# PATHWAYS project

**Exploring transition pathways to sustainable, low carbon societies**

Grant Agreement number 603942

## <u>Deliverable D.2.3:</u> Integrated analysis of D2.1 and D2.2 to assess the feasibility of different transition pathways

## <u>Country Report 4:</u> The German heat domain

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December, 2015

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## Executive Summary

In this report we assess the feasibility of different pathways towards a low-carbon heat domain in Germany as a contribution to a low-carbon society. In a first step, we assess the breakthrough probability of various niche innovations by appraising their internal momentum and analysing how they align with wider regime and landscape developments. We conclude that none of the niches analysed is about to break through in the short to mid term with the exception of a partial breakthrough of heat pumps in new buildings and low-energy standards for newly constructed buildings. An important aspect for discussion is that due to the low construction rate of new buildings, a transition depends largely on refurbishment of existing buildings. However, specific for the heat domain are very long investment cycles (about 20 years for heating systems, 30-40 years for buildings) and significant asset specificity of heating technologies. As summarized in Table 1, all niche innovations for heat supply have a low potential of break-through for existing buildings. For small-scale biomass heating systems the low potential especially relates to a currently missing joint position of manufacturers (incumbent firms with a diverse portfolio vs. specialised new market entrants), problematic asset specificity and high initial investment costs. The low break-through potential for solar thermal is mainly related to its inferior supply potential, i.e. the technology is not able to supply sufficient heat to completely substitute other heating appliances and can hence only be operated as an additional system. This further diminishes its already low cost efficiency. The third technology assessed, heat pumps, has a low momentum in existing building (medium for new constructions) and shows medium regime alignment, due to support from large electricity providers – providing a connection to the electricity domain. Even though all three niche technologies are promoted by policy through the market incentive programme (MAP) as renewable energy, the analysis reveals that this support is not sufficient to further spur their momentum.

The heat demand niche innovations show a similar picture. Smart metering and lower per-capita floor areas only have a low potential of break-through. The low per-capita floor area is a niche that is highly dependent on social changes (Pathway B), and even shows a negative trend. The diffusion of the other behavioural heat demand niche, smart metering, is hindered by high implementation costs and privacy concerns in spite of promotion by policy actors (connected to promotion of electricity smart metering). The only heat demand niche showing medium potential for a break-through is low-energy and passive housing. We judge the potential as medium due to its central importance to a potential heat system transition and the immense support the niche receives from parts of the regime. Policy makers, as important regime actors, take this niche as a role model for new building efficiency standards and promote the adoption of related technologies in the regime – also extending to the existing building stock. Therefore it seems, that whilst the government is trying to implement a top-down reorientation, the niche is not ready to break through. This, however, cannot entirely be blamed on the niche technology actors, but rather on a set of socio-cognitive and economic barriers, many of them related to other parts of the regime. Most relevant in this context are the significant up-front investments (monetary and transaction/information costs) that are still

required for high-efficiency buildings (both new buildings and retrofits). As discussed in the analysis, associations of house owners and of tenants fear rising costs for their stakeholders and are thus critical to this niche (split incentive dilemma). Thus, the momentum of this niche is currently still low but might increase in the future if barriers are addressed appropriately.

**Table 1: Summary table of the break-through analysis of niche-innovations in the heat domain in Germany.**

| Niche-innovation | Internal momentum | Strong or weak alignment with broader regime characteristics and developments | Likelihood of imminent breakthrough (and/or future potential) | Pathway A or B (or mixed) |
|---|---|---|---|---|
| **Small-scale biomass heating systems** | Medium to low | Low to medium | Low | A |
| **Heat pumps** | Low for existing buildings<br>Medium for new buildings | Medium | Low for existing buildings<br>Medium for new buildings (slow but steady) | A |
| **Solar thermal** | Low | Low to medium | Low | A |
| **Low-energy and passive houses** | Low, with medium outlook | High | Medium | A |
| **Smart metering** | Low, prospect medium | Medium | Low | A/B |
| **Low per-capita floor areas** | Low (negative) | Low | Low | B |

In a second step, the analysis focuses on the existing regimes. The main question to be answered is whether trends in a regime's development continue as "business as usual" or whether incremental changes are implemented in order to reduce $CO_2$ emissions. The results of the analysis are presented in Table 2. While all sub-regimes show strong or moderate to strong lock-in and stabilizing forces, there are only moderate or weak to moderate cracks and tensions visible.

Within the heat supply regime, the landscape trend favouring a cut-back of carbon emissions in general is taken up in the technological development of gas and oil heating systems through the development of high-efficiency technologies (condensing boilers). The main technology applied is gas heating (49 % market share, BDEW 2013). For this technology, substantial efficiency gains have been achieved, leading to reductions in $CO_2$-emissions with high-efficiency gas condensing boilers dominating the market. However, the technology relies on fossil fuel and will, on its own, thus not lead to the transition needed. Combined with a significantly reduced heat demand (i.e. with a change of the building stock to ultra-low energy buildings), this development may nonetheless lead to a more sustainable heat domain. The third sub-system, district heating is only of minor importance for the overall regime analysis since it only has a stable market share of 12.8 % (BDEW 2013) and no signs of relevant increase in the near future. As compared to e.g. the Swedish case, in which DH is powered by renewable fuels, in Germany, the system mainly relies on fossil fuels and prospects for a future switch like in Sweden are not in sight. All in all, there is thus only limited prospect for a heat supply regime reorientation.

From an analytical perspective, the heat demand regime is highly interesting due to the strong oppositions it comprises. While on the one side policy (regime) actors try to push for a regime reorientation (aiming e.g. at a 2 % refurbishment rate), associations of house owners and tenants argue against it. The reason for this divide is the financial investment connected to refurbishments and the split incentive dilemma. The subsidies in place are currently not sufficient to solve this. In addition, a building refurbishment is a large project requiring substantial knowledge, effort and will by the investor, which does often not exist. The main barrier to a transition is thus a lack of investment. Due to the immense will of policymakers to change the regime, we still rate the overall regime to be in a mode of reorientation with incremental changes. However, this reorientation has only a medium potential for the overall transformation, since several barriers would need to be overcome to actually achieve a transition. Besides financially enabling conditions and solving the dispute over the distribution of costs and savings between investors and users, this also includes the consistent planning of single refurbishment actions for the complete building in order to capture full energy saving potential. This whole-house perspective does not only relate to heat demand measures but also includes heat supply technologies.

**Table 2: Summary table of the Assessment of regime trends in the heat domain in Germany.**

| | **Lock-in, stabilizing forces** | **Cracks, tensions, problems in regime** | **Orientation towards environmental problems** | **Main socio-technical regime problems** |
|---|---|---|---|---|
| **Gas heating system** | Strong | Weak to moderate | Significantly increasing efficiency levels, compatible with biogas → Incremental changes | Reliance on fossil fuel |
| **Oil heating system** | Moderate to strong | Moderate | Increasing efficiency → Business as usual | Reliance on fossil fuel |
| **District heating** | Moderate | Moderate | Business as usual | Reliance on fossil fuel, limited availability of renewable fuels. No high market shares, thus not that relevant for regime change |
| **Residential building stock** | Strong | Moderate | Introduction of policy measures, Energetic refurbishment measures at higher level but low rates → Incremental changes | Resistance from tenants and house owners → insufficient private investment |

# 1. Introduction

In this report we assess the feasibility of different pathways towards a low carbon society with respect to the German heat domain. For this, we combine the analyses from previous work (D2.1 *"Niche innovations in the heat domain – case study of Germany"* (Thema et al. 2015 and D2.2 *"Regime analysis of stability and tensions in incumbent socio-technical regimes – Country Report 4: The German heat domain"* (Scabell et al. 2015)) and evaluate the results with regard to this question. As for the previous studies, the approach is based on the socio-technical regime analyses (Geels 2002).

In a first step, we assess the breakthrough probability of various niche innovations by appraising their internal momentum and analysing how they align with wider regime and landscape developments. Windows of opportunities may show in e.g. regime problems leading to more financial, ideological or political support for alternatives in niches. Instead of these positive alignments with the regime, mismatches may be visible that are related to stable regimes. This assessment leads to the discussion if niches are about to break though and if not, whether internal (momentum) or external (regime stability) factors are the dominant barrier.

In a second step, the analysis focuses on the existing regimes. The main question to be answered is whether trends in a regime's development continue as "business as usual" or whether incremental changes are implemented in order to reduce $CO_2$-emissions.

To structure the analysis of the heat domain, we apply the concepts developed in D2.1 (Thema et al. 2015) and D2.2 (Scabell et al. 2015). The domain is divided in two parts: one addressing heat demand and one heat supply. The central regime elements with regard to space heating that need to be examined in the two regimes are heating technologies and building stock characteristics. For each regime-element we identified different incumbent sub-systems. Since heat generation in Germany is mainly based on gas (49 %) and mineral oil (29 %) and to a minor share on (largely fossil-fuelled) district heat (12.8 %) (BDEW 2013, c.f. Figure 1), we chose these heating technologies as most dominating sub-systems to be analysed. For the building stock we focused on the residential building stock as sub-system.

The niches presented and assessed in the following, may destabilize the current regimes. Since they do not make the general system function (i.e. heat supply or demand) obsolete, they can also be classified according to their contribution into supply- or demand-related niches. For the heat demand side we focused on residential buildings, exhibiting a large potential for energy efficiency and energy savings through refurbishment and high-efficiency new buildings. Heat supply concerns transition pathways primarily relying on environmentally friendly technologies, especially with regard to reduced $CO_2$-emissions, and energy sources.

The regime analysis already showed that the two regimes are closely linked and a comprehensive analysis of the domain can only be conducted by taking both parts into account. This link can be explained by the fact that heat demand needs to be met by the supply. So, e.g. if demand is reduced (e.g. due to efficiency refurbishment) the dimensioning of a heating system may be reduced as well. Hence, to optimize the heat domain, the complete system needs to be taken into account.

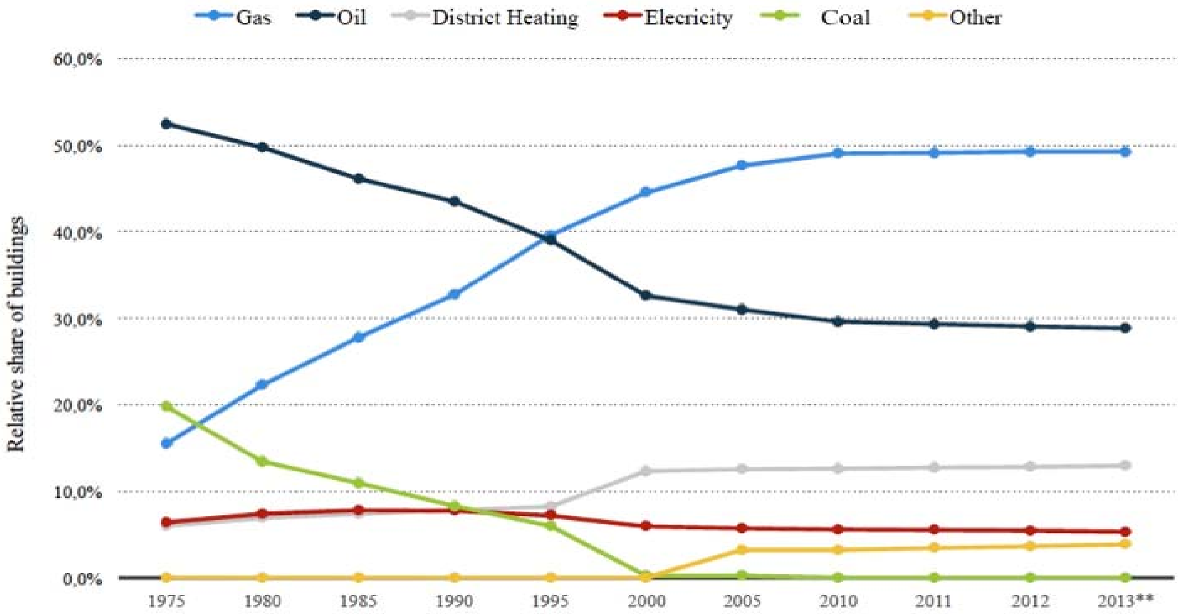


**Figure 1: Heating Structure of Residential Buildings in Germany from 1975 – 2013.** Source: Statista 2015.

Before starting with the analysis of niches and regimes, a short introduction into landscape characteristics which set the scene for the developments is given. Public environmental debates have a strong impetus in Germany. On the one hand this is reflected in the public perception (c.f. survey on the public opinion BMUB (2015)), and on the other hand in policy preferences displayed in the long (and short) term policy agenda and a multitude of legal provisions on all energy-related issues. This German energy transition ("Energiewende") encompasses a large policy framework with its most important pieces being the transition of the electricity system towards renewable sources (including a phase-out of nuclear plants by 2022 and a ramp-up of renewables), an increased use of renewable energy in the building sector and increasing energy efficiency. For this, targets have been translated to strategies and respective policies enacted (BMWi 2015a).

In the recent past, a high oil price has further triggered the debate. However, lately a decline in oil prices has slowed down the debate, so that import dependence and discussions on climate change are the most prominent issues to date. The recent Paris Agreement will certainly be an important landscape condition favouring further moves of the Federal Government. All in all, the landscape developments have created rather favourable conditions for an energy transition in Germany (Scabell et al. 2015).

These developments as well as actors from the different regimes influenced the legal framework of the heat domain. Since legislations and subsidy schemes in place affect niches and regimes and will be often referred to in the analysis, the most important regulations and interventions are shortly presented in the following.

The Energieeinsparverordnung (EnEV – Energy Saving Ordinance) sets the standards for energy performance in buildings, which have been gradually raised since 1979 with a last amendment in 2014 (BMWi 2014). The most relevant issues addressed are technical aspects such as the replacement of oil and gas boilers, the mandatory thermal insulation of ceilings and top floors in buildings or compulsory energy performance certificates.

Besides this binding legislation, there are market based incentives aiming to guide activities in the heat domain. A central funding instrument for investments in renewable energies for heating and cooling in the existing residential building stock (as well as in industrial or commercial processes) is the Marktanreizprogramm (MAP – market incentive program). It provides grants and preferential loans for a switch to renewable heating technology. Further market based incentives are set by the Kreditanstalt für Wiederaufbau (KfW), Germany's federal state bank for funding issues and subsidies. The KfW encourages investments in whole housing retrofitting and single measures and also for the construction and purchase of energy efficient homes or passive houses.

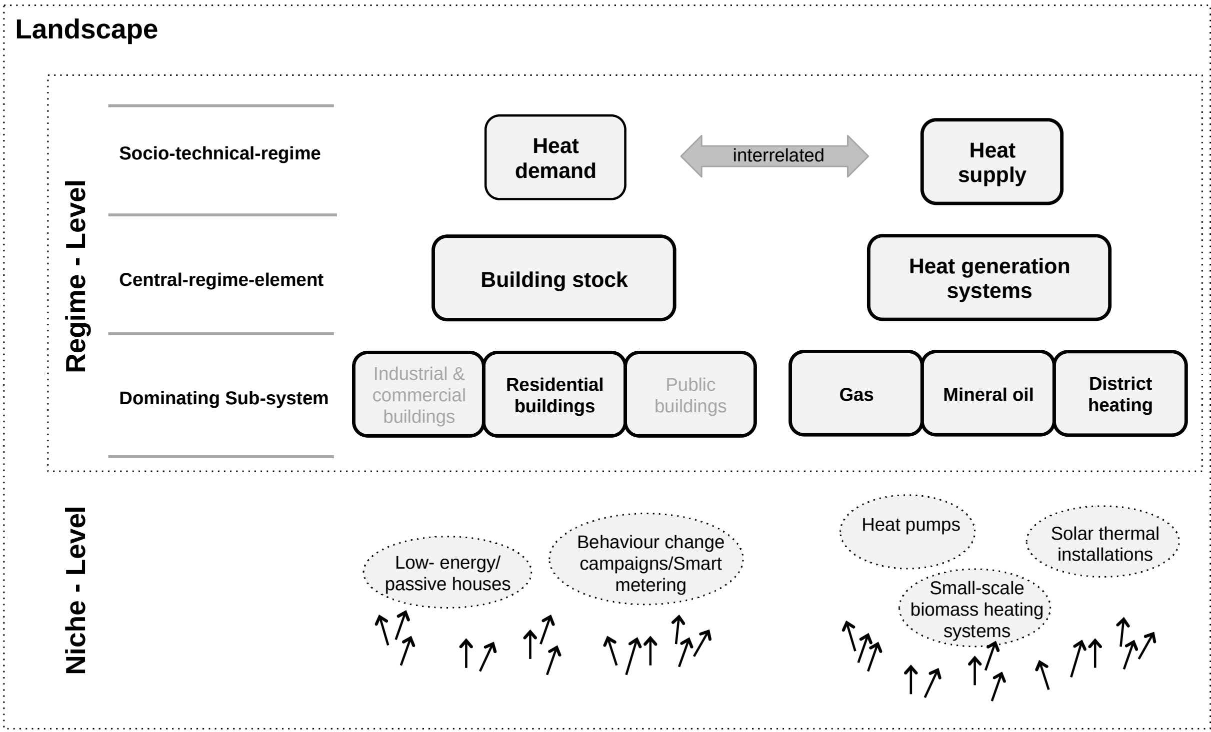


**Figure 2: The German heat domain from a multilevel perspective. (Echternacht/Berg 2015, p.4)**

# 2. Assessment of breakthrough feasibility of the various niche-innovations

## 2.1. Assessment of heat generation niche-innovations

The following section describes the three heat supply niche-innovations, analyses their internal momentum in a first step and then outlines their alignment with regime developments and the resulting probability of their break-through.[1]

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[1] The assessment of heat generation niches focuses on no/ultra-low carbon niches. The final assessment on the sustainability, carbon footprint and thus whether they can actually be regarded as a "low-carbon niche" of some (especially heat pumps) depends on how they are

### 2.1.1. Developments of the niches and internal momentum

*Small-scale biomass heating systems*

The German market is dominated by gas- and mineral oil-fuelled heating systems. Residential small-scale biomass heating systems represent only a small share. Figures on the market share diverge: BDEW speaks of 2.9 % solid fuel heating systems in Germany (incl. coal firing; BDEW 2013), while AGEB states that a share of 13.2 % of final energy consumption for space and water heating in 2011 is covered by wood (AGEB 2013, p. 19, own calculations). This discrepancy is due to the BDEW figure listing only primary heat appliances while the figures of AGEB as well include fuels for secondary heating (see as well D2.2, Scabell et al. 2015). In principle, solid fuel technology is compatible with e.g. infrastructures from gas-heating systems (heat distribution water pipes, chimneys etc.), but needs additional fuel storage facilities and often infrastructure adaptations (e.g. to chimneys).

As biomass heating is fuelled by renewable energy, it is *per se* a low-carbon technology[2]. But for reasons of fuel cost savings, resource savings and pollutant control (especially PM, $NO_x$), the efficiency and technological stage of development of the system installed matters. Over the last decade, high-efficiency and low-emitting systems have been developed and are available on the German market, especially pellet/wood chip burners but as well high-end wood log burners reach very low emission levels. They are, however, still significantly more expensive than standard fossil-fuelled systems. Since prices of renewable fuels have increased at a lower rate than heating oil (and gas) prices in the last decade and are still relatively competitive (FNR 2014a).

Many of the system suppliers are small and medium sized companies with less than 250 employees and specialisation in this niche technology. They position themselves clearly in this market and promote green beliefs together with their products. In addition, there are also several larger manufacturers offering biomass heating systems as one technology in their portfolio next to conventional fossil-fuel based systems that still constitute their main business. Therefore, they do not promote biofuel technologies on the cost of the alternatives (Thema et al. 2015).

The internal momentum of this niche technology is currently medium to low. However, it may increase, if the industry actors jointly promoted the renewable-fuelled heat appliances. This is currently not to be expected for the larger companies. Furthermore, smaller companies would need to scale up their production in order to achieve economies of scale for realising price reductions for high-efficiency biomass heating systems that would raise competitiveness relative to conventional systems.

implemented and specific framework conditions. These conditions can e.g. relate to the electricity mix.

[2] At least, the technologies considered in this report (fired by wood logs, chips or pellets) can be considered as low-carbon.

*Heat pumps*

The heat pump technology works like a reversed refrigerator, using electricity for extracting heat from the environment and supplying it to a building and/or water heating. Its efficiency is measured as the relation between the delivered heat output and the electricity input ("coefficient of performance", CoP; or adjusted for seasonal operation conditions, SCoP). Typical SCoPs range between 2.5 and 4, depending on the technology and measurement types (Thema et al. 2015). Because heat pumps are fuelled with electricity, they can only be regarded as a "green technology" if fuelled with "green electricity". Especially environmental NGOs argue that if fuelled with low-efficient lignite electricity, heat pumps may have a "true" SCoP about 1 – equal to direct brown coal firing (BUND 2008).

The heat pump technology is already mature, major efficiency gains are not expected in the near future and investment costs for the installation in households have remained stable on a relatively high level since 2008 (Thema et al. 2015). However, ground source HPs are more expensive that air-air systems, which lately are catching up on technological development and improving COP. In 2013, about 60 000 heat pumps for space heating were sold in Germany (BWP 2014). Echternacht & Berg (2015) estimated that over one third of those pumps are installed in new buildings (20 % of the 100 000 completed new buildings per year are equipped with heat pumps, i.e. 20 000 heat pumps).

Although sales of this technology are quite stable at a medium level, the internal momentum of a further breakthrough for this niche can therefore be regarded as low.

*Solar thermal installations*

The two most important solar thermal technologies are flat plate collectors and evacuated tube collectors, with the first representing the cheaper alternative, usually implemented in domestic applications and the second being the more efficient and costly alternative. Collectors are installed on the rooftop, capturing solar energy in a heat transport medium that is pumped into a heat exchanger, where the heat is transferred to the warm water storage for either hot water provision or heating. Solar thermal collectors typically cover only about 30 % of total heat demand and are therefore combined with other heat provision systems such as biomass or gas heaters (Knaack 2014) to secure heat energy provision when solar energy is not sufficiently available.

Since the year 2000, the number of yearly installed collector surfaces has been very unstable, in the early 2000s increasing from about 0.6 to a peak of 2.1 mn $m^2$ in 2008. Since then, it has fallen again to about 1 mn $m^2$. This development was probably largely driven by high oil prices in the respective period. Due to high commodity costs (e.g. copper), the costs for solar thermal installations were high over the last years and are expected to remain expensive in the near future. As in the case of heat pumps, large efficiency increases are also not expected (Thema et al. 2015). The internal momentum of this niche in Germany therefore seems low.

### 2.1.2. Assessment of alignment with regime and landscape developments

This section analyses how the internal niche developments align with the wider regime and landscape developments, how the niche-specific sub-regimes relate to this and whether, as a consequence, a break-through of the niche technologies can be expected.

*Small-scale biomass heating systems*

In principle, most small-scale biomass heating systems feature a good compatibility with existing building regime infrastructures (in-house heat distribution, chimneys etc.), but in some cases, costly adaptations have to be made. The technological alignment that is a precondition for a fast uptake of any niche is given in many cases but mismatches occur in others.

The main policy instrument supporting the uptake of this niche is the national market incentive programme (MAP). Also, fuel-switch is encouraged by funding in the housing retrofit grant schemes of the KfW.

The niche-internal sub-regime is of central importance: the niche market is highly competitive and comprises a large number of SMEs and large manufacturers. Some of these, especially the large suppliers, are also important players in fossil-fuelled technology (gas, oil) markets and therefore reluctant to a clear pro-renewable positioning that may threaten their main markets. For technology producing regime actors (and as well those that are both regime and niche actors), the niche technology is a competitive threat to the regime appliance markets.

In the end, consumers decide against the background of all public debates, campaigns, support schemes – between concrete alternatives. Here, small biomass heating systems can mostly be implemented, but are still several thousand euro more expensive than the fossil-fuelled alternative and often connected to costly adjustments to the infrastructure (chimneys, storage etc.). When such adaptation costs are significant, this implies a significant technological mismatch of the niche with the regime hindering its implementation. In addition, if heat demand per household decreases in the future (e.g. due to better insulation), the initial investment costs are more relevant for the buying decision than the costs for fuels (Thema et al. 2015), next to the time-preferences of consumers. The sum of these investment cost disadvantages is probably the most relevant current barrier for socio-cognitive momentum. To this adds the tendency of investors to stick to their already known regime technologies (i.e. oil and gas-based) and rather opt for a new, more efficient fossil fuel boiler. On the other hand, the rising public awareness and sensibility for climate change and other environmental issues can be seen as drivers for this niche. Biofuel prices (incl. wood, pellets etc.) have remained relatively stable over the last decade. However, overall supply in Germany is limited and a large-scale increase of demand would probably lead to increasing prices. Today, fuel availability and prices can be seen as well aligned with the niche, but if the niche would break through on large scale, there may occur substantial problems leading to the need for imports.

While the technological alignment of the niche with the regime is good in many cases, in others it not sufficient to generate high momentum. Thus, we judge the momentum as medium-low that however may have further potential in the future. A break-through would require further policy support in the form of information campaigns and more/higher incentives for investment. The framework for this is already in place but would need to be enhanced. In addition, niche actors also engaged with regime-related technologies (economic interests of suppliers engaged in renewable and fossil technologies) are a severe constraint. In sum, these barriers will make a niche break-through difficult.

*Heat pumps*

Heat pump technology is implemented mostly in new buildings (in up to 1/3 of new constructions, see above). Similar to the biomass heating niche, main technology supply actors are partly current heat regime actors and partly entirely new market entrants. The niche can be regarded as a “threat” to the main market of the heat regime suppliers (both technology and fossil-fuel energy suppliers), but some of the large regime technology suppliers limit the threat by entering the niche market.

The public discourse on this niche contains a differentiated debate on the effectiveness and efficiency of the technology, focusing on the issue of the electricity mix used for heat pump operation and resulting “true” coefficients of performance. NGOs point out, that only if run with renewable electricity they could be regarded as “green technology” (e.g. BUND 2008).

Opposition from established regime technology suppliers (gas, oil) has not been recorded. Large electricity providers (still relying on coal, gas and nuclear inputs) are strongly supporting the technology and are organised in the niche association (Bundesverband Wärmepumpe), a fact that has again raised suspicions of NGOs (BUND 2008).

However, on the policy level, heating energy from heat pumps is seen as “renewable energy” and is supported e.g. by the market incentive programme (Marktanreizprogramm, MAP) (Thema et al. 2015), leading to a relatively high application in new buildings. The heat pump momentum is further supported by requirements within building codes to generate part of the heat/cooling demand from renewable sources.

In existing buildings (and especially large/multi-family dwellings with high heat loads), the heat pumps technology does not align well with the regime technologies and are thus rarely implemented – although this may change in the near future, when air-air HPs may be applied in this market segment as well. In new buildings however, the niche developments align sufficiently with the regime orientation: heat loads are low, regime actors participate in the niche (some large technology manufacturers and electricity providers). This allows for a partly break-through in the sub-sector of new buildings which are already equipped to a significant extent with this niche technology (about 20% of new buildings (Statista 2015)). This, despite significant public debate about the net environmental impacts.

*Solar thermal installations*

The major draw-back of this technology is that solar energy in Germany is not always available at the levels needed to meet the heat demand of a building – especially in multi-family buildings. This makes it a secondary, additional heat source which can, however, be well combined with “traditional” regime-specific heating systems (gas, oil) or biomass systems. As such, it helps limiting the solid/liquid/gaseous energy carrier demand, which has in the past been one important driver of the technology. Consequently, sales were largely dependent on landscape factors such as fuel prices. Moreover, solar thermal installations compete for space with heavily subsidized Photovoltaic systems making a breakthrough even more difficult.

The very high specific costs of the technology have not decreased and are as well dependent on landscape factors (high commodity costs, e.g. for copper). This has been a major barrier partially addressed by policy through the above-mentioned policy package (MAP).

The current internal momentum in Germany is low for multi-family dwellings, slightly higher for single family housing, but market developments are driven largely by landscape factors. As well due to the high specific costs and limited applicability, the technology is not in the focus of attention both in the public debate and in politics, and thus not in the focus of support programmes and break-through probability of the niche is low.

The analysis of heat supply niches yields an ambiguous result. While the internal niche momentum is generally low, it is medium for the special application of heat pumps in new buildings. This is due to the degree of alignment of the respective niches with the regime – the most important aspect being the stakes of regime technology producers fearing to lose market shares and revenues from their established products. Together with long product life-times and investors sticking to known (regime) technology types in existing buildings, the break-through probability of niches is generally low – except for new buildings, where heat pumps already have a significant market share. Nevertheless, since new buildings only make up a small share of the overall building stock in Germany, this has only limited influence on an overall transition of the domain. An overview on niche momentum, regime alignment and break-through probability is given in Table 3.

**Table 3: Breakthrough analysis of heat supply niche-innovations in the heat domain in Germany.**

| Niche-innovation | Internal momentum | Strong or weak alignment with broader regime characteristics and developments | Likelihood of imminent breakthrough (and/or future potential) | Pathway A or B (or mixed) |
|---|---|---|---|---|
| **Small-scale biomass heating systems** | medium-low | LOW to MEDIUM | LOW | A |
| **Heat pumps** | low for existing buildings<br>medium for new buildings | MEDIUM | LOW for existing buildings<br>MEDIUM for new buildings (slow but steady) | A |
| **Solar thermal** | low | LOW to MEDIUM | LOW | A |

## 2.2. Assessment of heat demand niche-innovations

The total energy demand of the building stock depends on the energy efficiency of both retrofit and new buildings and the replacement rate of old inefficient stock. Therefore, these issues will all be looked at. We focus on ultra-low energy housing, i.e. whole house retrofits (WHR) and newly built passive houses. On the other side, total energy demand also depends on the heat supply technologies and is therefore interrelated with the previous sections: an old, non-refurbished house may reach low emission levels with a biomass heating system (albeit at high renewable energy demand) and a high-efficiency new built may reach the same emission levels with a new, small oil condensing boiler.

The following section describes the heat demand niche-innovations at infrastructural and behavioural level by firstly analysing their internal momentum and then outlining their alignment with sub-regime developments and the resulting probability of their break-through.

### 2.2.1. Developments of the niche and internal momentum

Because the heat demand of buildings determines the size and number of heating systems and energy consumption, they constitute an essential element of the heat domain. We distinguish between two niche developments: high-efficiency buildings (both retrofit and new built) and occupant's sustainable behaviour that may be influenced by "soft" measures such as information campaigns or smart metering.

*Low-energy and passive houses*

For the transformation of the building stock towards low-energy housing two options are of importance: the energy-efficient refurbishment of existing building stock (e.g. to a "KfW 50" level), and the construction of new buildings (e.g. "KfW50" or passive house standard) replacing old and inefficient stock. On the technology side, both options require a whole set of measures to be implemented consistently: thermal insulation of walls and roof, double- or triple-glazed windows and an efficient heating system. Over the last decade, typically implemented efficiency standards have increased (e.g. thickness of insulation material increased from about 80 mm in 2002 to 120 mm in 2012 (FIW 2013)).This development has been driven especially by the performance standards for new buildings set by the building code in Germany (ENEV, see development of standards in Figure 3).

In Germany, the majority of residential buildings (75 %) has been built before the enactment of the first Thermal Insulation Ordinance (WSchV)[3], an energy performance standard for buildings in 1977 (Schröder et al. 2011; Eicke-Henning 2011). It is estimated that 20 million residential buildings or 50 % require substantial retrofits. The overall refurbishment rate in Germany is estimated to be between 0.9-1.3 % (BMWi 2014a), the KfW-supported refurbishment rate for (high-efficiency) buildings is at 0.6 % (IWU 2013). At this rate it will take around 100 years for a complete refurbishment of the residential building stock. The main reasons for low refurbishment rates are the high up-front investment costs (an EE retrofit is usually implemented in addition to non-energetic refurbishments that are due anyway) and the perceived gap between energy savings and economic profitability of energetic measures. If total investment costs (of energetic and non-energetic refurbishment)

[3] Exact wording: *Verordnung über energiesparenden Wärmeschutz bei Gebäuden* commonly known as *Wärmeschutzverordnung* (WSchV).

are weighted against energy savings, as often done, investments often do not pay off (KfW 2013).

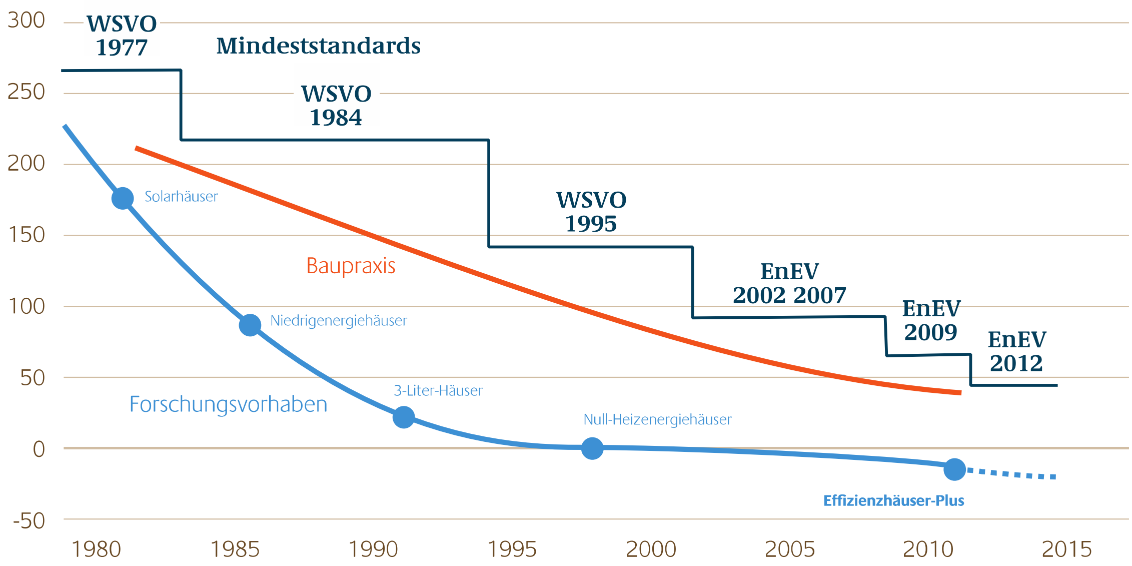


**Figure 3 Development of building efficiency and regulations in Germany (kWh/m$^2$a primary energy). Source: BMVBS 2011, p.4.**

Note: Primary energy consumption for space heating in German 2-family dwellings (kWh/m$^2$a). Best available technology (light blue curve) and legal minimum performance standards for new buildings (dark blue) and typically implemented standards (red curve).

The construction of new buildings (together with a respective market exit of old inefficient buildings) as well constitutes a low-carbon niche, since they can be expected to comply to a significant share with the existing building codes, mandating relatively low-energy consumption levels. Currently, around 140 000 new buildings are being constructed annually, with a total stock of about 18.4 mn buildings (Destatis 2010). Of these newly built apartments, about half have been financially supported by the public development bank KfW to reach high energy-efficiency standards. Regarding ultra-low energy standards (passive house: energy consumption < 15 kWh/m$^2$a), Germany is leading in this niche technology: The total number of passive houses in Germany is not exactly known, figures oscillate between 10 000 and 15 000[4]. Compared to the total building stock, however, this is an almost insignificant share of about 0.05-0.08 %, a picture very similar to Sweden, where the share is 0.04 % (Dzebo et al. 2015) About 500 passive houses are constructed annually, the resulting market share in new constructions is thus only 0.4 % of authorized constructions 2011 (all figures based on Destatis 2013).

This niche bears probably the largest potential with regard to a transition of the German heat domain. The technologies are available, but still increasing in efficiency (k-values of window and wall insulation) as well as (slowly) decreasing in costs. However, an important caveat to a transition lies in user behaviour, capacity and attitudes towards the niche. One important issue are the very substantial required up-front investments costs. As long as the question who (among the most important stakeholder groups owners/investors and occupants/tenants) will

[4] Figures do not distinguish single/multi-family dwellings.

bear the additional costs is not solved, the internal niche momentum will probably remain limited.

Especially the building owner association (Haus und Grund) argues that the focus on whole-house retrofits gives a disadvantage to incremental refurbishment measures and thus does not meet the specific needs of certain building types and ages and of problems with raising the high up-front investments. However, the consistent retrofitting of a building system is essential to avoid lock-in effects. On the other side, renters associations (Deutscher Mieterbund) fiercely oppose cost shifting to renters and are critical of their cost-effectiveness. This "split incentives dilemma" will keep being a major barrier due to the high tenant rates in Germany.

Further internal barriers in this niche are the lack of market transparency and trust of actors, leading to reservations with regard to investments. Moreover insufficient information regarding the complexity of refurbishment measures as well as uncertainties about quality and reliability add to this problem (Galvin 2013, Dena 2013): Any deep refurbishment of a building (i.e. going beyond low-cost shallow measures like a simple replacement of single-glazed windows) is a complex undertaking. It requires a thorough technical analysis of the building, identification of the technically and economically most sensible measures to be implemented, a market review, contacting and comparing of offers from different craftsmen and finally the contracting, management and controlling of works. Where these tasks are already challenging to competent and motivated investors, they are a severe obstacle to the majority.

There may be ways to politically address this e.g. by promoting a kind of "one-stop-shop": a (possibly free-of-charge) consultant managing all steps involved in the project of a building refurbishment, local experts that already have all relevant knowledge and management capacities to help those private investors out that feel incapable of coping with some or all steps involved in the refurbishment of their building.

As the refurbishment and building replacement/new build rate has remained stable over the last decade, and the number of new-built passive houses is marginal, we currently see a low momentum of this niche. However, efficiency levels of buildings that *are* being built or refurbished are continuously increasing. All above-mentioned major barriers to higher refurbishment rates cannot be expected to be solved in the short term. However, if policies would address these barriers adequately, this could significantly increase the niche's momentum.

*Behaviour change and smart metering*

The heat consumption of a building depends not only on the building infrastructure, but also on user behaviour and the (heat) appliances inside a building. Campaigns and smart metering are therefore of additional relevance, directly and indirectly addressing consumer behaviour as another niche within the heat domain. User practices can lead to differences in energy consumption of a factor 5-7 within technologically similar buildings (Liedtke et al. 2014).

Individual metering and billing of electricity, gas and water based on actual consumption has already been implemented in German households during the interwar years (1918-1939) (in contrast to e.g. Sweden, where it is applied in only 1.2 % of households) and nowadays is the standard (Thema et al. 2015). However, smart metering, especially of gas, comprising e.g. monthly or just-in-time consumption reporting can be seen as a “next generation” technology of metering that has been implemented only in test projects by now.

A regular metering and billing of energy consumption is expected to trigger and promote behaviour change on the consumer side – the more frequent, the better. Smart meters offer feedback information, e.g. via displays, in real time. However, estimates of amount and over-time stability of energy savings triggered by smart meters vary significantly from 0 to 15% but can expected to be not overly large (e.g. Darby 2006, Faruqui et al. 2010, Hargreave et al. 2013, The Guardian 2013). Recently, the discussion on smart metering has moved forward, not so much focusing on energy savings anymore, but rather on demand side management (DSM), i.e. load shifting from peak to off-peak demand times. As well, a discussion has evolved around the term ‘advanced metering infrastructure’ (AMI), referring to the system of meters and associated communications (Darby 2010).

A study by Ernst & Young (2013) estimated that to date, the installation and operation of smart meters in German private household is not cost-effective, especially against the baseline of already existing individual yearly metering and billing. This techno-economic barrier might be one reason why the niche has not gained momentum beyond pilot programs yet. Another barrier is related to data security, as smart metering requires the recording and processing of sensitive data. Such “big data” may not be controlled by end-users anymore and consumer associations are thus very critical of the technology. Possibly, accounting for data security issues e.g. via stakeholder dialogues with consumer associations may help to raise acceptance of roll-outs (Thema et al. 2015).

Compared to other countries, Germany is clearly lagging behind with respect to smart metering (for electricity and, even more, gas), and the overall momentum is low. If policy measures are further intensified, momentum may increase to a medium level in the mid term, especially if linked to electricity smart metering.

A very important behavioural factor in heating energy demand is the heated floor area per person. **Error! Reference source not found.** shows that average energy demand per $m^2$ of living space has continuously decreased since the 1970s, but due to steadily increasing living space per capita from around 25 $m^2$ in 1970 to currently about 45 $m^2$ (with projections of almost 60 $m^2$ in 2050), total space heating energy demand has not fallen equivalently. The – in terms of energy consumption unsustainable – increasing per-capita living space can e.g. be explained by the trend towards one and two person households. Consciously deciding to live in below-average living spaces can therefore be regarded as a behavioural socio-technical niche. Having a closer look at the issue, not surprisingly, the share of practitioners of this niche behaviour increases with the number of persons in the household. High per-capita floor areas are found especially for single and 2-person-households (see **Error! Reference source not found.**) and elderly people (While underage persons have around 30 $m^2$ of living space, 65-year-old persons have approximately 55 $m^2$ (BiB 2013). One explanation for this is the remanence effect that arises when couples or later bereaved partner, stay in their house or apartment after children moved out (Matthes et al. 2009).

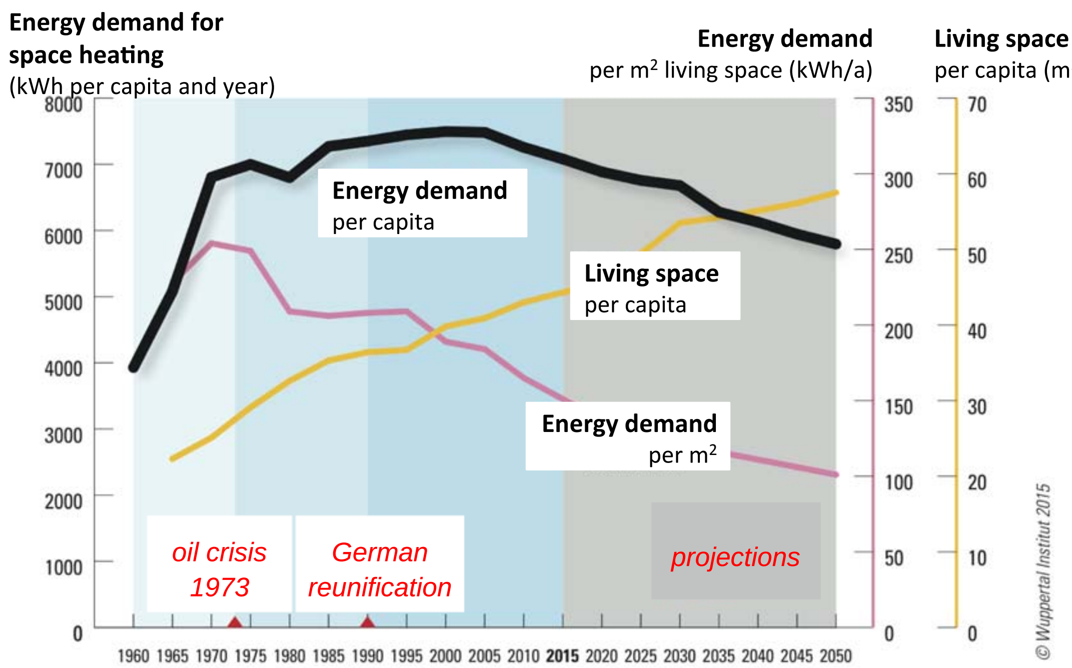


**Figure 4: Development of heating efficiency, floor area and total space heating energy demand**

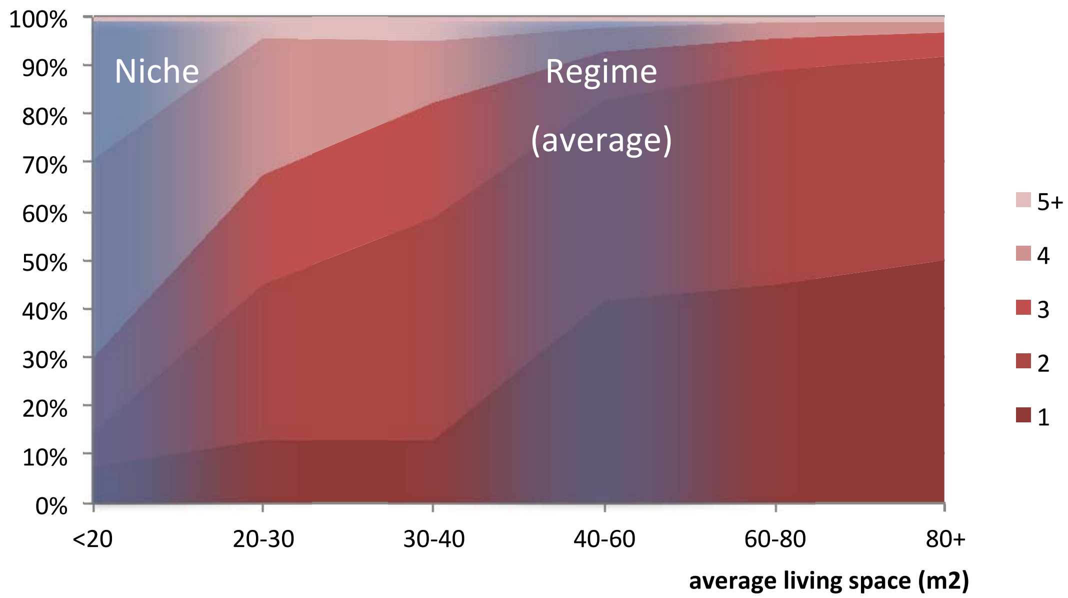


**Figure 5: Average living space by number of persons in the household**[5]

Data source: Mikrozensus Zusatzerhebung (Destatis 2010).

[5] The figure builds on recalculations from total living space areas by number of persons/household. Because the statistic contains only 6 classes, for multi-person-households quotients for per-capita spaces cannot be derived for all per-capita classes. For being able to depict the graph, we imputed the missing values by assuming an approximated F-distribution of the cases in the highest/lowest available per-capita class across the missing classes.

Because the average number of household members is declining in Germany, the two graphs provide a consistent picture of the niche development. The over-time analysis shows a trend towards higher average areas (Figure 4). This means that the low-carbon socio-technical niche of low per-capita living space is actually in recession, i.e. exhibits a negative momentum. In a sustainable pathway this trend would be halted or even lead to a break-through of the niche, reversing the aforementioned trend. All available projections however point towards a continuation of average increases.

### 2.2.2. Assessment of alignment with regime and landscape developments

The German heat demand regime is characterised by a relatively high energy consumption per building. This is due to several issues and developments: a large fraction of the building stock has been constructed before building codes have been enacted that mandate higher efficiency levels. Since then, building codes have been tightened and current new buildings do reach low-energy standards. However, both the rate of new constructions and the rate of refurbishments are very low leading to very slow energy efficiency increases of the overall stock. In addition, the trend towards larger living spaces per capita countervails an overall reduction of energy consumption. A broader description of the regime and landscape developments of the heat demand field is provided in section 3.2. This section looks more closely on how the niche development and its internal momentum aligns with the regime and landscape developments and tries to assess, whether a break-through of the respective niche technology can be expected.

*Low-energy and passive houses*

There are two challenges to a low-carbon transformation of the buildings stock: Efficiency performance per building type and the overall replacement and refurbishment rate.

Regarding the first issue, typical “deepness” of retrofits and efficiency standards for new buildings have constantly increased over the last decades, but there still remains substantial potential towards low and ultra-low energy buildings. The potential of the niche has been acknowledged and is supported by politics (e.g. through building codes), i.e. by a part of the regime. As a consequence, the average consumption of new buildings has decreased from 208 kWh/m$^2$a in buildings built between 1949-1978 to today´s low-energy houses with <50 kWh/m$^2$a (BMWi 2014). In addition, an encompassing subsidy and preferential loan scheme is operated by other regime actors (the state bank KfW, handed out by local banks), supporting low-energy new built and refurbishments as well as heat technology renovation (for further developments see section 3.2). Equally, the niche aligns well with the general public debate that is relatively favourable for high-efficiency buildings, environmental NGOs generally support the construction and refurbishment according to low energy or passive house standards. Still running rumours about dangerous inflammable insulation materials and rising dampness with mould in high-efficiency buildings as a consequence to air-tight windows and walls exist, but have not dominated the debate.

The niche does not align well however with other parts of the regime: owner and renter associations as very important regime actors are very critical on (especially deep) retrofits as they fear rising costs to their stakeholders.

In addition, total numbers of refurbished and newly constructed buildings on ultra-low efficiency levels matter. Here, we find that despite the support, both rates of refurbishment and new buildings remained largely constant on low levels, implying that at this pace, a transition of the German building stock would take almost 100 years. This is probably due to the misalignments between niche and regime mentioned above and to the limited transparency and reliability of costs and cost-effectiveness of low-energy housing. Most private building owners do not have the detailed technical knowledge and management skills necessary for executing a "deep retrofit" exploiting the technical potentials. Addressing these barriers could create substantially more internal momentum.

On the other hand, the demographic landscape developments may help the momentum of this niche: about half of the building owners are 60 years old or above (BMWi 2014). Due to heritage of buildings, a significant change in ownership will occur in the short to mid-term future that may be accompanied with increasing refurbishment rates (Scabell et al. 2015).

Overall, the assessment of this niche alignment with the regime yields the surprising result, that it is rather the relatively flexible polity trying to "pull" and promote the niche technology. This specific part of regime actors struggles with other regime as well as niche actors: owners, renters and their respective strong and traditional associations with a strong influence when it comes to actually investing in niche technologies – and the main unsolved question on who has to bear the high costs of refurbishment (split incentives dilemma). In this situation it seems likely, that the number of annually additional high-efficiency buildings will not increase substantially: a number of buildings are refurbished and constructed at a low-energy "niche" level, but a break-through of the respective numbers/rates cannot be expected in the medium term.

*Behaviour change and smart metering*

The legal framework for smart meters in Germany links gas and electricity metering (Energiewirtschaftsgesetz, §21) and thus the smart meter discussion concerns both the electricity and heat domain. In the German public debate, smart metering is often considered critical. This is due to mainly two reasons: firstly, cost-effectiveness of a full roll-out is doubted and secondly, there are major concerns of data security issues, especially put forward by important regime actors (NGOs and consumer associations). Here, the niche is not well aligned with the regime, which severely hampers the niche momentum – possibly with good reasons. However, an initiation of a stakeholder dialogue might possibly eliminate at least the second barrier and help the niche momentum.

As indicated, the Federal government as one element of the regime supports the development and testing of smart meters as one strategy to achieve its energy efficiency targets for private households. However, a precondition for their effectiveness regarding energy savings is that they effectively induce more sustainable behaviour, which is not certain. If policy measures were intensified, the niche might gain momentum, but due to the low cost-effectiveness and data security concerns of customers, a full break-through can only be expected if legally mandated.

The current regime development of living space per capita trends in Germany towards continuously increasing average floor areas, compensating great parts of the efficiency gains from other niches. The socio-technical niche of small per-capita living spaces (below today's average levels) is in recession.

All studies known to the authors take this development of average living space (both historically and projections) as exogenous factor. Politics do not discuss it as an issue that may be influenced by policy yet. This may be due to the issue being perceived as a decision that is inherently private and any political interference would raise strong objection. The current trend is not questioned, but rather seen as a welfare increase and taken as exogenous development. The regime seems very stable, the niche absolutely misaligned with the regime and windows of opportunity seem tightly shut for any change at this stage.

A change to the situation may prospectively come from landscape developments such as rising real estate prices (especially in the attractive urban areas) and slowly rising ownership rates. If these are coupled with rising interest rates, a decrease of average floor spaces may come as a consequence of sheer economic affordability (Capital 2015). However, the probability of this scenario is uncertain: already in the past, real estate prices and ownership rates have been rising without changing the trend of floor areas, probably because available incomes have risen accordingly.

This behavioural niche holds very a large potential but due to the low (even negative) internal momentum, the very stable regime and no other substantial developments in sight, the socio-technical niche is positioned orthogonally to the regime and a break-through is very unlikely in the medium term.

Without substantial changes in the public debate and paradigm shifts in the polity, or alternatively sheer economic restrictions, the trend is expected to continue towards higher averages in the future, "eating up" efficiency gains and hampering the realisation of a low-carbon transition in the heat demand regime. The results are summarized in Table 4.

**Table 4: Summary of assessment on niche momentum, regime alignment and break-through probability of niches for heat demand.**

| Niche-innovation | Internal momentum | Strong or weak alignment with broader regime characteristics and developments | Likelihood of imminent breakthrough (and/or future potential) | Pathway A or B (or mixed) |
|---|---|---|---|---|
| **Low-energy and passive houses** | low, prospect medium | High | Medium | A |
| **Smart metering** | Low, prospect medium | Medium | Low | A/B |
| **Low per-capita floor areas** | Low (negative) | Low | Low | B |

The analysis of niche momentum, regime alignment of niches and their break-through probability for heat demand and heat supply revealed that a break-though is unlikely to happen in the near future. The transition of the heat domain towards a more sustainable state thus depends on a reorientation of the regime. Whether developments in the regimes hint to such a reorientation or not, is assessed in the following chapter 3.

# 3. Assessment of regime reorientation

The first step in the regime analysis of the German heat domain lead to a subdivision into two interrelated regimes: the heat supply and the heat demand regime (Figure 2). To assess the regime, we first analysed developments within and between the subsystems and therefore looked into characteristic tangible and intangible elements. While tangible elements are defined as measurable aspects such as infrastructure and technology, intangible elements address rules, beliefs, strategies, social relations and governance style defined by actors in concrete contexts (Geels & Kemp 2007). An in-depth analysis of the regimes has been conducted in D 2.2 of pathways project (Scabell et al. 2015), which is taken as starting point for the assessment presented here. To still present a complete picture, the most important findings are shortly summarized in 3.1.1 and 3.2.1.

After the introduction of the subsystems, we discuss the trends visible in the regimes. The analysis aims at revealing if the regime trend is continuing as business as usual with limited regime change or regime actors actively steer a development and implement changes to address environmental problems.

## 3.1. Analysis of the heat generation regime

As mentioned in chapter 1 the sub-systems analysed for the German heat generation regime are the gas- and oil heating technologies and district heating. In the following section we firstly present the developments in these three sub-systems in detail and then assess the occurrence of signs for a reorientation of the regime.

### 3.1.1. Developments in the regime

*Gas-heating system*

With 49 % of households using gas-heating systems as the primary heating source, this technology is the predominant heating system in Germany. Since the oil crises in the 1970s, sales figures steadily increased leading to a replacement of oil-heating systems as the most applied technology in residential buildings in 1995 (Statista 2015). While the gas grid covers most urban areas, it is not as developed in rural areas leaving some regions still unconnected (Presseportal 2013). This all in all well-developed infrastructure is one important driver for the success of the technology, since household survey indicated that the grid-based supply to buildings as compared to oil storage appliances is one of the perceived advantages of the gas-heating system (BDEW 2013a). The survey also revealed that 45.2 % of households would prefer gas to any other heating system. This preference is also reflected in market figures: in over 50 % of newly constructed buildings, gas-heating systems are being installed (BDEW 2013a). The overall market share of gas heating appliances on the market for heating systems was 75 % in 2013.

The industry actors within the sub-system come from a strong industry of gas suppliers and heating system manufactures. All in all, the German gas industry employs 38 800 people, has a revenue of 35.7 billion Euro and invests up to 1.4 billion Euro annually (BDEW 2012). The companies producing and selling gas heating appliances are mainly German companies (Statista 2015), which is an important factor for the interaction with policy makers. The sector is organised in influential associations and unions actively working on a political and societal level to promote gas as a reliable heating source, arguing for more incentives for consumers to refurbish their old heating systems, and for a stronger concentration on domestic exploration of gas and fracking (Scabell et al. 2015). The latter aspect is evoked by the fact, that Germany mainly depends on gas imports (89 % mainly sources from Russia and Norway) and only 11 % is extracted domestically. A success for the gas industry was the new law enacted in April 2015 that puts fracking under critical surveillance but does not prohibit this technology as had been demanded by e.g. environmental organizations.

Even though based on fossil fuels, consumers perceive gas and gas-heating systems as an environmentally friendly heating technology (BDEW2013a). A big advantage for the manufacturers is the flexibility of their technology. For example, to further improve environmental performance, condensing boilers can also be operated in combination with solar thermal installations. Furthermore, the system can be fuelled with biogas without encountering any technological restrictions (BDEW 2015). This way, they fit well in the energy transition strategy of the German government. A consumer survey indicated that the acceptance for biogas is at present medium: 46 % of the responding house owners rate biogas as an attractive product and potential substitution for conventional gas (BDEW 2013a). These issues contribute greatly to the stability of the heating regime.

The support for replacing old heating systems by high-efficiency systems is part of the general political agenda since it promotes the energy transition. A concrete means of support are governmental funds directed to end-users via grants of the Federal Office for Economic Affairs and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle – BAFA) and included in building refurbishment schemes from KfW. A measure to trigger refurbishment has been set with the EnEV of 2014. This ordinance decrees the replacement of oil and gas heating boilers that are older than 30 years by more efficient systems from 2015 onwards (with several exceptions).

The political strategies show that policy makers are aware of the fact that in the next decades, gas will still largely contribute to the German heat and energy market (e.g. the plans of the Federal Network Agency (Bundesnetzagentur (BNetzA)) include plans for new constructions of about 750 km gas pipes until 2024 which is nevertheless moderate considering a current grid length of 510 000km (BMWi 2015). This support of the system can be interpreted in the light of the German energy transition (Energiewende). Here, gas and its established infrastructure might serve as a (long-term) bridge technology for power generation and storage (e.g. “power to gas”) (Schüwer et al. 2010).

*Oil heating system*

In accordance with the upward trend of gas heating systems, the share of oil heating system declined since the 1970s. In 2015, 26.8 % of households rely on oil-heating as primary heating energy source (Statista 2015). The majority of consumer households perceive the technology as dirty and with no viable future (Statista 2014). According to statistics, 43 % of existing oil heating systems currently installed were built between 1991 and 1997 (Statista 2015) and are thus out-dated and do not meet present environmental standards. Industry actors try to promote technical improvements of oil heating systems (especially with respect to energy efficiency and a combined application with renewable energy sources) and to exploit market opportunities opening up due to the out-dated technology in place. In fact, the $CO_2$-emissions of oil condensing boilers with the current state of the art are not much higher than those of gas heating appliances. Still, with regard to other emissions such as $NO_x$ and particulate matter, they still have higher impacts[6]. These emissions are gaining importance in terms of air quality and health impacts which drives respective regulations.

In comparison to other heating technologies (gas-heating systems, wooden pellets and heat pumps) consumers rate oil-heating technology as least attractive with respect to economic feasibility and efficiency, supply security, comfort in use, environmental compatibility, technical security and potential of innovation (BDEW 2013a). This bad reputation also shows in the sales figures for heating systems in new constructed buildings: oil-heating systems are only installed in 0.7 % of the cases. Figures for new constructions are especially interesting to analyse, since they reveal the preference of consumers that are not yet bound to an existing system and related asset specificity. These factors lead to significant changes in buying decisions.

Accordingly, Scabell et al. (2015) show in their analysis that households that already use oil for heating are more likely to refurbish with a modern oil-heating system rather than with a different technology. Therefore, the share of oil heating systems on overall installed heating-systems only declined little over the last ten years. A reason for relying on the same heating technology is past positive experience (IWO 2015). Other reasons are the role of asset specificity mentioned above that leads to significantly higher costs when changing the complete system rather than exchanging one oil heating appliance (e.g. only the burner) for another and the fact that households in some rural areas are not connected to a gas or district heating grid. An advantage of oil is that it can be bought and stocked in advance when prices are relatively low. But just as it is the case with gas, Germany depends on imports, and prices are sensitive to international developments.

The oil-heating system actors include e.g. producers, traders, service providers, chimneysweepers and installers. Similar to the structure in the gas heating industry, the majority of oil-heating systems are constructed and sold by German companies and the sectors is organised in politically active associations and trade unions. Since the current sales mainly arise from refurbishments of oil-heating systems (as described above), actors work

[6] For an analysis of heating systems for residential buildings in Germany with regard to $CO_2$-emissions e.g. see for Bettgenhäuser & Boermanns (2011: VIII - IX) https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4070.pdf

towards further incentives and subsidies for refurbishments. As already seen in the analysis of the gas-heating system, the policy measures aim for a change in the heat domain through market-oriented incentives and some measures of legal enforcement.

*District Heating*

The third heating technology analysed within the heat regime is district heating (DH). Even though the German grid is among the longest in Europe (with 20 000 km length), DH only has a market share of 12.8 % in Germany (BDEW 2013). While the German case does not reveal significant potential for "greening" the heat domain, in other countries such as Sweden, there is a great potential for a more sustainable heat supply (Scabell et al. 2015). Sustainability in the context of DH depends on the energy source it relies on and on the efficiency of the system (because DH in Germany is mostly provided via high-efficiency combined heat and power plants). A life cycle analysis conducted for Swedish DH reveals that biofuels are the preferable energy source. "Waste incineration is often (but not always) the preferable choice when incineration substitutes landfill disposal of waste […] but never the best choice (and often the worst) when incineration substitutes recycling" (Eriksson et al. 2007). German district heating mainly relies on fossil fuels as energy source: In 2013, gas, hard coal and lignite were the main sources, with 42 %, 33 % and 13% respectively. Biomass and waste heat only added up to a share of 12 % (AGFW 2013).

Combined heat and power generation (CHP) plants are the main technology applied for DH generation in Germany (82 %) (AGFW 2013). Due to the significantly higher energy efficiency of these plants, their application has positive effects on the environmental performance of the total energy system (as aggregate of heat and electricity). To use this positive effect within the German energy transition, the German government promotes CHP by setting the target of generating 25 % of electricity with CHP by 2020 (in 2012, the share was 16 %) (Wünsch et al. 2013). Due to the interrelatedness, the target set for the energy sector also promotes DH in the heat domain, which demonstrates the connection between the two domains (Echternacht & Berg 2015).

### 3.1.2. Assessment of reorientation

The main question steering this assessment is whether the regime continues with business as usual or whether existing regime actors implement changes to address environmental issues. The answer to this research question differs for each of the three sub-systems described above and has different implications that need to be discussed. After first assessing each subsystem separately, the scope is widened to address the whole heat supply regime.

For gas-heating technology, we observe that actors implement incremental changes to address environmental problems. As described above, the heating appliances become more and more energy efficient (condensing boilers) and could in principle also run on organic gas or in combination with other renewable energy appliances (e.g. solar thermal). These developments will only have a small influence on the actor configuration of the regime (e.g. shift in power and importance). Biogas only accounts for 1 % of the overall final energy consumption for heat in Germany (BDEW 2015) and the substitution of energy source thus has only limited effects. Implications could be more relevant with respect to other domains, namely agriculture. The promotion of biogas in recent years in Germany already led to farmers reconsidering their choice of crops since the production of biogas yields higher revenue than the production for direct consumption or fodder. This caused a drastic shift in production to energy crops, leading to maize monocultures, overpriced leasing costs for scarce cultivation areas and toxic fermentation residues in soil and water resources (BR 2012). This issue clearly shows that transitions always need to be analysed in a systemic perspective that in some cases even need to be broader than just a domain. This might have implications for the concept of Pathways 0, A and B since it might be necessary to add a description for which impact/indicator the pathways leads to a sustainable transition (e.g. carbon emissions vs. biodiversity).

With regard to the oil heating systems, we see similar developments. Manufacturers implement incremental changes to increase energy efficiency and be able to promote their technology as environmentally friendly. Nevertheless, current oil heating technology still induces more $CO_2$ and other emissions than gas. The changes appear to be less significant than the ones in gas heating systems and the strategy rather aims to retain the users still applying oil heating systems, relying on the supply gaps of the gas grid infrastructure in decentralized and rural areas.

The trend for district heating seems to continue as business as usual. Here, we do not see substantial changes that work towards low-carbon technologies. The main technologies applied are relying on fossil fuels. Since in Germany the absolute amount of energy needed is higher than e.g. in Sweden and the availability of renewable fuel lower, the potential for renewable-powered DH is limited (Scabell et al. 2015).[7] Nevertheless, since DH is closely linked to CHP with high energy conversion efficiency, it is more environmentally friendly than for example oil heating systems. In line with the political targets for an increase in CHP, DH will probably slightly increase in the future. Still, we expect that due to its relatively small share on the overall heat supply, its influence for greening the regime will stay relatively small compared to the other subsystems. The interrelation of the heat and energy domain will be taken up again in the discussion in chapter 4.

Having outlined trends of the individual sub-systems, we now analyse developments affecting all three systems and the conclusion for the heat supply regime as a whole.

A group of actors relevant for all three dominant sub-systems are policy makers. Their activities are guided by $CO_2$-reduction targets on the national level leading to policies such as ordinances and market-based incentives. These regulations, however, seem to have only limited effect on the heating systems that are already in place. The only ordinance (EnEV) directly targeting the upgrading to new, more efficient systems addresses oil- and gas-heating

[7] There is still a large potential for the use of heat from waste incineration which today is mostly used for electricity generation only due to a lack of local heat distribution grids. Often, these are not feasible at the plant locations (rural and little populated areas and high investment costs). In the longer term, if CHP from waste incineration was supported more by the policy framework, this may gain momentum (UBA 2006).

systems older than 30 years. With some exceptions, these old heating systems have to be replaced. Since few incentives for a change in technology applied[8] are given and consumers tend to stick with the technology used before (IWO 2015), the regulation rather tends to stabilise the regime.

With regard to the technological development of new systems and thus the availability of efficient heating systems on the market, the Ecodesign Directive (2009/125/EC) is an important measure. According to this directive, manufactures of energy-related products must meet certain energy and environmental performance criteria for their products, taking lifecycle aspects into account. It sets minimum mandatory requirements for energy efficiency. The Energy Labelling Directive (2010/30/EU) ensures the communication of this performance, to enable consumers to include these information into their purchase decision.

For the overall assessment of the heat supply regime, we argue that some reorientation takes place, but with a strong focus on increasing efficiency levels of new appliances and incentives to replace old inefficient ones. Minor changes towards and addition of renewable sources are visible as well. As summarized in Table 5, changes mainly occur in the sub-system of gas-heating. Due to its relevance for the complete regime (dominance in market share), we judge these changes as relevant enough for a regime reorientation.

**Table 5: Assessment of heat supply regime trends in the heat domain in Germany.**

| | **Lock-in, stabilizing forces** | **Cracks, tensions, problems in regime** | **Orientation towards environmental problems** | **Main sustainability problems related to the socio-technical regime** |
|---|---|---|---|---|
| **Gas heating system** | Strong | Weak to moderate | Significantly increasing efficiency levels, compatible with biogas → Incremental changes | Reliance on fossil fuel |
| **Oil heating system** | Moderate to strong | Moderate | Increasing efficiency → Business as usual | Reliance on fossil fuel |
| **District heating** | Moderate | Moderate | Business as usual | Reliance on fossil fuel, limited availability of renewable fuels. No high market shares, thus not that relevant for regime change |

8 The only incentives for a fuel-switch towards renewable fuels are the „biomass labelling factor“ implemented with the EU-efficiency label, classifying biomass boilers in higher efficiency categories and additional financial incentives provided via the KfW/MAP programmes for the installation of renewable-fuelled boilers.

## 3.2. Analysis of the heat demand regime

A substantial part of the information on the heat demand regime is important to understand the heat demand niche developments and were thus already presented in chapter 2.2. In the following, we will provide additional information on the state of the building stock and regime actors relevant for the analysis of a possible reorientation of the regime.

### 3.2.1. Developments in the heat demand regime

The German residential building stock is very heterogeneous. The about 19 mn buildings with almost 41 mn dwellings (BMWi 2014) exhibit a great diversity with regard to types of buildings, building age and architectural/constructional characteristics and energy consumption. The energy consumption per square meter is an important indicator for the differentiation of niche and regime. The niche relates to a significant reduction of energy consumption (per capita) achieved by e.g. the application of up-to-date technology leading to the compliance to latest standards of 50 kWh/m$^2$a area-related energy consumption (and 40 kWh/m$^2$a from 1 January 2016 on) (EnEV 2009/2014) or even passive houses standard with < 15 kWh/m$^2$a.

The heat demand regime is characterised by higher energy consumption values resulting from the age structure of the building stock and the history of energy performance standards. The first energy performance policy, the first thermal insulation ordinance (WSVo)[9], was enacted in 1977 as a reaction to the oil crisis. After several amendments, a new ordinance was enacted in 2002, the "Energieeinsparverordnung" (EnEV), combining the thermal insulation and heating system ordinance, which has been amended several times and increased energy efficiency standards steadily. This development is clearly visible in statistics on average area-related energy consumption (Figure 6) 64 % of the current building stock were built before the first Thermal Insulation Ordinance (1.WSVo). The majority of dwellings have not been refurbished in terms of EnEV 2002 or later, leaving a large potential for energy efficiency improvements (Dena 2012).

Building envelopes can be taken as one example to illustrate the potential. Assuming refurbishment cycles of 30 to 40 years for building envelopes, and taking into account that about 7 million buildings were constructed in the 1950s to 1970s and 3.6 million between 1979 and 1995 (about 50 % of total residential building stock), fundamental refurbishment and retrofitting is needed within the next 20 years (BMWi 2014). Another aspect relevant with regard to the energy consumption per capita is the increase in living space used per person, already been discussed in chapter 2.2.

[9] Exact wording is: *Verordnung über energiesparenden Wärmschutz bei Gebäuden* commonly known as *Wärmeschutzverordnung* (WSVo).

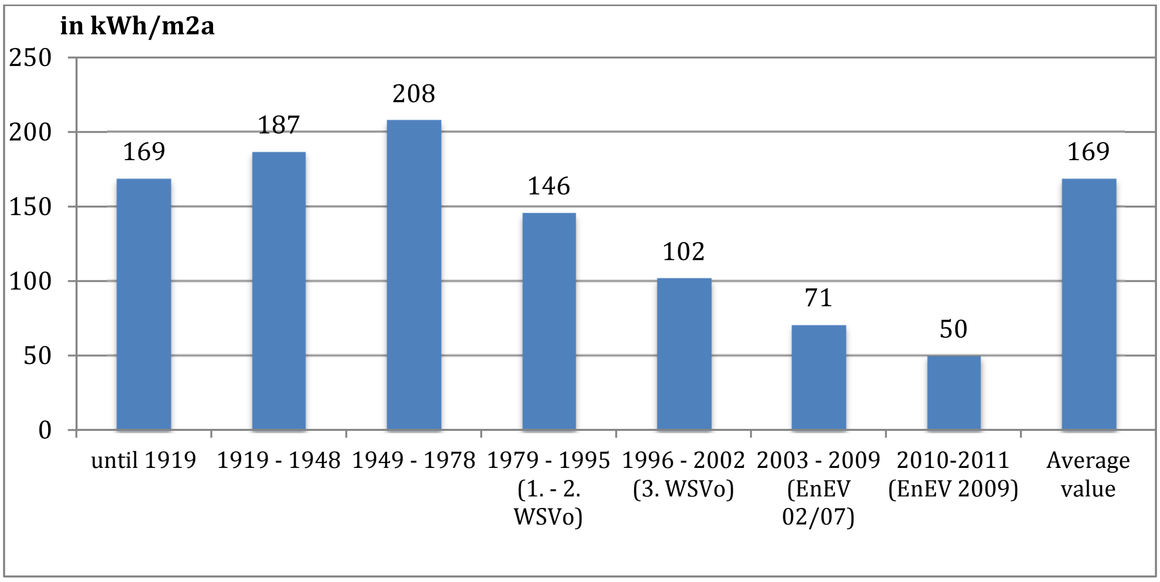


**Figure 6 Allocation of the area-related energy consumption of existing buildings by year of construction** Source: Data BMWi 2014.

In the heat demand regime, there are several important actors e.g. in politics (responsible for ordinance and incentive schemes), owners and occupants of houses. About 46 % of dwellings are occupied by the owners, the rest is rented. For detached houses, for single- or two-family houses, this rate is considerably higher with 88 % and 59 % respectively. About 14.5 mn rental apartments are rented out by owners with only few properties (i.e. private owners, not housing corporations). With regard to owners living in their houses, today, approximately 50 % are 60 years old or older. The demography of owners will thus lead to considerable change of ownership in the coming decades, possibly connected with energetic refurbishment and investment measures in the near future (BMWi 2014).

Many owners and tenants are organised in interest groups. The biggest association for private building owners is the “Haus und Grund” that works toward an adjustment of the current ordinances and incentive programs to shift from WHR funding towards support of incremental measures (HuG 2014). The most influential interest group for investors, commercial suppliers and cooperatives is the GdW (Federal Association of German Housing and Real Estate Companies). For tenants, the “Deutscher Mieterbund” is the biggest association, as well critical towards this niche: In order to avoid the shifting of costs for energy efficiency refurbishments to the tenants, the Mieterbund formulates doubts on their cost-effectiveness (Deutscher Mieterbund 2014). The individual associations do not deny the need for an improvement of the energetic performance of the system itself, but they try to save their stakeholders from bearing the related costs.

### 3.2.2. Assessment of reorientation

The assessment of reorientation of the heat demand regime is rather complex. On the one hand, the heat demand regime is a very static regime with long investment cycles/product lifetimes (of buildings), and many different actors e.g. owners and tenants and their respective strong associations with a long tradition and strong political influence catering for regime stability. One the other hand, there are political actors aiming at achieving specific environmental/climate targets and thus trying to implement measures that foster the realisation of these goals. As already pointed out in the niche analyses, this second group of actors seems to work towards changing the heat demand regime – not only towards a gradual reorientation, but to an adaption of niche characteristics. To promote this, new and enhanced regulations and standards for the energy efficiency of buildings (EnEV) and funding schemes are implemented.

However, the low rate of new constructions in Germany to date clearly shows that new buildings alone will not lead to a transition in the mid term. Instead, the refurbishment of the existing building stock is crucial. The combination a generation change of owners and a (theoretical) beginning of a refurbishment cycle may instil some hope for reorientation here. Still, with regard to the constantly low energetic refurbishment rates, we argue that even though parts of the regime (policy makers) are strongly in favour for a change and strive for a reorientation, the regime as a whole rather follows a "business as usual" pathway. The main reasons for this are most likely to be found in other parts of the regime: The most important barriers concern the investment that is needed for the refurbishment and that in many cases neither owners nor renters want or can bear the costs. Consequently, owners' and tenants' associations fiercely oppose any regulation that may oblige their stakeholders in this way. Bringing down those costs and solving the distributional problem (split incentives dilemma) is thus crucial for which the existing funds that support refurbishment are apparently not sufficient.

These unsolved problems of cost distribution may partly be the reason why the regulations mostly address new constructions and changes in ownership instead of the overall building stock in general (exemption: obligation of thermal insulation of ceilings in heated rooms beneath unheated attics with EnEV). Policy makers at present cannot/do not impose mandatory investment costs of significant heights to either house owners or renters.

A crux is that only a comprehensively planned refurbishment leads to an optimal energetic performance of the building stock (also heating technology needs to be taken into account as pointed out in chapter 1). Instead of using a holistic approach, many single refurbishment measures are currently planned and conducted separately. Even though each single activity may reduce the overall energy consumption and related $CO_2$-emissions, it fails to reach the optimum. Furthermore, due to the long investment cycles, single non-consistent measures lead to a lock-in at high energy consumption levels and further stabilization of the current pathway of the regime – and the targets (set by the regime actors striving towards reorientation) are unlikely to be met.

In light of this heterogeneous picture, we rather judge the regime to be dominated by incremental changes. All actors relevant to induce a change seem to be aware of the necessity of a transition – the challenge is (how) to finance it. Whether the reorientation will be sufficient for a sustainability transition or not will depend on changes in the political framework. If policies are altered in a way that refurbishment measures are planned for the complete building (even if they may be carried out in in succession) and the challenge of split incentives is solved, it may become possible. The results of the analysis are summarized in Table 6.

**Table 6: Assessment of heat demand regime trends in the heat domain in Germany.**

| | Lock-in, stabilizing forces | Cracks, tensions, problems in regime | Orientation towards environmental problems | Main socio-technical regime problems |
|---|---|---|---|---|
| **Residential building stock** | Strong | Moderate | Introduction of policy measures, Energetic refurbishment measures at higher level but low rates → Incremental changes | Resistance from tenants and house owners → insufficient private investment |

Hinging on the observation that existing niches do not seem to cater for a sustainability transition, this chapter has outlined approaches and potential beginnings of regime orientations and barriers to change. The next chapter will conclude this paper with a discussion of the findings made and by opening up a wider perspective of the issues analysed here.

# 4. Conclusions and wider discussion

The aim of relating niche and regime developments of the German heat domain in this paper was to assess the transition pathways of the domain. Besides assessing the break-through potential of niches, which depends on the internal niche momentum and its alignment with the regime, the mode of reorientation of regimes was accounted for. The results of these assessments are presented in Table 7.

**Table 7 Overview of results of niche and regime assessment.**

| | Sub-regime | Mode of reorientation | Potential impact on Regime performance |
|---|---|---|---|
| **Heat supply** | Gas heating | Incremental changes | High |
| **Heat supply** | Oil Heating | Business as usual | Medium |
| **Heat supply** | District heating | Business as usual | Low |
| **Heat demand** | Residential building stock | Incremental changes | Medium |

| | Niche technology | Break-through probability |
|---|---|---|
| **Heat supply** | Small-scale biomass heating systems | Low |
| **Heat supply** | Heat pumps | Low |
| **Heat supply** | Solar thermal | Low |
| **Heat demand** | Low-energy and passive houses | Medium |
| **Heat demand** | Smart metering | Low |
| **Heat demand** | Low per-capita floor areas | Low |

*Limited momentum and break-through probability of niche innovations*

We conclude that none of the niches analysed is about to break through in the short to mid term. In general, an important aspect to keep in mind for discussion is that since the construction rate of new buildings is rather low and that a transition therefore highly depends on refurbishment. Specific in this respect for the heat domain are very long investment cycles (approximately 20 years for heating systems, 30-40 years for buildings) and significant asset specificity of heating technologies.

With regard to the niche innovations for heat supply, all technologies analysed have a low potential of break-through. For small-scale biomass heating systems the low potential especially relates to the currently missing joint position of manufacturers (incumbent firms with a diverse portfolio vs. specialised new market entrants), problematic asset specificity, i.e. the installation requires further changes in a building's heating infrastructure, and high initial investment costs (for the appliances and construction adaptations). The low break-through potential for solar thermal is mainly related to its complementarity, i.e. the technology is not able to supply sufficient heat to completely substitute other heating appliances and can hence only be operated as an additional system. This further diminishes its already low cost efficiency. The third technology assessed, heat pumps, has a low momentum and shows medium regime alignment. The assessment as "medium" is due to the support from large electricity providers (connection to electricity domain). Even though all three niche technologies are promoted by policy through the market incentive programme (MAP) as renewable energy, the analysis reveals that this support is not sufficient to further spur their momentum.

The heat demand niche innovations show a similar picture. Smart metering and the low per-capita floor area only have a low potential of break-through. The low per-capita floor area is a niche that is highly dependent on social changes (related to Pathway B), which even shows a negative trend. The diffusion of the other heat demand niche, smart metering, is hindered by high implementation costs and privacy concerns in spite of promotion by policy actors (connected to promotion of electricity smart metering). The only heat demand niche showing medium potential for a break-through is low-energy and passive housing. We judge the potential as medium due to the immense support the niche receives from parts of the regime. Policy makers, as important regime actors, take this niche as a role model for new building efficiency standards and promote the adaption of related technologies in the regime – also extending to the existing building stock. It seems, that a part of the regime is trying to implement a top-down reorientation, but that the niche is not ready to break through. This, however, cannot entirely be blamed on the niche technology actors, but rather on a set of socio-cognitive and economic barriers, many of them related to other parts of the regime. Most relevant in this context are non-monetary investments (including information, management and contracting of a building refurbishment) and the significant up-front investment costs that are still required for ultra-low-energy buildings (both for new buildings and retrofits). As discussed in the analysis, associations of house owners and of tenants fear rising costs for their stakeholders and are thus critical to this niche (split incentive dilemma).

*Stable regimes, partly heading for incremental changes*

With no niche innovation (analysed) ready to break through and leading to a transition in the short to mid-term, a potential transition of the German heat domain will need to rely on the regimes (or at least central regime actors) with their respective sub-systems. The general public debate analysed as landscape development provides good framework conditions, as it very much favours a cut-back of carbon emissions in general and would support such a pathway.

With respect to the heat supply regime this trend is taken up in the technological development of gas and oil heating systems. Nevertheless, the interests of the regime actors are diverse, leading to heterogeneous interest groups arguing for different solutions. The main technology applied is gas heating. For this technology, substantial efficiency gains have been achieved, leading to reductions in $CO_2$-emissions. High-efficiency gas condensing boilers dominate the market – still, the technology relies on fossil fuel and will, on its own, thus not lead to the transition needed. However, combined with a significantly reduced heat demand (i.e. with a change of the building stock to ultra-low energy buildings), this development may nonetheless lead to a more sustainable heat domain. Because heat demand niches are unlikely to break through on a large scale, reduced heat demand and its realisation relies on the reorientation of the heat demand regime.

From an analytical perspective, the heat demand regime is highly interesting due to the strong oppositions it comprises. While on the one side policy (regime) actors try to push a regime reorientation (aiming at a 2 % refurbishment rate), house owners and tenants argue against it. The reason for this divide is the financial investment connected to refurbishments and the split incentive dilemma. The subsidies in place are currently not sufficient to solve this. The main barrier to a transition is thus a lack of investment. Due to the immense will of policymakers to change the regime, we still rate the overall regime to be in a mode of reorientation with incremental changes. However, this reorientation has only a medium potential for the overall transformation, since several barriers would need to be overcome to actually achieve a transition. Besides financially enabling conditions and solving the dispute over the distribution of costs and savings between investors and users, this also includes the consistent planning of single refurbishment actions for the complete building in order to capture full energy saving potentials. This whole-house perspective does not only relate to heat demand measures but also, as indicated above, includes heat supply technologies.

*No immediate transition unfolding, but possibilities in the medium term*

In 2015, every single niche innovation in the German heat supply and demand sub-domains exhibit low to medium internal momentum and none is expected to immediately break through on a large scale. However, there are several niches with a high transformative potential that still face substantial barriers, if those were removed, this may quickly lead to an unfolding transition, that may, depending on which niche(s) break through, follow pathway A or B. Possible scenarios for the medium term may be:

- **Heat supply niches break through** (especially biomass and heat pumps): this may happen due to landscape changes, if e.g. fossil fuel prices rise dramatically or fossil fuel supply becomes unsecure, due to changes within the regime, if e.g. large market players strongly push for biomass heating (unlikely) or due to changes in the niche, if producers manage to substantially reduce technology costs (unlikely). This scenario thus largely depends on landscape changes. It would involve mainly technical component substitution with radical changes and thus follow **pathway A**, however with lead actors being both incumbent and new market entrants (pathway B).

- **Heat demand niches/ low energy housing break through:** this may also be supported by landscape changes (i.e. rising fuel prices), but the main barriers that would have to be removed are within the regime and the niche. If the perceived benefits of low-energy housing outweigh the costs to both owners and tenants, this niche may take off. For this to happen, either technology costs have to decrease dramatically (possible in the medium term), monetary incentives have to increase dramatically (unlikely in the short term) or the policy part of the regime has to enable and enforce it via legislation, which is only possible by providing private investors with the information, knowledge and possibly management of their refurbishment project and by solving the split incentives dilemma. This seems unlikely given the high stability of other regime elements, at least in the short term. Whether this break-through scenario is realistic is highly uncertain, but it would substantially change the existing system through a radical technical change, mostly by incumbent actors and thus follow **pathway A**.

More generally, the likeliness of a further increase of niche momentum and eventual break-through increases as well, if landscape pressures on the regime increase, leading to cracks and tensions and opening up windows of opportunity. Certainly, the recent Paris Agreement fits into this scenario and the general German context ("Energiewende") is favourable. After decisions on a nuclear phase-out and a full energy transition, discussions now move forward towards a coal phase-out. The residential heat domain still seems to be a very stable regime, but as the public discourse continues, this may change in the decades to come.

*Links of the German heat domain to other domains*

The analysis showed in many points that links to other domains are relevant when discussing a transition of the heat domain. These links can on the one hand help to trigger a change (as e.g. the support of DH by a law originally promoting CHP, as well as smart metering of gas connected to electricity). These links are important to have a broader perspective to evaluate systemic changes. An example for the latter case is biogas. While for the heat domain, it is perceived as a renewable and thus sustainable energy source, from the perspective of the German agri-food domain it needs to be seen critically due to the competition of energy crops and crops for direct consumption or fodder and due to biodiversity threats of large monocultures. Potential negative environmental impact of the cultivation of energy crops on soil and water resources as compared to nutrition also need to be taken into account.

*Conceptual outliers: A niche in decline and regime actors as promoters of a transition*

Two aspects we would like to point out as interesting for a further development of the analytical framework applied are related to the niche of per-capita floor areas and the heat demand regime. We showed, that the living space per capita steadily decreased since the 1970s. This can be seen as one element of the heat demand regime. Sustainability science nowadays promotes e.g. 20 $m^2$/capita as a target for sustainable living (Lettenmeier et al. 2014). Analysing low per-capita living spaces as a “sustainable niche”, actually leads us to conclude that this niche is declining, revealing a transition towards a less sustainable state. The other interesting finding from the analytical framework perspective was that part of the regime actors may promote a niche, while others work against it (Policy actors promote energetic refurbishments, while house owner and tenant associations have reservations). This aspect may be taken up for the discussion of the niche-regime relation. On the one hand this action could be interpreted as regime actors destabilizing the regime in order to open a window of opportunity for the niche, on the other hand this could be seen as reorientation of the regime itself.

For the definition of Pathways 0, A or B the analysis revealed that an indication of which sustainability aspect is promoted with the respective transition might be helpful. This is dues to that fact that trade-offs between different criteria may exist. As discussed in chapter 3, a positive development with regard to carbon emissions may lead to negative impacts on biodiversity. Socio-technical analysis in this regard should cater fur such competing goals (e.g. also found in struggles of renewable energy promotion and nature protection).

Our analysis concludes with the observation that the heat demand system was shown to be unlikely to perform a sustainability transition soon. Neither technical nor behavioural niche innovations were found to be potential assets for a swift regime change. However, incremental improvements are visible and were shown to strongly depend on governmental intervention. A look at the wider perspective has shown that the heat regime is intricately linked to other domains such as agriculture, land use (in the case of biomass) and electricity – when it either relies on renewables to arrive at truly sustainable systems (e.g. in the case of heat pumps) or competes with them as in the case of roof top space. An in-depth analysis of these connections thus seems to be an important next step.

# 5. References

AGEB - AG Energiebilanzen e.V. (2013). Erstellung der Anwendungsbilanzen 2011 und 2012 für den Sektor Private Haushalte. Endbericht - Oktober 2013. Berlin.

AGFW – Der Energieeffizienzverband für Wärme, Kälte und KWK e.V. (2013). Hauptbericht 2012. Available online: https://www.agfw.de/zahlen-und-statistiken/agfw-hauptbericht/ [15.04.2015].

BDEW – Bundesverband Energie- und Wasserwirtschaft e.V. (2012). Energiemarkt Deutschland Zahlen und Fakten zur Gas-, Strom- und Fernwärmeversorgung. Link: http://docs.dpaq.de/2436-energie-markt_2012d_web.pdf [04.11.2015].

BDEW – Bundesverband Energie- und Wasserwirtschaft e.V. (2013). Beheizungsstruktur des Wohnungsbestandes, Ed: AG Energiebilanzen: Energieverbrauch in Deutschland, Daten für das 1. Halbjahr 2013, Berlin.

BDEW – Bundesverband Energie- und Wasserwirtschaft e.V. (2013a). Erdgas am Wärmemarkt: Die Verbraucher wünschen eine wirtschaftliche Heiztechnologie. Available online: https://www.bdew.de/internet.nsf/id/110615DF116D4BB4C1257C6D005048EB/$file/bdew_Folder-Positionierungsstudie_FINAL%20ES.pdf [04.11.2015].

BDEW – Bundesverband Energie- und Wasserwirtschaft e.V. (2015). Wärmemarkt – Erdgas. Available online: https://www.bdew.de/internet.nsf/res/E40F096E25DB3054C1257BCE0051429A/$file/BDEW-13-00025_Erdgas_komplett%20Kapitel.pdf [04.11.2015].

Bettgenhäuser, K. & Boermans, T. (2011). Umweltwirkung von Heizsystemen in Deutschland, Umweltbundesamt, Berlin. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/4070.pdf [04.11.2015].

BiB – Bundesinstitut für Bevölkerungsforschung (2013). Bevölkerungsentwicklung 2013 - Daten, Fakten, Trends zum demographischen Wandel. Available at: http://www.bib-demografie.de/SharedDocs/Publikationen/DE/Broschueren/bevoelkerung_2013.pdf?__blob=publicationFile&v=12 [04.11.2015]

BMUB – Bundesministerium für Umwelt, Bau und Reaktorschutzsicherheit (2015). Umweltbewusstsein in Deutschland 2014 – Ergebnisse einer repräsentativen Bevölkerungsumfrage. Available online: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/umweltbewusstsein_in_deutschland.pdf [04.11.2015].

BMVBS – Bundesministerium für Verkehr, Bau und Stadtentwicklung (2011). Wege zum Effizienzhaus-Plus. Available online: http://www.baulinks.de/webplugin/2011/i/1668-effizienzhaus-plus-broschuere.pdf [30.11.2015].

BMWi – Bundesministerium für Wirtschaft und Energie (2014). Sanierungsbedarf im Gebäudebestand, Ein Beitrag zur Energieeffizienzstrategie Gebäude. Available online: http://www.bmwi.de/DE/Mediathek/publikationen,did=676178.html [04.11.2015].

BMWi – Bundesministerium für Wirtschaft und Energie (2014a). Bericht über die langfristige Strategie zur Mobilisierung von Investitionen in die Renovierung des nationalen Gebäudebestandes. Available online: http://www.bmwi.de/BMWi/Redaktion/PDF/B/bericht-ueber-die-langfristige-strategie-zur-mobilisierung-von-investitionen-in-die-renovierung-des-nationalen-gebaeudebestands,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf [04.11.2015].

BMWi – Bundesministerium für Wirtschaft und Energie (2015). Gas. Available online: http://www.bmwi.de/DE/Themen/Energie/Konventionelle-Energietraeger/gas.html [04.11.2015].

BMWi – Bundesministerium für Wirtschaft und Energie (2015a). Eine Zielarchitektur für die Energiewende: Von politischen Zielen bis zu Einzelmaßnahmen. http://www.bmwi.de/DE/Themen/Energie/Energiewende/zielarchitektur.html

BR – Bayerischer Rundfunk (2012). Der Biogas-Boom. Available online: http://www.br.de/themen/wissen/biomasse-maiswueste-alternativen100.html [04.11.2015].

BUND – Bund für Umwelt und Naturschutz e.V. (2008). Die elektrische Wärmepumpe: Eine verkappte Kohleheizung. Available online http://www.bund.net/fileadmin/bundnet/publikationen/klima/20080407_klima_elektrische_waermepumpe_klimafakten.pdf [04.11.2015].

BWP – Bundesverband Wärmepumpe e.V. (2014). Absatzzahlen 2013: Wärmepumpen-Markt trotzt hohen Strompreisen; Presseinformation vom 24.01.2014. Available online: http://www.waermepumpe.de/presse/pressemitteilungen/details/details/absatzzahlen-2013-waermepumpen-markt-trotzt-hohen-strompreisen/ [04.11.2015].

Capital (2015). Die Pro-Kopf-Wohnfläche wird sinken. Available online: http://www.capital.de/immobilien/die-pro-kopf-wohnflaeche-wird-sinken.html [04.11.2015].

Darby, S. (2006). The Effectiveness of Feedback on Energy Consumption: A Review for Defra of the Literature on Metering, Billing and Direct Displays. Environmental Change Institute, University of Oxford. Oxford.

Darby, S. (2010). Smart metering: what potential for householder engagement?. In: *Building Research & Information*, 38(5), p. 442-457. Available online: http://www.biblioite.ethz.ch/downloads/Smart-meter-alone-saves-little_Darby_2010.pdf [04.11.2015].

Dena – Deutsche Energieagentur (2012). Energiewende im Gebäudebereich – Herausforderungen und Chancen bei energieeffizienten Bauen und Sanieren, Berlin. Available online: http://www.dena.de/fileadmin/user_upload/Veranstaltungen/Vortraege_GF/sk/Energiewende_im_Gebaeudebereich_-_Herausforderungen_und_Chancen_bei_energieeffizientem_Bauen_und_Sanieren.pdf [04.11.2015].

Dena – Deutsche Energieagentur (2013). Die Hauswende – Strategien für mehr Schwung bei der energetischen Gebäudesanierung. Available online: http://www.dena.de/fileadmin/user_upload/Veranstaltungen/Vortraege_GF/sk/130820_SK_Viessmann_Energieforum_Allendorf_Die_Hauswende.pdf [04.11.2015].

Destatis – Deutsches Statistisches Bundesamt (2010). Bauen und Wohnen. Mikrozensus-Zusatzerhebung 2010, Bestand und Struktur der Wohneinheiten, Wohnsituation der Haushalte. Available online: https://www.destatis.de/DE/Publikationen/Thematisch/EinkommenKonsumLebensbedingungen/Wohnen/WohnsituationHaushalte2055001109004.pdf?__blob=publicationFile [04.11.2015].

Destatis – Deutsches Statistisches Bundesamt (2013). Wohnen und Haushalte. Available online: https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/EinkommenKonsumLebensbedingungen/Wohnen/Wohnen.html [04.11.2015].

Deutscher Mieterbund (2014). Zahlen, Daten Fakten. Link: http://www.mieterbund.de/startseite.html [15.04.2015].

Echternacht, L. & Berg, H. (2015). A multi-level perspective of the German heat domain – Findings from in-depth research on landscape, regime and niche interactions. Wuppertal.

Eicke-Henning, W. (2011). Kleine Geschichte der Dämmung - „Erster Teil“. Available online: http://www.energiesparaktion.de/downloads/Kacheln/Energieeinsparung/Geschichte_Daemmung.pdf [04.11.2015].

EnEV – Energieeinsparverordnung (2014). Kurzinfo für die Praxis. Available online: http://service.enev-online.de/bestellen/EnEV_2014_Neue_Energieeinsparverordnung_Kurzinfo_Praxis.pdf [04.11.2015].

Eriksson, O., Finnveden, G., Ekvall, T., & Björklund, A. (2007). Life cycle assessment of fuels for district heating: A comparison of waste incineration, biomass-and natural gas combustion. In: *Energy Policy*, 35(2), p. 1346-1362. Amsterdam.

Ernst & Young (2013). Kosten-Nutzen-Analyse für einen flächendeckenden Einsatz intelligenter Zähler. Endbericht zur Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie (BMWi). Available online: https://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/Studien/kosten-nutzen-analyse-fuer-flaechendeckenden-einsatz-intelligenterzaehler,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf [04.11.2015].

EU – European Union (2009). DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast). Available online: http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0125 [04.11.2015].

EU – European Union (2010). RICHTLINIE 2010/30/EU DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 19. Mai 2010 über die Angabe des Verbrauchs an Energie und anderen Ressourcen durch energieverbrauchsrelevante Produkte mittels einheitlicher Etiketten und Produktinformationen (Neufassung). Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0001:0012:DE:PDF [04.11.2015].

Faruqui, A., Sergici, S., & Sharif, A. (2010). The impact of informational feedback on energy consumption—A survey of the experimental evidence. In: *Energy*, 35(4), p. 1598–1608. Available online: doi:10.1016/j.enpol.2012.03.027 [04.11.2015].

FIW – Forschungsinstitut für Wärmeschutz e.V. (2013). Technologien und Techniken zur Verbesserung der Energieeffizienz von Gebäuden durch Wärmedämmstoffe – Metastudie. Available online: http://www.fiw-muenchen.de/metastudie_waermedaemmstoffe.php [04.11.2015].

FNR – Fachagentur Nachwachsende Rohstoffe e.V. (2014). Bioenergy in Germany: Facts and Figures. Available online: http://mediathek.fnr.de/bioenergy-in-germany-facts-and-figures.html [04.11.2015].

Galvin, R. (2013). Warum deutsche Hauseigentümer ungern energetisch sanieren. Aachen.

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31 (8/9), 1257–1274.

Geels, F. & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. In: *Technology In Society*, 29, p. 441-455. Eindhoven.

Hargreaves, T., Nye, M., & Burgess, J. (2013). Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. In: *Energy Policy*, 52, p. 126–134. Available online: doi:10.1016/j.enpol.2012.03.027 [04.11.2015].

HuG – Haus und Grund (2014). Energetische Modernisierungen lohnen sich für Hauseigentümer nur selten. Haus & Grund: Energiepolitische Ziele korrigieren Available online: http://www.haus-und-grund.net/presse_971.html [04.11.2015].

IWO – Institut für Wärme und Öltechnik (2015). Warum die Deutschen ihre Ölheizung schätzen, Available online: https://www.zukunftsheizen.de/fileadmin/user_upload/5_Service/5.3_raffiniert/Fachmagazin/PDF/raffiniert_IWO_Fachmagazin_1_2015.pdf [04.11.2015].

IWU – Institut Wohnen und Umwelt GmbH (2013). Monitoring der KfW-Programme „Energieeffizient Sanieren“ und „Energieeffizient Bauen“ 2012. https://www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-alle-Evaluationen/Monitoring-EBS-2012.pdf [04.11.2015].

KfW – Kreditanstalt für Wiederaufbau (2013). Deutschland profitiert von der Energiewende, Pressemitteilung 19.03.2013. Available online: https://www.kfw.de/KfW-Konzern/Newsroom/Aktuelles/Pressemitteilungen/Pressemitteilungen-Details_63488.html [04.11.2015].

Knaack, J. (2014). Telephone interview with Jan Knaack (26 June 2014); Senior Projekt Manager Internationales und Forschung, BSW Solar.

Lettenmeier, M., Liedtke, C., & Rohn, H. (2014). A production-and consumption-oriented reference framework for low resource household consumption—Perspective for sustainable transformation processes of lifestyles. In: *Resources*, *3*, p. 488-515.

Liedtke, C., Baedeker, C., Hasselkuß, M., Rohn, H., & Grinewitschus, V. (2014). User-integrated innovation in Sustainable LivingLabs: An experimental infrastructure for researching and developing sustainable product service systems. In: *Journal of Cleaner Production*. Available online: doi:10.1016/j.jclepro.2014.04.070 [04.11.2015].

Matthes, F., Gores, S., Harthan, R., Mohr, L., Penninger, G., Markewitz, P., ... & Ziesing, H. J. (2009). Politikszenarien für den Klimaschutz V–auf dem Weg zum Strukturwandel. Treibhausgas-Emissionsszenarien bis zum Jahr 2030. Climate Change Report, 16, 2009. Available online: http://www.isi.fraunhofer.de/isi-wAssets/docs/e/de/publikationen/politikszenarien-V_Langfassung.pdf [04.11.2015].

Presseportal (2013). BDH: Verbot für Ölkessel torpediert Energiewende. Available online: http://www.presseportal.de/pm/63532/2544430/bdh-verbot-fuer-oelkessel-torpediert-energiewende [04.11.2015].

Scabell, C., Echternacht, L., Reckhaus, H., Manirjo, N. & Berg, H. (2015). Regime analysis of stability and tensions in incumbent socio-technical regimes. Country Report 4: The German heat domain. Wuppertal. Available online: www.pathways-project.eu.

Schröder, M., Ekins, P., Power, A., Zulauf, M. & Lowe, R. (2011). The KfW Experience in the Reduction of Energy Use in and CO2 Reduction from Buildings: Operation, Impacts and Lessons for the UK. Available online: http://sticerd.lse.ac.uk/dps/case/cp/KfWFullReport.pdf [04.11.2015].

Schüwer, D., Arnold, K., Dienst, C., Lechtenböhmer, S., Merten, F., Fischedick, M., Supersberger, N. & Zeiss, C. (2010). Erdgas: Die Brücke ins regenerative Zeitalter, Bewertung des Energieträgers Erdgas und seine Importabhängigkeit, Hintergrundbericht im Auftrag der Greepeace Deutschland e.V. Endbericht. Available online: http://epub.wupperinst.org/frontdoor/index/index/docId/3536 [04.11.2015].

Statista (2014). CO2-Ausstoß nach Heizsystem. Available online: http://de.statista.com/statistik/daten/studie/165421/umfrage/co2-ausstoss-nach-heizsystem-in-deutschland/ [04.11.2015].

Statista (2015). Wärmemarkt in Deutschland – Statista-Dossier. Hamburg.

The Guardian (2013). Will smart meters really help homeowners save energy? Available online: http://www.theguardian.com/environment/blog/2013/jun/28/smart-meters-homeowners-save-energy [04.11.2015].

Thema, J., Nanning, S., Buhl, J., Götz, T., Adisorn, T., Kurth, J., Manirjo, N., Echternacht, L., Berg, H. (2015). Analysis of momentum of green niche innovations – Country report 4: German heat niches. Available online: www.pathways-project.eu [04.11.2015].

UBA – Umweltbundesamt (2006). Energie aus Abfall. Ein bedeutender Beitrag zum Klimaschutz. Dokumentation des Workshops.

Wünsch, M., Klotz, E. M., Koepp, M., & Steudle, G. (2013). Maßnahmen zur nachhaltigen Integration von Systemen zur gekoppelten Strom-und Wärmebereitstellung in das neue Energieversorgungssystem. Available online: http://www.prognos.com/fileadmin/pdf/publikationsdatenbank/130719_Prognos_BDEW_AGFW_Studie_KWK-Studie.pdf [04.11.2015].