PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

Grant Agreement number 603942

Deliverable D2.5: 'Forward-looking analysis of transition pathways with socio-technical scenarios'

Country Report 4: The German heat domain

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July, 2016

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Executive Summary

This report develops two socio-technical scenarios for a low carbon heat and building domain in Germany. Scenario 1 is a storyline whereby technologies in the heat and building area have come forward to solve fossil fuel dependency. In contrast, Scenario 2 concentrates on social and behavioural changes or specific policies, while technologies have a lesser dominance. The scenarios build on earlier findings in this work package and on simulations performed in WP 1 of the PATHWAYS project. In contrast to other scenarios in this deliverable, country specific simulations were not available at the time of writing so that the scenarios have been developed more freely albeit with a look at an IMAGE-based simulation targeted at Europe and, of course, available data on future development.

Two different basic assumptions are used to clarify how change came about in the scenarios, these regard two different Pathways conceptualizations – Pathway A and B. Pathway A will focus on technological change on the side of incumbents driven by very active political intervention. Pathway B assumes bottom-up evolution instigated and promoted by private activities with policy and businesses only becoming of more importance late in the scenario. Both scenarios are presented below. Underlying argumentation and lessons can be found in the report.

Scenario 1 (Pathway A)

The "Pathway A Socio-Technical Scenario" (STS A) describes the storyline of a scenario from today until 2050, whereby technical components especially on the side of heat appliances have been developed and substituted to cater for a low carbon domain. This is hence a technology driven scenario leading to a transition of the German heat and building regime. The scenario follows a reconfiguration scheme as devised by Geels and Schot (2007). We follow a path where basic adjustments of the regime occur through regime-internal adaptation and innovation processes in the form of economic and technological innovations. Hence, with reliance on the present German appliances market, incumbents have major role in both regime and niche development.

Phase 1: 2015-2025 - Master plan

In this phase, **landscape development** was characterised by several trends and political developments. One of these was a strong increase in urbanisation, leading to major change in technology demand, as more centralized and cleaner technologies were needed in cities and cheaper appliances were demanded in rural areas. Fossil fuel prices remained volatile at medium price levels, but uncertainty and volatility in fossil fuel prices and supply support increased.

Regime Development

Direct consequences of the COP agreement fleshed out aiming to keep a global temperature rise in this century well below 2 degrees Celsius (by reaching an 80% reduction in GHG emissions in 2050 compared to 1990 levels). As heating energy in domestic use had a significant share in Germany (about 60%), a masterplan was enacted by the German federal government, providing a plan for a consistent legal framework to help pushing technological

niches in the heat domain to reach the COP agreement. The government further decided that new fossil-fuelled installations were prohibited from 2030 on and until 2045 all existing installations would have to be based on renewable technologies and/or district heat from waste incineration, waste heat or CHP. Support schemes for fossil-based appliances had been dismissed and replaced by an investment scheme for district heat based on renewable energies and high-efficiency gas to fuel cities. Thus, incumbents now had a clear long-term perspective for phasing out their fossil fuel-based products without unbearable sunk costs and the split-incentive dilemma could be overcome. Also, in 2016 a maximum heat energy consumption of <45kWh/m^2 for new buildings was forced by the next step of EnEV.

Niche Development

Incumbent companies, who had invested early into less carbon intense technologies already dominated most niches. Already in 2015, more than one third of all newly constructed buildings (that already met low-energy standards) were equipped with heat pump technology. Small-scale biomass heatings were increasingly installed in new and retrofitted buildings in predominantly rural areas after 2025 due to the master plan. Altogether, regime actors including architects, construction companies and craftsmen as well as technology producers benefitted from the market development and ongoing price declines.

Phase 2: 2025-2035 Take-off for low-carbon

Landscape Development

The overarching trends continued as climate change concerns increased and peak oil had been reached. This put increasing pressure on German policy-makers. A trend, that strongly affected the **regime.** As users of fossil-based appliances had to bear increasingly rising heating costs and rents in cities were rising as well, a rent support scheme was introduced and the master plan was updated as effects of the newly introduced policies became detectable as the market for low carbon technologies within the heat and building domain was growing. This supported the **niche development:** Incumbents profited from intensified investments, and were also able to export their newly developed or improved technologies worldwide. The share of heat pumps installed annually continuously rose to over 50% in new buildings and about 25% in retrofitted buildings. In rural areas a real hype for solar heating started and the grid for district heat grew slowly but steadily after 2030.

Phase 3: 2035-2050 – A new technological regime

Landscape Development: After 2035, the effects of the COP agreement, urbanisation and demographic change settled in. The population had sunk to about 70 Mio. (cf. statista 2016) inhabitants and urbanisation had led to abandoned villages in the countryside and overcrowded urbanised areas. Fossil fuel prices now were clearly trending downward.

The **regime** further developed as actors now collaborated to push the low carbon technologies and a consistent legal framework was enacted. Furthermore, the investments undertaken by incumbents have led to a maturity of former niche products and by 2040, the coal electricity phase-out was completed, replaced mostly by on- and offshore wind energy. Thus the heat regime had changed significantly by 2050.

The **niches developed** differently in this phase. Biomass heating became an attractive option for high-efficiency buildings with small heat loads. Solar thermal panels contributed an important share of heat supply in rural areas and the grid for DH kept extending, connecting about 20% of households by 2050 (40% in urban areas). To full compliance of the EnEV a new building monitoring system was put in place after 2040.

	2015-2025	2025-2035	2035-2050
Landscape			
	COP agreements put pressure on the domestic regime. Price relations from fossils and renewables without significant changes. Repeated extreme weather phenomena foster public awareness for climate change and thus put rising political pressure.	← Repeated extreme weather phenomena: climate change as one core policy topic.	← CO_2-emmissions have started to significantly decrease worldwide, in Germany, a 85% reduction was reached in 2050. Decreased population to about 70 Mio. people, due to demographic change. Decreasing fossil fuel prices since 2035, as an effect of the COP agreement and demand reductions.
Regime			
	Still strong resistance from fossil-based regime actors to a. low-carbon transition of residential heating. Subsidies for fossil appliances are phased out. Oil-based appliances are planned to be phased out. All new buildings require few energy, being low-energy or passive houses. Incumbents developed a long-term perspective for phasing out their fossil fuel-based products and geared their R&D strategy towards the development of the supported renewable technologies. The electricity domain is in transition: termination of the nuclear phase-out in 2023, a coal phase-out until 2040 is running, and renewables are booming. → Heat pumps become increasingly low-carbon intense. Introduction of a subsidy	Introduction of a rent support schemes for people living in social housing, students and elderly. Implementation of an updated and consistent masterplan, leading to technological progress. Repeated extreme weather phenomena were widly attached to climate change and thus putting pressure on policymakers..	Actors now collaborated to consistently push the technological change. A consistent legal framework was now enacted, including financial promotion scheme, information campaigns and a top-runner programme linked to minimum efficiency performance standards (MEPS). Decreasing share of fossil fuels, by 2040 down to 15% and less than 5% in 2050, and thus shrinking prices for fossil fuels. Biomass has become a major source of heat in rural areas.

	programmes to overcome the split-incentive dilemma.		
Niches			
Heat pumps	Increasing technology advances: more cost-effectiveness. Already one third of all newly constructed buildings were equipped with heat pump technology, but still not widely applied for retrofits.	←	Heat pumps became extensively applied also in refurbished buildings and are driven by renewable energy.
Small scale biomass	Appliances became increasingly more cost-effective and efficient.	Increasing market share of biomass is limited by fuel supply and thus increased biomass fuel prices.	← Biomass and waste share rose to 30% by 2050.
Solar thermal	Solar thermal appliances experienced a slight increase in cost effectiveness and efficiency, but still not acknowledged much by consumers.	Solar thermals are increasingly applied in rural areas as complementary heat source.	First hype for solar thermal panels until 2040, when subsidies were phased out. But since then, an important share of heat supply in rural areas
District Heat	No change	DH grids are expanding and DH increasingly relies on heat from waste incineration and biomass co-combustion.	DH kept extending grew slowly (by 2050 connected about 20% of households to DH, 40% in urban areas).
Low energy/ passive housing (new build)	Low energy housing is already BAT and passive houses have an increasing share.	←	EnEV building code as standard for new buildings mandated, but no full compliance until 2040, when a building monitoring system was introduced.

Scenario 2 (Pathway B)

The pathway B scenario entails broader system changes and reconfiguration. It describes the low-carbon transition trajectory of residential heating until 2050 towards a broader regime transformation including behavioural and lifestyle changes, and to some extent the technological transformation already described in the pathway A scenario (because a behavioural and lifestyle change does not come alone but hand in hand with the technology-based transition).

This scenario is therfore largely based on changes in behaviour of consumers (private housing). In contrast to Scenario 1, change largely comes about through bottom-up activities and innovation in niches that eventually scale up with public support. Hence the state will have a less important role in this scenario and only react to niche pressures in the later phase towards 2050.

Phase 1: 2015-2025 – Building pressure from below

In this phase, **landscape development** was characterised by several trends and political developments that catered for a need of new ways of housing and heating behaviour: increase in urbanisation (booming cities/rural abandonment), demographics (ageing population, increasing share of single households, high immigration rates) and a series of over- and undersupply phases for oil and gas due to geopolitical challenges. The federal government felt unable to address this development so that people started to search for new possibilities on their own, looking for low-invest solutions with major impact.

The **regime** still remained stable in this phase. The coalition of state and incumbents as well as a dominance of lobby groups working against changes did support the lock-in. Calls from scientists and activists addressing increasing social and environmental problems caused by heating and energy poverty were mainly not registered.

The slowly growing unrest caused by rising rents, demographic change and volatile prices led to an increase in locally organized groups and advanced **niche development**. At first these groups addressed different problems like food waste, renewable energies or smart quarter solutions. Initially driven by idealism, they largely emerged in the densely populated urban areas. When the public opinion faced a strong turn towards climate change awareness after severe extreme weather phenomena, demand for new technology and product-service systems started rising.

Phase 2: 2025-2035 – Opening of cracks

In this phase the overarching **Landscape development** trends continued and great parts of the population started to feel neglected in their needs. The teaming up of state and incumbents and missing interest from lobby groups increased these feelings and lead to dissatisfaction. Offers from large utilities on allegedly green solutions were met with distrust caused by earlier failures from these companies.

The **regime** didn’t alter much in the first half of this phase. For incumbents, heat appliance sales kept falling through the first years of this decade. Therefore, the government introduced new subsidy schemes to keep these companies running. Even renewable heating technologies remained expensive and still largely incompatible with the existing infrastructure. On the customers side, conventional heating appliances became less and less attractive as they did not address their new and changing needs. The cracks and tensions between the old regime and new demands (i.e. a stricter environmental legislation) and needs therefore increased in this period.

The changes in attitudes of actors were opening a window of opportunity for more radical regulations and niche development. By 2030 the federal government hence enacted regulations and subsidy schemes that fostered niche development. New models for living and housing became more prominent in this phase. Initiatives, activists and social entrepreneurs became increasingly connected and a country-wide self-reinforcing knowing and doing network for new low-energy living emerged. Transition design had become to be acknowledged as a powerful instrument by the niche protagonists, a number of social and economic innovations as well as new business models were created. Rising distrust towards established organizations and institutions also created a will for more autarchy and autonomy on the side of the citizens.

Phase 3: 2035-2050 - Turnover

Landscape Development

Based on international pressure and dedicated EU guidelines, the German government no longer ignored the problems resulting from the old heat/building regime and fully oriented towards a regime shift. In this period, CO2-emmissions in Germany caused by heating and building declined fast. Due to demographic change the population sunk which solved some issues especially in the areas peripheral to city centres. For other parts, urbanisation led to abandoned villages in the countryside while urbanised areas still were crowded.

By 2035 a new **regime** based on change in behaviour, models of living, and new housing concepts significantly opened cracks and tensions in the old regime. The federal government had by now adopted a holistic, behaviour-oriented policy design. By 2050 the old regime stopped to exist by and large. Those incumbents who could make it, switched to producing renewable technologies others ceased to exist or moved abroad.

The former **niches** became part of a newly emerging regime. Due to state support and private investments, initiatives were increasingly able to also include novel technologies, which became more affordable in this wake. People now moved into cities and refurbished quarters because the advantages and social innovations developed in more collective living models had become accepted and fashionable in most parts of society. Public housing companies became engaged in the construction of flexible space apartments. In this phase, average living space was reduced and new concepts for furniture and sharing lead to an increase in overall satisfaction and quality of life. Energy consumption in this phase was thus falling incrementally both driven by social and technological innovation.

	2015-2025	2025-2035	2035-2050
Landscape			
	Demographics: Ageing population, more single households, immigration; Housing prices: booming cities↗, shrinking cities↘, rural areas↘ Repeated extreme weather phenomena fostered public awareness for climate change. Problems and the high costs of the “Energiewende” yield to major distrust in public action.	Increasing fossil fuel prices since peak oil had been reached. Increasing number of people due to demographic change. Repeated extreme weather phenomena: climate change became one core policy topic and wide-spread public interest.	Decreased population to about 70 Mio. people, due to demographic change. Introduction of the “heating transition act” in 2035: Upscaling of support schemes (financial, audits, advice) for retrofits, passive/plus energy (+E) houses.
Regime			
	Massive upscaling of support schemes (financial, audits, advice) for retrofits, passive/+E houses, and development of new housing/living types. But the government still was reluctant to come up with ambitious programmes to fulfil the COP agreement.	Climate Change awareness became mainstream. → Change in attitudes and behaviour towards a) energy end-use and b) focus of technology manufacturers on sustainable products. → Political majorities to change/sustain political/legal framework for a heat transition.	Pro-low-carbon attitudes of energy use and technology supply has become the mainstream discourse. → Political majorities have lead to a coherent legal framework in place (pro-RES, efficiency and sufficiency legislation): • Electricity domain transition in completion • DH system in transition towards renewable & electricity fuel • Energy taxes raised, especially for fossil fuels • Full subsidy scheme for low-carbon niche technologies • Sufficiency policies in place
Niches			
Per capita living space	Urban: Increasing prices (also due to retrofits). → Slow-down of increasing p.c. floor-areas.	Urban: Increasing prices (also due to retrofits) and increased shared apartments. → Decreasing p.c. floor areas New models for living	← 2050: Average p.c. living space has decreased to around 20 m^2 per person.

		and housing and low-energy living became more prominent, also due to new networks. Transition design had been acknowledged as a powerful instrument. Average living space in cities decreased to about 35 square meters per person by 2035.	
Temperature	-	-	-
Smart metering/housing	Further development and testing of most promising technologies.	Increasing demand due to climate change awareness. → New business emerged.	← 2050: Around 75% share of houdholds with smart metering, and 50% with DSM.
Low-energy housing retrofits	Technology: Cost decreases, development of easy-to implement standardised packages. Large-scale policy programmes tackled main barriers: Split incentives, finance, information, administration. → Uptake of retrofit rates	Experience with policy programmes. → Reviews, ameliorations were launched. → Deep retrofits become mainstream. Renovation rate doubled to almost 3%. → From 2015 to 2035 almost 27% of the building stock had been refurbished. → Decreasing CO2-emissions, by 2035 to about 35%.	← 2050: Around 75% of building stock retrofitted to low-energy standards.

Concluding comments

Starting conditions:

- Heat in buildings is among the most hidden but important domains for a transition towards CO2-neutrality.
- Renewable alternatives are not breaking through yet and are in part dependent on the ‘Energiewende’ to be successful.
- The demand side regime is inert to a low refurbishment rate, the split incentive-dilemma caused by resistance from owners and tenants towards bearing refurbishment costs, and a low rate of newly builts.

Scenarios

- In both scenarios, policy had to play an important role as driver and enabler of change. Regulations like the EnEV will have to play an important role, as rules, that are becoming stricter will provide incentives for change and may even create markets for more efficient and eco-friendly appliances and buildings.
- Scenario 1 seems to be more in the comfort zone of the current regime and its affiliated institutions, norms and organizations whereas.
- Scenario 1 may require more spending and regulation activities on the side of the state.
- Scenario 2 assumes a broader transition towards a new regime in which at least current incumbents on the supply side could be highly disadvantaged.
- Scenario 2 is both more optimistic and pessimistic than its counterpart. It is more optimistic because it assumes potential for real bottom-up change driven by idealists and state support. It is more pessimistic in using harsher framework conditions that enforce change, and also introduces a more radical and therefore less foreseeable transition.
- A scenario that mixes both projections and thus jointly and directly addresses change in supply and demand from the beginning both through change in technology and in behaviour mightbe most successful. Still it would have to a) solve the split incentive-dilemma, and b) clarify the role of incumbents in the change process and within the new regime.

Conclusions:

- the close relationship to the Energiewende will have to be taken into regard where technologies (heat pumps) demand renewable sources to be CO_2-mitigating or are in competition with renewable electricity production (solar thermal vs. PV).
- Importance, efficiency and effectiveness of respective support and investments will have to be calculated.
- The domain discussion and the scenarios showed that heat is closely coupled to megatrends that affect lifestyles and population like urbanization and demographic change.
- Since the domain is inert by nature with high burdens on capital and investment, it will be important to reflect upon these interdependencies when policies are designed.

The following core constraints in terms of Loftus et al. (2015) can be identified:

- technology readiness:
  - There are several ready and applicable technologies in place that could be put to use.
- Barriers to application
  - Economic reasons (price and market incentives) and regulation.
  - The dual role of incumbents who are both producers of fossil-fuelled appliances and of CO_2-neutral technologies will have to be solved.

  - Moreover, support for sufficient investments will have to be devised that may work out the split incentive dilemma and cater to close an alleged gap between necessary investments and potential payback.
  - Risks stemming from this category in Scenario 1 are freeriding on subsidies so that state and citizens afford comfortable change for others or companies unwilling to undertake necessary R&D.
  - In Scenario 2 economic risk is affiliated with job-loss on the side of the incumbents, introduces energy poverty among the working poor as a consequence of public inertia, and it is unclear if market or niche size, respectively, can become sufficiently large to introduce a transition.
- Integration:
  - Technology readiness will support integration.
  - District heating and CHP will be most difficult where the necessary infrastructure is not installed, yet.
  - For biomass, two aspects could be important: a) Availability of fuel and its quality, which may be in a trade-off situation. b) Coupling of heat supply and demand More energy-efficient houses and behaviour will need less effort for heating.
- social and non-cost areas
  - public resistance may emerge from fear for loss of comfort and safety, due to new technologies and necessity of lifestyle change.
  - major (re)construction of installed infrastructure could meet strong opposition (“not-in-my-backyard”) and have little acceptance.

Further tentative recommendations:

- German policy towards a transition in the heat domain will have to weigh between bold moves to create demand for niche technologies, set incentives and abolish climate unfriendly structures on the one hand, and to eye the costs and effects of such programmes on jobs, budgets and welfare on the other.
- It will be important in this to provide a strategic prospect to all those who will have or want to invest.
- Another promising stream is the rising number of transdisciplinary projects, in the form of living labs and real-world laboratoriess that combine research, companies, and the population for change in heat.

1. Introduction

Goals and aims

D2.5 aims to develop qualitative storylines that describe plausible socio-technical transition pathways for the revised quantitative scenarios that have been developed in WP 1 of the PATHWAYS project. Figure 1 below is useful to elaborate the goals and strategy of D2.5. The outcomes from D2.1, D2.2 and D2.3, which analysed the historical trajectories (black line in Figure 1) in heating in buildings suggest that contemporary developments appear more likely to develop in the ‘wrong’ direction (i.e. along the blue line in Figure 1). That is the existing regime is rather inert due to sunk costs and resistance to change from powerful interest groups while the radical green niche-innovations have limited or moderate momentum. Hence, there is a substantial discrepancy (or ‘transition challenge’) between current trajectories (black and blue lines) and the required ‘turn-around’ to move towards sustainable transition pathways (green line).

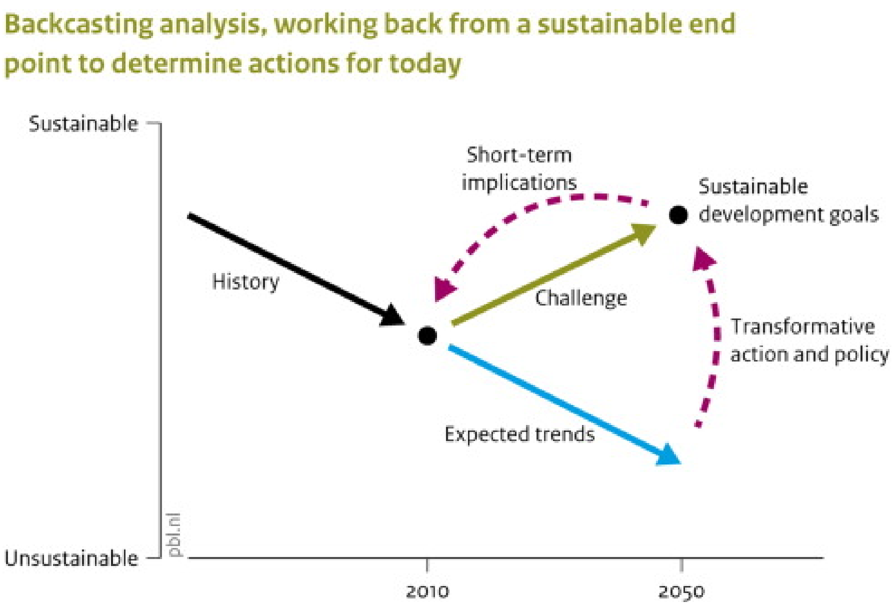

Figure 1: Transitions from historical trajectories towards future goals (Van Vuuren et al., 2015).

Against this background, the task for this deliverable is to develop storylines that indicate and explain how turn-arounds and transitions can be made in the German heat domain. D2.5 is a forward-oriented analysis, which builds on the previous deliverables that investigated historical trajectories to the present (the black lines in Figure 1):

- D2.1 analysed green niche-innovations and their momentum.
- D2.2 analyses stability and tensions of incumbent socio-technical regimes.
- D2.3 integrated findings from D2.1 and D2.2 to asses feasibility of different transition pathways.
- D2.4 made a comparative country analysis of contemporary transition pathways in different domains.

D2.5 makes the step from the recent past towards future transition pathways. To develop future transition pathways from a socio-technical perspective, D2.5 uses a relatively new methodology: socio-technical scenarios.

Structure of report

The report is structured as follows: First, the quantitative scenarios Pathway A and B are described in chapter 2, which lead to the stated climate change targets by 2050 (an 80% reduction in GHG emissions in 2050 compared to 1990 levels in the European Union).

Chapter 3 describes the empirical findings about contemporary developments in green-niche innovations and existing regimes in the German heat domain. These findings come from D2.1 and D2.2, based on socio-technical analysis.

As an intermediate step, chapter 4 articulates the ‘transition challenges’ by comparing outcomes from chapter 2 and 3. These transition challenges offer specific guidance for the socio-technical scenarios, which contain endogenous storylines for how the challenges can be overcomed.

Chapter 5 and 6 describe two socio-technical scenarios for pathway A and B. These scenarios, which pay more attention to actors and contexts, aim to offer a socio-technical explanation for the quantitative developments (described in chapter 2).

The report ends with concluding remarks in chapter 7.

2. Quantitative scenarios from WP1

The following section has been taken and adapted over from the "Preliminary Discussion Document: Heating domain from WP1" (Hof et al. 2016).

2.1. Model assumption

This chapter describes the different storylines for the German heat and building domain in representing Pathway 0, A and B in the different models, which have been developed in WP1. The three pathways are based on the following assumptions:

- ***Pathway 0*** shows the model tendencies *without any new climate-policy interventions*, based on market-driven developments of fuel prices and technology cost. However, it is assumed that the EU countries meet their RES targets as defined in their National Renewable Energy Action Plans (NREAPs).
- ***Pathway A*** and ***B***, with strong climate policies, are aiming to both reach an 80% reduction in GHG emissions in 2050 compared to 1990 levels. However, the specifics of the transition pathways are quite different because they represent different analytical ideal-types, which differ both in terms of lead actors, depth of change and scope of change (Table 1). The main policy driver in both Pathways is an assumed high CO_2 price or carbon cap, which improves the economic competitiveness of low-carbon options (like nuclear, CCS or renewables).

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

	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)

Source: Scheme developed in the Project

Thus, the three key dynamic elements or key drivers of change that characterize transition pathways are technology change and innovation, actors and strategies, and institutional changes.

To quantify the scenarios for the heat domain, a **global** Integrated Assessment Model (IAMs) – IMAGE– has been applied (WP1) and another, more detailed **national** modelling LEAP, will be applied later in the project (see Hof et al., 2016). Hence, a model for the German heat domain only was at this stage of the project not available.

In **IMAGE**, fulfilling energy demand in the building domain for various end-use functions, is determined on the household level, for which six end-use functions are considered: cooking, appliance use, space heating and cooling, water heating and lighting. All these energy functions depend on the use of eight 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 etc.), 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 etc.)) is more problematic within IMAGE.

LEAP is an integrated modeling tool that tracks energy consumption, production and resource extraction in all sectors of an economy by applying a bottom-up end-use calculation of energy use and GHG emissions. For Pathways, this has been implemented covering residential buildings over the period until 2050. This bottom-up structure is split into space and water heating; analysis of space heating is on a per m^2 basis while water heating is based on a “per dwelling” analysis. The following heating technologies are differentiated: gas- and oil-fired boilers and heaters, heat pumps, pellet wood stoves, solar water heaters,, district heat, electric resistance heaters. Further, there is a distinction in types of buildings (single and multi dwellings) as well as in existing and new building stock. 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 respectively are affecting the useful energy intensity (heat) of the model.

The following Table 2 and Table 3 provide an overview of the key technology and contextual factors in household energy demand for the two models.

Table 2: Overview of key technology factors in household energy demand

	Definition	IMAGE	LEAP
Energy demand	**Direct (exogenous) drivers**	• GDP • Population • Household expenditures • Household sizes • Ownership rates • Unit energy consumption • Floor space	• Population • Number of dwellings • Floor space • Class share
	Indirect (exogenous) drivers	• Urbanization • Inequality (GINI coefficient) • Population density • Electrification	• Population density • Indoor temperature
	Contextual factor	Heating/Cooling degree days calculated endogenously, but desired indoor temperature is set exogenously.	Heating degree days Insulation (U-values)
Technology choice	**Technology cost**	Annualized investment costs (lifetime, consumer discount rate).	
	Fuel use and costs	Annual fuel costs (fuel price, conversion efficiency).	Conversion efficiency
	Constraints **(Expansion and decline)**	• Consumer discount rates decrease as income increases • Efficiency of appliances increases exogenously based on literature	• Penetration of technologies • Efficiency of technologies increases exogenously based on literature

Source: Hof et al., 2016, Page 7.

Table 3: Overview of key contextual factors in household energy demand

	IMAGE	LEAP
Social and behavioural change (demand, preferences)	Preferences for different energy technologies (non-price)	Preferences for different energy technologies (non-price)
Regulatory change (intervention, governance)	• Carbon tax • Subsidies	

Source: Hof et al., 2016, Page 7.

The different factors in the models are often calibrated on the basis of historical information. There is an **implicit** presence of various actors in the investment decisions made in the model (see Table 3). For example, households may choose to lower their temperature, thereby decreasing the heating degree days. Insulation companies may play an important role in insulating buildings, thereby lowering the U-values of building components.

2.2. Scenarios for the heat domain

Pathway A (Technological substitution):

Within the modelling through IMAGE, among the studied niche innovations for the buildings domain, only one clear pathway A technology has come forward, which is **waste heat recovery** with low to medium momentum. In order to represent this technology, a **45% efficiency increase** is applied to secondary heat use.

Pathway B (Broader regime change)

The storyline for pathway B is based on transforming existing systems through the involvement of new actors, changing preferences and adopting different lifestyles. Within WP2 the case-studies have focused on **smart metering** and **passive-housing** as a form of changing lifestyles. However, the typical pathway B options are overall rated as having a “very low” to “low” momentum, resulting in limited quantitative material to underpin IAM scenario design thus requiring the modellers’ own interpretation. There are several ways to implement behavioural change in a model focused on matching energy demand with energy production, utilizing the existing model-parameterisation. For example, several processes that are modelled include implicit assumptions for e.g. a representative household and representative user. By **changing the parameterisation of the model**, we implicitly also model (though exogenously and static) behavioural change which can be explained in the narrative of higher awareness by homeowners due to e.g. smart metering. A more in-depth discussion of the implementation and the initial parameterisation can be found in (van Sluisveld et al., 2016), but with parameterisation we manage to implement **heating demand reduction**, **lower size for dwellings**, **reduced rate for appliances**, more **efficient use of household appliances**.

The table below visualizes the implementation of abovementioned storylines into the various models **-** the models vary in making changes in technology factors or in contextual factors.

Table 4: Model intervention to create a typical pathway A or B scenario

	PATHWAY A		PATHWAY B	
	IMAGE	LEAP	IMAGE	LEAP
Heat pumps		Change in penetration and efficiency of technologies		
Small-scale biomass heating systems		Change in penetration and efficiency of technologies		
Solar Thermal installations		Change in penetration and efficiency of technologies		
District heating		Change in penetration and efficiency of technologies		
Waste heat recovery	Improved secondary heat efficiency (45%)			
Low-energy housing			15% energy reduction due to improved insulation	• Energy reduction due to improved insulation (lower U-values) • Introduction of passive houses
Behavioural change/ Smart metering			• Change temperature setting by 1˚C • Switch off standby mode appliances • No growth of appliance ownership after 2010 • No tumble dryer after 2010 • More efficient use of appliances	Lower indoor temperature
Lower size of dwelling			• Floor space is fixed to 2010 values (rural 50m2/cap and urban 40m2/cap)	Floor space reduction

Legend:

(white)	Not modified relative to PATHWAY 0
(orange)	Social and behavioural change (demand, preferences)
(green)	Regulatory change (intervention, governance)
(blue)	Technical change (acceleration)
(red)	Shock (Shift away)

Source: Hof et al., 2016, Page 9f.

Pathway B entails **broader** system changes and reconfiguration. The table below summarizes how models characterize the reconfiguration of actors, infrastructure, preferences and policies or technology priorities.

Table 5: Reconfiguration in pathway B relative to pathway A scenario

Reconfiguration in Pathway B relative to Pathway A	IMAGE	LEAP
Reconfiguration of actors		
Reconfiguration of infrastructure		New building stock has passive houses standards
Reconfiguration of preferences of consumers	Diffusions of energy- saving behaviors Conscious decisions to not desire a bigger house, household equipment.	Diffusions of energy- saving behaviors (lower indoor temperature) Conscious decisions to not desire a bigger house, household equipment. (lower floor area)
Reconfiguration of preferences of policies/technology priorities		

Source: Hof et al., 2016, Page 10.

2.3. Model results for the European heat domain

This section provides the main results for the EU28 as modelled in WP1 (modelling results from LEAP are still in progress).

As each model has been set up to achieve the 2050 EU emission target of at least 80% GHG emission reductions, the GHG emission pathways are very similar across the models (see Figure 2). The steep decreases in GHG emissions in the two mitigation pathways clearly show the mitigation challenge. In Pathway 0, the models show more-or-less constant emission levels. Note that Pathway 0 is a hypothetical scenario used as counterfactual as no climate policies are assumed to be in place, which is not in line with reality.

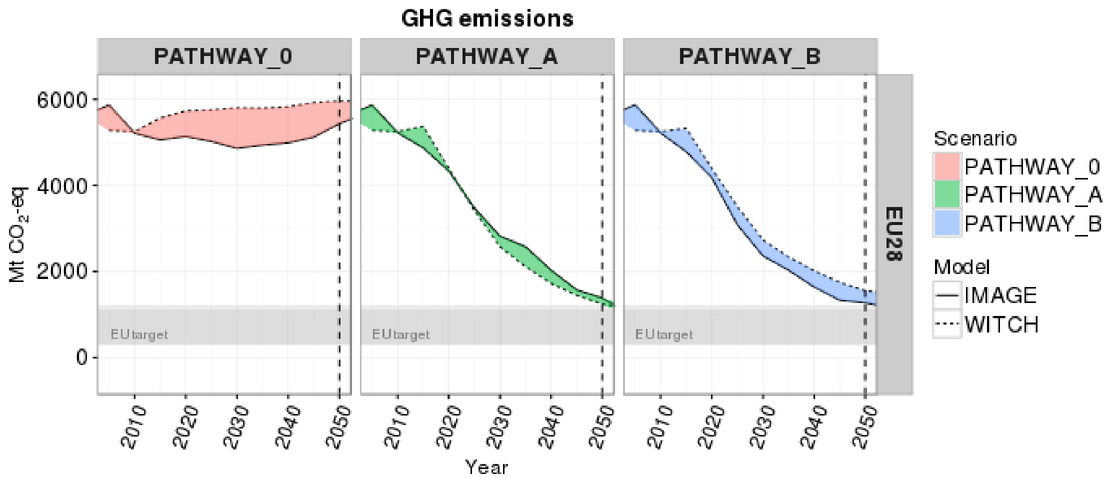

Figure 2: GHG emission pathways for the European heat and building domain[1] (Hof et al., 2016, Page 22).

As shown in Figure 3 pathway A as modelled with IMAGE/WITCH is in line with meeting the long-term climate target of COP21[2], whereas this is not so clear for pathway B. We focus here mainly on the time period until 2050. Clearly, the challenge post-2050 is larger in Pathway B than in Pathway A (as the possibility of negative emissions is largely excluded in Pathway B).

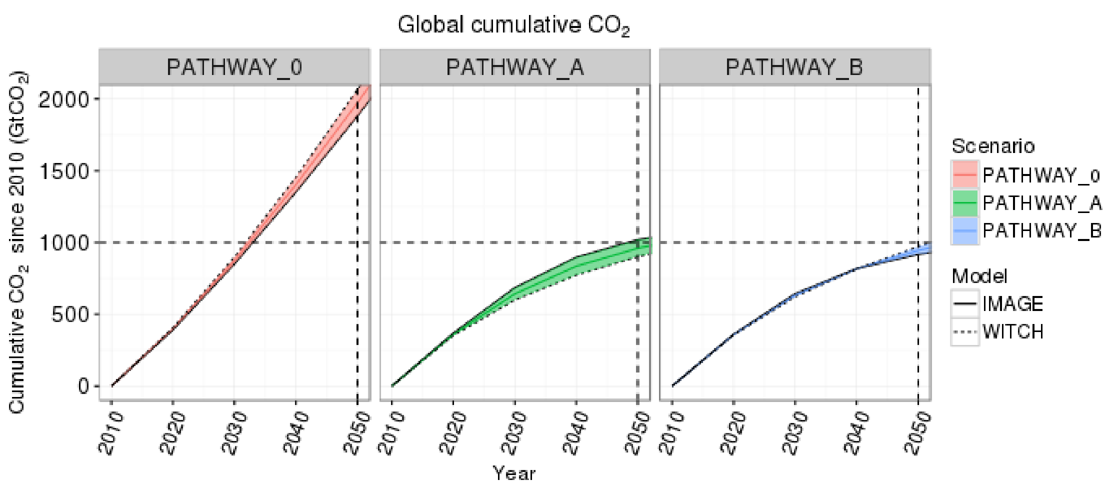

Figure 3: Cumulative global CO_2 emission pathways for the European heat and building domain (Hof et al., 2016, Page 23).

[1] Note: The grey bar represents the EU 2050 target of reducing GHG emission levels by 80%-95% compared to 1990

[2] The target of COP21 is to keep the global temperature increase below 2˚C, which can be translated to not exceeding more than 1000 $GtCO_2$ between 2010 and 2100 (IPCC AR5 WGIII).

Figure 4 shows that CO_2 emissions in the residential sector are already projected to decrease in the Pathway 0, due to increased efficiencies, electrification, and increased use of hydrogen. The decrease in the mitigation scenarios is much stronger, however. In Pathway B, the decrease is stronger than in Pathway A, as energy demand is assumed to decline more strongly in Pathway B due to behavioural changes.

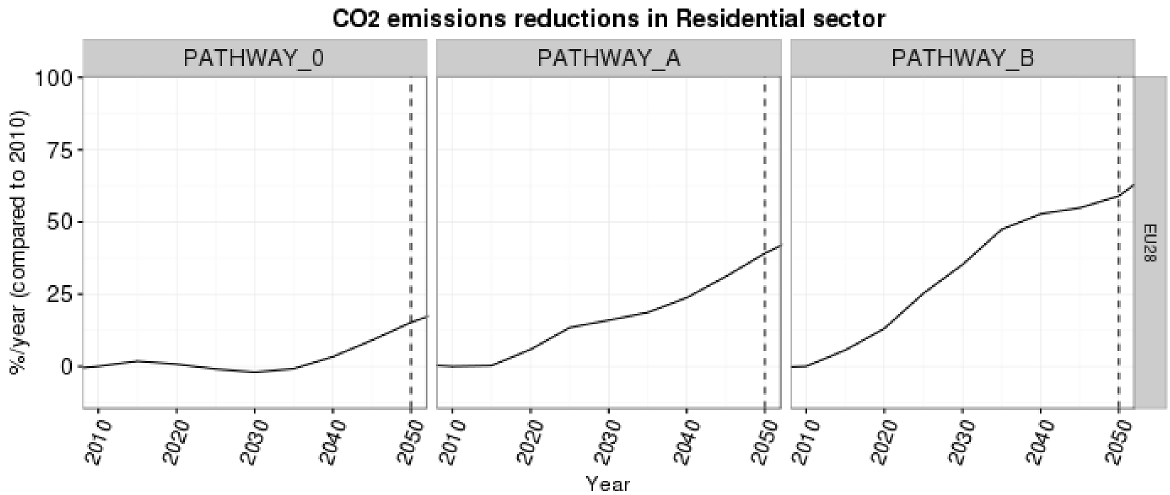

Figure 4: Total CO_2 reduction pathways in the residential sector for the EU28 (Hof et al. 2016, Page 23).

A closer look at the heating technologies shows that currently the largest share of heating (50%) is provided by natural gas boilers in Europe (as seen in Figure 5). 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 2030**, 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).

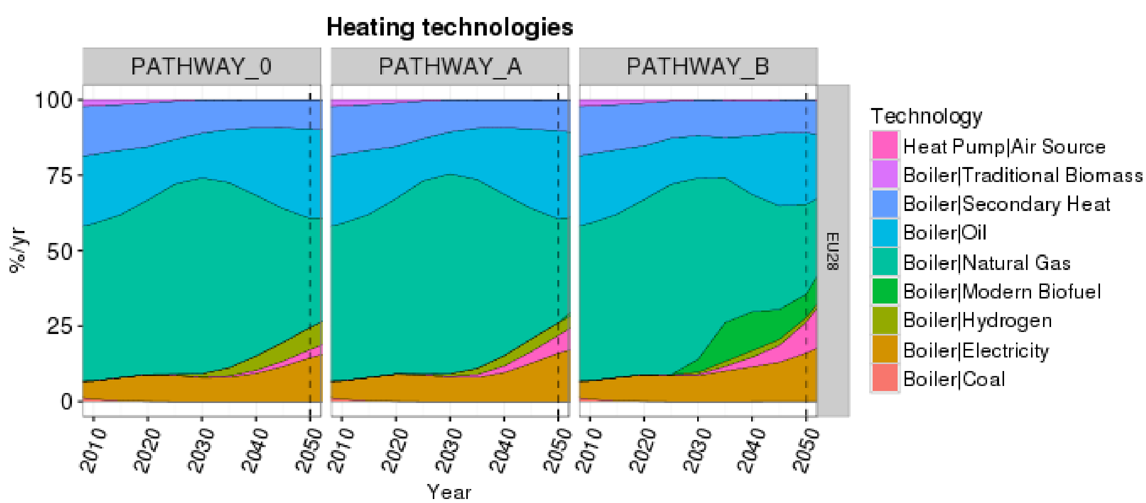

Figure 5: Heating technologies used pathways for the EU28 (Hof et al. 2016, Page 36).

The heating demand in total remains broadly constant over time without any further action in energy and climate mitigation (as seen pathway 0 in Figure 6) – but **needs to be halved by 2050** to stay in line with the EU 2050 target. The energy demand decline is mainly driven by autonomous efficiency improvements (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.

In the absence of negative emissions in the power sector, as prescribed in Pathway B, the model allocates more carbon neutral fuels to the demand sectors. **Greater effort in fuel switching** (less oil and gas, and more biofuels), in combination with behavioural changes in Pathway B, lead to lower CO_2 emissions in Pathway B, as was shown in Figure 4.

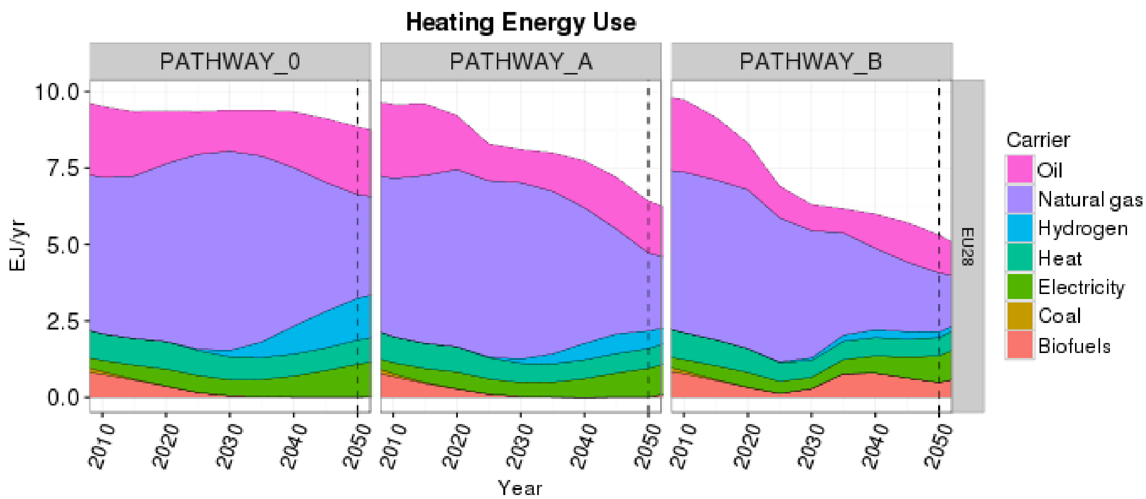

Figure 6: Heating energy demand pathways for the EU28 (Hof et al. 2016, Page 36)[3].

[3] Note: For the visualisation of the total household energy demand and the appliance energy demand pathways see Hof et al. 2016.

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

Chapter 3 provides insight into the main characteristics of the German heat and building system in recent history (ca. 20 years). These were developed in the project's deliverable D2.1, D2.2, and D2.3 (Thema at al. 2014, Echternacht et al. 2015).

3.1. Niche-innovation

Table 6 summarises the conclusions of the niche-analysis of the German heat domain, with regard to relative ranking of perceived momentum, main drivers of momentum through *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) dimensions, and our interpretation of whether the niche fits better with Pathway A or B.

Table 6: Summary findings on momentum of German heat and building niche-innovations

Niche innovation and ranking	**Momentum**	**Assessment of momentum through techno-economic, socio-cognitive and governance dimensions**	**Path way**
***1.* Heat pumps**	*Medium - high*	**Techno-economic:** - Heat pumps have a strong market potential: about 24% of new buildings are equipped with this heating technology. - Strong lobbying of large energy companies and regional distributors have strengthened the continuous sales. - Significant increases in terms of efficiency cannot be expected at this moment. **Socio-cognitive** - Environmental associations and consumer associations criticize the environmental protection effect based on the resources for electricity consumption of heat pumps. Heat pumps are no "green niche innovation" per se. - Investment costs have not decreased significantly over the last years **Policy/governance:** - The market incentive programme (Marktanreizprogramm), based on the German renewable energy law (EEG) offers attractive subsidies for the installation of heat pumps in buildings (exception: heat pumps providing process heat) to private persons, small and medium businesses, and municipalities.	**A**
***2.* Small-scale residential biomass heating systems**	*Moderate*	**Techno-economic:** - Persisting barriers for faster technology adoption and heterogeneous interests among the actors. Small niche actors concentrate on exclusive biomass niche technologies and promote green beliefs with a clear positioning towards markets and policy, while larger more influential producers have biomass products among others. Their main business is with fossil-fuelled products – they do not intend to change the regime completely. Chances for further upscaling depend on the collaboration of the niche actors	**A**

		and whether they overcome conflicts of interest when producing both biomass and fossil-fuelled installations - New small biomass technologies have to be further optimised for large-scale production to activate economies of scale. **<u>Socio-cognitive:</u>** - Most relevant barriers for consumers are linked to higher initial investment costs and potentially higher maintenance efforts. - Rising public sensibility regarding environmental impacts of residential heating systems (possible trade-off between CO_2-reduction and air quality aspects). **<u>Policy/governance:</u>** - New small biomass technologies need also the support by appropriate policies and information campaigns. - Upscaling depends on governmental activities for changing the regulatory and incentive frameworks.	
***3.* District heating**	*Momentum depends on landscape and energy price developments*	**<u>Techno-economic:</u>** - There is a strong link between CHP and DH in Germany. - The niche´s state is complicated by persevering fossil-fuel dominance. It depends on a direct link to the Energiewende to become a green niche per se. High uncertainties for investors and an often non-existent but cost-intensive infrastructure. - Due to high gas prices and low ETS certificate prices for coal, cleaner gas-fired CHP/DH is uneconomic. - DH energy prices are rising with input fuel prices. This is generally seen as one factor contributing to the stagnating market share of DH. **<u>Socio-cognitive:</u>** - Environmental NGOs are very critical on carbon-fuelled plants, which represent almost 90% of district heating plants. Another point they raise is to reverse privatisationsof the 1990s. Support from this side for a large-scale instalment is limited at best. **<u>Policy/governance:</u>** - If the framework conditions (carbon prices, grid regulations, others) change in favour of gas-fired CHP plants, the technology may gain further momentum in Germany. Higher prices of ETS certificates would e.g. increase the relative competitiveness of CHP plants and thus make CHP-connected district heating more attractive to operators. CHP/DH based on renewables would be desirable for a true transition, however a clear trend towards this is not visible at the moment.	A / B
***4.* Low-energy/passive houses**	*Medium-high for new buildings, Low-medium for retrofits*	**<u>Techno-economic:</u>** - Germany has one of the highest instalment rates in absolute numbers. - Although technologies are on the market for decades now, and current technological development is very low in speed, it involves many dimensions (technical base, markets, organisational, political, social, cultural, and practices) and multiple technological elements (appliances, infrastructures, policies, etc.) - Installation and refurbishment rates are very low compared to opportunities in place. **<u>Socio-cognitive:</u>** - Niche actor configuration remains difficult: 1. Environmental NGOs support low-energy housing building 2. Owner and tenant associations fear rising costs – both sides are therefore highly critical with respect to building renovations. - Negative publicity (e.g. in the media) is hindering instead of accelerating investment.	**<u>A (new) / B (existing)</u>**

		- The split incentive dilemma between tenants and owner slows refurbishment rates. **<u>Policy/governance:</u>** - Minimum standards aim at phasing out least efficient buildings while financial subsidies incentivise building owners to use best-available technologies. Information schemes and refurbishment activities in public buildings aim at raising awareness and generating private sector confidence. Public buildings are usually refurbished or constructed on low-energy/passive house standards to provide positive examples. - Although there are several instruments in place fostering low-energy housing, there is no reason to expect substantial growth in the momentum of low-energy or passive houses.	
***5.* Behaviour change campaigns /Smart metering**	*Low (medium momentum outlook)*	**<u>Techno-economic:</u>** - Technically and legislatively metering for gas and electricity is in general directly linked. - Individual metering is standard since the interwar years. - The niche has not gained momentum beyond pilot programmes in Germany yet. - Studies show limited saving potential of smart-metering induced behavioural change due to high instalment costs. **<u>Socio-cognitive:</u>** - Cost and data security are identified as the most potent barriers to a larger rollout in Germany. If the consumers have the freedom of choice, acceptance problems would be reduced. **<u>Policy/governance:</u>** - Smart metering will probably gain momentum in the future due to ambitious policies that rely on substantial potential for energy efficiency gains. However, they will only be effective with regard to savings if complementary behaviour is promoted by these technologies. - Germany does not seem to take the role of an ambitious driver in favour of smart metering for gas. Germany is lagging behind with respect to smart metering for gas and there are few economic incentives for end-users on a market-based level.	**<u>B</u>**
***6.* Solar thermal installations**	*Limited*	**<u>Techno-economic:</u>** - Technical efficiency is almost exhausted (with some exceptions in specialised applications) and significant price decreases have not occurred and are not expected in the near future - Competition between solar thermal installations and photovoltaic (roof area) and other building efficiency measures in terms of investments and funding. **<u>Socio-cognitive:</u>** - As only one technical component is added to an existing system, institutions and socio-cultural practices remain stable and technological progress is incremental. No strong influence here. - Especially single dwelling house owners are investing in solar thermal technology in spite of relatively high costs. **<u>Policy/governance:</u>** - Technology manufacturers are lobbying for a more supportive policy framework. - Momentum of the further development of this niche into the mainstream system will largely depend on landscape conditions such as energy carrier prices and conditions influenced by the regime such as market incentive programmes or tax exemptions. - Legislative incentives/ obligations for new buildings to produce	**<u>A</u>**

		parts of their heating and cooling demand through the use of renewable energy. When using solar thermal, the share of renewable energy of the entire building energy consumption had to be at 15%.	

Source: Thema et al. 2015, Page 50ff.

3.2. Regime developments

Table 7 and 8 summarise the main findings from the analysis of the heat supply and demand regime in Germany (D2.2) with regard to degree of stability, lock-in of the regime, and degree of tensions and cracks. The analysis of the German heat generation system covers the sub-systems: Gas-heating, oil-heating and district-heating, which are the three dominant sub-systems in Germany.

Table 7: Summary findings of regime lock-in and tensions in the German heat supply regime

	Lock-in, stabilising forces	**Cracks, tensions, problems**
External landscape pressures	For gas: MODERATE • Gas maintains a constant and growing role for German heat energy supply • Discourse about climate change is stabilising gas, as it is perceived to be a more reasonable resource than oil (bridge technology) For oil: MODERATE • In more peripheral areas oil plays an important role for energy supply when there is no connection to the gas grid. This will likely remain for at least the mid-term For district heating: MODERATE • Long History since 1950s and well expanded grid of 20.000 km • The whole subsystem is dominated by fossil fuels as energy source. • Biomass production as energy source is limited in Germany. • Long history of sunk cost and failed investment.	For gas & oil: MODERATE/STRONG • Strong discourse about climate change and CO_2-emissions and fossil fuels as finite resources • Political unrest in eastern Europe reveals import dependency as a weakness. For gas: MODERATE • Criticism on fracking For oil: STRONG • Oil crises in the 1970s, and • Recent volatility of prices For district heating: LOW • Dependence on fossil fuels • and therefore price uncertainties and fluctuations. • CHP mainly based on gas is seen as bridge technology (for heat and power generation) towards transition processes. • Biomass as energy source has lower market prices
Industry	For gas & oil: STRONG • Well organized in associations and interest groups • Strong German enterprises: producers, suppliers etc. • Extensive investments in recent and upcoming years into (already well developed) gas infrastructure. • Development of new technologies follow consumer preferences: more efficient and	For gas & oil: MODERATE/WEAK • Low domestic potential of gas and oil exploration shows evidence of import dependency leading to public concern. For gas: MODERATE • Development of technical alternatives for gas heating (organic gas). But these function as hedging strategy not as full reorientation strategy.

	combinable with renewable energy sources but no essentially new technologies. For district heating: MODERATE • In some cases: existence of monopoly positions leading to high fares. • Only few companies driving innovations. • High uncertainties for investors • Cost intensive infrastructure	For oil: STRONG/MODERATE • Low share of oil-heating systems on the sales market • Innovation potential of the oil heating technology is assumed to be exhausted caused by a lack of investments in the sub-system. For district heating: MODERATE • Lobbying for better framework conditions, norms, and providing information on DH for an expansion of the market share. In context of CHP and Gas there is an emerging windows of opportunity for energy efficient technologies (bridge technology)
Consumers	For gas: STRONG • Gas is most appreciated heating technology by the consumers. • Majority would choose gas-heating system in the future (75% of the overall new installed heating generators are gas-heating systems, consumers formally using oil heating tend to stick to this technology). For oil: MODERATE • Oil is best available conventional resource in rural areas without access to the gas or DH grid. Effects of asset specificity. • Still appreciated by consumers that already own a oil-heating system For district heating: STRONG • Constant market share • The access is geographically bounded. • High uncertainties for investors (for public grids) • Cost intensive infrastructure (for public grids)	For gas: WEAK • No objections of customers against gas-heating systems. For oil: MODERATE • Since the oil-crisis in the 1970s and the rising prices for heating oil: declining acceptance of the oil-heating sub-system • Perceived as dirty and out-dated by the majority of consumers and thus very low share in new constructed buildings
Policy-makers	For gas & oil: MODERATE/STRONG • On a political level, fossil fuel-based heating is integrated into the funds and subsidies schemes that provide incentives for refurbishments For gas: MODERATE • Fracking law: no legal prohibition of fracking improves resource supply outlook. For district heating: MODERATE • No consistent strategy to fully switch to DH even in regions where this is technically and economically sound. • Uncertainties about further ordinances and incentives in context of the Energiewende.	For gas & oil: MODERATE/WEAK • CO_2-reduction and climate protection policy provides steps towards less fossil fuel-based technologies but has strong ties to prevailing regime. • Funds are only available for refurbishments applying a combination of gas & oil with renewable energy sources. • Legal enforcement to replace oil- and gas-heatings older then 30 years For gas: MODERATE • Fracking law: harsh penalties for fracking related environmental contaminations somewhat reduces the supply prospect. For oil: MODERATE: • A central overall strategy to promote the

		industry like it exists in the case of gas is missing. For district heating: MODERATE • Political target is to generate 25% of electricity from CHP by 2020 (16% / 2012). This could as well increase DH share in heat generation.
Public debate and opinion	For gas & oil: STRONG • No general ban of either technology but incentives for refurbishment with the same (but more efficient) technology. • Especially for gas: strong support as bridge technology both in single-house and DH due to flexibility of use with organic gas and good image of environmental performance.	For gas: WEAK • Concerns about fracking, especially due to possible ecological damages • Dependency on gas-imports is critically discussed • Biofuel production leads to critical debate on competing land use and mono-cultures. For Oil: MODERATE • In light of the discourse about climate change, oil is generally perceived as an energy source with no future prospects in the long term.
Pressure from social movements, NGOs, scientists	For gas and oil: MODERATE • Present importance of gas as a heating medium is generally acknowledged. • Focus on implementing changes WITHIN the heating sub-system, like modernization of existing gas- /oil-heating systems instead of replacing the system For district heating: MODERATE • No uniform position • Lobbying for an extended use of CHP (which supports mainly big private companies and investors)	For gas & oil: WEAK • Critical on implemented political measures (funds, subsidies for refurbishments) as ineffective, contradictory and non-transparent. For district heating: MODERATE • Lobbying for more public ownership (plants & grids) • Promoting CHP & DH as a more environment friendly technology.

Source: Scabell et al. 2015, Page 36 and 51f.

Table 8: Summary findings of regime lock-in and tensions in the German heat demand regime

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	MODERATE • General inertia of society visible in low retrofitting rate (0,9 – 1,3% p.a.) Environmental problems caused by housing not perceived as major national problem in society	MODERATE • Global-, EU- and Federal conventions towards lowering GHG-emissions/improving climate friendliness • Insecurity of supply and uncertainties in energy prices as a general motivator
Industry	STRONG • Low rate of new construction provides little opportunity for basic innovations • A study of the KfW (German Bank for Reconstruction and Development)	WEAK • Need for refurbishment of 50% of the current building stock within the next 20 years; but owners and tenants are reluctant.

	indicates that needed investments for a complete refurbishment of the residential building stock cannot be covered by energy saving potential. • Homeowners and investors lobbying for market-based measures for refurbishment (incentives). They fear the political ordinances due to uncertainties of economic profitability. • Tenants lobbied successful for a "rent brake" strengthening the "split incentive dilemma", reducing owners' motivation for investment.	• Some lobbying for flexible alignments and gradual development opportunities in terms of energetic refurbishment measures (instead of whole house retrofit) and an increase of subsidies. • Support for the new exchange platform ("Energiewende Platform Gebäude") implemented by the Federal German Government • Some open-mindedness for debates and re-adjustment of EnEV and more specific incentive programs
Consumers	STRONG • Growing living space per capita and age. • Changing lifestyles towards self-fulfilment and single households lead to a flexible way of life and therefore to a low ownership rate. • Low ownership rate (43%) resulting in a disproportionate "split-incentive dilemma" especially in multi-flat houses. Long-time investment cycles.	MODERATE • Rising awareness for energetic saving behaviour • 50% of all owners are 60 years and older. Therefore a change of ownership will occur in the near future creating windows of opportunity for energetic investment measures • Urban-rural gap leads to residential shortages in urban spaces and to vacancies in peripheral areas → changing requirements to the residential building sector.
Policy-makers	MODERATE • Ordinances and subsidies in the past decades support especially Whole House Retrofitting (WHR) building up barriers for gradual development. • Lack in flexibility of subsidies, lack of transparency regarding support and orientation	MODERATE/STRONG • Legislation enforces change: Enactment of first Thermal Insulation Ordinance (WSVo 1978) and the enhancement to the Energy Conversation Ordinance (EnEV 2002 and later). • Since 2014 stepwise re-adjustment of subsidies, ordinances and guidelines to meet the specific needs of homeowners and investors • Measures to improve market transparency are being taken
Civil Society & Public debate and opinion	STRONG • Interest in energetic refurbishment rather low with a view to the entire population • Lack of appropriate and objective information on refurbishment in the media (WHR is discussed controversially which results in uncertainties.) • Disagreement on the economic feasibility for private homeowners (investment vs. amortisation cycles) though energetic performance and reduction of energy costs are the most relevant factors for homeowners to conduct refurbishments	MODERATE • The basic attitude towards energetic performance of house owners is positive • Change in the public, scientific and political debate towards a re-adjustment of current ordinances, subsidies and guidelines resulting in build-up of pressure on policy makers • Rising awareness for energy saving behaviour through media and debates
Pressure from social movements,	MODERATE/STRONG • Most active are groups that represent tenants or owners working mostly towards regime stability or mild	MODERATE/STRONG • Scientific studies and public awareness pushed the critical debate addressing current barriers for energetic

NGOs, scientists	modernization. • No specific pressure groups towards drastic regime transformation	refurbishment • Pressure for adoption of financial and tax aid schemes addressing energy efficiency, strengthening of energy consultancy, widespread refurbishment guidelines and campaigns and also flexible alignments of the current ordinances • NGOs rather work toward refurbishments than for drastic measures Government seeks to initiate an alliance with important players through a common exchange platform.

Source: Scabell et al. 2015, Page 53f.

4. Specifying transition challenges

Before developing socio-technical scenarios, we articulate several tensions and contradictions between the quantitative scenarios from WP1 (described in chapter 2) and socio-technical findings from WP2 (described in chapter 3). These tensions form the 'transition challenges' between contemporary trends and developments, on the one hand, 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.

As of now, the German heat domain has not been modelled separately in the LEAP environment but only as part of the larger European context in IMAGE. Assumptions and specificity are therefore not straightforward. As they are also in part taken from WP 2 analysis, congruency is relatively high. At present therefore, quantitative and qualitative scenarios will have to face the same problems rather than contradicting each other. Present assumptions on technology development (table XXX) in LEAP and IMAGE may be too limited with regard to WP 2 findings. For example IMAGE just fixes floor space while WP 2 suggests a lowering of living space per capita. Assumptions on tumble dryers and cooking show also divergence between different European regimes and behaviours, as these may rather be attributed to the electricity domain in Germany. However, these are at present mainly guesses as a more intricate simulation is still pending. We thus refrain from too detailed discussions here, but start from obvious challenges which are rather common between WP 1 and WP 2.

WP 2 has identified a rather inert and therefore slowly moving heat and building regime for Germany. It will thus be important to clarify how change came about in Pathways A and B. As will be shown in the following chapters, two different basic assumptions will be used for this. Pathway A will focus on technological change on the side of incumbents driven by very active political intervention. Pathway B assumes bottom-up evolution instigated and promoted by private activities with policy and businesses only becoming of more importance late in the scenario.

5. Scenario 1 (Pathway A)

The "Pathway A Socio-Technical Scenario" (STS A) describes the storyline of a scenario from today until 2050, whereby technical components in the heat domain have been developed and substituted. This chapter tentatively describes the outcome of such a trajectory, i.e. its contribution towards a low-carbon transition of residential heating in the year 2050. This is a technology driven scenario leading to a transition of the German heat and building regime. The scenario follows a *reconfiguration* scheme as devised by Geels and Schot (2007). Hence, we follow a path where basic adjustments of the regime occur through regime-internal adaptation and processes in the form of economic and technological innovations.

5.1. Phase 1: 2015-2025 – Master plan

Landscape:

In this phase, landscape development was characterised by several trends and political developments that slowly but surely eroded former "cash cow technologies". This catered for a renewed interest in alternative and renewable technologies in heating appliances as well as in new low-energy housing and retrofitting.

One trend that led to major change in technology demand was a strong increase in urbanisation with a concentration on few fast growing cities with other cities shrinking and rural abandonment as a consequence. Hence a need for more centralized and cleaner technologies arose in crowded city districts while more decentralized and cheaper to run appliances were asked for in the rural areas. Increasing uncertainty and volatility in fossil fuel prices and supply supported this. Fossil fuel prices remained volatile at medium price levels, fluctuating between 40-80$/bl oil, due to turbulences in supply (recovery of Middle East and African production but repeated conflicts in these areas) and demand (decreasing demand in OECD regions, increasing demand in emergent economies, but everywhere repeated economic ups/downs). Geopolitical challenges resulted in uncertainty for investment into unconventional fossil fuel production through a series of over- and undersupply phases on global markets for oil and gas.

Moreover, the direct political consequences of the Paris agreement fleshed out aiming to keep a global temperature rise this century well below 2 degrees Celsius and to drive efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels (UNFCCC.2015). Because of the significant share of heating energy in domestic energy use in Germany (about 60%) this led to first actions in this field.

Regime

In this time period, the regime was still locked in to the use of fossil fuel-based heating appliances. However, motivated by landscape development the EU Commission and the German government enforced a phase out for oil and gas fuelled heatings. Already very early the German government enacted a "pathway A masterplan", providing a plan for a consistent legal framework to help pushing technological niches in the German heat domain to reach the

COP agreement on GHG reduction. However, the German heat domain had a largely fossil-fuel based history: in 2015, about half of all heat energy was supplied from natural gas, another quarter from fuel oil and only the remainder from district heat, biomass, heat pumps and electricity. Consequently, the national government decided in 2020 that new fossil-fuelled installations were prohibited from 2030 on and until 2045 all existing installations would have to be based on renewable technologies and/or district heat from waste incineration, waste heat or CHP. The government also dismissed any support scheme for fossil-based appliances. This long planning period allowed incumbents already active in both fields (conventional and renewable heating appliances) to adjust their strategies accordingly without immediate pressure. Technology providers to the large market of heat appliances had until now earned their money mainly from gas condensing boilers. Furthermore, incumbents now had a clear long-term perspective for phasing out their fossil fuel-based products without unbearable sunk costs. They hence geared their R&D strategy towards the development of the supported renewable technologies. Many of them had already started the development and production of biomass and heat pump technology and others in the decade to 2025. As the market for those was growing, opposition of the powerful manufacturer’s association also faded. At the same time, the electricity transition had advanced: by 2023 the nuclear phase-out was completed, the coal phase-out enacted in 2020 was already effective and phasing out electricity from coal entirely until 2040.

The federal government also introduced a strong investment scheme for district heat based on renewable energies and high-efficiency gas to fuel cities and created a subsidy programme based on a tax-fed fund for private investments into renewable heating systems. This effectively helped to overcome the split-incentive dilemma, as now a large share of the costs was taken over by the state. Through this, major lobby groups of both owners and tenants backed this programme as well and gave up their resistance towards new investments into eco-friendly appliances. Up to this point, these groups had strongly resisted any political intervention that would result in either unprofitable investments for home-owners or in an increase in rents for tenants.

Niches

In this period, incumbent companies who had invested into technological alternatives early on already dominated most niches. These niches hence took a double role that effectively linked any developments to the form, institutions and intentions of the existing regime.

Niches categorised to form part of “pathway A” (mostly heat supply technologies) started from different positions in the year 2015 and their success varied.[4]

Already in 2015, more than one third of all newly constructed buildings (that already met low-energy standards) were equipped with heat pump technology. But several issues limited further implementation:

[4] Mostly because some niches can only unfold their full potential in combination with heat demand niches that are categorised as being “pathway B” and thus only considered in scenario 2 (see section 0).

- The electricity mix was still largely dependent on carbon-intensive fuels, leading to emissions from heat pumps similar to the level of direct coal heating.
- Although the technology was ready and already implemented, there were still many inefficient and costly appliances on the market.
- High heat loads of e.g. non-renovated urban multi-family dwellings were not easily covered by heat pumps.

The first two issues became increasingly less relevant with the fast pace of the electricity domain transition and substantial technological progress until 2025.

A similar story occurred to small-scale biomass heating. Technology efficiency increased as producers transferred their knowledge from fossil condensing boilers to biomass. Thus costs decreased in the first decade after 2015 with scale effects from rising sales and production figures. The coherent legal framework of the pathway A masterplan afterwards led to a broad uptake in new and retrofitted buildings after 2025. Solar thermal panels were at this timeframe not acknowledged much by consumers, as they were continuously expensive relative to other heat sources.

Since the oil crises, German district heat (DH) systems have been mostly equipped with combined heat and power (CHP) plants leading to relatively high efficiencies. However, in 2015 they were almost entirely fired by gas and coal and the DH grid was limited to densely populated urban areas and only in few cases expanding slowly. Low ETS carbon permit prices further did not help the dissemination of high-efficiency CHP plants. At this point, a fuel switch to biomass or heat pumps was not possible due to high heat loads and limited fuel supply. This situation did not change until 2025.

The only heat demand niche categorised as purely technical component substitution (pathway A) is low/passive/plus energy housing for *new buildings*. This, because already in 2015, German building codes (Energieeinsparverordnung, EnEV) were relatively strict, especially for new buildings (also for retrofits, but here, a multitude of exceptions and barriers remained), and was already implemented widely. By 2016, the next step of EnEV entered into force, already mandating a maximum heat energy consumption of $<45kWh/m^2$ for new buildings. This may already be defined as "low energy standard". For building retrofits on the other hand there was severe opposition and many barriers, also due to the public discourses. As experience with low-energy constructions was growing in the following decade, regime actors including architects, construction companies and craftsmen as well as technology producers benefitted from the market development and ongoing price declines.

5.2.Phase 2: 2025-2035 – Take-off for low carbon

Landscape

In this phase the overarching trends continued. Still on-going climate change and continuance of global warming catered for increasing concern worldwide. In the meantime peak oil had by now clearly been reached and sources for cheap extraction became scarcer fast. At the same time oil and gas companies were reluctant to invest into production from unconventional oil or gas fields since worldwide efforts to abandon fossil fuels altogether were already felt and the fear of unprofitable investment became too high. The COP Paris Agreement and follow-up conferences on climate change put increasing pressure on German policy-makers to tighten GHG emission-relevant policies. Only after 2025, a binding agreement including the major global emitters was signed, mandating a global cut of emissions by 50% until 2050 and distributing the targets leading to a reduction target for Germany of -80%.

Regime

The landscape trends still strongly affected the regime in this phase. User of fossil-based appliances had to bear increasingly rising heating costs, which resulted in energy poverty for some not so well off households. Together with rising rents in the growing agglomerations demand for a quicker shift rose. The federal government reacted by introducing rent support schemes for people living in social housing, students and elderly. These were financed by a levy on fossil fuel for cars and on cars with more than 120 fuel-based KW. Moreover, efforts in District Heat were intensified with support for the installation of DH in inner city quarters.

In this phase first effects of the newly introduced policies became detectable: Soon after 2025 the growing market and related developments lead to a window of opportunity to implement an updated and consistent “pathway A masterplan” that was backed by both producer and consumer associations. The (updated) masterplan lead to technological progress and enabled a slow take-up of niches. Incumbents effectively stopped producing fossil based appliances until 2035 with minor numbers still being exported into the few countries that have not yet devised an abandonment regulation. At the same time homeowners face growing pressure to invest into clean appliances from tenant organizations as reasons to dismiss investments have largely been overcome through state support. Meanwhile, all this has led to a very positive development of the domestic economy as specifically the incumbents profit from intensified investments and are also able to export their newly developed or improved technologies worldwide.

Since weather extremes such as heavy rain and very dry summer periods increasingly occurred, those extremes have at first been denied to be climate change effects, but after 2025 were widely attached to climate change, and thus putting pressure on policymakers to engage in action.

Niches

Since 2025, the share of heat pumps installed annually continuously rose to over 50% in new buildings and about 25% in retrofitted buildings, with on-going technological progress. However, as building retrofits were restricted, in many buildings that not met low-energy standards, heat pumps were not a real option.

For small-scale biomass, the biomass fuel prices rose significantly due to the rise in number of installed appliances and consequent biomass fuel demand – and by 2035 stabilized at a higher level, as domestic supply was very limited.

As the effect of the 2025 “Pathway A masterplan” with initially high subsidies for solar thermal kicked in, some large heat appliance manufacturers of fossil-based appliances entered the market. Soon, in rural areas where solar heating as a complement to another source was sensible, started a real hype similar to the post-2000 photovoltaics hype in Germany.

In 2025 it became clear that new buildings and substantial retrofits would require less heat in the future due to efficiency improvements – which could in principle be covered more easily by DH but would require the development of grid connections. Thus, new DH legislation mandated to maintain existing grid connections and set substantial incentives for the connection of new urban buildings while at the same time pushing for fuel switch to biomass and waste as well as upgrade to high-efficiency gas CHP. As an effect of these initiatives, the grid grew slowly but steadily after 2030.

Former antonymous or competing relationships to the Energiewende for some of the niches became increasingly solved. Especially for solar thermal and biomass technological solutions were devised which helped to combine technologies or to improve efficiency through small CHP solutions.

5.3.Phase 3: 2035-2050 – A new technological regime

Landscape

In this phase CO_2-emmissions have started to significantly decrease worldwide. In Germany, a reduction to about 85% was reached in 2050. After 2035, the effect of the COP agreement and significant fossil fuel demand reductions settled in, with fossil fuel prices now clearly trending downward, but still highly volatile. Urbanisation and demographic change have contrary effects in this phase. Due to demographic change the population has sunk to about 70 Mio. (cf. statista 2016) inhabitants which has solved some issues especially in the areas peripheral to city centres. For other parts, urbanisation has led to abandoned villages in the countryside while urbanised are still overcrowded.

Regime

By 2035 the full effect of the master plan set in: all actors now collaborated to consistently push the technological change, also helped by the landscape pressures of COP agreements and extreme weather-induced public awareness, a consistent legal framework was now enacted: an encompassing financial promotion scheme, information campaigns and a top-runner programme linked to minimum efficiency performance standards (MEPS), increasing standards every few years according to the top technology performers. Fossil fuel prices have become irrelevant at this point since their share in the regime was only 15% in 2040 and decreased to less than 5% in 2050. Interestingly, it was specifically public buildings like administrations and schools that took longest to adjust due to empty state budgets. Meanwhile, the investments undertaken by incumbents have led to a maturity of former niche products. Specifically, heat pumps have reached a high number of sales now and biomass has become a major source of heat in rural areas.

By 2040, the coal electricity phase-out was completed, replaced mostly by on- and offshore wind energy. This parallel transition in the electricity domain lead to heat pumps becoming a "green" source of heat. By 2050, the heat regime has changed significantly.

Due to these developments, in 2035 the federal government decided to phase out investment support programmes to the end of 2050 which was strongly opposed by incumbents, but finally put through in 2038. Incumbent companies were compensated in part as new research and R&D grants for improved appliances and production facilities were provided.

Niches

As the biomass fuel prices stayed at a high level, biomass heating was not an option for non- and shallow-renovated buildings. For high-efficiency buildings with small heat loads this was still an attractive option.

The hype for solar thermal panels slowed down when subsidies were first cut sharply and then phased out until 2040. But since then, the technology contributed an important share of heat supply in rural areas.

The grid for DH kept extending slowly but steadily after 2035 and by 2050 connected about 20% of households to DH (40% in urban areas). This expansion was able to offset the heat demand reductions per building, maintaining total DH heat loads. While coal-based plants were phased out with the electricity transition until 2040, they were mostly replaced by gas plants as the large heat loads could not entirely be covered by biomass. However, some complementary biomass plants were integrated to the grids and in some cases supply switched to waste incineration, such that both the biomass and waste share rose to 30% by 2050.

In regard to low/passive/plus energy housing for *new buildings*, EnEV was stepwise tightened to mandate passive house standard for new buildings (<15kWh/m^2) from 2035. However, soon it became clear that about 50% of new buildings did not comply with the code but only fulfilled low-energy standards (<45kWh/m^2). Thus, a new building monitoring system was put in place that ensured full compliance after 2040.

The following table summarises scenario 1, categorized by the three timeframes from 2015 to 2050.

Table 9: Overview of Scenario 1 (Pathway A)

	2015-2025	2025-2035	2035-2050
Landscape			
	COP agreements put pressure on the domestic regime. Price relations from fossils and renewables without significant changes. Repeated extreme weather phenomena foster public awareness for climate change and thus put rising political pressure.	← Repeated extreme weather phenomena: climate change as one core policy topic.	← CO_2-emmissions have started to significantly decrease worldwide, in Germany, a 85% reduction was reached in 2050. Decreased population to about 70 Mio. people, due to demographic change. Decreasing fossil fuel prices since 2035, as an effect of the COP agreement and demand

			reductions.
Regime			
	Still strong resistance from fossil-based regime actors to a. low-carbon transition of residential heating. Subsidies for fossil appliances are phased out. Oil-based appliances are planned to be phased out. All new buildings require few energy, being low-energy or passive houses. Incumbents developed a long-term perspective for phasing out their fossil fuel-based products and geared their R&D strategy towards the development of the supported renewable technologies. The electricity domain is in transition: termination of the nuclear phase-out in 2023, a coal phase-out until 2040 is running, and renewables are booming. → Heat pumps become increasingly low-carbon intense. Introduction of a subsidy programmes to overcome the split-incentive dilemma.	Introduction of a rent support schemes for people living in social housing, students and elderly. Implementation of an updated and consistent masterplan, leading to technological progress. Repeated extreme weather phenomena were widly attached to climate change and thus putting pressure on policymakers..	Actors now collaborated to consistently push the technological change. A consistent legal framework was now enacted, including financial promotion scheme, information campaigns and a top-runner programme linked to minimum efficiency performance standards (MEPS). Decreasing share of fossil fuels, by 2040 down to 15% and less than 5% in 2050, and thus shrinking prices for fossil fuels. Biomass has become a major source of heat in rural areas.
Niches			
Heat pumps	Increasing technology advances: more cost-effectiveness. Already one third of all newly constructed buildings were equipped with heat pump technology, but still not widely applied for retrofits.	←	Heat pumps became extensively applied also in refurbished buildings and are driven by renewable energy.
Small scale biomass	Appliances became increasingly more cost-effective and efficient.	Increasing market share of biomass is limited by fuel supply and thus increased	← Biomass and waste share rose to 30% by 2050.

		biomass fuel prices.	
Solar thermal	Solar thermal appliances experienced a slight increase in cost effectiveness and efficiency, but still not acknowledged much by consumers.	Solar thermals are increasingly applied in rural areas as complementary heat source.	First hype for solar thermal panels until 2040, when subsidies were phased out. But since then, an important share of heat supply in rural areas
District Heat	No change	DH grids are expanding and DH increasingly relies on heat from waste incineration and biomass co-combustion.	DH kept extending grew slowly (by 2050 connected about 20% of households to DH, 40% in urban areas).
Low energy/ passive housing (new build)	Low energy housing is already BAT and passive houses have an increasing share.	←	EnEV building code as standard for new buildings mandated, but no full compliance until 2040, when a building monitoring system was introduced.

6. Scenario 2 (Pathway B)

The pathway B scenario describes the low-carbon transition trajectory of residential heating until 2050 towards a broader regime transformation including behavioural and lifestyle changes, and to some extent the technological transformation already described in the pathway A scenario (because a behavioural and lifestyle change does not come alone but hand in hand with the technology-based transition). The latter will not be repeated here, only where interactions between social and technological aspects are determining the outcome.

This scenario is therfore largely based on changes in behaviour of consumers. In this case this specifically relates to private housing. In contrast to Scenario 1, change largely comes about through bottom-up activities and innovation in niches that eventually scale up with public support. Hence the state will have a less important role in this scenario and only react to niche pressures in the later phase towards 2050. However, also this scenario should lead to a regime change towards massive CO_2 reduction. In the landscape development we assume overarching trends affecting both scenarios to allow for consistency.

6.1. Phase 1: 2015-2025 – Building pressure from below

Landscape:

In this phase, landscape development was characterised by several trends and political developments that catered for a need of new ways of housing and heating behaviour. One trend that led to major change in technology demand was a strong increase in urbanisation with a concentration on few fast growing economically booming cities with other cities shrinking and rural abandonment as a consequence. Thus, the housing market showed divergent trends: while in some urban centres, building prices (and consequently rents) were high and continuing to increase, in other shrinking cities and many remote rural areas prices were lower and falling. Both developments made retrofits difficult because in high-price areas renters could not afford even higher rents and thus entered in strong opposition, in low-price areas owners feared that investments would not pay off.

Demographics (an ageing population, increasing share of single households and high immigration rates) were leading to an overall increasing heat demand after 2015. Demographic change came to be felt already which caused major problems in health support especially for elderly people and in increasing undersupply of child care. Moreover, immigration and an increasing income gap between educated and undereducated labour have created a segment of society unable to afford increasing heating prices. Increasing uncertainty and volatility in fossil fuel prices and supply complicated this difficult social situation. Geopolitical challenges resulted in uncertainty for investment into unconventional fossil fuel production through a series of over- and undersupply phases on global markets for oil and gas.

Since incumbent companies and a stale-mate between the lobby groups of owners and tenants put strong pressure on state actors, the federal government felt unable to interfere. Also problems and the high costs of the “Energiewende” in the area of electricity had yielded major distrust in public action so that people started to search for new possibilities on their own, looking for low-invest solutions with major impact.

Regime

In this phase the regime still remained stable. First cracks appeared through a reduction in appliance sales between 2023 and 2025. Since investment support schemes for efficient fossil fuel-appliances were still enacted, this decrease remained small and was blamed on a dent in economic development, it was projected to be overcome within three years. Moreover, the coalition of state and incumbents as well as the dominance of the lobby groups did support the lock-in. Calls from scientists and activists addressing increasing social and environmental problems caused by heating and energy poverty were not registered.

Since as of 2020 only few governments worldwide had acted on the Paris agreement, the German government as well was reluctant to come up with ambitious programmes, as it feared major disadvantages for German companies on the global market.

Developments towards a low-carbon transition of residential heating therefore regarded a small but increasing share of biomass, a substantial share of heat pumps installed in new buildings, the strict building standards of new buildings and the technological readiness of low-energy retrofits which, however, were only applied at very low rates. Pressures on policymakers slowly increased after 2015: the Federal Ministry of Environment called in a commission on "heating transition for residential buildings", comprising representatives from producers, end-users, policy, science, grid operators and fuel suppliers. The commission presented a full report with recommendations. The report identified the following two problems as crucial:

- Deep-renovation rates were still too low, due to split incentives between owners-investors and renters, insufficient information, organisational complexity of the undertaking and financial restrictions.
- The per capita floor areas were still rising in total, albeit at a decelerating pace due to high prices in some urban centres.

While the average living space area was increasing in the first decade after 2015, several influences led to a deceleration of this phenomenon: large increases of rents in booming cities, the increasing construction of public housing (with comparatively small flats) as a reaction to living space scarcity in urban areas and the influx of immigrants and refugees that could not afford large apartments.

Niches

The slowly growing unrest caused by rising rents, demographic change and volatile prices led to an increase in locally organized groups acting independently from each other. At first these groups addressed different problems: Organizing care for children or elderly, providing shelter in cold times for the not so well-off, and creating new forms of housing and living due to visions of low energy lifestyles. These groups largely emerged in the densely populated urban areas initially driven by idealism. Also single engineers, practitioners and small companies started to become interested in the affiliated problems and began to develop solutions, many of these based on product-service systems or services only. At this point, these transition designers were regarded as nerds by the established regime. As metering and billing were already executed on an individual (household) basis by 2015, smart metering was not a promising option in Germany at first. However, especially public utilities and some technology developers kept testing and implementing this niche. When the public opinion faced a strong turn towards climate change awareness after severe extreme weather phenomena, demand for this technology started rising slowly after 2020 and in 2023, and a full smart meter roll-out was postulated by incumbent firms. Early opposition from consumer associations due to data privacy and security issues were fully accounted for and a roll-out based on a subsidy scheme started in 2025.

The most complex but also most important niche turned out to be building retrofits. While technologies and know-how were available early, renovation rates remained at very low levels at first. However, as the knowledge base was broadening policy discovered this field as promising as well. As a first consequence the German government enacted the “heating transition act” in 2024. This comprised a massive upscaling of support schemes (financial, audits, advice) for retrofits and passive/plus energy (+E) houses. In addition, public and social housing companies were mandated to explore and test new housing/living types (including apartments with variable walls/sizes, shared flats and community facilities) in order to bring down per-capita floor areas. This programme was financed by a new “low energy housing (LEH) levy” on fossil fuels. In this time and support schemes were tripled until 2025, renovation rates were starting to rise slowly but mostly based on single home owner, as the split incentive dilemma had not been solved.

6.2. Phase 2: 2025-2035 – Opening of cracks

Landscape

In this phase the overarching trends continued. Still on-going climate change and continuance of global warming catered for increasing concern worldwide. Peak oil had by now clearly been reached and sources for cheap extraction became scarcer fast. Demographic change was still taking place, increasing the number of people in need in the first half of this phase.

Through all this, great parts of the population started to feel abandoned in their needs. The teaming up of state and incumbents and missing interest from lobby groups increased these feelings and lead to dissatisfaction. Offers from large utilities on allegedly green solutions were met with distrust caused by earlier failures from these companies. Also, the split incentive dilemma remained unsolved, further maintaining the inertia of the regime.

Regime

For incumbents heat appliance sales kept falling through the first years of this decade. Therefore, the government introduced new subsidy schemes to keep these companies running. To compensate the decline in national demand, especially efforts to increase export were supported. Since larger investments into novel technology niches were not made, economies of scale or scope were not attainable for these. Renewable heating technologies therefore remained expensive and still largely incompatible with the existing infrastructure. A state and technology-driven “Wärmewende” was therefore not in sight. On the side of the customers, conventional heating appliances became less and less attractive as they did not address their new and changing needs.

The cracks and tensions between the old regime and new demands and needs therefore increased in this period. The changes in attitudes of actors were opening a window of opportunity for more radical regulations, as voter turnout resulted in political majorities for a stricter environmental legislation. Thus, by 2030 the *heat transition act* was enacted to including a set of further measures:

- The subsidy scheme for low-carbon technologies was further backed up.
- Free public energy audits and access to grants from the German Bank for Reconstruction and Development (KfW) were scaled up.
- Income and property taxation deductions were given for lower per-capita living spaces.

Fossil fuel taxes were raised further by carbon taxation.

Niches

New models for living and housing became more prominent in this phase. Initiatives, activists and social entrepreneurs became increasingly connected personally and via the Internet. IP-free open source publications of inventions and crowd sourcing supported the spread of newly devised practices and products backed by the Transition act. Initially separated through different goals, these groups realized that their challenges were rather connected and could be more effectively dealt with if addressed systemically. Through this, a country-wide self-reinforcing knowing and doing network for new low-energy living emerged. Transition design had become to be acknowledged as a powerful instrument by the niche protagonists.

The change in behaviour and demand and the challenge of care and housing created a number of social and economic innovations as well as new business models. NGOs such as labour welfare institutions and nature conservation organizations offered back-up in publicity and know-how.

A full success was the new legal framework, which assured that renters would not have to bear the financial burden of renovations, but the cost difference and other costs would be covered by the KfW programmes and by fossil fuel taxes: Renovation rates doubled to about 3% p.a. Especially in the cities average living space per person decreased to about 35 square meters by 2035 based on increased prices and changed lifestyles. These new approaches also resulted in a larger number of dedicated plus-energy newly builds from 2030 on. Rising distrust towards established organizations and institutions also created a will for more autarchy and autonomy on the side of the citizens. Therefore, quarter-based refurbishment activities and micro-grids for heat emerged supported by the Transition act. These were mostly organized as cooperatives or limited companies with citizens as shareholders. By the end of the decade institutional investors like banks and insurances looking for safe and sustainable investments increasingly invested into such efforts, support their replication and substantial upscaling. This improvement in financing potential also allowed initiatives to switch to renewables and higher investive products. As a reaction, the KfW did a rigorous review of its support schemes in 2033 introducing wide monitoring and evaluation activities, scaling up all programmes for deep renovations (from audits and subsidies to loans), introducing special financing schemes for the established cooperative initiatives and dismissing all schemes for less ambitious retrofits. As a consequence to these developments, the refurbishment rate doubled in this phase from about one to almost two per cent so that from 2015 to 2035 almost 27% of the building stock had been refurbished. All these efforts have caused CO_2-emissions to decrease by about 35% at the end of the period.

6.3. Phase 3: 2035-2050 - Turnover

Landscape

Based on international pressure and dedicated EU guidelines, the German government could no longer ignore the problems resulting from the old heat/building regime. In this period, CO2-emmissions in Germany caused by heating and building declined fast. A 55% reduction was realized in 2040 and 93% were reached in 2050. Due to demographic change the population has sunk to about 70 Mio. (cf. statista 2016) inhabitants which has solved some issues especially in the areas peripheral to city centres. For other parts, urbanisation has led to abandoned villages in the countryside while urbanised are still overcrowded.

Regime

By 2035 a new regime based on change in behaviour, models of living, and new housing concepts had started to open up significant cracks and tensions in the old regime. The federal government had by now adopted a holistic, behaviour-oriented policy design (Cf. e.g. Liedtke et al. 2015) Incumbents had become less and less important in the national economy, and classic owner and tenant organizations lost a large part of their members eventually destroying much of their former influence. By 2050 the old regime stopped to exist by and large. Those incumbents who could make it, switched to producing renewable technologies others have ceased to exist or moved abroad.

Niches

The former niches have become part of a newly emerging regime. Due to state support and private investments, initiatives were increasingly able to also include novel technologies, which became more affordable in this wake. Most of these were produced by novel businesses, which by now have reached considerable growth. People now increasingly move into cities and refurbished quarters because the advantages and social innovations developed in more collective living models have become accepted and fashionable in most parts of society. Public housing companies became engaged in the construction of flexible space apartments.

In this phase, average living space is reduced to 20 square meters per person. However, new concepts for furniture and sharing lead to an increase in overall satisfaction and quality of life. Energy consumption is thus falling incrementally both driven by social and technological innovation.

By 2050, about 75% of households were equipped with smart meters, and 50% were also participating in demand-side management (DSM) schemes of utilities, contributing to mitigate grid tensions due to volatile renewable electricity supply.

The following table summaries scenario 2, categorized by the three timeframes from 2015 to 2050.

Table 10: Overview of Scenario 2 (Pathway B)

	2015-2025	2025-2035	2035-2050
Landscape			
	Demographics: Ageing population, more single households, immigration; Housing prices: booming cities⬈, shrinking cities⬊, rural areas⬊ Repeated extreme weather phenomena fostered public awareness for climate change. Problems and the high costs of the "Energiewende" yield to major distrust in public action.	Increasing fossil fuel prices since peak oil had been reached. Increasing number of people due to demographic change. Repeated extreme weather phenomena: climate change became one core policy topic and wide-spread public interest.	Decreased population to about 70 Mio. people, due to demographic change. Introduction of the "heating transition act" in 2035: Upscaling of support schemes (financial, audits, advice) for retrofits, passive/plus energy (+E) houses.
Regime			
	Massive upscaling of support schemes (financial, audits, advice) for retrofits, passive/+E houses, and development of new housing/living types. But the government still was reluctant to come up with ambitious programmes to fulfil the COP agreement.	Climate Change awareness became mainstream. → Change in attitudes and behaviour towards a) energy end-use and b) focus of technology manufacturers on sustainable products. → Political majorities to change/sustain political/legal framework for a heat transition.	Pro-low-carbon attitudes of energy use and technology supply has become the mainstream discourse. → Political majorities have lead to a coherent legal framework in place (pro-RES, efficiency and sufficiency legislation): • Electricity domain transition in completion • DH system in transition towards renewable & electricity fuel • Energy taxes raised, especially for fossil fuels • Full subsidy scheme for low-carbon niche technologies • Sufficiency policies in

			place
Niches			
Per capita living space	Urban: Increasing prices (also due to retrofits). → Slow-down of increasing p.c. floor-areas.	Urban: Increasing prices (also due to retrofits) and increased shared apartments. → Decreasing p.c. floor areas New models for living and housing and low-energy living became more prominent, also due to new networks. Transition design had been acknowledged as a powerful instrument. Average living space in cities decreased to about 35 square meters per person by 2035.	← 2050: Average p.c. living space has decreased to around 20 m^2 per person.
Temperature	-	-	-
Smart metering/housing	Further development and testing of most promising technologies.	Increasing demand due to climate change awareness. → New business emerged.	← 2050: Around 75% share of houdholds with smart metering, and 50% with DSM.
Low-energy housing retrofits	Technology: Cost decreases, development of easy-to implement standardised packages. Large-scale policy programmes tackled main barriers: Split incentives, finance, information, administration. → Uptake of retrofit rates	Experience with policy programmes. → Reviews, ameliorations were launched. → Deep retrofits become mainstream. Renovation rate doubled to almost 3%. → From 2015 to 2035 almost 27% of the building stock had been refurbished. → Decreasing CO2-	← 2050: Around 75% of building stock retrofitted to low-energy standards.

		emissions, by 2035 to about 35%.	

7. Concluding comments

Heat in buildings is among the most hidden but important domains for a transition towards CO2-neutrality. 60% of domestic energy use per year in Germany relates to heating. Earlier reports have shown that the German heat domain is in a relatively stable state with a rather rigid supply side regime (heating appliances), that still promotes fossil-fuelled, albeit more efficient, technologies. It was also shown that renewable alternatives are not breaking through yet and are in part dependent on the 'Energiewende' to be successful. Heat pumps, for example, will only contribute significantly to CO2-mitigation if they use electricity generated to a significant share from renewables instead of coal. The demand side regime on the other hand was shown to be too inert for swift and sufficient change due to a low refurbishment rate, the split incentive-dilemma caused by resistance from owners and tenants towards bearing refurbishment costs, and a low rate of newly builts.

These challenges had to be addressed in both scenarios to different degrees and on different premises. In both, policy had to play an important role as driver and enabler of change. This is in consistency with past and present developments and the dominant role national policy played in the transition of the electricity domain. There was no need or task to develop a Pathway 0 scenario, however, we can easily conclude that the business-as-usual character of such a scenario would not lead to significant and needed change.

Shortly evaluating both scenarios, Scenario 1 seems to be more in the comfort zone of the current regime and its affiliated institutions, norms and organizations whereas Scenario 2 assumes a broader transition towards a new regime in which at least current incumbents on the supply side will be highly disadvantaged. Also, Scenario 1 may require more spending and regulation activities on the side of the state. Scenario 2 is both more optimistic and pessimistic than its counterpart. It is more optimistic because it assumes potential for real bottom-up change driven by idealists and state support. It is more pessimistic in using harsher framework conditions that enforce change, and also introduces a more radical and therefore less foreseeable transition.

Obviously, a scenario that mixes both projections and thus jointly and directly addresses change in supply and demand from the beginning both through change in technology and in behaviour is supposed be most successful. Still it would have to a) solve the split incentive-dilemma, and b) clarify the role of incumbents in the change process and within the new regime. Currently, steps are taken in these directions, for example in open deliberations to abolish oil-fired heating altogether in the near future. Also regulation like the EnEV will have to play an important role, as rules, that are becoming stricter will provide incentives for change and may even create markets for more efficient and eco-friendly appliances and buildings. Last but not least, the close relationship to the Energiewende will have to be taken into regard where technologies (heat pumps) demand renewable sources to be CO_2-mitigating or are in competition with renewable electricity production (solar thermal vs. PV). Importance, efficiency and effectiveness of respective support and investments will have to be calculated.

The domain discussion and the scenarios showed that heat is closely coupled to megatrends that affect lifestyles and population like urbanization and demographic change. Since the domain is inert by nature with high burdens on capital and investment, it will be important to reflect upon these interdependencies when policies are designed.

The following core constraints in terms of Loftus et al. (2015) can be identified: With regard to technology readiness, there are several ready and applicable technologies in place that could be put to use. Niches discussed were inter alia heat pumps, small biomass, district heat, passive houses and smart metering. All of these already exist and are understood. Barriers to application are to be found in economic reasons (price and market incentives) and regulation. Apart from the problems already discussed, the dual role of incumbents who are both producers of fossil-fuelled appliances and of CO_2-neutral technologies will have to be solved. Moreover, support for sufficient investments will have to be devised that may work out the split incentive dilemma and cater to close an alleged gap between necessary investments and potential payback. Risks stemming from this category in Scenario 1 are freeriding on subsidies so that state and citizens afford comfortable change for others or companies unwilling to undertake necessary R&D. Furthermore the interest groups affiliated with the present regime could strive for a perpetuation of the current status prolonging change towards (more) CO_2-neutrality. In Scenario 2 economic risk is affiliated with job-loss on the side of the incumbents, introduces energy poverty among the working poor as a consequence of public inertia, and it is unclear if market or niche size, respectively, can become sufficiently large to introduce a transition.

Integration as a third category seems to be possible as to some extent already explained for technology readiness. District heating and CHP will be most difficult where the necessary infrastructure is not installed, yet. For biomass, two aspects could be important. One is the availability of fuel and its quality, which may be in a trade-off situation. For high-quality fuel sources like rapeseed, discussions regarding land-use for fuel or food are relevant as well as a preference cascaded utilization as for example in the case of wood. Maybe using less efficient but existing biomass, e.g. manure from feedstock, could be more effective although more costly. It is especially this area where the coupling of heat supply and demand becomes most important: More energy-efficient houses and behaviour will need less effort for heating which can then more easily be provided by alternative CO_2-neutral appliances.

Two barriers that may originate from social and non-cost areas are public resistance to change for fear of comfort and safety, due to new technologies and necessity of lifestyle change. Also major (re)construction of installed infrastructure could meet strong opposition (“not-in-my-backyard”) and have little acceptance among those directly affected.

All in all, German policy towards a transition in the heat domain will have to weigh between bold moves to create demand for niche technologies, set incentives and abolish climate unfriendly structures on the one hand, and to eye the costs and effects of such programmes on jobs, budgets and welfare on the other. It will be important in this to provide a strategic prospect to all those who will have or want to invest. Like in the Energiewende, entrepreneurship and provision of equity will be more likely in the face of a reliable regulatory and support conditions. Another promising stream is the rising number of transdisciplinary projects, in the form of living labs and real-world laboratories (Liedtke et al. 2012), that combine research, companies, and the population for change in heat.

8. References (to be amended)

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