PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

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Deliverable 2.5: Forward-looking analysis of transition pathways with socio-technical scenarios

Country report 3: The Swedish heat domain

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Executive summary

This report will develop forward-looking, qualitative scenarios that describe plausible socio-technical pathways for the quantitative scenarios from WP1 for the Swedish heat energy domain. The quantitative scenarios for the Swedish case study are derived from the IMAGE model for the European Union as a whole and from the LEAP model for Sweden specifically. The quantitative scenarios developed in WP1 are used as starting point, and complemented with findings from the socio-technical analysis, using MLP as a theoretical approach, in WP2 in order to develop plausible and imaginative storylines of which changes are needed for the scenario to happen.

The report creates two scenarios, Pathway A and Pathway B. Both scenarios are assumed to reach the national target of 50% reduction in energy consumption by 2050 (with 1995 as a baseline). The specifics of the transition pathways are, however, quite different because they represent different analytical ideal-types, which differ both in terms of lead actors, depth of change and scope of change.

In order to make the scenarios more realistic, the report also analyses the tensions between the quantitative scenarios and the findings from the socio-technical analysis in WP2 in order to highlight the transition challenges.

Niche	**Pathway A**	**Pathway B**	**Constraint**
Heat pumps	Almost all energy efficiency in total energy demand is expected to occur through heat pumps replacing the more inefficient direct electricity. The share of heat pumps is expected to double. However, the current momentum of heat pumps is moderate.	Same as Pathway A, but not to same extent.	Technology Economics
District Heating	Expected to take market shares from heat pumps in multi-dwellings. However, currently there is both stagnation and saturation in the heat regime. Heat pumps are competing over market shares with district heating in multi-dwellings	Same as Pathway A	Economics
Solar heating	Very little solar heating in Pathway A	Solar heating is expected to take market shares in Pathway B. However, with its current state and momentum it is difficult to explain such an uptake from a socio-technical perspective. Solar heating in Sweden did not even register as a niche in D2.1	Policy and governance
Low energy housing	No low-energy buildings in Pathway A.	All new dwellings after 2020 are expected to be low-energy housing following the passive house standard. However, the current	Policy and governance Economics

		momentum for this niche is low and the incumbent actors are opposing strongly. Similarly, there is an issue with lagging implementation of EU Directives.	
Lower indoor temperature	Not part of Pathway A	Pathway B assumes strong energy efficiency measures through lower indoor temperature (through e.g. individual metering and billing IMB). While there is a high potential in this measure, the social mantra in Sweden is relatively high indoor temperatures, which are also supported by national recommendations. Moreover, tradition of communal and central heating systems mean that individual tenants in multi-dwelling do not have control over their heating.	Social acceptance Policy

The two scenarios are divided in two main periods (2015-2030 and 2030-2050). The approach is one of 'history of the future', which means that the scenario descriptions are written in past tense. The scenarios focus broadly on key landscape trends, shocks and pressures, regime developments, and niche developments for the two time periods.

Scenario 1 – Pathway A

This scenario provides a socio-technical storyline for Pathway A. This pathway builds on the continued strength of the incumbent regime actors in industry and policy. It focuses on radical technical change, mainly through substitution. It focuses on change in one or two dimensions and leaves most other system elements (e.g. households, markets, user practices, public opinion, civil society, socio-cognitive aspects) mainly intact. Major transition challenges concern technology and economics. The regime is expected to continue its dominance. However, the momentum for various regime components is currently varying from low to moderate (Table 3).

(2015-2030)

Key landscape trends, shocks and pressures: When the Paris agreement was adopted in 2020 Sweden reaffirmed its ambition to become a climate neutral country by 2045. What is more relevant for the heat energy domain, which is more or less carbon neutral, Sweden repeated its target of 50% reduction in energy consumption by 2050. The government also agreed to phase out oil by 2020. From 2020 and onwards, oil was only used in back-up plants for extremely cold weather. These measures put Sweden on path to achieve the target of lowering total energy consumption with 20% by 2020 from 2008 levels. This policy path had strong cross-party support and it was well grounded in public opinion as there were few proponents for expansion of oil in the Swedish heat sector.

In 2016, the government agreed on a plan to make all Swedish electricity production 100% renewable by 2040. This also included a phase out of nuclear electricity in the long-term. However, the cross-party agreement also guaranteed a replacement of 10 nuclear reactors, guaranteeing a continued significant share of electricity from nuclear energy, between 50-70 TWh/year. This agreement was seen as a victory both for the proponents of nuclear energy and for the environmental NGOs who celebrated the long-term renewable energy target.

Regime developments: Since Sweden's heat energy system was already more or less decarbonised, during the first 10 years not much changed in terms of total demand for DH and small-scale biomass. The dominance of HP, DH and small-scale biomass was maintained. The most dominant heat energy source, DH, continued to expand with help from new combined heat and power (CHP) plant development. Several new plants were built thanks to the government's decision to expand the tradable green certificates (TGC) system. TGC was designed so to premiere established energy sources such as wind and CHP over less developed, including solar, wave, and hydrogen. The logic behind CHP expansion arose from the nuclear energy debate and the needed shift to renewable energy in the electricity regime.

Another effect from CHP expansion was the increased use of waste incineration. The new plants were fuelled on waste, which was mainly imported from Sweden's neighbouring countries. Over the course of the first few years, this was not seen as a problem. However a few years later the public opinion had started to shift against further import of waste. Environmental NGOs initiated campaigns against increase of waste import. Three problems arose in the debate; first, the high costs of import; second, the increased emissions of transporting of waste; and third, the waste discourse had started to shift more towards recycling and reuse rather that incineration. Another consequence of this was that supply of heat was constant, even though the number of buildings increased and the demand-based initiatives were lagging behind. However, as nuclear energy was losing its historically strong position and biomass in Sweden had reached its peak, there were few alternatives that importing waste. As a consequence, NGOs started targeting the Swedish government for falling behind on its energy efficiency targets. Public opinion started to shift, which pushed the government and the municipalities, by the end of this period, to undertake country-wide refurbishments of the building sector, particularly the multi-dwellings. Many of the buildings constructed before 1975 needed to be renovated before 2050. This was done through massive subsidies for both single- and multi-dwellings. The government funded 30-50% of the total costs up to a certain limit in investments in HP, effective ventilation systems, insulation, and advanced systems for heat recovery.

For multi-dwellings, during this period the demand for DH decreased significantly. However, the relative share of DH in multi-dwellings remained more or less constant. For single-dwellings, DH was at a constant rate over the time period. Despite strong initiatives from the incumbent DH actors, the business model of reaching out to single-dwelling customers was seen as more expensive. The only market expansion was in newly built single-dwellings, which was small. For HP, on the other hand, this time period led to a significant expansion. By 2020, Sweden decided to go further with energy efficiency measures by a decision to phase out direct electricity. Through a strong policy support with subsidies and investments in research and development, the government set out a plan to support HPs. The coefficient of performance (COP) for HP increased from

2,8 in 2015 to 3,8 in 2030. Development was encouraged by the fact that residents rarely move, which allows for large private investments in rather costly HP systems. Replacement of direct electricity with HP met little resistance, as it was merely an add-on to an existing system rather than a total replacement. The key incumbent actors, the utility providers, were behind this initiative.

Niche developments: Following the backlash in public opinion of waste import for incineration and the glooming news that the Swedish government was lagging in energy efficiency measures. The government strengthened the policy on third party access (TPA) to the DH networks against the will of the incumbent actors who were already threatened by the forthcoming energy efficiency measures. Despite this opposition, the public opinion against the energy waste was strong and the amount of waste heat from industry, large server rooms, shopping malls etc. increased its share as a fuel input to DH. By the end of the time period, waste heat and refurbishment of the building stock were the main factors for lower energy demand in multi-dwellings.

Another niche, small-scale biomass through pellet burning boilers remained relatively constant during the time period. By 2030, biomass potential in Sweden had reached its limit. Whilst biomass was mainly used as fuel for DH, small-scale pellet was profiting on the same supply-chain. There was some switching from traditional wood to pellet burners. However, the relative share of biomass in single-dwellings remained constant.

(2031-2050)

Key landscape trends, shocks and pressures: In the beginning of this time period, Sweden was more or less on its way to reach the target of 50% less energy consumption compared to 1995. However, there were a few landscape pressures that started to have an impact. One of these was climate change. The increased average temperatures led to a decrease of demand in heating and contributed towards achieving the energy efficiency targets. By 2050, energy demand for heating had decreased by 11% (Gode and Jarnehammar 2007).

Another landscape shock was the phase out of nuclear energy. By 2040 the last reactors had been shut down. The replacement from renewable energy sources did not manage to replace all supply even though there was an expansion of hydro. Sweden became a net-importer of electricity, which led to higher electricity prices. Higher prices further sped up the conversion of direct electricity to HP and by 2050, direct electricity boilers for heating in the Swedish building sector were phase out and replaced by HP. By 2050, COP for HP had increased to 5 (Nowacki 2011).

Regime developments: The competition between the two dominating regime components was settled and decreased as DH found difficulties in expanding further in the single-dwelling sector. For HP, multi-dwelling sector offered few opportunities due to dominance of DH. Despite lower demand or DH, it managed to increase its market share. DH had support from its main owners, which were public, as well as relatively competitive prices. Instead HP turned towards outward expansion through export, mainly to Europe, which had developed an apetite for HP expansion. For DH providers, new opportunities in smart homes arose through the introduction of smart systems and big data access. As many of DH companies were publicly owned, their business models extended towards providing smart services to their customers.

By the end of this time period, Sweden had not only reached its target, but also exceeded it by lowering energy consumption by 60% compared to 2005. In multi-dwellings, DH maintained its dominance with over 90% share. The rest were HP, which had fully replaced direct electricity. In single-dwellings HP, again, had fully taken over from direct electricity. DH had slightly increased from its initial levels, mainly due to new buildings, which were easier to connect to the DH network. Biomass remained at a relatively constant level throughout the time period.

Scenario 2 – Pathway B

This scenario provides a socio-technical storyline for Pathway B. This pathway builds on a substantial departure from existing system performance. It focuses on new entrants rather than incumbent actors, including new firms, social movements, and civil society actors. It represents radical transformative change in the entire system in several dimensions (technical, market, organisational, policy, cultural, social, consumer and user change). Major transition challenges between the quantitative scenarios and the socio-technical analysis are concerns about social acceptance, policy, governance and economics in a system that is already more or less decarbonised. Another issue is that Pathway B niches are currently facing a very low momentum (Table 3).

(2015-2030)

Key landscape trends, shocks and pressures: The signing of the Paris agreement in 2015 and the sequential implementation of the agreement in 2020 was a policy bomb in Sweden. The government increased its ambitions and set a course to become a carbon neutral country by 2045. The red-green coalition had strong support from the public and the opposition was on-board as well to implement the necessary national measures. For the heat energy domain, this meant an enhanced focus on energy efficiency. The discourse started to shift from the current supply-based regime to a more demand-focused with emphasis on efficiency and user- and consumer behaviour. One strong reason for this discourse shift is that the measures to decrease energy consumption in the housing sector would leave space for maintain the energy intensive heavy steel and metal industry in northern Sweden intact. This occurred with strong and targeted information campaigns from the civil society organisations. In parallel, worker unions and employer associations initiated a task force for creating a business case for this transition. This development was also helped with advancements in information technology and big data, which led to an ever-increasing knowledge base in governments, academia and the private sector.

The first decree of the government after the Paris agreement was a phasing out of oil before 2020. The government also increased its emphasis on implementing the EU Directives on energy efficiency, energy use in buildings and waste. In 2016, a bi-partisan agreement on phasing out of nuclear and a 100% renewable energy system by 2040 was signed. This agreement included replacement of 10 nuclear reactors, which was a demand from the opposition. However, by 2020 when the Paris agreement was implemented in national policy, pressure on the government from high maintenance costs of the existing reactors as well as civil society organisations and the public opinion was to scrap the reactor replacements and further emphasise energy efficiency and renewable energy. With support from the work of International Energy Agency, Energy efficiency measures became quickly seen as the most effective way to decrease CO_2 emissions. The number of new reactors to be replaced decreased from 10 to 4.

At the same time, in 2022, the red-green government coalition, with a reinforced mandate, created a coalition with academia and the private sector in order to increase communication around energy efficiency in buildings, focusing on awareness campaigning, information sharing, attitude shifting, target setting and action setting across all energy-consuming sectors.

Regime developments: As a consequence of landscape pressures described above, the government decided, early in the time period, to phase out direct electricity as a source for heating. Information campaigns about energy consumption were rolled out across the country. Municipalities offered support and guidance on how individuals and households could lower their consumption. The government also increased its support to HP as a replacement option for electric boilers through subsidies and investments in research and development. The roll-out of HP also had a small effect on biomass where a few biomass boilers were replaced by HP. In general, this was accepted among the population. Mainly thanks to the debate about nuclear energy and fear of higher electricity prices when nuclear was phased out and Sweden became a net importer of energy by the end of the period.

For DH, this period led to stagnation and saturation. The shift towards energy efficiency in buildings and the backlash on new CHP plants and import of waste for incineration faced strong resistance due to environmental costs. This meant that there was little scope for further development of DH systems. The price monopoly that DH has benefited from in over 60 years meant that the public support for DH shifted quickly. By the end of this period, no new DH systems were being developed. The key incumbent actors in DH fought against this current. However, the tide of the opinion was too strong. The transition was helped by the fact the majority of the actors were public actors (mostly municipalities) and could shift their financial structure. The large private actors, however, suffered severe economic damage. During this period, energy demand decreased with 20%. Notwithstanding, in terms of relative dominance, DH maintained its shares in both single- and multi-dwellings. In multi-dwellings, DH accounted for over 90% of the demand and around 10% in single-dwellings, which were dominated by HP, and biomass, now the dominant source in this domain.

However, the dominant regime had started to crack. By the end of the time period, a new regime emerged, focusing on breakthrough of several niche-innovations, including buildings efficiency, socio-cognitive and collective social values, user-friendly technology and solar heating.

Niche developments: By 2020, the government ordered that all new buildings have to be passive house standard. This occurred at the same time as the National board of Housing, Building and Planning (Boverket) issued a report stating that 1 million new buildings needed to be built by 2030 and another 500 000 by 2050 - volumes that have not been seen in Sweden since the 1960s. After an intense and controversial debate, where current contractors were reluctant to build low-energy housing, the government introduced stronger regulation and issued penalties for contractors. The government also stepped in with subsidies and rewards for early adopters. This acted as a catalyst and the transition, which started slowly gathered traction.

For single-dwellings, large investments were made possible due to the fact that residents rarely move. The government stepped in with subsidies for conversion of boilers to HP. By the end of this period, 'smart grids' and 'smart homes' became catch phrases. In this development the large actors in the energy domain played an important role. When the market for energy supply started shrinking, these actors diversified their activities to provide services to lower the energy bill. New business ideas such as Energy Performance Contracting (EPC), a method that offers customers guaranteed improvements in buildings' energy performance without the need to expend capital, became profitable for both the provider and the buyer of this service. By the end of the time period, solar heaters started to develop its own business model, and with help from government subsidies a new green niche was initiated. Efficiency improvements continued in the single-dwelling sector and by 2030 it had decreased to 60 kWh/m^2 from 126 kWh/m^2 in 2010.

For multi-dwellings, in order to increase efficiency, the National Board of Health and welfare (Socialstyrelsen) decided to lower its recommendations of indoor temperature from 21°C to 20°C. There was a broad agreement in the government for this decision, despite strong opposition in the public opinion. However, since most multi-dwellings are centrally controlled, and most DH companies are publicly owned, this was a rather easy measure to implement top-down. Similarly as for the single-dwellings, EPC was widely employed with good success.

Another niche that enjoyed success was individual metering and billing (IMB). Initially IMB was met with scepticism. The main reason for this was that the standard practice for multi-dwelling housing is for heat to be included in the rent and that building management company is the agent rather than the tenant. IMB of heating was also problematic because energy consumption is dependent on the building envelope and operating systems; and hence of measures of the property owner, the residents can only affect the smaller part (Boverket 2008). However, when big data started to have impact, smart systems were rolled out, which contributed to a fair ownership and responsibility of actions and costs.

By the end of this time period, most of the new buildings were passive houses, which had a significant impact on energy consumption in Sweden. The development was radical, with 30% total reduction in the buildings sector.

(2031-2050)
Key landscape trends, shocks and pressures: The second period was less dramatic than the first. With 30% reduction achieved around 2030, the development slowed down. The main reason for this was the new Swedish million-programme with a million new passive house dwellings being built between 2015 and 2030. In addition, after 2030 there were a few landscape pressures that started to have an impact. One of these was climate change. The increased average temperatures led to a decrease of demand in heatingand between 2015 and 2050, energy demand for heating had decreased by 11% (Gode and Jarnehammar 2007). This development had led to deep cultural shifts in the Swedish population.

Regime developments: The new buildings regime was stable over this time period. The efficiency measures slowed down slightly with the end of the new million programme. Between 2031 and 2050, only a half of the buildings arose compared to the previous period. Big data was a key development for further dissemination of smart system, which had become cost efficient and became standard even in the older building stock.
For single-dwellings, solar heaters increased and doubled their share 2050 compared to 2030. Improvements in technological capacity and warmer temperatures in Sweden led to high investments.

The report **concludes** with following observations:

Pathway challenge: The report shows that both scenarios reach Sweden's target of 50% lower energy consumption in the resident buildings sector by 2050 with 1995 as a baseline. The first scenario (Pathway A) shows higher potential than the second scenario (Pathway B). This is mainly due to refurbishment of the existing building stock, which has by far the highest potential to lower energy consumption. For pathway B, the decision to build low energy buildings with passive house standard combined with the high demand in new dwellings led to a regime breakdown of the supply-dominated Swedish heat regime. The dominance of DH was significantly diminished and a cultural shift in energy consumption in the Swedish population had occurred. However, both scenarios deviate substantially from pathway 0. This means that for this development to take place, there is a strong need to solve the transition challenges in technology, economics, policy and governance, and social acceptance.

The role of policy: In both scenarios, the Swedish government plays a crucial role. As section 3 showed, pressure from public opinion, civil society and academia is weak to non-existing, it is up to the policy-makers to provide leadership for the transition to happen. Tax breaks, subsidies, and support to research and development are key instruments. However, conversely, for the policy-makers to introduce tough policies, there needs to be pressure from the civil society and public opinion. Issues such as waste import and lack of energy efficiency measures, as well as the looming climate change discourse, can act as catalysts for the transition to occur. Both scenarios also imply a total phasing out of direct electricity, which is replaced by HP. For this to happen, again, strong policy support is necessary.

Similarities and differences in the two scenarios: In terms of similarities between the two scenarios, it is clear that DH will continue its dominance as the major source for heating. This is directly connected to the electricity regime where a phasing out on nuclear energy will either lead to lower consumption or an increase of CHPs. Biomass is constant in both scenarios. In pathway B, it will be slightly lower, but will mainly keep its share. Small-scale biomass is benefitting from DH where it is a major fuel source. Furthermore, in both scenarios an emphasis on buildings increases significantly from pathway 0. In pathway A scenario the focus will be on the existing building stock, whilst in pathway B scenario, it will be on new low-energy buildings.

However, pathway B scenario also indicates a clear diversion from the pathway A, where a total regime breakdown is necessary and a new regime takes its place. DH particularly is expected to suffer severe losses, albeit whilst keeping its relative market shares. This is implied already in the first time period, which indicates that transition efforts required are substantial in terms of the speed, scale, and scope of change of individual practices and socio-technical configurations. In other words, a radical change is necessary.

Methodological issues: This exercise was based on quantitative models, which tend to neglect important developments related to, for example, different actor groups and their interactions; policies; beliefs, decisions, struggles and conflicts; or lock-ins. To make the scenarios richer, socio-technical analysis was introduced as a complement, which led to the socio-technical scenarios. However, the development of these scenarios did not occur without problems. The main problem was the lack of a coherent scientific methodology, which provides speculative and fictional stories rather than coherent and robust scenarios.

1. Introduction

This report will develop qualitative scenarios that describe plausible socio-technical pathways for the quantitative scenarios from WP1. Figure 1 indicates potential transition path (green arrow), which suggest a potential move from unsustainable to sustainable development goals, provided by WP1 scenarios. This scenario will be challenged from the findings of WP2, which analysed the historical socio-technical development in the heat/buildings domain in Sweden.

In terms of the figure below, many of the empirical domains show a substantial discrepancy between current trajectories (black and blue lines) and the desired ambition to move towards sustainable pathways (green line) towards sustainability goals. This is the transition challenge for the coming decades. The quantitative scenarios from WP1 assume that this shift is possible, and offer some ideas on how to do this (e.g. strong policies, investments, price/performance improvements). However, from a socio-technical point of view, some of these ideas are a bit simplistic (e.g. limited attention for actors, struggles, lock-in).

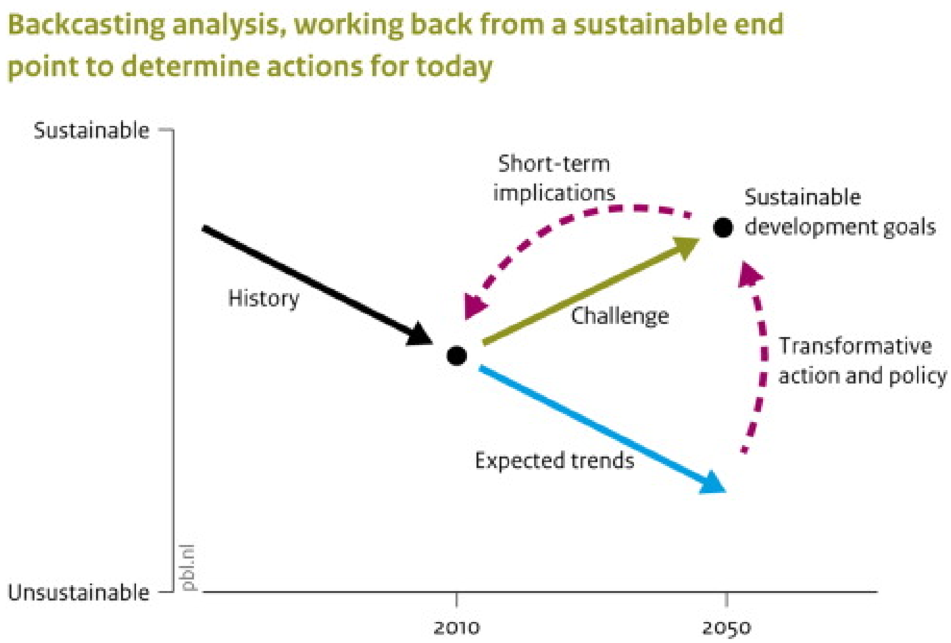

Figure 1: Transitions from historical trajectories towards future goals (Van Vuuren et al., 2015: 305)

Against this background, this report will develop more detailed storylines on how this development can occur in the Swedish heat energy system context. This means that the report will focus on socio-technical scenarios, which combine the WP1 findings from the IMAGE and the LEAP model with the findings from three WP2 delivery reports (D2.1, D2.2, D2.3). The scenarios that discuss how current trends could further develop in the coming decades, focusing on the time period 2015-2050. Some of the key issues and questions include:

- Which regime cracks can become bigger (leading to major tensions and windows of opportunity)?
- Which niche-innovations can gain more momentum?
- What landscape developments can assist niche-innovations (or pressure regimes)?
- What (kinds of) policies can further stimulate niche-innovations or lead to gradual regime reorientation. How may actor strategies (beliefs, commitments, investments)? change over time, leading to new developments?

The report will develop two socio-technical scenarios (STSc), following the PATHWAYS logic of pathway A and B (Table 1). The two scenarios will be contrasted with Pathway 0, which is business as usual. Both scenarios are assumed to reach the national target of 50% reduction in energy consumption by 2050 (with 1995 as a baseline). The specifics of the transition pathways are quite different, however, because they represent different analytical ideal-types, which differ both in terms of lead actors, depth of change and scope of change (Table 1).

	Pathway 0: Business as Usual	**Pathway A: Technical component substitution**	**Pathway B: Broader regime transformation**
Departure from existing system performance	Minor (no transition)	Substantial	Substantial
Lead actors	Incumbent actors (often established industry and policy actors)	Incumbent actors (often established industry and policy actors)	New entrants, including new firms, social movements, civil society actors.
Depth of change	Incremental change	Radical technical change (substitution), but leaving other system elements mostly intact	Radical transformative change in entire system (fundamentally new ways of doing, new system architectures, new technologies)
Scope of change	Dynamic stability across multiple dimensions	1-2 dimensions: technical component and/or market change, with socio-cultural and consumer practices unchanged	Multi-dimensional change (technical base, markets, organisational, policy, social, cultural, consumer preferences, user practices)

Table 1: Ideal-type transition pathways and their defining elements

The logic behind STSc should address changes in the various dimensions of socio-technical systems. Hofman and Elzen (2010: 656) suggest that socio-technical scenarios "should show socio-technical development", i.e. they should describe the co-evolution of technology and its societal embedding (a continuous action–reaction dynamic of technical and societal change). This implies a scenario should pay attention to technical development as well as to societal or behavioural aspects such as institutional change, different types of actors, their goals, strategies and resources, etc.

The storylines in STSc in this report will be guided by a logic that draws on socio-technical theories. The STSc references provided above all build on the Multi-Level Perspective (MLP), and discuss interactions between niche-innovations, incumbent regimes and broader ‘landscape’ dynamics.

The structure of this paper is as follows. Section 2 gives a short summary of the WP1 quantitative scenarios for Europe and Sweden. Section 3 describes the empirical findings of contemporary developments in green-niche innovations and the existing regime in the Swedish heat energy domain. Section 4 highlights some of the transition challenges through a comparison of the quantitative scenarios and the findings from the socio-technical analysis. Section 5 and 6 describe the two socio-technical scenarios for Pathway A and B. And section 7 offers some concluding remarks.

2. Quantitative scenarios from WP-1[1]

2.1 Model specifics

The quantitative heat energy scenarios are derived from the IMAGE model for the EU and from the LEAP national model for Sweden specifically. For more detailed info on the model specifics, see Hof et al. 2016.

IMAGE is a global integrated assessment motel (IAM). Models of the energy system focus on describing key drivers of change and the associated investment decisions, given specific objectives (e.g. reducing overall costs, meeting a climate target etc). Key dynamic factors in these models are activity levels, technology change, and price-based factors, specifically regarding the different components of technology costs (e.g. fixed and variable costs of technologies, fuel taxes or subsidies).

One key output of IAM models is the use of different technologies over time (given specific societal goals). The use of alternative technology options is influenced by 'technology' related factors and 'contextual' factors:

1. **Technology-related factors** include factors such as the lifetime, efficiency, and learning determining the total cost of a technology. The lifetime of technologies creates path dependency, which can be somewhat lessened by early capital retirement.
2. **Contextual factors** include changes in social and behavioural aspects or specific policies, and can be translated into cost factors that are added or deducted from the "real" total costs. An example of a non-cost related factor is lowering indoor temperature levels.

For IMAGE, fulfilling energy demand in the buildings domain for various end-use functions is determined on the household level, for which six end-use functions are considered: cooking, appliances use, space heating and cooling, water heating and lighting. All these energy functions depend on the use of 8 different energy carriers and their total energy demand is mostly modelled in a non-technology explicit manner. Only for a few energy functions more explicit detail for (representative) technologies is implemented, such as household appliances (air conditioning, refrigerators, entertainment systems), and to a more limited extent in (household) heating technologies (boilers, electric heaters and a representative heat pump). Further representation of more large-scale or technology specific substitution (such as district heating, solar thermal, geothermal heating) is more problematic within IMAGE.

The national model for Sweden, the Long range Energy Alternatives Planning System (LEAP) has a bottom-up end-use oriented tree structure that is used to calculate energy use for heating for residential buildings for the period 2015-2050. This structure is split into space and water heating; analysis of space heating is on a per m2 basis while water

[1] This section is a summary of the WP1-WP2 Preliminary discussion document: Heating domain.

heating is based on a "per dwelling" analysis. There is a distinction in types of buildings (single and multi-dwellings) as well as in existing and new building stock. It describes key drivers of change given specific objectives under the EU energy policy.

In the model, policies may have an impact on the penetration of each technology. Factors such as efficiency and share of heating devices are influencing the evolution of heating demand. Changes in behavioral aspects and policies affecting building shell improvement such as lower indoor temperature and refurbishment measures respectively are affecting the useful energy intensity (heat) of the model.

Energy intensities were specified in final units for each building type (not for each heating device). Fulfilling energy demand in households for space and water heating in Sweden depends on the use of 7 different energy carriers. The share of energy for each carrier and the efficiency of the respective device are specified. The technologies represented are shown in table 2.

Table 2: Heating devices represented in LEAP model

Space heating	Water heating
Ground Source Heat Pumps	Electric Resistance Water Heaters
Electric Resistance Heaters	Heat Pump Water Heaters
Pellet Wood Stoves	Solar Water Heaters
District heating	Pellet Wood Stoves
Gas-Fired Boilers	District heating
Oil-Fired Boilers	Gas-Fired Water Heaters
	Oil-Fired Water Heaters

2.2 IMAGE scenarios

For the Pathway A and B, the starting point is an 80% reduction in GHG emissions in 2050 compared to 1990 levels in the European Union – or less if the models are not able to achieve this target, due to for instance technology restrictions in the pathways.

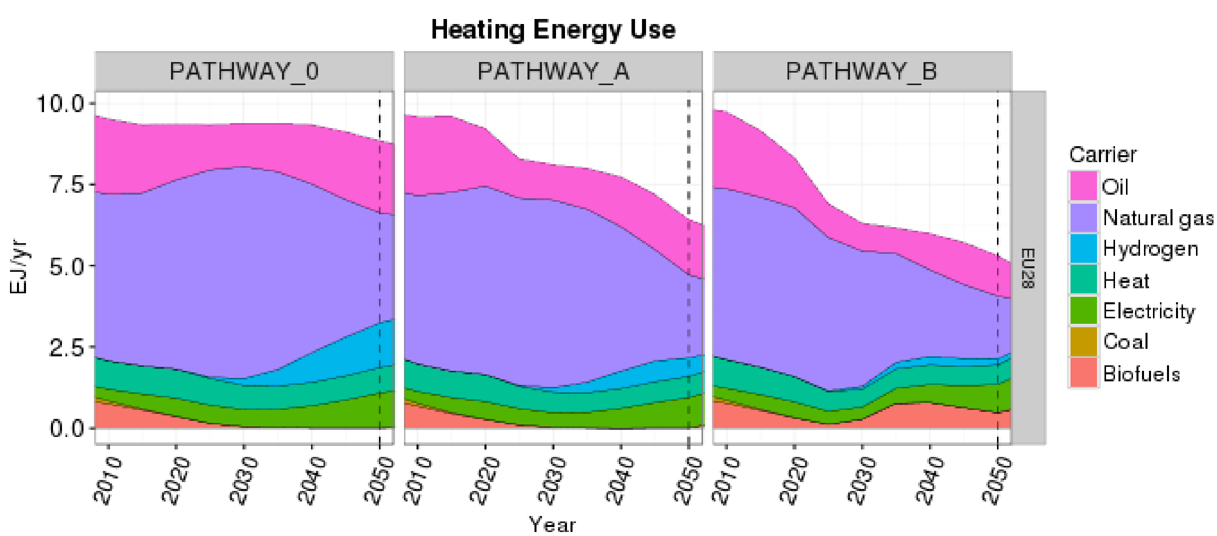

Figure 2: Heating energy demand (IMAGE)

Figure 2 shows that without any further action in energy and climate mitigation we find that heating demand remains broadly constant over time. However, it needs to be halved by 2050 to stay in line with the EU2050 target. The energy demand decline is mainly driven by autonomous efficiency improvements (as shown under Pathway 0) and price driven efficiency improvements (Pathway A). As similar autonomous and price driven efficiency improvements are subject in Pathway B as well, any further and more timely energy reductions are instigated by behavioural change – in particular changes in temperature setting which can find immediate implementation.

A closer look at the heating technologies in Figure 3 shows that currently the largest share of heating (50%) in Europe is provided by natural gas boilers. Over time, the heating market shows to be rigid as the relative shares are not changing much for either pathway. Pathway A shows very similar developments over time as projected in Pathway 0. However, only after 2050, heating technology use is diverging from pathway 0 with most notably the switch to more modern biofuel boilers and heat pumps in Pathway B (reducing the share of natural gas boilers to less than 30% by 2050).

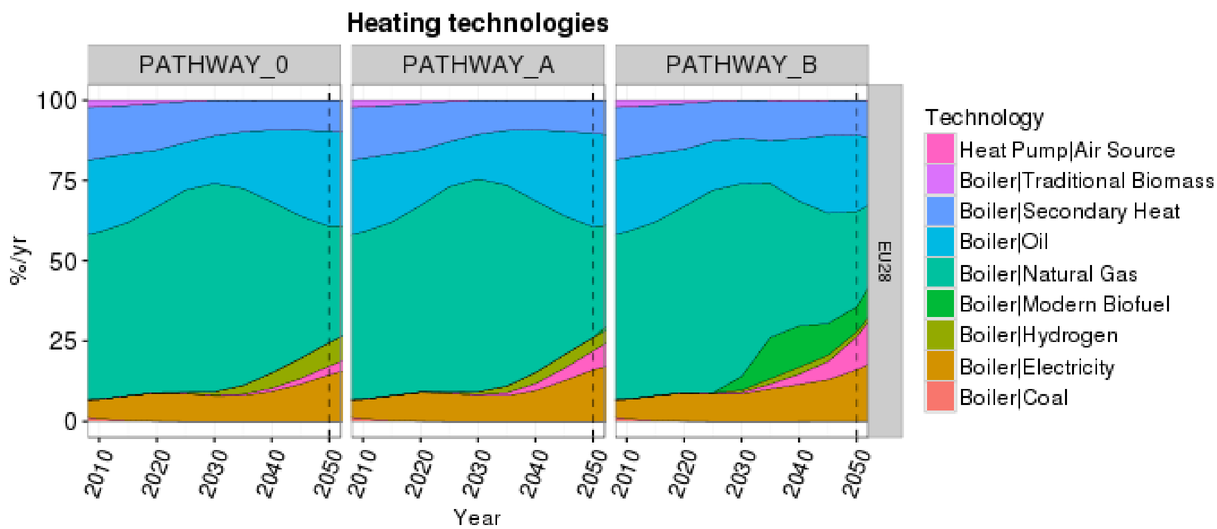

Figure 3 – Heating technologies used (IMAGE)

2.3 LEAP scenarios

The LEAP model makes the following assumptions: In Pathway 0, the only drivers changing over the scenario period are the population and efficiency. The efficiency improvement under Pathway 0 was introduced to show energy demand reduction over time due to learning. For comparative reasons, population evolves in the same way across the three scenarios.

In Pathway A, the share of heating devices changes over the scenario period. Oil and natural gas shares in heating have decreased rapidly over the last years. Their shares in Pathway A are diminished by 2020. Electricity for direct heating is fully replaced by the use of electricity through heat pumps by 2050 as heat pumps are considered more efficient. Biomass is assumed to be constant while district heating slightly increases. Next to the share of heating devices, their efficiency is improved reflecting technology improvement. Finally, the useful demand of the model is halved by 2050 to reflect improvement of the building stock (refurbishment).

In Pathway B, similar to Pathway A, oil and natural gas disappear by 2020. Electricity for direct heating use is also phased out by 2050, considered as an inefficient way of using electricity. In this scenario, electricity for direct heating is replaced by an increased penetration of both heat pumps and solar thermal. The share of biomass is kept constant, while district heat slightly increases. In Pathway B, all new dwellings after 2020 are following passive housing standards. Useful energy demand is adjusted to reflect a reduction in indoor temperature to 20 C degrees. Finally, a 10% reduction in floor space is applied, to reflect reduction in living space as part of a behavioral change.

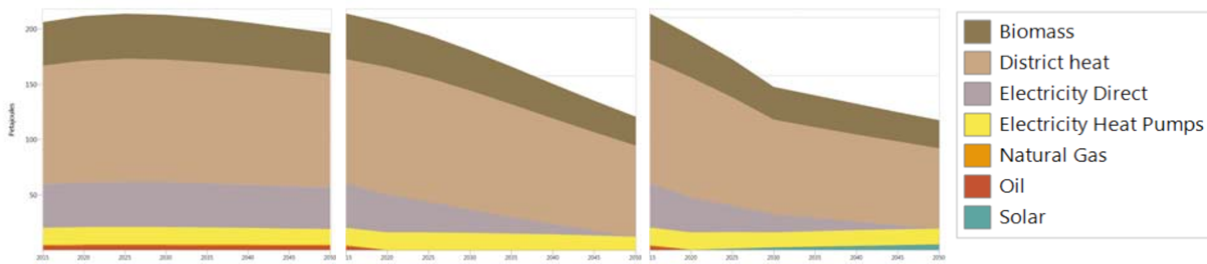

Figure 4: Total energy demand in Pathway 0, Pathway A and Pathway B

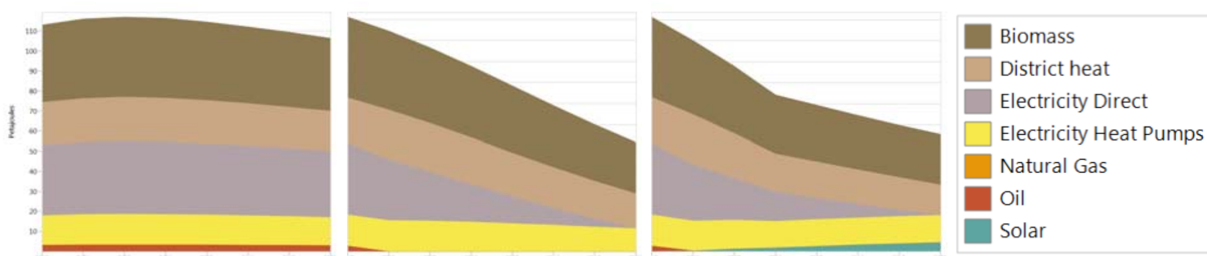

Figure 5: Energy demand in <u>single dwellings</u> in Pathway 0, Pathway A and Pathway B

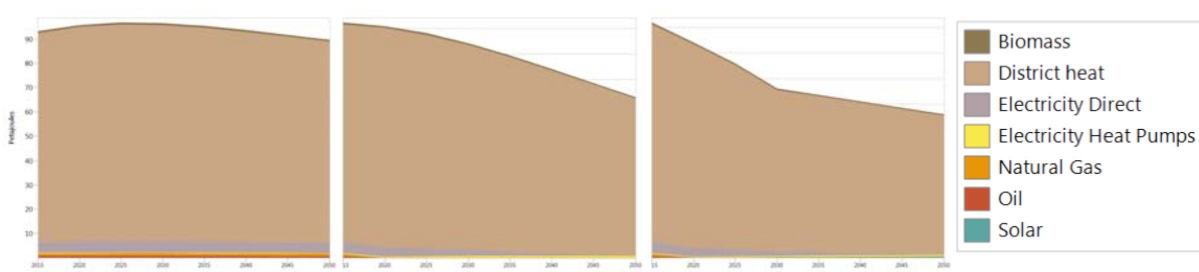

Figure 6: Energy demand in <u>multi dwellings</u> in Pathway 0, Pathway A and Pathway B

Figures 4-6 show total energy demand for the three scenarios 0, A, and B. The figures indicate that biomass, district heating and heat pumps will continue to dominate the heat energy domain until 2050. Both Pathway A and Pathway B indicate strong production decrease and phasing out of oil. Pathway B also indicates that solar heating will enter the market, but with a rather small share. For single-dwellings, biomass and heat pumps are expected to be prominent, whilst direct electricity is expected to be phased out in both Pathway A and B. The share of district heating in single-dwellings is expected to stay at a constant relative rate. It is interesting to note that Pathway A leads to lower heat demand in single-dwellings than Pathway B. The reason for this is that that the energy savings from the combination of building refurbishments and increasing efficiency of technologies (e.g. heat pumps) in Pathway A is higher than the potential of Pathway B measures, including lower indoor temperature, lower floor space and passive standard for newly built houses in single-dwellings.

With regards to multi-dwellings, district heating is expected to continue its domination in both Pathway A and B. Heat pumps increase, but not through crowding out DH, but through efficiencies in output. Pathway B leads to slightly lower demand of heat than Pathway A. This is mainly because the number of new, low-energy, multi-dwellings is higher than new single-dwellings. Another reason is that the main carrier in multi dwellings is district heat, for which efficiency is kept at 100% while for example for heat pumps the efficiency increases with a factor 3-5.

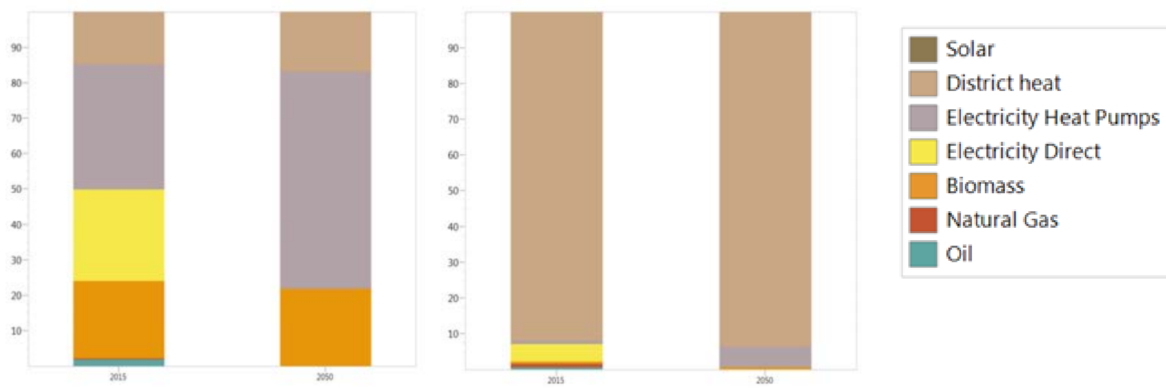

Figure 7: Share of heating devices in single- and multi-dwellings under Pathway A

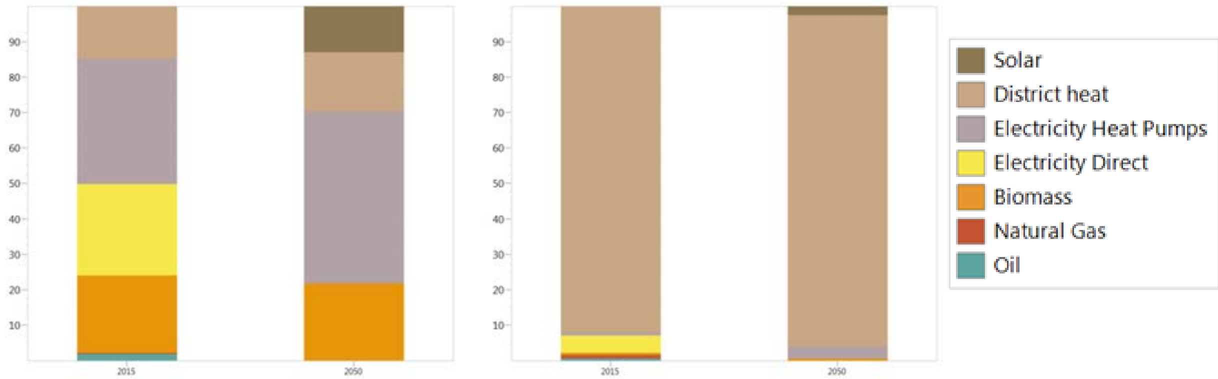

Figure 8: Share of heating devices in single- and multi-dwellings under Pathway B

Figures 7 and 8 show the share of energy carriers in single- and multi-dwellings under Pathway A and B in 2015 (left column) and 2050 (right column). For Pathway A, the main difference in single-dwellings is the phasing out of direct electricity and the significant increase, almost doubling, of heat pumps. For multi-dwellings, the main story is the continued dominance of district heating and the phase out of direct electricity, whose share is taken over by heat pumps.

Figure 8 shows that the share of heating devices in single-dwellings in Pathway B is relatively similar to Pathway A, with the exception of solar heating, which is expected to have a ca 15% share. Similarly for multi-dwellings, solar heating is expected to have a small share (3-5%), but other than that the two pathways are relatively similar.

Finally, Figure 9 shows that both pathways are aligned with the target of 50% reduction in energy consumption by 2050 in relation to the consumption in 1995.

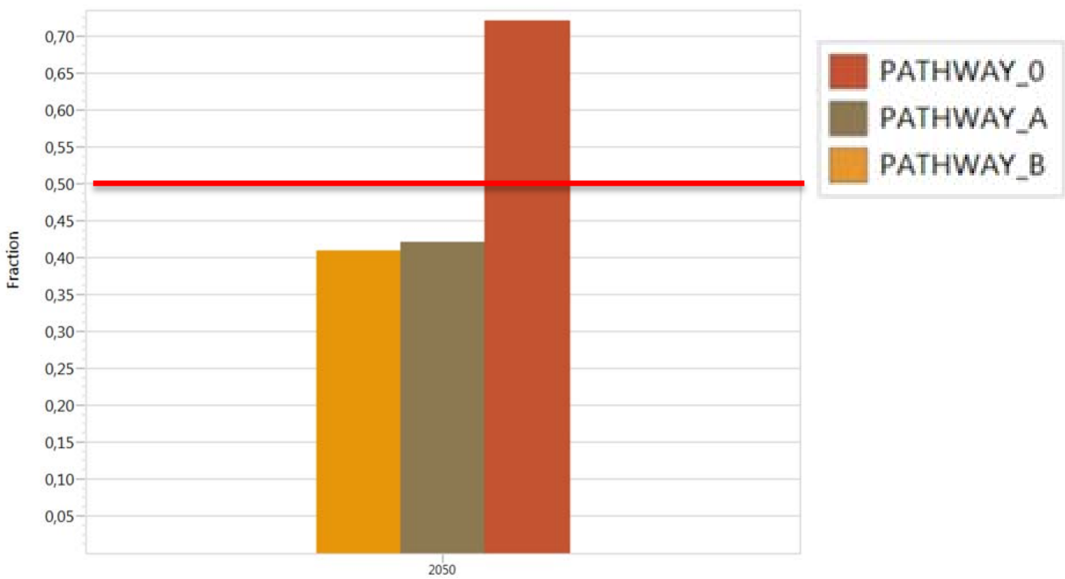

Figure 9: Alignment with national target of 50% reduction in energy consumption by 2050 (LEAP)

3. Socio-technical developments in the recent past and present (2000-2015)

This section briefly describes the main developments of the Swedish heat energy system in the last 15 years. The section summarises findings from D2.1, D2.2, and D2.3 (Nykvist and Dzebo 2014; Dzebo and Nykvist 2014; 2016).

3.1 Niche-innovations

Table 3 summarises the conclusions of the niche-analysis of the Swedish heat energy system with regards to six selected niches. The table includes the assessments of the specific dimensions of niche-momentum*: techno-economic* (market share, price/performance improvements), *socio-cognitive* (size of social networks, learning processes, coherence of future vision), and *governance* (degree of policy support), and our interpretation of whether the niche fits better with Pathway A or B.

Niche Innovation and ranking	**Path way**	**Momentum**	**Drivers of momentum**
1. Heat pumps	A	Moderate	Mainly driven by techno-economic factors. The most cost competitive option when DH is not available and often used combined with other heating technologies. Few socio-cognitive changes needed, and not thus not a driver. Policy (e.g. R&D support and subsidies) has been important historically. Heat pumps are prominent in the single-dwellings, but are trying to take market shares in the multi-dwelling segment. Heat pumps have successfully made the transition from niche to regime.
2. District Heating	A (Hist orical ly B)	Moderate	Mainly driven by policy and governance and socio-cognitive dimensions, e.g., culture and tradition of large-scale system solutions developed by state and municipalities. District heating dominates the heat energy system and is a regime rather than a niche. Today, the techno-economic factors are more important. DH is the most cost-competitive option in Sweden. However, the momentum is low because of the natural monopoly of district heating. District heating has been complemented by heat pumps historically. Recently there has been encroachment and increased competition between the two dominating regime elements.
3. Waste heat recovery	A	Moderate	For waste heat, the techno-economic factors are those that dominate. Waste heat is considered as an add-on to district heating and has no chance of breakthrough on its own. There is also a policy/governance driver to some degree as there have been two national investigations and also a, relatively toothless, bill on third party access to the district heating networks. There is an additional 30-60% potential increase of waste heat. However, the dominant actors have been somewhat reluctant to third party access.
4. Small Scale biomass	A	Low	Socio-cognitive driver is historically key in terms small biomass being a technology in single house dwellings, but recently the cognitive aspects is more of a barrier due to user (un)friendly technology. Key driver over time is more related to techno-economic factors. First the oil crisis, which shifted a discourse towards biofuels. Second, the abundant biomass resource in Sweden. Small-scale biomass' success is also related to district heating, which is mainly fuelled through biomass.

5. Low energy housing	B	Low	The housing sector with large contractors and construction companies is very conservative and changes only gradually. Adopting low-energy housing technologies requires far reaching institutional change, and there is very limited progress in Sweden. The momentum is thus low. From a policy perspective, the core drivers are the EU directives, which themselves are lagging in Sweden. Key barriers are socio-cognitive and include the unwillingness of contractors to develop knowledge of building techniques that are more expensive and not currently demanded by public and private actors procuring new housing projects. There are no discernable increases in investments or projects, no socio-cognitive band-waggon effects, and limited political and institutional support. Developments of the niche innovation are rather hindered as concrete sharpening of building regulation implementing the directive is lagging behind.
6. Individual metering and billing	B (some components of A)	Very low	Socio-cognitive aspects dominate. The use of IMB systems is low, leading to relatively high indoor temperatures. From a policy perspective, there is strong opposition from incumbent actors for compulsory actions or legislation. The Swedish rental system, where heat and water is included in most dwellings is another factor that works against the increase of IMBs. This creates financial disincentives for property owners to install IMB systems. Techno-economic aspects are even a barrier as some researchers suggest solution is even increasing demand. Governance/policy is not driving either, rather resisting this development.

Table 3. Niche innovations sorted by relative momentum.

3.2 Regime developments

In table 4 and 5, we summarise some of the main findings from D2.2 about the degree of stability and lock-in of the Swedish heat energy regime, and the degree of tensions and cracks, which offer opportunities for wider change. Table 4 shows the supply sub-regime and table 5 the demand sub-regime. The heat energy regime is dominated by two main energy sources: district heating (DH) and heat pumps (HP).

	Lock-in, stabilising forces	**Cracks, tensions, problems**
External landscape pressures	- Energy (oil) independence - Societal values on climate change and sustainable development - Natural monopoly of DH	- Climate change (warmer temperatures equals lower demand) - EU policy directives (energy efficiency and waste)
Industry	STRONG - Sunk investments in DH infrastructure – pipes, plants (centralised power generation) - Natural monopoly of DH - High investment costs for HPs - High level of renewable energy in system and low amount of CO_2 in electricity generation - Interconnectedness between HP and DH - Strong trade associations - Large forestry sector means easy access to biofuels for DH	MODERATE - Stagnation and saturation in the heat domain - Increased competition between DH and HP - Waste incineration lock-in - Increased import of waste - Third Party Access for DH
Consumers/ households	STRONG - Sweden has a high demand for heating	WEAK/NON-EXISTING - No tensions. Very stable regime dynamics from

	- Generally low interest in heating from consumers and households - Natural monopoly of DH - High investment costs for HP	consumer side
Policy/gover-nance	MODERATE - Public sector own the majority of DH companies - Historically strong policy support for HP - Tradable Green Certificates premiers DH (through CHP) over other less developed renewable energy sources	MODERATE - New legislation for TPA might threaten DH dominance. - Current political attention on nuclear energy might affect electricity prices and future HP sales.
Public debate and opinion	STRONG - Strong support of carbon-tax - Strong support of renewable energy - 70-80% of heat is renewable, which leads to little contention in the public opinion towards the current regime.	MODERATE - Negative opinion about long-term dependence on waste import and waste incineration
Pressure from civil society and academia	STRONG - Sweden is a world leader in both DH and HP, which have a strong support from academia through research programmes – supported by the government together with the trade associations – which are contributing to the lock-in of the regime	NON-EXISTING - Potential issues around increased waste import
Overall assessment	STRONG - The heat domain is more or less fully renewable. DH and HP have in the past decades formed the new regime and the stabilizing forces are strong	MODERATE - Most interesting cracks and tensions are with the new interactions between DH and HP, and for the processes opening up DH for competition.

Table 4. Stability and tensions in incumbent socio-technical regimes – Supply

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	- Collective societal values explain culture of leaving limited control over heat to residents.	- Very limited
Industry	STRONG - 70-80% of heat is renewable, limited pressure on industry to further change practices - Low interest from industry towards low-energy buildings and passive houses	NON-EXISTING
Consumers/ households	STRONG - Single-dwellings – Residents rarely move, which encourages large investments in e.g. HP. - Multi-dwellings – Heat is usually incorporated in the rent and, thus, is not usually controversial or something on which users have capacity to act - Stable culture of high indoor temperatures.	WEAK - Smart-meters could decrease the demand for heating, but very few signs that this put any substantial pressure on the regime
Policy/gover-nance	MODERATE - Very few polices and governance arrangement that influence heat consumption. Some information	MODERATE - Policy on additional energy efficiency measures, such as lower limitations on energy use /m2 in buildings and stronger regulation on passive

	campaigns on energy savings. - Some norms from health policy makers on indoor temperature makes lower indoor temperature in multi-dwelling housing difficult to implement.	houses, might contribute to destabilise the regime. - The building code gives preference to HP over DH and other heating systems
Public debate and opinion	STONG - 70-80% of heat is renewable, which leads to little contention. - Little interest in demand-side actions for heat reduction	MODERATE - Public opinion against the higher costs (due to the natural monopoly) for connecting a building to the DH infrastructure. - Flagship constructions (such as the New Karolinska Hospital) opting for HP over DH. - Some debate on energy efficiency measures, through Energy Performance Contracting
Pressure from civil society and academia	WEAK - Few campaigns from NGOs on reduced heat use.	NON-EXISTING - Potential to raise voice around the lack of energy efficiency measures.
Overall assessment	MODERATE/STRONG - General low interest in heat demand side from many actors as system has high share of renewables, and the regime is stable. Stabilising forces that limit low energy buildings, maintains regime stability with regard to high heat demand focus.	WEAK - Very limited cracks and tensions in the buildings regime due to high degree of renewable energy. Some tensions on renovation of housing and energy efficiency, else the tensions that exist are rather related to the implementation of the two dominating supply technologies DH and HP.

Table 5. Stability and tensions in incumbent socio-technical regimes – Demand

4. Specifying ‘transition challenges’

This section discusses some of the tensions between the quantitative scenarios in section 2 and socio-technical analysis in section 3 as a preparatory step for the subsequent development of socio-technical scenarios. These tensions form the ‘transition challenges’ between contemporary trends and developments and the future changes that are needed to achieve the climate change goals. If current trends point in a completely different direction, this means that the transition challenge is large, which implies that drastic policies would be required to bend trends in the right direction. If current trends are already moving in the right direction, the transition challenge is less drastic, and mainly requires acceleration of on-going dynamics.

Table 6 describes these tensions over five particular issues disaggregated for Pathway A and B. The last column also qualifies the transition challenges in terms of different *kinds* of constraints, using categories from Loftus *et al*. (2015): 1) technology readiness, 2) economics, 3) integration issue 4) social and non-cost barriers (both policy commitment and social acceptance). The socio-technical scenarios in chapter 5 and 6 aim to offer plausible pathways for how these transition challenges can be overcome via socio-technical interactions.

Niche	**Pathway A**	**Pathway B**	**Constraint**
Heat pumps	Almost all energy efficiency in total energy demand is expected to occur through heat pumps replacing the more inefficient direct electricity. The share of heat pumps is expected to double. However, the current momentum of heat pumps is moderate.	Same as Pathway A, but not to same extent.	Technology Economics
District Heating	Expected to take market shares from heat pumps in multi-dwellings. However, currently there is both stagnation and saturation in the heat regime. Heat pumps are competing over market shares with district heating in multi-dwellings	Same as Pathway A	Economics
Solar heating	Very little solar heating in Pathway A	Solar heating is expected to take market shares in Pathway B. However, with its current state and momentum it is difficult to explain such an uptake from a socio-technical perspective. Solar heating in Sweden did not even register as a niche in D2.1	Policy and governance
Low energy housing	No low-energy buildings in Pathway A.	All new dwellings after 2020 are expected to be low-energy housing following the passive house standard. However, the current momentum for this niche is low and	Policy and governance Economics

		the incumbent actors are opposing strongly. Similarly, there is an issue with lagging implementation of EU Directives.	
Lower indoor temperature	Not part of Pathway A	Pathway B assumes strong energy efficiency measures through lower indoor temperature (through e.g. individual metering and billing IMB). While there is a high potential in this measure, the social mantra in Sweden is relatively high indoor temperatures, which are also supported by national recommendations. Moreover, tradition of communal and central heating systems mean that individual tenants in multi-dwelling do not have control over their heating.	Social acceptance Policy

Table 6 Tensions between future model scenarios for and WP-2 findings of niche-momentum and path dependencies

5. Scenario 1 – Pathway A

This scenario provides a socio-technical storyline for Pathway A. This pathway builds on the continued strength of the incumbent regime actors in industry and policy. It focuses on radical technical change, mainly through substitution. It focuses on change in one or two dimensions and leaves most other system elements (e.g. households, markets, user practices, public opinion, civil society, socio-cognitive aspects) mainly intact. Major transition challenges concern technology and economics. The regime is expected to continue its dominance. However, the momentum for various regime components is currently varying from low to moderate (Table 3).

5.1 (2015-2030)

Key landscape trends, shocks and pressures: When the Paris agreement was adopted in 2020 Sweden reaffirmed its ambition to become a climate neutral country by 2045. What is more relevant for the heat energy domain, which is more or less carbon neutral, Sweden repeated its target of 50% reduction in energy consumption by 2050. The government also agreed to phase out oil by 2020. From 2020 and onwards, oil was only used in back-up plants for extremely cold weather. These measures put Sweden on path to achieve the target of lowering total energy consumption with 20% by 2020 from 2008 levels. This policy path had strong cross-party support and it was well grounded in public opinion as there were few proponents for expansion of oil in the Swedish heat sector.

In 2016, the government agreed on a plan to make all Swedish electricity production 100% renewable by 2040. This also included a phase out of nuclear electricity in the long-term. However, the cross-party agreement also guaranteed a replacement of 10 nuclear reactors, guaranteeing a continued significant share of electricity from nuclear energy, between 50-70 TWh/year. This agreement was seen as a victory both for the proponents of nuclear energy and for the environmental NGOs who celebrated the long-term renewable energy target.

Regime developments: Since Sweden's heat energy system was already more or less decarbonised, during the first 10 years not much changed in terms of total demand for DH and small-scale biomass. The dominance of HP, DH and small-scale biomass was maintained. The most dominant heat energy source, DH, continued to expand with help from new combined heat and power (CHP) plant development. Several new plants were built thanks to the government's decision to expand the tradable green certificates (TGC) system. TGC was designed so to premiere established energy sources such as wind and CHP over less developed, including solar, wave, and hydrogen. The logic behind CHP expansion arose from the nuclear energy debate and the needed shift to renewable energy in the electricity regime.

Another effect from CHP expansion was the increased use of waste incineration. The new plants were fuelled on waste, which was mainly imported from Sweden's neighbouring countries. Over the course of the first few years, this was not seen as a problem. However a few years later the public opinion had started to shift against further import of waste. Environmental NGOs initiated campaigns against increase of waste import. Three problems arose in the debate; first, the high costs of import; second, the increased emissions of transporting of waste; and third, the waste discourse had started to shift more towards recycling and reuse rather that incineration. Another consequence of this was that supply of heat was constant, even though the number of buildings increased and the demand-based initiatives were lagging behind. However, as nuclear energy was losing its historically strong position and biomass in Sweden had reached its peak, there were few alternatives that importing waste. As a consequence, NGOs started targeting the Swedish government for falling behind on its energy efficiency targets. Public opinion started to shift, which pushed the government and the municipalities, by the end of this period, to undertake country-wide refurbishments of the building sector, particularly the multi-dwellings. Many of the buildings constructed before 1975 needed to be renovated before 2050. This was done through massive subsidies for both single- and multi-dwellings. The government funded 30-50% of the total costs up to a certain limit in investments in HP, effective ventilation systems, insulation, and advanced systems for heat recovery.

For multi-dwellings, during this period the demand for DH decreased significantly. However, the relative share of DH in multi-dwellings remained more or less constant. For single-dwellings, DH was at a constant rate over the time period. Despite strong initiatives from the incumbent DH actors, the business model of reaching out to single-dwelling customers was seen as more expensive. The only market expansion was in newly built single-dwellings, which was small. For HP, on the other hand, this time period led to a significant expansion. By 2020, Sweden decided to go further with energy efficiency measures by a decision to phase out direct electricity. Through a strong policy support with subsidies and investments in research and development, the government set out a plan to support HPs. The coefficient of performance (COP) for HP increased from 2,8 in 2015 to 3,8 in 2030. Development was encouraged by the fact that residents rarely move, which allows for large private investments in rather costly HP systems. Replacement of direct electricity with HP met little resistance, as it was merely an add-on to an existing system rather than a total replacement. The key incumbent actors, the utility providers, were behind this initiative.

Niche developments: Following the backlash in public opinion of waste import for incineration and the glooming news that the Swedish government was lagging in energy efficiency measures. The government strengthened the policy on third party access (TPA) to the DH networks against the will of the incumbent actors who were already threatened by the forthcoming energy efficiency measures. Despite this opposition, the public opinion against the energy waste was strong and the amount of waste heat from industry, large server rooms, shopping malls etc. increased its share as a fuel input to DH. By the end of the time period, waste heat and refurbishment of the building stock were the main factors for lower energy demand in multi-dwellings.

Another niche, small-scale biomass through pellet burning boilers remained relatively constant during the time period. By 2030, biomass potential in Sweden had reached its limit. Whilst biomass was mainly used as fuel for DH, small-scale pellet was profiting on the same supply-chain. There was some switching from traditional wood to pellet burners. However, the relative share of biomass in single-dwellings remained constant.

5.2 (2031-2050)

Key landscape trends, shocks and pressures: In the beginning of this time period, Sweden was more or less on its way to reach the target of 50% less energy consumption compared to 1995. However, there were a few landscape pressures that started to have an impact. One of these was climate change. The increased average temperatures led to a decrease of demand in heating and contributed towards achieving the energy efficiency targets. By 2050, energy demand for heating had decreased by 11% (Gode and Jarnehammar 2007).

Another landscape shock was the phase out of nuclear energy. By 2040 the last reactors had been shut down. The replacement from renewable energy sources did not manage to replace all supply even though there was an expansion of hydro. Sweden became a net-importer of electricity, which led to higher electricity prices. Higher prices further sped up the conversion of direct electricity to HP and by 2050, direct electricity boilers for heating in the Swedish building sector were phase out and replaced by HP. By 2050, COP for HP had increased to 5 (Nowacki 2011).

Regime developments: The competition between the two dominating regime components was settled and decreased as DH found difficulties in expanding further in the single-dwelling sector. For HP, multi-dwelling sector offered few opportunities due to dominance of DH. Despite lower demand or DH, it managed to increase its market share. DH had support from its main owners, which were public, as well as relatively competitive prices. Instead HP turned towards outward expansion through export, mainly to Europe, which had developed an apetite for HP expansion. For DH providers, new opportunities in smart homes arose through the introduction of smart systems and big data access. As many of DH companies were publicly owned, their business models extended towards providing smart services to their customers.

By the end of this time period, Sweden had not only reached its target, but also exceeded it by lowering energy consumption by 60% compared to 2005. In multi-dwellings, DH maintained its dominance with over 90% share. The rest were HP, which had fully replaced direct electricity. In single-dwellings HP, again, had fully taken over from direct electricity. DH had slightly increased from its initial levels, mainly due to new buildings, which were easier to connect to the DH network. Biomass remained at a relatively constant level throughout the time period.

6. Scenario 2 – Pathway B

This scenario provides a socio-technical storyline for Pathway B. This pathway builds on a substantial departure from existing system performance. It focuses on new entrants rather than incumbent actors, including new firms, social movements, and civil society actors. It represents radical transformative change in the entire system in several dimensions (technical, market, organisational, policy, cultural, social, consumer and user change). Major transition challenges between the quantitative scenarios and the socio-technical analysis are concerns about social acceptance, policy, governance and economics in a system that is already more or less decarbonised. Another issue is that Pathway B niches are currently facing a very low momentum (Table 3).

6.1 (2015-2030)

Key landscape trends, shocks and pressures: The signing of the Paris agreement in 2015 and the sequential implementation of the agreement in 2020 was a policy bomb in Sweden. The government increased its ambitions and set a course to become a carbon neutral country by 2045. The red-green coalition had strong support from the public and the opposition was on-board as well to implement the necessary national measures. For the heat energy domain, this meant an enhanced focus on energy efficiency. The discourse started to shift from the current supply-based regime to a more demand-focused with emphasis on efficiency and user- and consumer behaviour. One strong reason for this discourse shift is that the measures to decrease energy consumption in the housing sector would leave space for maintain the energy intensive heavy steel and metal industry in northern Sweden intact. This occurred with strong and targeted information campaigns from the civil society organisations. In parallel, worker unions and employer associations initiated a task force for creating a business case for this transition. This development was also helped with advancements in information technology and big data, which led to an ever-increasing knowledge base in governments, academia and the private sector.

The first decree of the government after the Paris agreement was a phasing out of oil before 2020. The government also increased its emphasis on implementing the EU Directives on energy efficiency, energy use in buildings and waste. In 2016, a bi-partisan agreement on phasing out of nuclear and a 100% renewable energy system by 2040 was signed. This agreement included replacement of 10 nuclear reactors, which was a demand from the opposition. However, by 2020 when the Paris agreement was implemented in national policy, pressure on the government from high maintenance costs of the existing reactors as well as civil society organisations and the public opinion was to scrap the reactor replacements and further emphasise energy efficiency and renewable energy. With support from the work of International Energy Agency, Energy efficiency measures became quickly seen as the most effective way to decrease CO_2 emissions. The number of new reactors to be replaced decreased from 10 to 4.

At the same time, in 2022, the red-green government coalition, with a reinforced mandate, created a coalition with academia and the private sector in order to increase communication around energy efficiency in buildings, focusing on awareness campaigning, information sharing, attitude shifting, target setting and action setting across all energy-consuming sectors.

Regime developments: As a consequence of landscape pressures described above, the government decided, early in the time period, to phase out direct electricity as a source for heating. Information campaigns about energy consumption were rolled out across the country. Municipalities offered support and guidance on how individuals and households could lower their consumption. The government also increased its support to HP as a replacement option for electric boilers through subsidies and investments in research and development. The roll-out of HP also had a small effect on biomass where a few biomass boilers were replaced by HP. In general, this was accepted among the population. Mainly thanks to the debate about nuclear energy and fear of higher electricity prices when nuclear was phased out and Sweden became a net importer of energy by the end of the period.

For DH, this period led to stagnation and saturation. The shift towards energy efficiency in buildings and the backlash on new CHP plants and import of waste for incineration faced strong resistance due to environmental costs. This meant that there was little scope for further development of DH systems. The price monopoly that DH has benefited from in over 60 years meant that the public support for DH shifted quickly. By the end of this period, no new DH systems were being developed. The key incumbent actors in DH fought against this current. However, the tide of the opinion was too strong. The transition was helped by the fact the majority of the actors were public actors (mostly municipalities) and could shift their financial structure. The large private actors, however, suffered severe economic damage. During this period, energy demand decreased with 20%. Notwithstanding, in terms of relative dominance, DH maintained its shares in both single- and multi-dwellings. In multi-dwellings, DH accounted for over 90% of the demand and around 10% in single-dwellings, which were dominated by HP, and biomass, now the dominant source in this domain.

However, the dominant regime had started to crack. By the end of the time period, a new regime emerged, focusing on breakthrough of several niche-innovations, including buildings efficiency, socio-cognitive and collective social values, user-friendly technology and solar heating.

Niche developments: By 2020, the government ordered that all new buildings have to be passive house standard. This occurred at the same time as the National board of Housing, Building and Planning (Boverket) issued a report stating that 1 million new buildings needed to be built by 2030 and another 500 000 by 2050 - volumes that have not been seen in Sweden since the 1960s. After an intense and controversial debate, where current contractors were reluctant to build low-energy housing, the government introduced stronger regulation and issued penalties for contractors. The government also stepped in with subsidies and rewards for early adopters. This acted as a catalyst and the transition, which started slowly gathered traction.

For single-dwellings, large investments were made possible due to the fact that residents rarely move. The government stepped in with subsidies for conversion of boilers to HP. By the end of this period, ‘smart grids’ and ‘smart homes’ became catch phrases. In this development the large actors in the energy domain played an important role. When the market for energy supply started shrinking, these actors diversified their activities to provide services to lower the energy bill. New business ideas such as Energy Performance Contracting (EPC), a method that offers customers guaranteed improvements in buildings' energy performance without the need to expend capital, became profitable for both the provider and the buyer of this service. By the end of the time period, solar heaters started to develop its own business model, and with help from government subsidies a new green niche was initiated. Efficiency improvements continued in the single-dwelling sector and by 2030 it had decreased to 60 kWh/m^2 from 126 kWh/m^2 in 2010.

For multi-dwellings, in order to increase efficiency, the National Board of Health and welfare (Socialstyrelsen) decided to lower its recommendations of indoor temperature from 21°C to 20°C. There was a broad agreement in the government for this decision, despite strong opposition in the public opinion. However, since most multi-dwellings are centrally controlled, and most DH companies are publicly owned, this was a rather easy measure to implement top-down. Similarly as for the single-dwellings, EPC was widely employed with good success.

Another niche that enjoyed success was individual metering and billing (IMB). Initially IMB was met with scepticism. The main reason for this was that the standard practice for multi-dwelling housing is for heat to be included in the rent and that building management company is the agent rather than the tenant. IMB of heating was also problematic because energy consumption is dependent on the building envelope and operating systems; and hence of measures of the property owner, the residents can only affect the smaller part (Boverket 2008). However, when big data started to have impact, smart systems were rolled out, which contributed to a fair ownership and responsibility of actions and costs.

By the end of this time period, most of the new buildings were passive houses, which had a significant impact on energy consumption in Sweden. The development was radical, with 30% total reduction in the buildings sector.

6.2 (2031-2050)

Key landscape trends, shocks and pressures: The second period was less dramatic than the first. With 30% reduction achieved around 2030, the development slowed down. The main reason for this was the new Swedish million-programme with a million new passive house dwellings being built between 2015 and 2030. In addition, after 2030 there were a few landscape pressures that started to have an impact. One of these was climate change. The increased average temperatures led to a decrease of demand in heatingand between 2015 and 2050, energy demand for heating had decreased by 11% (Gode and Jarnehammar 2007). This development had led to deep cultural shifts in the Swedish population.

Regime developments: The new buildings regime was stable over this time period. The efficiency measures slowed down slightly with the end of the new million programme. Between 2031 and 2050, only a half of the buildings arose compared to the previous period. Big data was a key development for further dissemination of smart system, which had become cost efficient and became standard even in the older building stock.
For single-dwellings, solar heaters increased and doubled their share 2050 compared to 2030. Improvements in technological capacity and warmer temperatures in Sweden led to high investments.

7. Conclusion

The aim of this report was to develop qualitative scenarios that describe plausible socio-technical pathways for the quantitative scenarios from WP1, complemented with socio-technical analysis from WP2. This section makes a few concluding comments about the transition pathways as described in section 5 and 6.

Pathway challenge: The report shows that both scenarios reach Sweden's target of 50% lower energy consumption in the resident buildings sector by 2050 with 1995 as a baseline. The first scenario (Pathway A) shows higher potential than the second scenario (Pathway B). This is mainly due to refurbishment of the existing building stock, which has by far the highest potential to lower energy consumption. For pathway B, the decision to build low energy buildings with passive house standard combined with the high demand in new dwellings led to a regime breakdown of the supply-dominated Swedish heat regime. The dominance of DH was significantly diminished and a cultural shift in energy consumption in the Swedish population had occurred. However, both scenarios deviate substantially from pathway 0. This means that for this development to take place, there is a strong need to solve the transition challenges in technology, economics, policy and governance, and social acceptance.

The role of policy: In both scenarios, the Swedish government plays a crucial role. As section 3 showed, pressure from public opinion, civil society and academia is weak to non-existing, it is up to the policy-makers to provide leadership for the transition to happen. Tax breaks, subsidies, and support to research and development are key instruments. However, conversely, for the policy-makers to introduce tough policies, there needs to be pressure from the civil society and public opinion. Issues such as waste import and lack of energy efficiency measures, as well as the looming climate change discourse, can act as catalysts for the transition to occur. Both scenarios also imply a total phasing out of direct electricity, which is replaced by HP. For this to happen, again, strong policy support is necessary.

Similarities and differences in the two scenarios: In terms of similarities between the two scenarios, it is clear that DH will continue its dominance as the major source for heating. This is directly connected to the electricity regime where a phasing out on nuclear energy will either lead to lower consumption or an increase of CHPs. Biomass is constant in both scenarios. In pathway B, it will be slightly lower, but will mainly keep its share. Small-scale biomass is benefitting from DH where it is a major fuel source. Furthermore, in both scenarios an emphasis on buildings increases significantly from pathway 0. In pathway A scenario the focus will be on the existing building stock, whilst in pathway B scenario, it will be on new low-energy buildings.

However, pathway B scenario also indicates a clear diversion from the pathway A, where a total regime breakdown is necessary and a new regime takes its place. DH particularly is expected to suffer severe losses, albeit whilst keeping its relative market shares. This is implied already in the first time period, which indicates that transition efforts required are substantial in terms of the speed, scale, and scope of change of individual practices and socio-technical configurations. In other words, a radical change is necessary.

Methodological issues: This exercise was based on quantitative models, which tend to neglect important developments related to, for example, different actor groups and their interactions; policies; beliefs, decisions, struggles and conflicts; or lock-ins. To make the scenarios richer, socio-technical analysis was introduced as a complement, which led to the socio-technical scenarios. However, the development of these scenarios did not occur without problems. The main problem was the lack of a coherent scientific methodology, which provides speculative and fictional stories rather than coherent and robust scenarios.

8. References

Dzebo, A. and B. Nykvist (2016). Integrated analysis of D2.1 and D2.2 to assess the feasibility of different transition pathways in Sweden. PATHWAYS FP7 Project Report, Deliverable 2.3.

Dzebo, A. and B. Nykvist (2014). Analysis of stability and tensions in incumbent socio-technical regimes. PATHWAYS FP7 Project Report, Deliverable 2.2.

Gode, J. and A. Jarnehammar (2007). Analys av värme- och kylbehov för bygg- och fastighetssektorn i Sverige SOU2007_60, bilaga B11.

Hofman, P.S. and Elzen, B., 2010, 'Exploring system innovation in the electricity system through sociotechnical scenarios', *Technology Analysis & Strategic Management*, 22(6), 653-670

Loftus, P.J., Cohen, A.M., Long, J.C.S., and Jenkins, J.D., 2015, A critical review of global decarbonization scenarios: what do they tell us about feasibility?, *WIREs Climate Change*, 6(1), 93-112

Nowacki, J.-E. (2011). Efficiency and implementation of heat pumps, Svenska Värmepumpsföreningen.

Nykvist B. and A. Dzebo (2014). Analysis of green niche-innovations and their momentum in the two pathways. PATHWAYS FP7 Project Report, Deliverable 2.1.

Van Vuuren, D.P., Kok, M., Lucas, P.L., Prins, A.G., Alkemade, R., Van den Berg, M., Bouwman, L., Van der Esch, S., Jeuken, M., Kram, T. and Stehfest, E., 2015, Pathways to achieve a set of ambitious global sustainability objectives by 2050: Explorations using the IMAGE integrated assessment model, *Technological Forecasting & Social Change*, 98, 303-323