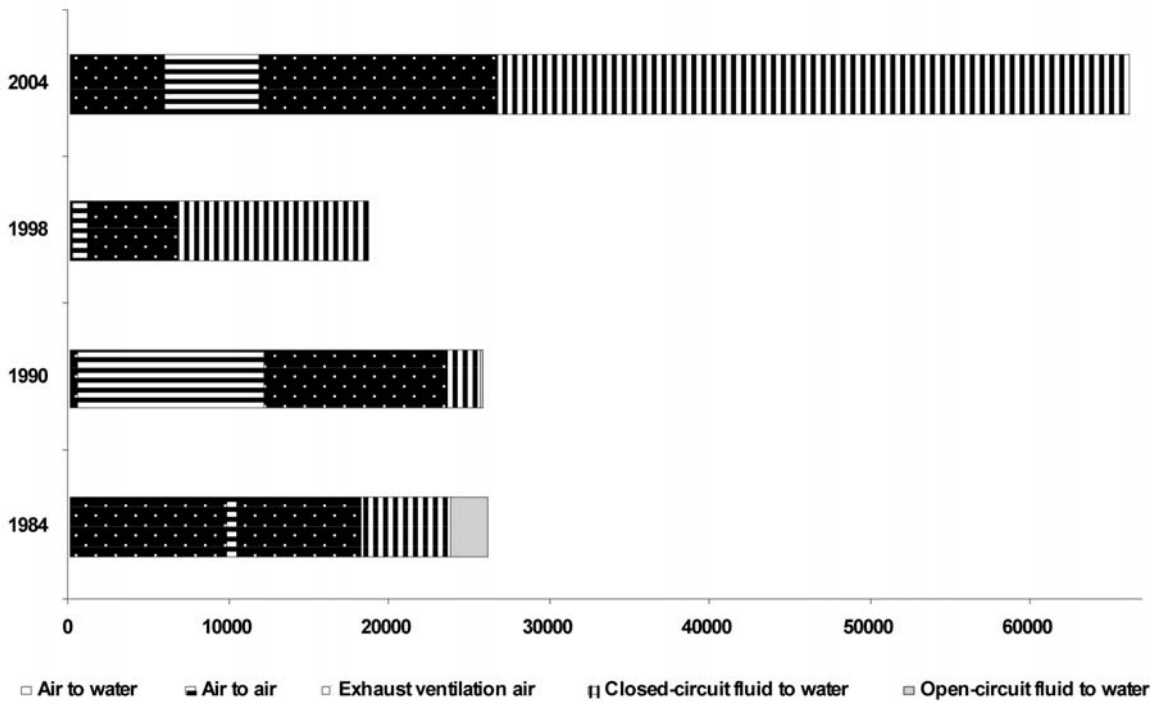


Figure 2. Heat pump sales in Sweden 1984, 1990, 1998 and 2004; by technology. Source: data provided by SVEP (the Swedish Heat Pump Association) 2005.

period. The Montreal protocol on ozone depleting substances was signed in 1987.

Market support in the refurbishing programme, through soft government loans, was directed towards multi-family buildings, and energy-savings loans for the installation of heat pumps in these buildings survived until 1987. Private house-owners, however, were left without any support at all for energy-efficiency measures, including heat pumps, and many of those who had made heat-pump investments in the early 1980s now battled with technical problems. The drop in oil prices in 1986 may have contributed to dampening the interest in heat pumps, but increased taxes on oil kept the electricity-to-oil price ratio at 1.7 in 1987.

Through the mistakes done in the boom period, heat pumps had now gained a relatively poor reputation in Sweden, something which the Building Research Council had warned against already in 1982 (BFR 1982). References were made to the US experience in the 1950s when the market went through a similar boom and bust period due to the poor operating performance and durability. Also, a similar market crash took place in Germany in 1981-83, just a couple of years before the Swedish one. However, in contrast to Germany, the interest in heat pumps in Sweden among key actors, such as civil servants and energy companies, did not wane very much. Although world market oil prices were decreasing, and the general attention now turned to reducing electricity demand to facilitate a phase-out of nuclear power, heat pumps were still considered as the solution, even if the problem was new. The use of electric resistance heating in buildings had increased more than five-fold from 1970 and reached 25 TWh in 1985. In addition, perhaps 10-15 TWh of electricity were used in boilers for (resistance) heat production in district heating and in industry. Heat pumps

clearly offered a thermodynamically much better alternative for the production of this heat.

PHASE 4: SURGE FOR CONVENIENCE (1989-1993)

Heat pump R&D continued throughout this period but the responsibility was gradually shifted from the Building Research Council to STEV and the Board for Industrial and Technology Development (NUTEK) (Rantil 2002). This also marked a change in focus towards developing heat pumps for industrial competitiveness and commercialisation. Research was financed and undertaken in collaboration with industry.

There had been no market support policies addressing heat pumps since 1984, but between 1990 and 1993 two initial market transformation efforts we undertaken (Energianvändningsrådet 1994). (At the same time NUTEK’s successful and much publicised refrigerator technology procurement was ongoing.) These two initiatives had character of demonstrations and market surveys, with relatively little market impact. The main technology procurement and market transformation effort started in 1993.

The sales of small double-air units (typically 0-3 kW), often called convenience heat pumps (or reversible pumps since they can also be used for cooling in the summer) had increased slowly during the late 1980s and peaked in 1990. Electricity prices increased slightly faster than inflation, and with the expectation of even higher electricity prices many private house-owners with electric resistance heating equipped their homes with such units. There was also a marked increase in the sales in heat pumps that, in accordance with the building code, used exhaust ventilation-air as a heat source. The building code is mirrored in the relatively steady sales of exhaust ventilation-air heat pumps from 1984 to 2004. The development around 1990 was largely driven

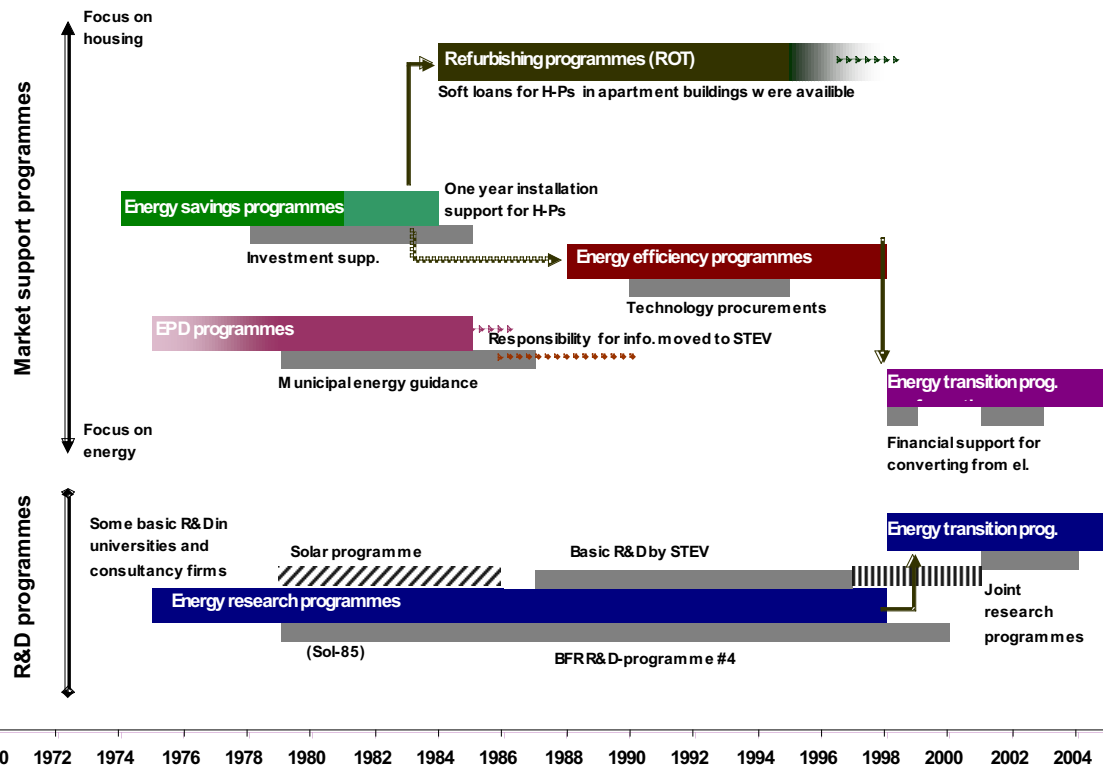


Figure 3. Major Swedish public support programmes of relevance to heat pumps between 1974 and 2004. (Based on several official sources.)

by the building boom in the generally overheated economy at this time. An abrupt end came with sky-rocketing interest rates and the economic crisis in 1992.

PHASE 5: NEW FOCUS (1993-1998)

In terms of technology development and market support, the technology procurement effort that ran between 1993 and 1995 stands out as the most important activity during this period. The subsequent break-through of ground-source heat pumps for single-family houses is often attributed to this market-transformation programme, organised by NUTEK. The objective was to support the development of more efficient, reliable, and less expensive ground source heat pumps for single-family houses. One of the main barriers to market diffusion that had been identified was the poor reputation of heat pumps caused by malfunctioning equipment in units installed during earlier years. A group of potential buyers drafted, together with experts and NUTEK, a list of performance criteria and the buyer group committed to buying 2000 units of the winning concept. Six manufacturers met the criteria and two heat pumps were announced as winners. The programme was also complemented with information campaigns and a customer hot-line for questions. However, even these winning technologies proved to have some technical problems and the reputation of heat pumps remained somewhat tarnished.

Nevertheless, starting in 1995 the sales figures started to climb again. This time, the ground-source heat pumps for single- or two-family houses were capturing an increasing, and eventually the largest, share of the market. In contrast to imported convenience heat pumps, ground-source heat

pumps are manufactured in Sweden for Swedish conditions. In 1998 an investment subsidy was introduced for conversion from direct electric resistance to other means of residential heating. The support scheme allowed new heat pumps to benefit, as well as other solutions including pellet boilers. Reducing electricity consumption was still high on the political agenda. In the latter part of the 1990s there was also a general economic recovery.

PHASE 6: MATURE MARKET (1999 -)

The investment subsidy from 1998 for conversions from electric resistance heating to alternative heating technologies was suspended in 1999, and briefly reinstated between June 2001 and January 2003 but with negligible effect on the Swedish heat-pump market. Since 1999 the sales of heat pumps have taken off considerably, increasing from less than 20 000 units in 1998 to more than 66 000 units in 2004 (see Figures 1 and 2). Considering that there are about 1.5 million single- and two-family dwellings in Sweden the current level of sales is not sustainable in the long term (assuming a life time of 20 years it would correspond to 1.2 million houses being equipped with heat pumps). There are still complaints, however, that heat pumps, also relatively new ones, are too prone to failure with 3 800 insurance claims amounting to a total cost of 4.8 million Euro in 2003 according to the insurance company Folksam. Hence, the cost of repair per unit is about 1 200 Euro to be compared with the heat pump system investment costs which may range from 3 thousand Euro to 16 thousand Euro. For illustrative purposes, 4.8 million Euro spread out over a population of 200 000 units corresponds to 24 Euro per unit and year. This

indicates that the technical reliability can be improved, but the numbers do not seem unreasonably high for maintenance and repairs.

The markets for residential heat pumps seem to be heating up in other countries. Sweden used to dominate the market completely but since 2004 the total sales in Europe exceed the sales in Sweden according to a Swedish weekly technical magazine, *Ny Teknik*. One indication of the potential for market development is that one of the leading manufacturers, IVT, was acquired in November 2004 by BBT Thermotechnik, a part of the Bosch group and a leading manufacturer of heating equipment in Europe. IVT will be responsible for heat pump R&D, training and manufacturing in the BBT Thermotechnik group

Discussion

For many reasons, we feel that the Swedish heat-pump experience is an interesting, actual case to examine within the context of program evaluation and theories on technical change. In this context we want to underscore a few topics worthy of further discussion.

- The importance of the wider context, e.g. the energy system and the organisational and institutional setting, in which the development takes place.
- The dynamics of the cast of actors and of their agendas.
- The prospects for managing technical change.
- The contextuality of evaluations for assessment of innovation-promoting policy instruments.

The discussion is organised in two sections where the first one deals mainly with the first two topics. The technical change and evaluation topics are addressed in the second section.

A SWEDISH "ADVOCACY COALITION" IN A CHANGING CONTEXT?

Although public market-support programmes for heat pumps had been withdrawn in the mid-1980s, R&D funding continued, and several of the people involved in forming the visions of the 1970s, as well as in the build-up of the market segment in the early 1980s, continued to be committed to the "cause". Personal commitment among people at key research institutes on the one hand, and authority institutions as well as different branch fora on the other, created an environment where "experts" were able to have an impact, subtly or directly, on policy and market formation, despite a series of policy shifts and organisational changes in civil service departments and agencies during the 1980s and 1990s. Borrowing terminology from the theories of Sabatier and Jenkins-Smith (1993), there had been established an advocacy coalition of sorts – a group of interacting stakeholders sharing similar beliefs in a particular policy context. Within this circle of actors, arguments in support of the "heat pump vision" were continually adapted to the changes in energy paradigms that took place over the course of time: from oil dependency and energy security, through the debate over nuclear energy and the drive to conserve electricity, to the focus on sustainability and climate protection. No matter

the nature of the problem on the energy agenda, heat pumps would constitute part of a reasonable solution.

A characteristic and noteworthy property of the Swedish heat pump arena of the late 20th century was the almost complete absence of opposing "advocacy coalitions". This situation makes Sweden very much different from other countries, such as Germany, where influential voices have long argued that heat pumps, being dependent on electricity for their operation, in essence constitute a coal-based heating technology that threatens the sustainable development of the entire energy system. In Sweden, where electric resistance heating accounts for a large share of the residential heating segment, and where electricity is traditionally conceived of as clean, heat pumps were instead, and mainly, associated with the promotion of energy efficiency and a more rational use of electricity. The heat pump duckling, seen as a pariah in German waters, was in Sweden a cygnet swimming freely without opponents.

Of late, however, other voices may also be heard that criticise the expansion of the residential heat-pump segment in Sweden, with arguments based on scepticism towards the use of electricity for heating. In such rhetoric, heat pumps are not compared with electric resistance heating technologies, however, but with biomass-based systems such as district heating or household-size pellet boilers. The electricity-market reforms and the visions of an integrated European market place – through which a substantial share of fossil-based electricity suddenly enters the "Swedish system" – have contributed to the stirrings of this kind of reasoning. For the main part of the period investigated though, such concerns have not been present to influence the policy arena in Sweden. Thus, even during the mid-to-late 1980s, when there were no policy instruments explicitly supporting the heat pump market, the adaptation of the heat pump vision to changing external circumstances continued relatively unchallenged by the broader community of energy experts and policy makers – along with the continuation of heat-pump related R&D programmes. This condition constitutes an important, but perhaps unrecognised, piece of the background leading up to the goings-on on the policy arena and the market during the 1990s. Not the least among these events is the decision to include heat pump systems in the series of technology procurement programmes, which had been then put in place by NUTEK.

When referring to the heat pump proponents in Sweden as an "advocacy coalition", it is important to note that this does not mean to say that there has existed one single, regular organisation of great influence, such as a think-tank or an organised lobby group, which has been determined in promoting a particular scenario. Rather, the scene has been staged with a set of important stakeholders, persons as well as organisations, whose interactions have been uncoordinated but mutually enforcing. In the beginning of the period there was an attempt made by the government to orchestrate, through policy programmes, a shift in energy paradigms. And, according to these ideals, heat pump technology was to constitute part of the future energy system. A winning concept had been picked. When the political attention shifted away from this type of societal energy-system engineering, to focus instead on other policy areas, institutional and actor networks were broken and dispersed,

but the choice of heat pumps as a winner remained virtually unchallenged, and the ideas of the heat pump vision, though no longer harboured or “owned” by central authorities, were able to stay alive among the collective of stakeholders, through a process of “unplanned coordination”. These stakeholders included researchers, market actors, civil servants in municipal and central administrative agencies, etc.

ON TECHNICAL CHANGE AND EVALUATION OF SUPPORT PROGRAMMES

The various support programmes were obviously not coordinated or conceived with a technology transition management perspective in mind. However, analysing the development from the perspective of such conceptual models may shed light on the difficult issues of managing technical change and the role of evaluation. For example, three government-supported procurement rounds for heat pump technologies have been organised in Sweden, the last one of which resulted, in 1995, in two winning marketable ground-source heat pump systems. This, the third heat pump procurement programme, is often and almost routinely referred to as the reason for the final breakthrough in Sweden for residential heat pumps systems as a mature and self-supporting market segment. From a different angle, however, the programme may also be described as a fiasco. One of the winning technology systems turned out to have difficulties when switching to alternative refrigerating agents that, in the wake of the Montreal Protocol, were being phased in to replace CFCs. This was an embarrassment that turned into a costly affair for many of the involved actors, including the state-owned energy company Vattenfall. Furthermore, in a review conducted 2002 of all malfunctions in heat pump installations, as reported to Swedish insurance companies, both of the procurement-winning systems rated highest in their respective categories.⁵ This caused the consumer journal Råd & Rön to comment on their relative inferiority to alternative makes and models.

Although acknowledging that the procurement programmes were of great significance to the eventual rehabilitation of the heat pump market in Sweden, we wish here to point to the fact that they should not, indeed they must not, be seen in isolation. Without preceding programs and the build-up of experience there would not have been actors that could pick up the challenge provided by the procurement programmes. They were, so to speak, only the tip of an iceberg of public support programmes, which have enabled heat pumps to finally play the part in Sweden’s residential heating sector that had been assigned to them already in the 1970s. Without the more or less uncontested consensus among key actors over the desirability of heat pumps in Sweden, and without the experiences made – technology-wise in research, development and demonstrations, as well as policy-wise through considerations of market developments over many years – the story would undoubtedly have been very much different, even if the procurements had still been carried out.

With the privilege of hindsight allowed to us by time, we may conclude that the procurement programmes were not

perhaps as successful as they have been made out to be. On the other hand, the investment-support programmes of the early 1980s might not have been the failures they appeared to have been in the latter half of that decade. It is true that many constructors, retailers and consumers of heat pumps paid dearly in the aftermath of the collapsed market. On the other hand, the dramatic roller-coaster market fluctuations of the 1980s and early 1990s also had consequences that contributed to the robustness of future market actors and mechanisms. These learning processes yielded concrete results such as the consolidation of serious market actors in branch organisations (SVEP and, later on, VET). Within this context, important institutional developments include the putting in place of a Heat Pump Guarantee in 1984, as well as of the formation a few years later of the a sector-specific Board of Complaints to administer and mediate in conflicts between customers and heat pump retailers, installers or constructors. An orderly and responsible set of actors on the supplier side was naturally an important factor allowing a successful procurement tendering procedure.

With the termination in 1985 of the Energi-85 venture, a host of evaluations of different programmes, policies and instruments were made. Today these documents constitute a valuable source of information concerning the energy agenda of the early 1980s. Similarly conscientious evaluative documents for subsequent energy policy efforts are not as frequent, except for the technology procurement programmes by NUTEK. It has not been within the scope of our work to analyse these evaluations but a few observations can be made. In retrospect, we can note that the evaluations tend to be very contextual, i.e. reflecting the energy policy agenda at that time. Also heat pumps are not fundamentally challenged anywhere. They focus on technical aspects as well as the energy savings realised through various support schemes, apparently for the purpose of adjusting and improving these schemes. This reflects the fact that the support programmes were not very controversial among the evaluators. The evaluations of the mid 1980s tend to fail, however, in recognising the actual incremental technical development and the learning-by-doing processes that took place among heat pump users and suppliers. Heat-pump technology is typically regarded as mature and the market is taken “as is”. Therefore and with hindsight, the evaluations seem “rigid” and not very innovation-oriented, mirroring perhaps the state-of-the-art knowledge of the people involved (i.e. civil servants and technical experts).

The technology procurement evaluations are different in character. They were in essence self-imposed monitoring efforts and primarily used for the purpose of facilitating adaptations and changes in the programmes. In addition to quantifying energy savings, there is a strong emphasis on other performance criteria and, not least, on the effects on market development. These evaluations can also be seen in light of the controversies around technology procurement, which in the view of some observers were getting to closely involved in manipulating markets and actors. Hence, the technology procurement programme evaluations seem to have played also a legitimising role.

5. The insurance company Folksam (www.folksam.se) publishes statistics on heat pump insurance claims.

With this in mind, the lessons learned here support the idea that evaluations should be seen and used as a vital part of the learning process within a programme or a market transformation scheme. When making far-reaching political decisions on whether to continue or abolish such schemes, however, evaluations generally provide poor justification for either choice, in the sense that they are intrinsically retrospective. Such decisions are dependent on other considerations than on expanding the experience-base for learning, which, in our perspective, is where the evaluative focus must rest. Cost and benefit aspects are an example of how evaluations can give only to-date information, which in the long-run perspective may turn out to have been poorly guiding or even misleading.

The total cost of the Swedish heat pumps effort is difficult to estimate. The reporting of total R&D funding to the IEA implementing agreement on energy efficiency holds that the Swedish government has invested roughly 10 million Euro into heat pump technology since 1973. However, this is not including the effort by Vattenfall (28 to 35 million Euro in the “Solar” program) or the Government EPD program (about 3 million Euro). In addition, there is the market investment support which we, based on various Government reports, estimate to 60 million Euro (between 1979 and 1983) and the technology procurement at about 0.5 million Euro. It has not been possible to estimate here how much of the soft loans under the refurbishing programs in the late 1980s can be attributed to heat pumps. In total, we estimate that at least 40 million Euro has been spent on RD&D, and at least 60 million Euro for market support. The total is at least 100 million Euro. In comparison, a market for 50 000 ground source heat pump systems at about 10 000 Euro is worth 500 million Euro annually.

The Swedish story of heat pump development has some interesting points relevant to theories of innovation and the role of government. The development of heat pumps in Sweden largely follows the theoretical outline of transition management process (a complex process with feed-backs, and simultaneous and timely efforts, along different parts of the chain). Thus, with hindsight, the Swedish development could well be described as an example of transition management. But, there is one important caveat; the idea of transition management is for governments, together with market actors, to *coordinate* a market transformation. The Swedish efforts were not coordinated and sustained over time. In spite of the mix of policy instruments, a linear view dominated the government agencies and research community engaged in heat pump technology at the time. In the early 1980s, the technology was erroneously perceived as mature and ready for large scale introduction. Despite the mistakes made at this time – which could have been a show-stopper in a different context – the development continued.

The Swedish heat pump experience largely supports the idea of transition management as a tool for technical change. A transition management strategy conceived in the late 1970s might have trotted down a similar, or hopefully better, path. With better information, the premature market introduction in the early 1980s might have been avoided. However, it is hard to envision how this approach could have foreseen or prevented the political changes, the switch to electric resistance heating, and the shifts in priorities and

driving forces for energy policy. Hence, a fundamental problem is the time aspect, where the road from idea (even with basic system components available) to stable market in this case took 25-30 years. It appears to be a considerable challenge to sustain a coordinated effort over such a long period. Thus, a hypothetical transition management strategy might have ended up doing the same or similar mistakes as were actually made in the real case.

It is a widely held belief that one should not attempt to pick winners in transition management efforts. It is an interesting observation that in our case, a winning technology concept was actually identified at an early stage, although the specific technical solution that would win required extensive experimenting and testing. This observation should add some balance to the sometimes strong position taken against picking winners. In our case, there were basic climatic and thermodynamic aspects governing the choice of a winning concept. On the other hand, transition management requires identifying and involving the relevant actors, as well as building a flexible management organisation allowing for the dynamics of the priorities and challenges of an unpredictable future. In retrospect, given the later market reforms and resulting changes in business strategy, Vattenfall did not become as important an actor on the heat pump market as one would have guessed in the early 1980s. Instead, three strong manufacturers grew from the mid-1980s shake-out phase when about 60 suppliers disappeared from the market. In summary, the Swedish heat pump experience underlines the need for an approach to transition management which is non-exclusive (with regard to actors and technical solutions), flexible and dynamic (with regard to changing contexts), as well as forgiving (with regard to mistakes and failures).

Conclusions

The tale of residential heat pumps in Sweden is a case study that brings some insights to theories about innovation systems, technical change, and policy evaluation. Despite failing policies, heat pump technologies and markets, and despite continuously changing drivers in national energy policy, this technology has now lived up to the expectations of its proponents of the 1970s. One part of the explanation is the relatively low electricity-to-fuel price ratios and the widespread use of electricity for heating. Another is the perseverance of key actors and the formation of an “advocacy coalition” with essentially no opposition. In addition, learning has taken place in the policy arena and among various actors. The evolution may be seen as an uncoordinated transition management process over 25-30 years. A coordinated effort might have produced better results, or made the same mistakes, but it is not clear whether it could have been sustained over such a long time period in changing organisational and political contexts. Evaluations made at the time of programmes and policy instruments are important sources of information when studying a process of such a long duration. They are, however, contextually bound and should be seen as parts of the wider learning process. In retrospect, evaluations commissioned during a programme or at the time of its termination often suffer from difficulties, similar to those of the original programme designers, to fully comprehend how

market transformation can actually occur and to appraise how different kinds of support may contribute: the long-term impact can only be judged in an extended time frame.

References

- Andersson, H.E.B., and Å.K. Setterwall. 1995. *Energiboken. Kunskapsläge och forskningsfront.* [The energy book. Current knowledge and research frontier.] T21:1995. Stockholm: Swedish Council for Building Research.
- BFR [Statens råd för byggnadsforskning]. 1982. *Byggsektorn 1990. Behov av forskning och utveckling under 80-talet.* [The construction sector in 1990. Needs for research and development in the 1980s.] G13:1982. Stockholm: Swedish Council for Building Research.
- Efn [Energiforskningsnämnen]. 1985. *Solvärme och värmepumpar.* [Solar heat and heat pumps.] Efn-rapport nr 13. Stockholm: Energy Research Board, Liber förlag.
- Energianvändningsrådet. 1994. *Programmet för effektivare energianvändning.* [The programme for more efficient use of energy.] B 1994:8. Stockholm: Board for Industrial and Technology Development.
- Engebeck, L., and A. Zingmark. 1987. *Utvärdering av investeringsprogrammet värmepumpar.* [Evaluation of the investment programme for heat pumps.] SB:8. Gävle: Swedish Institute for Building Research.
- Fagerström, Å. (ed.). 1992. *Värmepumpar för bebyggelse.* [Heat pumps for buildings.] G2:1992. Stockholm: Swedish Council for Building Research.
- Fikri, Z. 1975. *Heat Pump Applications in Sweden. Research and Development Needs.* D8:1975. Stockholm: Swedish Council for Building Research.
- Freeman, C. 1995. *The National System of Innovation in historical perspective.* *Cambridge Journal of Economics* (19), pp. 5-24
- Josefsson, T. 1990. *Stödformer för energiteknisk utveckling. En utvärdering.* [Means of support for the development of energy technologies. An evaluation.] Efn-rapport nr 36. Stockholm: Energy Research Board, Allmänna förlaget.
- Keller, S. 2004. *Wärmepumpen in Wohngebäuden – Technologie, Politik, Akteure und Märkte in Deutschland.* [Residential Heat Pumps – Technology, Policy, Actors and Markets in Germany.] *Statusbericht Nr. 2.* Hannover: Informationszentrum Wärmepumpen und Kältetechnik.
- Kemp, R., and D. Loorbach. 2003. *Governance for sustainability through transition management.* Paper for EAEPE Conference, 7-10 November 2003. Maastricht.
- Kemp, R., J. Schot and R. Hoogma. 1998. *Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management.* *Technology Analysis & Strategic Management* 10, no. 2
- Laurén, C. 2001. *En ny generation värmepumpar ser dagens ljus.* [The birth of a new generation of heat pumps.] *Energimagasinet* (3), pp. 34-35.
- Lindeberg, P. 1984. *Forskning kring värmepumpar. Teknikutveckling och systemuppbyggnad med Byggnadsforskningsrådets stöd – en översikt.* [Research about heat pumps. An overview of technical evolution and system design funded by the Swedish Council for Building Research.] T16:1984. Stockholm: Swedish Council for Building Research.
- Lundvall, B.Å. 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning.* London: Pinter Publisher.
- Näringsdepartementet. 2003. *EFUD – en del i omställningen av energisystemet.* [Energy RD&D – one part of the process to restructure the energy system.] Swedish Government Report SOU 2003:80. Stockholm: Government Offices of Sweden.
- Ny Teknik. 2004. *Boom för värmepumpar när oljepriset rusar i höjden.* [Boom for heat pumps when oil prices sky-rocket.] Article in Swedish weekly technical newspaper Ny Teknik (2004-11-10).
- Oldin, M.B. (ed.). 1987. *Energisvar '87. Frågor och svar om energihushållning i byggnader.* [Energy answers '87. Questions and answers about energy conservation in buildings.] G17:1987. Stockholm: Swedish Council for Building Research.
- Olofsdotter-Jönsson, B. (ed.). 1984. *Energi 85. Energianvändning i bebyggelse.* ["Energi 85." Energy use in buildings.] G26:1984. Stockholm: Swedish Council for Building Research.
- Rantil, A. 2002. *Personal communication.* The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning.
- Rosenberg, N. 1982. *Inside the black box: Technology and economics.* Cambridge: Cambridge University Press
- Sabatier, P.A., and H. Jenkins-Smith. 1993. *Policy Change and Learning: An Advocacy Coalition Approach.* Boulder, CO: Westview Press.
- SCB [Statistiska centralbyrån]. 2004. *Energistatistik för småhus 2003.* [Energy statistics for one- and two-dwelling buildings in 2003.] EN 16 SM 0403. Stockholm/Örebro: Statistics Sweden
- Schumpeter, J.A. 1934. *The theory of economic development.* Cambridge, MA: Harvard University Press.
- STEM [Statens energimyndighet]. 2000. *Effektiv energianvändning. En analys av utvecklingen 1970-1998.* [Efficient energy use. An analysis of the development from 1970 to 1998]. ER 22:2000. Eskilstuna: Swedish Energy Agency.
- STEM [Statens energimyndighet]. 2004. *Vil-lavärmepumpar.* [Heat pumps for detached houses.] ET 8:2004. Eskilstuna: Swedish Energy Agency.
- Vattenfall. 1989. *Små värmepumpar. Erfarenheter från Vattenfalls FUD-insatser 1979-1987.* [Small heat pumps. Experiences from Vattenfall's R&D efforts, 1979-1987.] U (S) 1989/28. Vällingby: Vattenfall.