PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

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Country report 5: the UK heating system

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Executive summary

The purpose of this document is to make an interpretive assessment of the feasibility of sustainability transitions pathways within the UK heating domain *today*, with reference to ideal pathways A and B, as part of PATHWAYS D2.3, and in accordance with the protocol agreed by all project partners. This document builds on the analysis of niche innovations and of regime stability in UK heating, as presented in Deliverables D2.1 and D2.2 respectively.

We first provide an overview of the main task at hand, with particular reference to the heating domain in the UK.

The bulk of the document is concerned with assessing the 'breakthrough feasibility' of specific niche-innovations. This is mainly done with attention to a multi-dimensional understanding and evaluation of niche momentum-in-context, and in relation to the identification of specific opportunities presenting themselves at regime level. Given these evaluations of niche progress, we seek explanation as to the main barriers, mismatches, or misalignment with sustainability transitions dynamics in the heating domain (see Table 1).

Table 1: Breakthrough potential analysis of 6 niche-innovations in the heat domain in the UK

Niche innovation	Internal momentum	Alignment with broader regime characteristics and developments	Likelihood of imminent breakthrough (and/or future potential)	Pathway A or B (or mixed)
Small biomass	Very low and limited market pocket	Low alignment: - off supply grid not challenging for housing - no policy ambition	Low / unlikely	B
District heating	Very low Potential for **high momentum** in future	Low/Moderate: - technical and socio-cognitive misalignment - but included in future policy visions	Currently low but High if policy ambitions are implemented	B with elements of A
Heat pumps	Very low Potential for **high momentum** in future	Moderate: - no major technical or policy incompatibility (except need for interaction with electricity regime) - prominent inclusion in future heat vision	Currently low but potentially high if policy ambitions are implemented	B
Solar thermal	Low and limited market pocket	Moderate alignment: - off supply grid - additional quality limits conflict but reduces overall potential	Moderate but quantitatively limited: housing regime not showing signs of preparedness for large-scale adoption	B

Low energy retrofits	Very low but large potential market	Very low, due to misalignments with housing regime: - infrastructure lock-in (old building stock) - technical difficulties and lack of skills - rigid building regulations - lack of incentives	Currently very low. Long-term breakthrough *possible* if rules were fundamentally re-adjusted, but currently not visible in the short- to medium-term.	A with elements of B
Smart heating controls and meters	Moderate	High. Strong alignment (framed as win-win for supply and demand energy savings): - technically unchallenging - socio-cognitive alignment with supply - policy support	High. Only doubt is maintaining budget for planned rollout. Unclear that this would lead to significant environmental impact reductions.	A but could enable B

We then assess current and foreseeable regime dynamics, with specific attention to the kinds of regime reorientation activities and strategies that can be observed in both the heating and housing sub-domains (see Table 2). This leads us to further specifying the scale of the transition challenge ahead.

Table 2: Assessment of regime trends in the heat domain in the UK (with indicative 'scores')

	Lock-in, stabilizing forces	**Cracks, tensions, problems in regime**	**Orientation towards environmental problems**	**Main socio-technical regime problems**
Heating	Moderate	Moderate	Moderate (incremental change towards efficiency improvements; promising new heat strategy)	Lack of skills and capabilities Scale of challenge not recognised
Housing	Strong	Weak/Moderate	Weak (piecemeal insulation; no consistent plan although efficiency gains expected under heat strategy)	Infrastructure inertia (building stock) Lack of skills, and incentives

The **heating regime** is fairly stable in particular due to strong infrastructural lock-in (gas grid / housing stock), the concentration of powerful actors on the (energy) supply side, the captivity and relative lack of awareness on the demand side (consumers), and a tendency for business as usual in the equipment installation and maintenance trade. However, this stability does not seem to be strongly related to active resistance strategies, which is hopeful for future change.

There are major tensions ahead for the heating regime, potentially developing towards a high degree of alignment (energy security and price stability, climate concerns, emergence of credible alternatives elsewhere). The current heating arrangement, relying on an increasing proportion of imported gas is thus seen as unsustainable in the long run. There are some signs of willingness to make strategic decisions and commitments on the policy side (although the credibility and durability of such discourse remains questionable). There are however substantial sources of uncertainty regarding current political ambitions to stimulate a transformation in this domain.

The **housing regime** in the UK is characterised by strong inertia, which is predominantly related to infrastructural elements such as the building stock, but is also translated in low consumer interest, and unpreparedness of the construction sector. The sources of inertia are mainly structural, rather than the fruit of active resistance strategies.

The scope for change in terms of cracks and tensions is currently relatively low, and unlikely to counterbalance the current stability. A number of early changes in social mobilisation, awareness raising with respect to energy efficiency, and the development of the Heat Strategy are however signs that the current situation could be changing.

We conclude by evaluating the foreseeable fate of niche-innovations, their potential for contributing to transitions dynamics (and qualification thereof), and reflecting on transitions dynamics in heating in the UK.

The importance of implementing large-scale changes in the heating regime is progressively being recognised. The UK has recently shown ambitious commitments for a transition to low-carbon heat, including an anticipated full decarbonisation of residential heat by 2050. There are however a number of challenges and barriers for reaching its goals. A particularly inefficient and slow moving building stock and a generally poor track record with low carbon heat are two challenges to be named. Nevertheless, if these commitments are taken seriously and hence the necessary steps implemented sincerely (e.g. effective roll-out of efficiency measures, a virtual replacement of all gas boilers with heat pumps, and support for District Heating (DH)), vast opportunities can open up for the development of a sustainable heat industry. However, a history of ‘changing moods’ in UK energy policy and the failure to guarantee long-term stable conditions for low carbon solutions raises further doubts as to the feasibility of the current ambitious strategic objectives for heat.

In sum, there are currently signs of the beginnings of a reorientation of heating towards decarbonisation, and related ambitious plans. There is, however, a rather concerning lack of preparedness on tangible dimensions, as well as substantial novel uncertainties at governance and policy levels that point towards more of the same (in fact with less movement towards decarbonisation). So, the current heating (and housing) regime is pursuing a business-as-usual strategy, with no strong or long-term commitments to decarbonisation in practice, despite the identification of a number of opportunities with only moderate barriers in the future.

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1 Introduction

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Section 2 is concerned with assessing the 'breakthrough feasibility' of specific niche-innovations. This is mainly done with attention to a multi-dimensional understanding and evaluation of niche momentum-in-context, and in relation to the identification of specific opportunities presenting themselves at regime level. Given these evaluations of niche progress, we seek explanation as to the main barriers, mismatches, or misalignment with sustainability transitions dynamics in the heating domain.

In section 3, we assess current and foreseeable regime dynamics, with specific attention to the kinds of regime reorientation activities and strategies that can be observed. This leads us to further specifying the scale of the transition challenge ahead.

We conclude by evaluating the foreseeable fate of niche-innovations, their potential for contributing to transitions dynamics (and qualification thereof), and reflecting on transitions dynamics in heating in the UK.

2 'Breakthrough feasibility' of niche-innovations

The analysis presented in this section is structured around the niche-innovations presented in D2.1, and seeks to address three main **research questions**:

1) What is the internal momentum of the niche-innovation
2) How does the niche-innovation align with wider regime and landscape developments?
3) What us the current feasibility of a breakthrough of the niche-innovation?

We analyse the following six niche-innovations:

- Small biomass
- District heating
- Heat pumps
- Solar thermal
- Low energy retrofits
- Smart heating controls and meters

2.1 <u>Small biomass</u>

2.1.1 Niche momentum

Techno-economic momentum. Small-scale biomass heating relies on relatively mature technology. However, the UK market is poorly developed, with penetration restricted to a small market pocket off-grid housing and with few British manufacturers and suppliers involved. Most technological development has not taken place in the UK, but rather in Scandinavia, where advances in combustion knowledge and technology developed for large-scale applications has been subsequently applied at smaller scales. The widespread availability of electronic controls and the development of markets for advanced combustion equipment have made miniaturisation possible and economical.

Socio-cognitive momentum. Micro-generation technologies require 'active' social acceptance of technologies, which is a particularly important hurdle in the case of heat technologies, given the current low public visibility and interest in heat. Reluctance to changeover to biomass technology, particularly if implying increased effort and potentially reduced convenience, is an important socio-cultural barrier to its development. On the other hand, the existing market for biomass or multi-fuel heating (in off gas network rural areas) is unlikely to resist changeover to more efficient and less polluting technologies if the economics are right.

Governance and policy momentum. Historically, there has been a relatively low level of support for biomass heat in the UK. The 2005 Biomass Task Force, the 2007 UK Biomass Strategy and the 2012 UK Bioenergy Strategy mostly focused on the potential of biomass in large-scale applications such as power generation and biofuels for transport. An important concern relates to the availability of sustainable sources of biomass. Heat has only recently become more than a marginal policy focus, with main policy emphasis set on medium- to large-scale developments that have greater promises for decarbonisation. Additionally, the poor development of local markets and low presence of manufacturers have not contributed to making small-scale domestic biomass heat market a policy priority. Recent pressure for change in the heat domain has led to the introduction of the Renewable Heat Incentive (RHI), and its subsequent application to the domestic sector, which provides financial support for the purchase of boilers and stoves. However, recent alleged scaling back of green heating subsidies indicates that the current policy climate is not offering the kinds of regulatory stability required for niche development.

Overall momentum. In sum, niche momentum is **very low** in the UK, despite a relatively mature technology, and small but stable off-grid market pockets.

2.1.2 Alignment with regime and landscape developments

Techno-economic dimension. Small biomass heating evolves outside the prevailing heating regime (off grid), but does not necessarily present a major challenge to the housing regime. It requires specific investments in supply chains (appliances and fuel). It is possible to envisage upcoming issues with fuel sourcing in the case of a large-scale diffusion scenario.

Socio-cognitive dimension. Small biomass heating does not present much departure from conventional individual heating habits, besides the additional maintenance and fuel certification required.

Governance and policy dimension. There is a lack of policy commitment and long-term signals to develop the necessary industry, consumer base, and supply chain. Small biomass is also notably virtually absent from government roadmaps and official discourse (with the exception of marginal pockets or back-up heating).

2.1.3 Feasibility of breakthrough

The breakthrough of small biomass heating in the UK is unlikely, as momentum is low and contained (lack of niche support, marginal pockets outside of regime), without signs of change, and a highly entrenched regime that is discursively looking elsewhere for future options.

2.2 <u>District heating</u>

2.2.1 Niche momentum

Techno-economic momentum. The UK market for heat networks is currently poorly developed. Early developments up to the 1980s were not followed through due to the availability of cheap natural gas and the generalisation of individual boilers. There are currently signs that the UK may be entering a new expansion phase, as climate change and energy security concerns are leading local authorities to seek for cheaper and more sustainable sources of heat, particularly for council housing and public utility buildings. The successful deployment of DH (in combination with CHP) in countries such as Sweden or Germany have proven that this mature technology can be perfectly functional in the appropriate context and lead to substantial energy efficiencies benefiting local network users. The UK context is however characterised by institutional, regulatory, infrastructural and market barriers to DH development. It is proving tremendously difficult to develop DH systems in the UK, and only highly enthusiastic local authorities seem to be succeeding in securing long-term commitments, thanks to a combination of technical and political skills (Bolton and Foxon 2015).

Socio-cognitive momentum. The British public is generally unfamiliar with DH, simply because it is very poorly developed. However, where it has been installed, DH has been generally received positively, although there has been some dissatisfaction with inefficient systems in the 1990s – namely due to the lack of user control on temperatures and heating patterns. One could expect some resistance stemming from the general cultural inclination towards private property in the UK – since DH is in essence a communal form of heating. Important consumer benefits of DH systems include the externalisation of heat provision and management, and affordable cost and long-term price stability. DH is nonetheless criticised for the control exerted by monopolist providers.

Considering the systemic nature of DH, technological legitimacy and credibility aspects are more crucial at the level of the main decision-makers involved in system building and operations: potential system operators and managers, municipalities (public) building administrators. Their preferences are shaped by anxieties about technological reliability, mutual trust and commitments, etc. Given the lack of dedicated regulations, institutional structures, and the lack of information about DH schemes, building legitimacy at local level has proved challenging so far in the UK.

Governance and policy momentum. DH is not yet the object of specific regulation (Hawkey 2012), but rather falls under broader umbrellas such as renewable energy, low carbon transition, and recently low carbon heat policy – but also electricity market regulations constraints in the predominant case of CHP. Similarly, public funding for DH schemes has so far been possible via non-specialised grants and subsidies.

However, DH's systemic particularities (infrastructure-intensive, need for coordination across jurisdictions, etc.) may warrant the erection of dedicated 'rules of the game' – namely overcoming the fact that it is currently "caught in the squeezed middle ground between greater efforts at large-scale national infrastructure investment on the supply side, and individual householder incentives on the demand side" (Hawkey et al 2013:29) – to support a breakthrough. Indeed, strong government involvement in the coordination of actors has been significant for the successful diffusion of district heating in Scandinavia (Summerton 1992).

Despite numerous difficulties and barriers, there are signs of growing interest of local authorities in the development of DH schemes, especially since the introduction of greater forms of functional and financial autonomy under the Local Government (2000) and Sustainable Communities Acts (2007). These pioneering local authorities are generating innovative organisational forms and can provide an important source of momentum for future developments.

Overall momentum. In sum, niche momentum is **currently very low**, with multiple institutional, regulatory, infrastructural and market barriers. However, there is **potential for substantial momentum in the future**, provided a constructive business/regulatory frame is set up to enable growing interest from local actors.

2.2.2 Alignment with regime and landscape developments

Techno-economic dimension. There is a substantial mismatch with dominant heating infrastructures, as DH requires (relatively heavy and costly) heat network infrastructure, essentially a decentralised centralisation of heat production and distribution.

In terms of the heating regime, DH is thus misaligned with a system based on individual appliances (as DH in turn is based on central heat production, distributed through a local heat network), and tends to make most sense in conjunction with alternatives energy sources (e.g. CHP, biomass, waste). However, power generation regulation raises further barriers for CHP-DH in the UK.

In terms of housing regime, DH calls for important retrofitting investments in terms of heat network installation.

Socio-cognitive dimension. There is a socio-cognitive mismatch between on the one hand an innovation that is about a collective decentralised approach to heating that is sustainable in the long-term but requires upfront investment and continuous commitment, and a heating (and more generally energy) regime that is based on individualism, short-termism, and disposability.

However, DH is highly compatible with growing concerns about energy security and independence, sustainability, and local territorial autonomy.

Governance and policy dimension. There has been only little commitment at national level to generate a frame conducive to the development of DH (e.g. dedicated regulation, standards, long-term funding, coordination, etc.), for local implementation. Recent support in the scope of the Heat Strategy however provides hope that existing barriers may eventually be lifted, although there are currently no visible signs of progress on this front.

2.2.3 Feasibility of breakthrough

Overall feasibility of breakthrough. Currently low, due to a lack of momentum, and stability of current regime (despite some symbolic discourse about change and investment).

Critically, what is needed to support the eventuality of breakthrough is the development of business models and institutional forms that reward long-term infrastructure commitments. For the DH market to develop in the UK, it is important to facilitate the multiplication of initiatives by local authorities, which could in turn strengthen knowledge networks, skills and supply chains (Hawkey 2012), leading to greater momentum and legitimation. For the greater diffusion of DH networks, it is also necessary to break the mould of the established preference for individual systems. While there seems to be a desire to develop such schemes, efforts should now focus on developing fitting models than can promote and support the large-scale diffusion of decentralised options.

2.3 Heat pumps

2.3.1 Niche momentum

Techno-economic momentum. Heat pump technology is considered mature, but there is not much experience in the UK. The current market for heat pumps in the UK is fairly small and "far from becoming mainstream" (Fritsch 2011:6). Indeed, there is no huge market interest besides marginal off-grid pockets. Commercial distribution and promotion networks are poorly developed, and there is a lack of installation expertise on the ground.

There are however high expectations about their future deployment. Within UK heating policy, heat pumps are seen as the main long-term option for domestic heating, especially from 2030 and onwards (while 'hybrid gas boilers are to be the dominant option for the transitional phase between 2020 and 2040) (RESOM projections in DECC 2013:78).

The deployment of heat pumps in the UK is likely to be dependent on the decarbonisation of the electricity system and efficiency improvements in the housing sector, without which they do not offer substantial environmental or economic benefits. These domain interlinkages are crucial determinants of future success.

Socio-cognitive momentum. There is a lack of exposure and understating of heat pumps among key actors of the building sector, "including developers, customers, policy makers, and building regulations legislators and authorities" (Pan and Cooper 2011:624), which means that most relevant practitioners "would not normally consider them in preference to dominant conventional heating systems" (Roy and Caird 2013:16). These supply-side deficiencies are a threat to the desirability of the technology. Only a limited number of proactive consumers are familiar with heat pumps, which are perceived as quite complicated and new. There is generally a lack of interest and awareness of heat pumps as compared to other renewable heat sources. Greater information, marketing and communication could go a long way towards addressing these deficiencies.

Governance and policy momentum. The UK government is keen on supporting the development of heat pumps for domestic heating, and the underlying industry. The Microgeneration Strategy explicitly supported heat pumps and called for more integrated research and development. DECC has been undertaking field trials to gather greater information on the performance of domestic heat pumps and possible improvements (DECC 2013). More recently, the RHI has put a strong emphasis on supporting heat pumps through financial means. The Microgeneration Certification Scheme provides guidance and certification of heat pump performance on a star-based system, as a basis for renewable tariffs calculation. Official forecasts of low carbon heat transitions assign an important role to heat pumps, as the RHI is expected to lead to an additional 100,000 heat pumps by 2020 (DECC 2011). However, recent alleged scaling back of green heating subsidies indicates that the current policy climate is not offering the kinds of regulatory stability required for niche development.

Overall momentum. In sum, niche momentum is **currently very low**, despite a relatively mature technology. There are high hopes pinned on the rollout of HPs in future heat decarbonisation roadmaps, so there is ground for substantial future momentum, although there are currently no visible signs of progress on this front.

2.3.2 Alignment with regime and landscape developments

Techno-economic dimension. Current niche activities are going on outside of the dominant heating regime, in off-grid pockets. Massive rollout of heat pumps would require consideration of interactions with the electricity regime, and related load management issues. This may be a positive aspect, as power generation is currently the domain that is most likely headed towards decarbonisation. Furthermore, while this would most likely call for a readjustment of supply chains, the substitution of electricity for gas is likely to remain compatible with a business model determined by the concentration of energy supply and distribution in the hands of a few powerful actors (which happen to be the same). Alternatively, there are visions of heat pumps associated with more decentralised self-generation of electricity that may prove more challenging and less aligned with the dominant regime.

Socio-cognitive dimension. Heat pumps are relatively aligned with current attitudes to heating, as they are individual heating devices that do not require much user involvement in their daily operation. Their substitution character makes them less potentially challenging for consumers, although currently exposure is very low.

Governance and policy dimension. HPs do not present major policy or regulatory challenges other than the need for innovation support in the development of markets, standards, and supply chains. However, potential interactions with electricity regimes should be seriously considered ahead of a substantial deployment.

2.3.3 Feasibility of breakthrough

The feasibility of HP breakthrough in the UK is currently low, due to lack of momentum. However, given that this mature technology is relatively aligned with heat supply and use regime, and that it figures prominently on future policy roadmaps, barriers for future rollout are not too high.

2.4 <u>Solar thermal</u>

2.4.1 Niche momentum

Techno-economic momentum. Residential solar thermal (water) heating technology is a relatively mature proposition, with well-developed markets in specific European countries, widespread availability of basic systems, as well as promising innovation avenues. Solar thermal technology has evolved from a very basic system widely spread around the globe (particularly energy poor countries). Modern SWH are quite sophisticated, integrating advanced materials in rooftop collectors, modern plumbing and piping components, and advanced electronic controls. In terms of skills base, solar thermal heating relies on pre-existing skills, including rooftop installation experience developed within the PV industry, and more standard heating and plumbing capabilities. Thanks to its development elsewhere, small-scale solar thermal technology also benefits from some degree of standardisation (e.g. size, etc.). In the UK, however, the market is fairly small, mainly restricted to off-grid houses.

Socio-cognitive momentum. Solar thermal systems are the most popular micro-heat option in the UK (albeit making up a tiny market). They benefit from a good reputation as they are seen as less risky and cheaper than alternatives (Roy et al 2008). Their relative simplicity and adaptability to existing systems also constitute major advantages. Solar thermal options benefit from much greater awareness, as “83% of homeowners had heard of solar thermal; 47% had heard of ground source heat pumps and biomass boilers; and 32% had heard of air source heat pumps” (DECC 2013:44). Public support to and interest in solar thermal is relatively low when compared to for instance heat pumps, although its supporting role is acknowledged. Paradoxically, consumers are more familiar with solar thermal technology than with any other renewable heat technology.

Governance and policy momentum. Solar thermal water heating is amongst the renewable heating options selected to be eligible for the domestic RHI. Under the dRHI, the owner of a solar thermal water heating system is offered an end-user tariff at a rate of £0.192/kWh for seven years, under a number of conditions: new builds are excluded (except in the case of self-built), the level of insulation should meet the Green Deal Assessment requirements, and installers should be certified from MCS. There are high expectations that the RHI will act as a market booster in a similar fashion as the feed-in tariffs have supported solar PV sales. However, recent alleged scaling back of green heating subsidies indicates that the current policy climate is not offering the kinds of regulatory stability required for niche development.

Overall momentum. In sum, niche momentum is **low**, despite a relatively mature technology, and marginal market penetration. While it is an interesting additional source of renewable heat (particularly hot water), there are no indications that it has the potential for massive rollout to substitute for domestic heat demand in the UK.

2.4.2 Alignment with regime and landscape developments

Techno-economic dimension. Solar thermal (water) heating has proved possible as an additional (water) heating supply option, particularly in off-grid locations. The low likelihood that solar thermal will become a substitute for individual gas heating (the dominant technological option) makes this option perhaps less of a threat. So, in a way, the perceived technical (and market) marginality of this heating option vs the dominant regime contributes to reducing foreseeable mis-alignments.

In terms of the housing regime, this option seems less relevant for rented properties and shared ownership (e.g. apartments), with the exception of housing estates.

Socio-cognitive dimension. Solar thermal heating is by-and-large perceived as an additional source of renewable heat (particularly hot water). In that sense, it is does not present much departure from conventional individual heating habits, besides small technical adjustments.

Governance and policy dimension. Solar thermal is not a highly visible heating option from a policy perspective, and so does not figure prominently in government roadmaps and official discourse.

2.4.3 Feasibility of breakthrough

Overall feasibility of breakthrough. The feasibility of solar heating in the UK is limited in terms of overall contribution to heating (due to a capped market pocket consisting of off-grid or additional water heating). So, a massive (substitution) breakthrough is highly unlikely, due to inherent technology limitations.

However, in terms of breaking through within its limited market boundaries (off-grid, and additional water heating for individual houses), this may be more likely, though momentum is currently low, incentive structure not pointing in the right direction. The housing regime is not showing signs of preparedness for large-scale adoption, although this may not necessarily be seen as a threat to individual activities (e.g. construction sector, etc).

2.5 Low energy retrofits

2.5.1 Niche momentum

Techno-economic momentum. There could be a large *potential* market for low energy retrofits in the UK, because British homes are on average old and poorly insulated. In terms of innovation, energy efficient retrofits rely on a number of proven techniques (insulation, glazing, ventilation) that have matured over the last decades, and have been deployed successfully elsewhere (e.g. Sweden, Finland, Germany, etc.).

However, the market for high performance retrofits is poorly developed in the UK. A number of publicly funded demonstrations are accumulating experimental knowledge on the ground. Important barriers to deployment include costs, building regulations (e.g. conservation requirements), a lack of skills and knowledge in the building industry, and poor material supply, which are unlikely to be overcome through markets alone.

Socio-cognitive momentum. There are major barriers to energy efficiency refurbishment (costs, disruption, uncertainties about return on investment in terms of reduced bills, etc.), but also a lack of appeal as compared to other consumer options, which means that it is not a priority for most individuals. In the case of rented properties, there is also an absence of incentives for landlords to pay for refurbishments that will pay off through reductions of the tenant's bills (split incentives dilemma). A number of organisations promote the development of low energy skills in the building sector. There are a number of information sources about low emission retrofitting standards and practice. Under the Green Deal, a form of supply and installation certification has been introduced, to ensure a proper evaluation of the contractors performing the funded installations.

Governance and policy momentum. While ambitious targets have been formulated for new buildings, retrofits remain largely voluntary, with some targeted funding programmes dedicated to priority action such as the poorest housing. A number of funding mechanisms have been introduced in relation to targeted energy efficiency improvements in homes. The Carbon Emissions Reduction Target (CERT), running from 2008 to 2011, obliged large energy suppliers to reduce carbon emissions in the household sector, leading to nearly 4 million loft insulations, 2.6 million cavity wall insulations and the distribution of DIY loft insulation materials to nearly 3 million households. The Community Energy Saving Programme (CESP), running from 2009 to 2012, targeted energy efficiency improvements in buildings with a community approach (e.g. whole house, or street). Around 100 community schemes were funded through an obligation on energy suppliers, leading to improvements in around 90,000 homes (Dowson et al 2012). Specific initiatives have been targeted at more vulnerable heat users: 'Decent homes' and 'Warm front' have targeted fuel poverty and offered support to energy efficiency measures in the worst performing public sector and private dwellings, respectively.

Currently, the Green Deal Home Improvement Fund, launched in 2014, is set up to address the main economic barrier to retrofits: upfront costs. Its finance mechanism displaces upfront costs by spreading them over time. Private sector consortia may fund the capital costs of energy efficiency improvements, and get their returns from installments on the consumers' energy bills. It has been criticised as targeting the low hanging fruits made up by the easiest retrofits, and it is not clear how less cost-efficient retrofits will be funded in order to meet the targets. However, recent alleged scaling back of green heating subsidies indicates that the current policy climate is not offering the kinds of regulatory stability required for niche development.

Overall momentum. In sum, niche momentum is **very low**, despite proven techniques, and in the face of infrastructure, knowledge and supply chain barriers.

However, there is a large potential for economies of scale, supply chain and skills development if substantial demand could be generated, through e.g. mandatory performance requirements on *existing* buildings. This means that if substantial momentum were to be created by lowering the barriers, the long-term potential for breakthrough could be high.

2.5.2 Alignment with regime and landscape developments

Techno-economic dimension. Low-energy retrofits are currently misaligned with current building renovation practices (tendency for piecemeal, non-systemic approaches), skills, supply-chains, and standards, but besides these major shortcomings, no major conflict of interests in the long-term (and indeed potential for construction sector growth if barriers were lowered). Furthermore, there are important market issues related to building stock (old), housing ownership structures and the principal-agent problem for rented properties.

Socio-cognitive dimension. There is a long way to go in the UK to get a sector (supply) and market (customers) interested in long-term economic gains from energy savings through thermal improvement.

Governance and policy dimension. Low-energy retrofitting is misaligned with current building regulations, and incentives for heat improvement investment (mostly short-term and piecemeal).

The emphasis on low-efficiency standards for new builds has qualities of a policy 'smokescreen' distracting attention away from practical difficulties with retrofits and the virtual inexistence of performance standards for old existing buildings.

2.5.3 Feasibility of breakthrough

Overall feasibility of breakthrough. Long-term breakthrough of low-energy retrofitting in the UK is *possible*, but currently not expected in the short- to medium-term, due to very low momentum, a number of barriers, and no visibility as to how these would be lifted (despite a strong reliance on heat efficiency improvements for decarbonisation roadmaps in the short to medium term). Regime stability and inertia play a strong role, but in a rather passive form embedded in infrastructures (rather than enacted through active resistance).

2.6 <u>Smart heating controls and meters</u>

2.6.1 Niche momentum

Techno-economic momentum. There are important plans to deploy smart meters and the supporting data and communication infrastructure in the UK, in parallel to other similar initiatives worldwide. These plans promise the rapid materialisation of visions of smarter energy delivery and use network, which could tap into latent domestic energy savings where other behavioural measures have failed. The innovation challenge of smart metering and controls resides in widespread rollout and effective management, rather than on the technical issues related to specific components.

In terms of initial momentum, the national plans are highly promising, and represent a massive infrastructure investment that should materialise over the next 7 years. However, the current accumulation of delays in starting the programme raises concerns as to its management and the likelihood of delivering the promises on time (by 2020) without further disappointment or qualitative setback. In terms of transition pathways, the current smart meter rollout plan is highly compatible with the existing regime and led by incumbent actors.

Socio-cognitive momentum. Smart energy metering has attracted substantial support, most importantly from energy utilities, facing important potential gains in efficiency and data access crucial to more efficient operations and 'grid' management. While consumer benefits remain questionable, effective smart meter rollout is likely to enable further innovation and market opportunities for ICT-based products and services. This means that once kick-started, smart metering may accelerate and gain momentum quite rapidly.

The main consumer issues with smart heating controls and meters relate to privacy and surveillance, device usability, and user involvement and consultation. Privacy has come to the fore of public debate as a consequence of the multiplication of scandals and data protection failures by public and private organisations. The prospective development of smart homes questions the ability of system managers to protect personal data on individual behaviours in homes, with concerns related to privacy, fraud, criminal data use, and malicious remote control of domestic technologies.

Usability of controls is crucial. Users who do not understand heating controls are less likely to operate their systems properly. Standardisation and interoperability are important, but also one bear trade-offs with privacy. Consumer interest in heating controls is low (Consumer Focus 2012). The effectiveness of feedback devices in influencing heating practices may be limited, particularly because one simply cannot assume the householder to be a 'micro-resource manager' responding to information feedback (Pullinger et al 2014). Improvements in this direction might be enabled by more interactive interfaces and designs that encourage user engagement with the technology. Energy management applications could open the way to greater user involvement and interest through the introduction of playful interaction.

Governance and policy momentum. Heating controls have not historically been a high profile policy issue, but rather one for regulations and standards. Minimum standards for heating controls in new buildings and new boiler installations are to be found in National Building Regulations. Central Heating System Specifications have been issued by the Energy Saving Trust, presenting basic and best practice for heating controls.

A Government proposal for smart meter rollout was published in 2010. Following a consultation in 2011. The scale of this programme is impressive and unprecedented, as it seeks the installation of 53 million devices by 2020. The Smart Meter Implementation Programme (SMI) has been criticised as being mainly producer-led in its composition, which is in contrast with the 'consumer' focus of its aims (Pullinger et al 2014). Furthermore, energy suppliers will be able to pass on the cost of rollout to consumers but are unlikely to do so for the benefits (e.g. savings on meter reading, etc.)□(Connor et al 2014). Other contentious issues about the rollout include its cost, questionable effectiveness, and the liberal mobilisation of external expertise through costly consultancy contracts.

In terms of implementation, the original intention was to initiate mass rollout mid-2014, and set an obligation on suppliers to provide in-home displays. This main installation stage has been pushed back, due to lack of preparedness. In November 2014, however, it was proposed to delay the start of the programme by another year, to October 2016, because of problems on DCC's part to deliver the data and communication system on time.

Overall momentum. In sum, niche momentum is **moderate**. Despite a relatively poorly developed market, there appears to be strong policy support that is likely to act as a push for ambitious rollout (though this is proving slower than planned).

2.6.2 Alignment with regime and landscape developments

Techno-economic dimension. Smart metering is strongly aligned with the heating and housing regime, as meters promise a win-win situation for energy savings on both the supply and demand side. Metering technology can be seen as an incremental information-based add-on to existing systems, It does not call for any changes of the current regime besides its organisational adaptation to this new layer of information.

Socio-cognitive dimension. Smart metering is fully aligned with supply-side cognitive rules, towards greater control (seen as enabling efficiency improvements). There is scope for controversy on the demand side, around issues related to privacy and surveillance, device usability, and user involvement and consultation in design.

Governance and policy dimension. There is currently strong policy support for smart metering, and no major foreseeable misalignment with governance structures or policy style. There is also surprisingly little vocal resistance from the public, civil society or consumers.

2.6.3 Feasibility of breakthrough

Overall feasibility of breakthrough. The feasibility of breakthrough of smart heat metering is high (particularly with reference with current policy plans), as a result of moderate momentum and strong alignment with regime. However, in terms of effectiveness and contribution to decarbonisation objectives, there is little evidence that a massive rollout of smart heat meters will lead to corresponding efficiency improvements in practice.

2.7 Breakthrough potential analysis

In this section, we provide an assessment of potential for breakthrough for each niche-innovation, based on the consideration of niche momentum and (mis-)alignment with regime, as discussed above. The results are presented in Table 3, which also tries to assess momentum by using a rating.

Table 3: Breakthrough potential analysis of 6 niche-innovations in the heat domain in the UK

Niche innovation	Internal momentum	Alignment with broader regime characteristics and developments	Likelihood of imminent breakthrough (and/or future potential)	Pathway A or B (or mixed)
Small biomass	Very low and limited market pocket	Low alignment: - off supply grid not challenging for housing - no policy ambition	Low / unlikely	B
District heating	Very low Potential for **high momentum** in future	Low/Moderate: - technical and socio-cognitive misalignment - but included in future policy visions	Currently low but high if policy ambitions are implemented	B with elements of A

Heat pumps	Very low Potential for **high momentum** in future	Moderate: - no major technical or policy incompatibility (except need for interaction with electricity regime) - prominent inclusion in future heat vision	Currently low but potentially high if policy ambitions are implemented	B
Solar thermal	Low and limited market pocket	Moderate alignment: - off supply grid - additional quality limits conflict but reduces overall potential	Moderate but quantitatively limited: housing regime not showing signs of preparedness for large-scale adoption	B
Low energy retrofits	Very low but large potential market	Very low, due to misalignments with housing regime: - infrastructure lock-in (old building stock) - technical difficulties and lack of skills - rigid building regulations - lack of incentives	Currently very low. Long-term breakthrough *possible* if rules were fundamentally re-adjusted, but currently not visible in the short- to medium-term.	A with elements of B
Smart heating controls and meters	Moderate	High. Strong alignment (framed as win-win for supply and demand energy savings): - technically unchallenging - socio-cognitive alignment with supply - policy support	High. Only doubt is maintaining budget for planned rollout. Unclear that this would lead to significant environmental impact reductions.	A but could enable B

3 Assessment of regime reorientation

3.1 Current trends

3.1.1 Trends in the individual (gas-based) heating regime in the UK

The heating regime is fairly stable in particular due to strong infrastructural lock-in (gas grid / housing stock), the concentration of powerful actors on the supply side, the captivity and relative lack of awareness on the demand side (consumers), and a tendency for business as usual in the equipment installation and maintenance trade. However, this stability does not seem to be strongly related to active resistance strategies, which is hopeful for future change

There are major tensions ahead for the heating regime, potentially developing towards a high degree of alignment (energy security and price stability, climate concerns, emergence of credible alternatives elsewhere). The current heating arrangement, relying on an increasing proportion of imported gas is seen as unsustainable in the long run. There are some signs of willingness to make strategic decisions and commitments on the policy side (although the credibility and durability of such discourse remains questionable). There are however substantial sources of uncertainty regarding current ambitions to stimulate a transformation in this domain.

The distribution of fuels used for domestic space heating in the UK has been relatively stable for the past 20 years (Figure 1). This section reviews developments of the main tangible system elements, the main social groups and intangible regime elements, and their positioning vis-à-vis landscape changes.

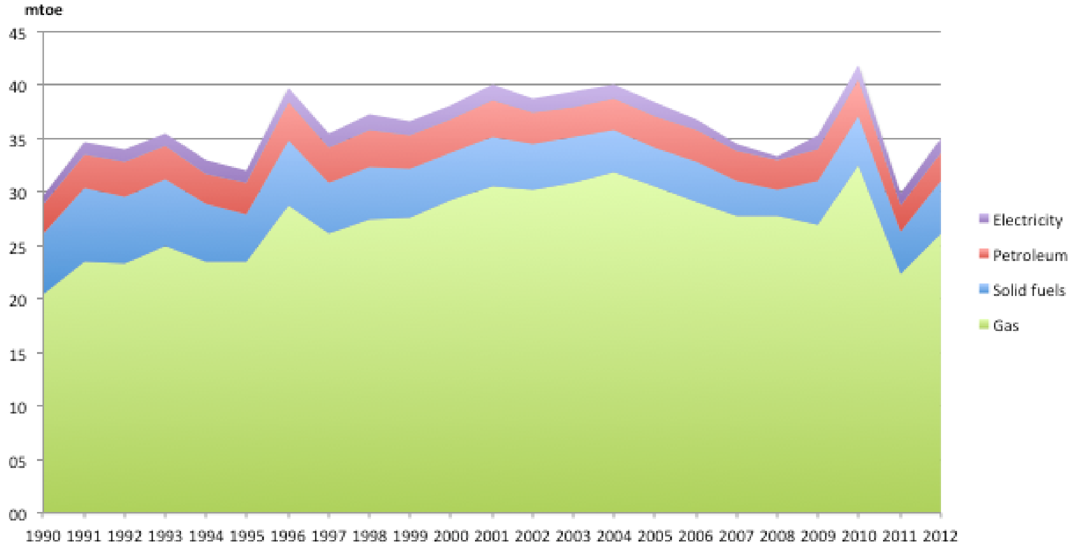

Figure 1: Space heating in UK households by fuel source, in primary energy equivalents (1990-2012). (Source: DUKES 2013)

Technology and markets. The technological system around individual (gas-based) heating is characterised by substantial inertia linked to commitments to a specific fuel (gas) in given appliances (gas boilers), and a stable and wide-ranging distribution infrastructure (gas grid). Despite inherent stability, the heating regime in the UK is also showing some early signs of change. Recent trends and developments point to the increasing recognition of external pressures and challenges, with greater attention to environmental issues, renewable heat options, experimentation with decentralised heat production and distribution, and the development of a dedicated heat policy strategy.

The current heating regime has marginally adapted to efficiency issues through performance improvements: the massive uptake of central heating from the 1960s to the mid-2000s, and the diffusion of more effective heating systems (combi boilers from the mid-1980s and condensing combi boilers from 2000). The gas boiler installation market is relatively stable, in the absence of major challenging alternatives, and so can be seen as determined by capital stock replacement rates. However, the current government plans, under the Heat Strategy (2013), suggest a very rapid phasing out of existing gas boilers, set to virtually disappear by 2030. Meeting such projections practically rules out any new installation of gas boilers past 2018, which is difficult to envision under present circumstances (Eyre and Baruah 2015).

The market is further characterised by a number of trends, including:

- greater user control and performance management (of which efficiency savings are difficult to evaluate)
- diversification of gas supply, energy security and price concerns
- high sunk costs in infrastructure, suggesting a strong role for the National Grid in a potential endogenous renewal pathway

Actors and institutions. The heating regime is stabilised by actors, initiatives and institutions that contribute to existing lock-in. These include powerful actors and their strategies to retain business models unchanged, the current lack of capabilities and skills to support innovative change, and the lack of awareness and expertise of individual heat operators. While there are a few central actors with concentrated power (e.g. the National Grid, the 'Big Six' gas suppliers), this domain is also characterised by highly decentralised agency as heat is currently predominantly produced on site of use (individual boilers). This means that any change is likely to involve individual heat users and heating equipment installers. Currently, these more distributed actors are characterised by little awareness and interest (something that the Energy Saving Trust is working hard to change), as well as a lack of preparedness to engage on a sustainable heat transformation of the scale that is called for.

Current heating habits are mainly determined by installation specifications and routines, so users are relatively passive, while the adoption of renewable micro-generation technology also requires an 'active' form of social acceptance by individuals (Sauter and Watson 2007). Given the current infancy of the renewable heat market in the UK, there are important barriers to renewable technology adoption, namely in terms of supporting necessary new skills and capabilities. The lack of specialised installers (i.e. skilled and accredited) is a foreseeable issue that will slow down change even in the case of significant consumer interest, acceptability and market demand.

Policy. The heat domain, although long overlooked, is increasingly becoming the focus of carbon emission reductions, which is manifest in the recently published Heat Strategy (DECC 2012, DECC 2013). While gas fares relatively well with respect to environmental performance compared to its historical alternatives (coal, petrol), substantial improvements in the past decades are challenging that position. Low-carbon heat policy can be seen as linked to climate targets and dedicated support to renewable energy technologies.

The development of heat-specific low-carbon policy is a very recent phenomenon in the UK, with strategies for the future of heating being published only in 2012 and in 2013 (DECC 2012, DECC 2013). This strategic policy framework stakes out major heat challenges and areas of priority focus. In the residential sector, the policy suggests a 3-tier strategy: a) expansion of heat networks in urban areas, b) expansion of renewable heat in remote, off-gas grid areas, and c) heating efficiency improvements throughout the building stock. In the Government's vision, the early years (up until 2020) shall be spent reaping the low hanging fruits (e.g. energy efficiency improvements) and preparing the market and supply chains for the roll out of renewable heat, initially penetrating over the 2020-40 in an initial hybridisation (with heat pumps) on the way to full electrification (Chaudry et al. 2014).[1] The widespread penetration of renewable heat technologies is only expected during the 2020s and 2030s (DECC 2013).

The historic lack of commitment to heat policy in the UK may be changing. However, the current Renewable Heat Incentive (RHI) is a long way away from a stable long-term frame for low-carbon heat, and is criticised for lacking ambition and commitment. When supporting technological niches, there is a clear need for policy stability, especially in terms of incentives as they can provide price and market stability. However, there are concerns that frequent renewable energy policy change in the UK has led to a great deal of instability and the reluctance of customers and investors to commit financial resources in the context of uncertain pay-back times (Williams 2010).

3.1.2 Trends in the housing regime

The housing regime in the UK is characterised by strong inertia, which is predominantly related to infrastructural elements such as the housing stock, but is also translated in low consumer interest, and unpreparedness of the construction sector. The sources of inertia are mainly structural, rather than the fruit of active resistance strategies.

The scope for change in terms of crack and tensions is currently relatively low, and unlikely to counterbalance the current stability. A number of early changes in social mobilisation, awareness raising with respect to energy efficiency, and the development of the Heat Strategy are however signs that the current situation could be changing.

Technology and market. The British housing stock is relatively mature and poorly insulated, which means that low energy retrofits are crucial to meet carbon reduction targets. Millions of British houses have poorly insulated solid walls, single glazed windows, and other sources of waste heat. The existing building stock is “by far the biggest challenge for housing and energy policy” in the UK (Boardman 2007:41). The overall poor state of housing conditions in the UK is not restricted to energy performance and insulation as an estimated 20% of all English homes does not meet the ‘Decent Homes’ standard, this figure rising to nearly 30% when considering only privately rented homes (DCLG 2015:53-6). There are over 20 million dwellings in the UK. Around 80% of the current building stock will still be in use by 2050 (Dowson et al. 2012). Despite some improvement over the last decade, most English houses have deceptively low energy performance, with over 80% of dwellings corresponding to Energy Efficiency Rating bands D or lower. To some extent, the current housing regime has adapted to some of the pressures it is facing through the diffusion of basic insulation options and thermal performance improvements. In a European comparative perspective, these improvements are not very impressive.

Actors and institutions. The UK construction sector lacks coordination between the different actors involved. The construction process is characterised by “largely separate operations undertaken by individual designers, constructors and suppliers who have no stake in the long term success of the product and no commitment to it” (Egan 2002:13). Energy efficient retrofitting remains a specialised niche with a small number of specialised architecture and engineering firms. There is a need for skills and supply chain improvements in the building industry. This involves measures such as improved training, professionalisation, and greater standard requirements. Programmes stimulating demand

[1] It is important to note that for the electrification of heat puts pressure on the development of low-carbon power generation, and cannot be taken for granted.

could also be crucial to support the development of a low-carbon refurbishments industry.

There is a certain degree of inertia attributable to building owners as “there are numerous, cost-effective measures that could be installed in many, if not most, houses, but the building owners are not putting them in” (Boardman 2007:41). Furthermore, until recently, energy efficiency improvements have been by-and-large the initiative of building owners with only limited government support. Of all types of occupancy, private tenancies (nearly 20% of the UK housing stock) tend to offer the least motives for efficiency refurbishments due to the principal-agent problem (it is the tenant, not the landlord, who would reap the benefits of investment), and the market structure, which does not value energy performance.

On the other hand, there is also evidence of the emergence of ‘greener’ homeowners that engage with lower carbon construction or refurbishment, aware of the environmental benefits, the potential financial savings from energy efficiency improvements, and the different kinds of financial incentives that can be sought. Energy efficient refurbishing is a growing market, though nowhere as dynamic as the Heat Strategy would require it to be.

Policy. Energy performance policies in the UK building sector include regulations and targeted financial instruments and rollout programmes. Energy Performance Certificates (EPC) have been introduced in the UK in 2007, and rate a building’s performance via and Energy Efficiency Rating (EER) from G to A+++. Eyre (2010) suggests that energy efficiency regulations in the UK have been successful in focusing and structuring improvements in specific product markets (appliances, insulation, etc.) but less so in the main trades involved (e.g. construction, builders, etc.). Regulations in the building sector (e.g. constraints on alterations that can be done on listed buildings) can also be seen as a major barrier to efficiency improvements, further contributing to inertia in the building stock (Royal Academy of Engineering 2012). The Low Carbon Building Programme (LCBP) grant, running from 2006 to 2010, counts as one of the early financial incentives supporting home energy efficiency refurbishments. In terms of energy efficiency, the Green Deal, introduced in January 2013, was intended as a broad programme to encourage energy efficient home improvements across the country, offering loans for refurbishments loans with the opportunity to pay them back through savings on bills. Following energy efficiency assessments, and eligibility checks, funding is made available via the Green Deal Home Improvement Fund. The policy scheme has been heavily criticised and received far less interest than expected in its first years. Core criticisms include the unfair nature of the scheme benefitting only well-off middle-class homeowners, the high interest rates and penalties it introduces, the uneven quality of assessments, and the fact that the company managing certification is owned by the Big Six, hence reproducing existing power structures in the energy sector.

So, all in all, recent trends in decarbonisation of the UK building sector are not very encouraging at all, characterised by substantial sources of inertia (infrastructure, supply industry, demand, policy), and no demonstration of a willingness to introduce substantial change measures.

3.1.3 Assessment of regime trends

In this section, we summarise findings concerning regime trends (in Table 4), before discussing regime reorientation potentials ahead.

Table 4: Assessment of regime trends in the heat domain in the UK (with indicative ‘scores’)

	Lock-in, stabilizing forces	Cracks, tensions, problems in regime	Orientation towards environmental problems	Main socio-technical regime

				problems
Heating	Moderate	Moderate	Moderate (incremental change towards efficiency improvements; promising new heat strategy)	Lack of skills and capabilities Scale of challenge not recognised
Buidling	Strong	Weak/Moderate	Weak (piecemeal insulation; no consistent plan although efficiency gains expected under heat strategy)	Infrastructure inertia (building stock) Lack of skills, and incentives

3.2 Potential for reorientation – brand new visions for a newly uncovered domain for decarbonisation

Towards a renewable heat strategy? The UK Government has ambitions to fully reconfigure the heat supply system through 1) encouraging energy efficiency in buildings, and 2) moving towards low carbon heat with an overwhelming reliance on the electrification of heat via heat pumps (see **Figure 2** for an indication of the kinds of technological scenarios put forward). While the feasibility of such ambitious plans to be delivered is questionable, it is becoming increasingly clear that reaching the legally binding targets of 80% GHG emission reductions by 2050 is "incompatible with retaining a residential heating sector with anything like the current structure" (Eyre and Baruah 2015:2).

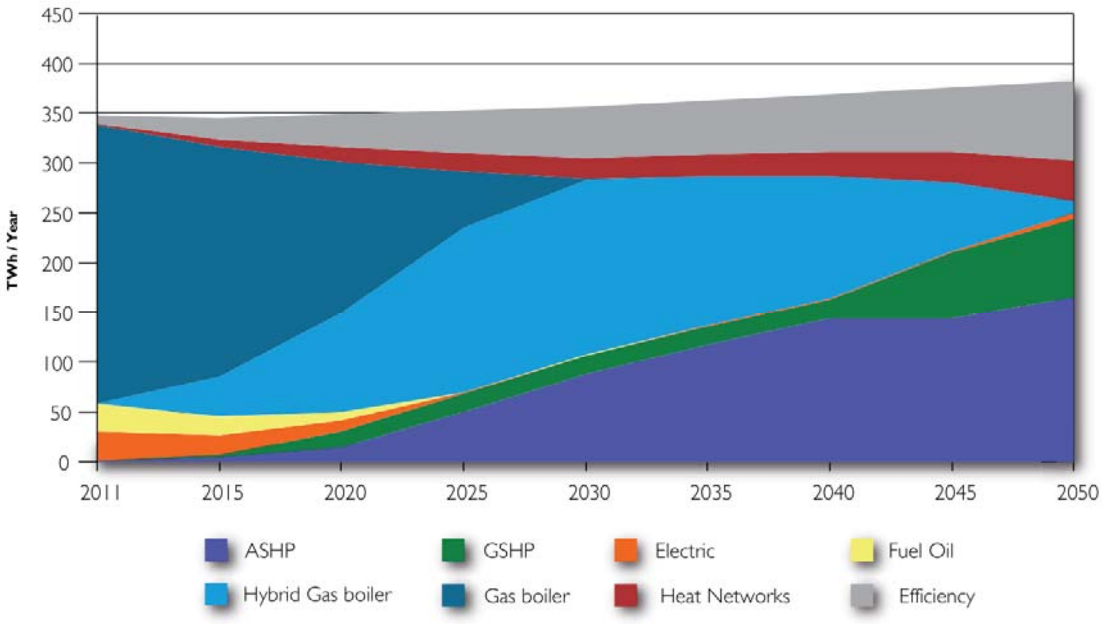

Figure 2: Domestic space heat and hot water output by technology, RESOM core run. (Source: DECC 2013:78)

Decarbonisation objectives and commitments are substantial in the UK, but there is great uncertainty as to the means and modalities for the required transformation of the heating domain. Within the Heat Strategy, the ambition is a full transition to heat pumps and district heating by 2050 (Figure 3), with the most part to be implemented by 2030 (**Figure 2**). Indeed, the Heat Strategy (DECC 2013) relies on 80% of residential heat requirements to be met by heat pumps by 2050.

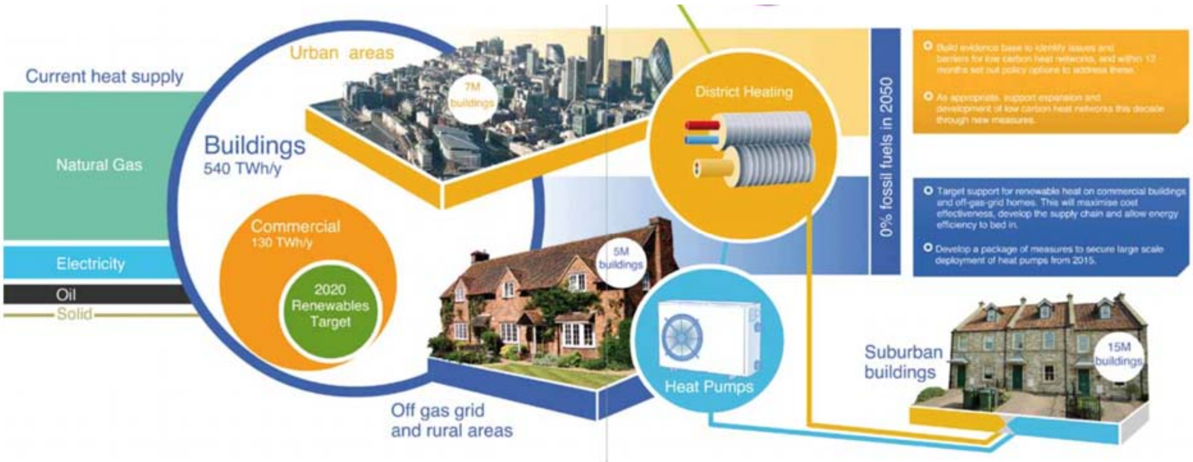

Figure 3: Domestic aspects of the heat decarbonisation strategy to 2050 (Source: DECC 2012)

However, the evidence of developments on the ground is pointing to a deep feasibility disconnect between policy ambitions and their materialisation. The Committee on Climate Change (CCC), although one of most fervent advocates of the 'all-electric' solution in 2008 (Bolton 2011), has underlined the slow progress to date (particularly with heat pumps) in its 4th Carbon budget review (CCC 2013), which has led it to revise its projections:

> "We have revised our assumptions about heat pump uptake down from 7 million installations in 2030 (meeting 143 TWh of heat demand) to 4 million (72 TWh). This is partly offset by an assumed increase in penetration of district heating (up from 2% (10 TWh) to 6% (30 TWh) in 2030" (CCC 2013:74)

These revisions have led to lower emission reduction predictions within the residential sector, down to 38% by 2030 on 1990 levels, with a significant contribution from low-carbon heat (around two thirds) and lesser contribution of energy efficiency (around one third).

Development of renewable heat options. While renewable heat is developing fast in some European countries (see other case studies in PATHWAYS D2.1 and D2.2), the UK Government recognises that the development of a mass market for low carbon heat is unlikely before 2020 (HM Government 2011:42). Most of its short-term carbon reduction potential is derived from the phase-out of dirtier heating systems. There are, however, high hopes to generate the conditions for a breakthrough of micro-generation heat technology and related expectations of positive market spillovers into new trade and skills base, leading to "new installer jobs, and upskilling of existing jobs as existing gas installers cross-train" (DECC 2013:74). Figure 4 displays the recent market uptake of renewable heat technology in the UK, which is on the rise, but remains very small when compared to the 700 TWh yearly heat consumption in the UK. With regards to domestic heat consumption in particular, biomass seems to be the only substantial market existing to date. Solar thermal and heat pumps are making shy early contributions (see also PATHWAYS D2.1).

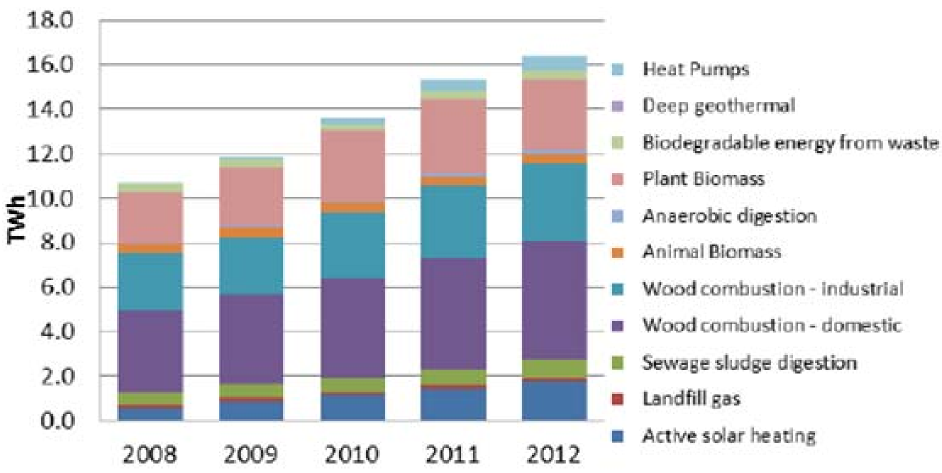

Figure 4: Annual Renewable heat consumption (Source: DECC, 2013:64)

So, in the UK, renewable heat is struggling to generate significant momentum (see PATHWAYS D2.1 for a detailed analysis, and section 2 of this document). Meanwhile, it is developing quite steadily in a number of other European countries (Germany, Sweden, Austria, etc.), which causes both emerging competitive pressure as well as a potential for future adaptation (if new technologies, skills, and infrastructure can be absorbed).

National Grid perspective. According to the National Grid's business plan, "the utilisation of gas will remain an efficient approach to space heating, particularly during winter peak demand".[2] National Grid projections foresee a gradual reduction of gas consumption for residential heating in two major steps: an initial reduction from 2020 to 2035 due to energy efficiency improvements, followed by a more pronounced reduction with the mainstream introduction of heat pumps from 2035 to 2050 (**Figure 5**).

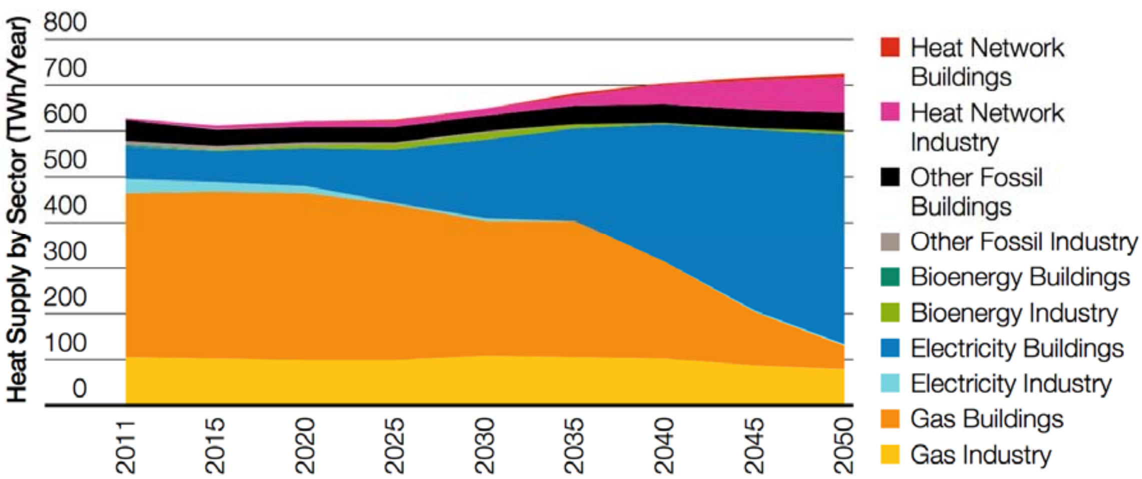

Figure 5: UK Heat Supply projections to 2050 by sector (Source: National Grid 2013:37)

Perhaps not surprisingly, the National Grid – which also has interests in the distribution of electricity – supports a gradual move to heat pumps:

> "In our projections heat pumps are initially concentrated in houses not connected to the gas grid, encouraged by government policy to electrify heat through the RHI, the Renewable Heat Premium

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2 www.talkingnetworkstx.com

> Payment (RHPP) incentive scheme, the high price of non-gas fuels and the Green Deal / ECO. The next tranche of heat pumps are installed in new houses with their better insulation and lower heat demand fuelled by changes in building regulations i.e. path to zero carbon homes by 2016. Finally heat pumps enter the mainstream heating market for houses on the gas network (assuming cost benefit) as economies of scale reduce heat pump installation and unit costs to levels similar to gas boilers today" (National Grid 2013:34)

In sum, low carbon heat is a very novel issue on the UK policy agenda. There are high hopes for decarbonisation, backed by ambitious policy visions. However, the reality on the ground is far from promising, with very little progress to date. On the up side, a renewable heat industry has built up internationally, providing a number of options to be implemented in the UK that may also be seen as attracting co-benefits in terms of job creation, etc. The main challenge for low carbon heat in the UK is to generate the conditions for the uptake of effective solutions. This calls for a rethinking of heat governance, including responsibilities and incentive structures for low-carbon heating, building regulations, as well as the support of skills and capabilities in the installation and maintenance of low-carbon heating systems, and the consideration of options to limit heat demand.

Unfortunately, most signals are pointing in the wrong direction, and the promise of heat strategy and underlying coherence to long-term objectives is lacking in credibility. The heat strategy is currently disconnected from the required change on the ground.

4 Conclusions and wider discussion

4.1 Few niches have a strong breakthrough potential

The UK heating regime is characterised by strong inertia ('grid-locked' individual gas heating and old/inadaptable building stock) and limited space for the development of alternatives due to a lack of commitment to decarbonisation. This means that only smart metering (the least challenging option, facing few barriers and requiring little commitment) has currently a high breakthrough potential. However, even in this case, there are substantial uncertainties as to the materialisation of rollout plans in practice. Furthermore, the expected carbon reduction benefits are questionable.

The recent announcement of heat decarbonisation plans under the heat strategy (DECC 2013) is presenting a more optimistic future outlook, with important expectations about the role of efficiency in buildings,[3] district heating and heat pumps. In this context, it is likely that heat pumps may have a strong potential to break through in the future, as they are relatively well aligned with the current heating regime. District heating, however, presents greater difficulties. At any rate, none of these options are currently well developed in the UK and would require substantial niche support.

Additionally, these policy announcements are to be taken with a grain of salt, for two main reasons: 1) a poor track record of supporting low-carbon options in the UK, and 2) recent cuts in low carbon innovation support that may have irreversibly damaged the prospects for low-carbon investment by further reducing the expectations of long-term commitment.

4.2 What kinds of transition pathways

So, assuming that smart metering currently enjoys high breakthrough potential, and that heat pumps and district heating are likely to enjoy high breakthrough potential in the future (in line with policy documents), what of the respective transition pathways ahead?

- Smart heating controls and meters have many elements of a Pathway A development insofar as they aim to tap into a latent energy saving potential, and are mainly driven by established energy utilities as a means to improve and balance their supply and distribution system through data-driven management at grid-level, etc. However, smart metering is inscribed in larger visions of smart energy systems for which it arguably may provide the infrastructure enabling all sorts of Pathway B type developments.
- Heat pumps are much more difficult to categorise. They have elements of a Pathway B development, as they rest on fundamentally different technical principles (heat transfer rather than combustion), are likely to involve dedicated actors and skills (installation, construction, etc.). However, in their present configuration, heat pumps are heavily reliant on large-scale centralised electricity supply and distribution network, and depend on decarbonisation in that domain.
- District heating has many elements of a Pathway B development as it implies a shift in mentality towards collective energy provision, and requires substantial new

[3] This is perhaps one of the better performing areas of low carbon heat in the UK, with substantial improvements in the energy performance of new builds, but has not been considered in the frame of this analysis as it plays only a small role compared to the relative inertia of the housing stock.

infrastructure investments in heat networks, involving new actors (and skills) coalescing around new business models allowing commitment to investments with long lead times. However, it also has elements of a Pathway A development insofar as it is compatible with large-scale stationary heat production (albeit with local distribution) and the involvement of large energy suppliers. Importantly, the low-carbon nature of DH is not straightforward, and inherently linked to decarbonisation in the electricity sector.

4.3 Wider discussion

The importance of implementing large-scale changes in the heat regime is progressively being recognised. The UK has recently shown ambitious commitments for a transition to a low-carbon heat regime, including an anticipated full decarbonisation of residential heat by 2050. There are however a number of challenges and barriers for reaching its goals. A particularly inefficient and slowly moving building stock and a generally poor track record with low carbon heat are two challenges to be named. Nevertheless, if these commitments are taken seriously and hence the necessary steps implemented sincerely (e.g. effective roll-out of efficiency measures, a virtual replacement of all gas boilers with heat pumps, and support for District Heating (DH)), vast opportunities can open up for the development of a sustainable heat industry. However, a history of 'changing moods' in UK energy policy and the failure to guarantee long-term stable conditions for low carbon solutions raises further doubts as to the feasibility of the current ambitious strategic objectives for heat.

So, in spite of a number of relatively mature options, a number of major hurdles stand in the way of progress towards low carbon systems and practices in the UK heating and housing domains. These concern socio-technical conditions, policy and governance, and their inter-linkages:

- Both sub-domains are characterised by strong degrees of infrastructural lock-in (high sunk costs in gas distribution grid and obduracy of associated heating practices, and old building stock complicating efficiency improvements), which can hardly be address by individuals alone but require a re-thinking of network architecture, and building regulations, as well as appropriate governance mechanism, financial resources, and incentive structures.
- There is currently no visibility as to the financial resources available to support new investment in the preferred options, whether this concerns collective infrastructure (e.g. DH), or individual heating solutions (e.g. electrification of heat, low-energy retrofits).
- There is currently little commitment to supporting the necessary new governance arrangements, regulations, and business models that can enable the development of low-carbon heat solutions in the UK (as they have been elsewhere). For instance, DH's systemic particularities (infrastructure-intensive, need for coordination across jurisdictions, etc.) warrant dedicated new 'rules of the game' to support a breakthrough, but pioneering municipalities currently receive very little support. What is needed is the development of business models and institutional forms that reward long-term infrastructure commitments. Strong government involvement in the coordination of such activities could be critical to success in this area.
- More generally, there seems to be an inability (or reluctance) of national policymakers to provide coherent long-term signals in terms of a coherent legal framework for motivated actors to engage in a low-carbon heat transition in the UK. National government support has so far been piecemeal and patchy. It has

predominantly focussed on zero- or low-cost options with contested decarbonisation benefits (e.g. smart metering), on marginal response to energy poverty, and highly contested individual investment incentives, but seems to shy away from those less straightforwardly popular or rapid-returns areas of action.

- Recent ambitious low-carbon heat rollout plans currently lack in credibility, as little attention seems to have been devoted to developing the conditions for their materialisation. This is conflated by a less than credible track record for creating stable and durable conditions for investment in low-carbon solutions. Indeed, the current low-carbon energy policy is characterised by little long-term consistency, and a tendency for mood swings, as illustrated by the recent scaling back of green heating subsidies (largely consistent with a similar U-turn with feed-in tariffs in the electricity domain). Although it has to be recognised that low-carbon heat is a relatively new policy area, trends observed in the electricity sector (where greater experience exist) are not inspiring much confidence in the ability for action to prevail over discourse.
- Perhaps most problematic, in addition to (and as a consequence of) the above obstacles, is that we are far from seeing the kinds of skills and capability developments, and supply-chain strengthening that will be necessary for a massive roll out low-carbon heating and efficiency measures called for. Ironically, this aspect could also be the greatest selling point for seriously engaging on a low-carbon heat transition: the prospects of economic co-benefits (job creation, innovative entrepreneurship, etc.).

In sum, there are currently signs of the beginnings of a reorientation of heating towards decarbonisation, and related ambitious plans. There is, however, a rather concerning lack of preparedness on tangible dimensions, as well as substantial novel uncertainties at governance and policy levels that point towards more of the same (in fact with less movement towards decarbonisation). So, the current heating (and housing) regime is pursuing a business-as-usual strategy, with no strong or long-term commitments to decarbonisation in practice, despite the identification of a number of opportunities with only moderate barriers in the future.

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