PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

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Deliverable D2.1: Analysis of green niche-innovations and their momentum in the two pathways

Country report 5: Green niche-innovations in the UK heat system

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Executive summary

The purpose of this document is to provide an analysis of promising niche-innovations in the heating domain in the United Kingdom, as part of PATHWAYS D2.1.

We first provide an overview of the prevailing heating domain in the UK, focussing specifically on domestic heating.

We then present a number of niche-innovations in this domain, and justify our choice for selecting 6 of them for analysis:

1. Small biomass
2. District heating
3. Heat pumps
4. Solar thermal
5. Low energy retrofits
6. Smart heating controls and meters

The remainder (and bulk) of the document presents the selected niche-innovations, and analyses their socio-technical characteristics (technical and system attributes, actors and organisational field, institutions and governance) before evaluating their potential in the frame of a prospective transition in the British domestic heating domain.

In a concluding section, we present a focussed analysis of the momentum of niche-innovations and how they fit to the PATHWAYS typology. The assessment of momentum for each niche-innovation, based on the consideration of innovation and market trajectory, supporting actors and networks, and policy and governance, is presented in a summary table. When assessing the degree of fit to current innovation trajectories to the ideal-types transition pathways A and B, ‘technical component substitution’ and ‘broader regime transformation’, we find a dominant leaning towards one of the ideal Pathways, but also some elements of the other.

The United Kingdom presents an interesting context for change in the heating domain as it lags so far behind other Western European countries in terms of efficiency and innovation. However, having only recently ‘discovered’ the issue, the UK is setting a number of ambitious commitments in the frame of its first Heat Strategy and may well pick up on technological innovation developed elsewhere if it manages to develop the necessary skills and markets.

Contents

1 Introduction

The purpose of this document is to provide an analysis of promising niche-innovations in the heating and cooling domain in the United Kingdom, as part of PATHWAYS D2.1, in accordance to the protocol agreed by all partners. We first provide an overview of the prevailing heating and cooling domain in the UK, focussing mainly on consumption and use in households. We then present a number of niche-innovations in this domain, and justify our choice for selecting 6 of them for analysis. The remainder (and bulk) of this document presents the selected niche-innovations, and analyses their socio-technical characteristics (technical and system attributes, actors and organisational field, institutions and governance) before evaluating their potential in the frame of a prospective transition in the UK heating and cooling domain.

Heating and cooling, unlike more concentrated energy forms such as electricity or fuels, tends to be diffuse. Because heat transfer is a dissipative process, heat is difficult to store or transport. Consequently, most current heating and cooling applications focus on point source conversion of stored energy to heat (appliances fuelled by a energy carriers such as gas or electricity), or heat transfer. The provision of heating and cooling services has tended to be highly decentralised, and to a lesser extent concentrated in localised networks. This makes heating a more complicated process to monitor and influence,[1] as the potential agents of change are highly distributed, inexpert, and poorly informed, rather than concentrated point sources run by technically skilled personnel (such as in electricity supply and distribution).

Heating demand follows seasonal patterns, with peak demand concentrated around a few winter weeks, and a much lower demand during the summer. In comparison to other European countries, the UK has a relatively high heating demand, and a very low demand for cooling (with natural ventilation being the main form of cooling), although there are indications that this may be changing with warmer weather conditions and changing preferences. Like electricity, heat demand varies considerably throughout the year and throughout the day, which means that the technical issue of balancing loads is a major consideration for overall system choices.

Unlike other forms of energy, heat has a relatively low policy salience. Only in recent years has heating become a policy focus in the UK, specifically in the frame of climate policy and housing policies, with a dedicated low carbon heat policy since 2011. Heating also has a relatively low socio-cultural visibility, although heating practices vary according to individual and collective preferences (e.g. comfort) that change over time and may present technological challenges (Chappells and Shove 2005). The low socio-cultural visibility of heating may be explained by the relative technical complexity and low experiential commensurability of technical choice related to heating. In the UK, because of the predominance of gas heating and rising fuel prices, heating has made its way in public debates mainly via issues of fuel poverty, energy security, and choice of supplier (following liberalisation).

Heating is one of the main energy uses in the UK. In 2012, heat represented 47,1% of total energy end use in the UK, a figure that rises to 77,5% when considering only static energy use (excluding transport) (DUKES 2013:1.07). This demand for heat is dominated by the residential sector (57%), with industry and services accounting respectively for 24% and 19%

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[1] Heating is also consequently difficult to trace from a statistical point of view. Household energy consumption by use is usually determined through modelling and estimation.

of total heat use (Figure 1). The substantial contribution to total energy use in the UK justifies looking at the residential sector.

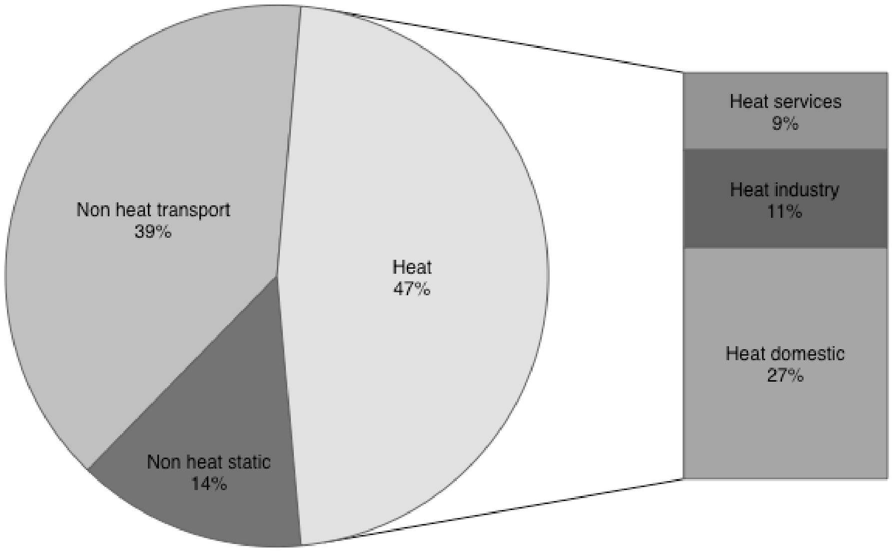

Figure 1: Heating contribution to energy consumption in the UK (2012) (Data: DUKES 2013)

Two main fuels largely dominate the heating domain in the UK: gas (71%) and electricity (15%). Household heat use is 80% gas-fired, 9% electric and 7% oil-fired (see Figure 2). The heating market represents an annual £32 billion yearly in the UK (DECC 2013a), which can make up to a substantial proportion of household costs, especially for poorer households. Heating is responsible for roughly a third of UK GHG emissions (DECC 2013a).

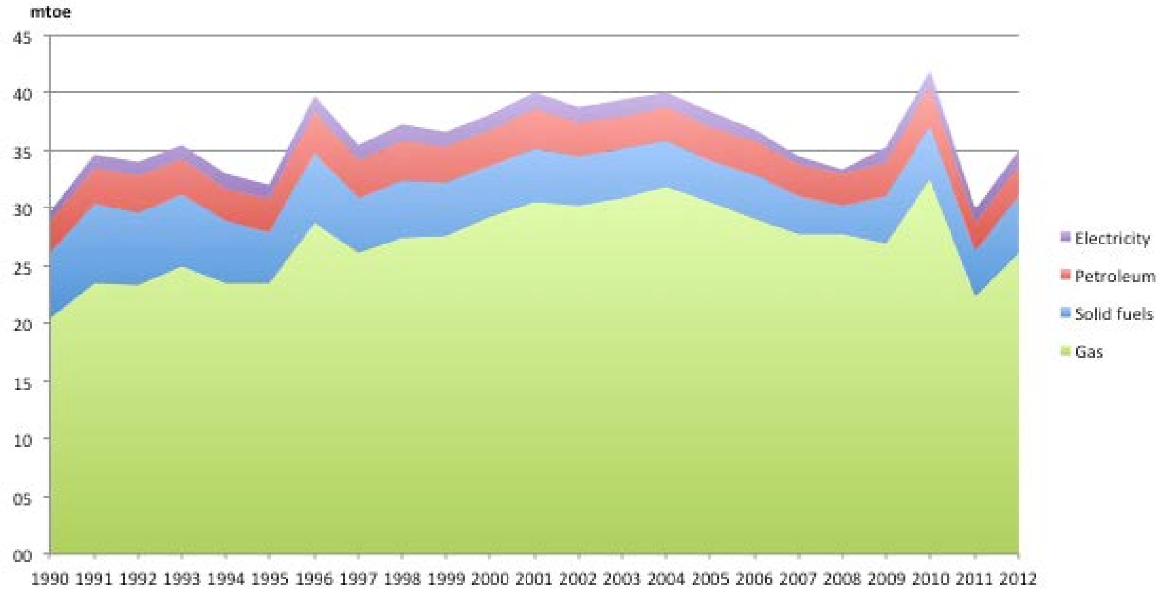

Figure 2: Space heating in UK households by fuel source (1990-2012) (Data: DUKES 2013)

In the UK, historically plentiful access to gas supply (first as a by-product of coal, and then from the North Sea) has resulted in a system relying mainly on gas, resting on a dense, centrally operated, piped gas network (see Figure 5). The UK domestic heating domain is largely dominated by natural gas boilers, with a low penetration of both heat networks and renewables heat. This market has also seen a rapid expansion of central heating systems, installed in 90% of homes (DECC 2013a), and the move to condensing and combi-boilers.

While central heating comes with an increasing potential for control (and related potential efficiency gains), thermostats for individual rooms are not commonly in use in the UK. It has also been observed that the penetration of central heating in the UK has been accompanied by a rise in internal temperatures.

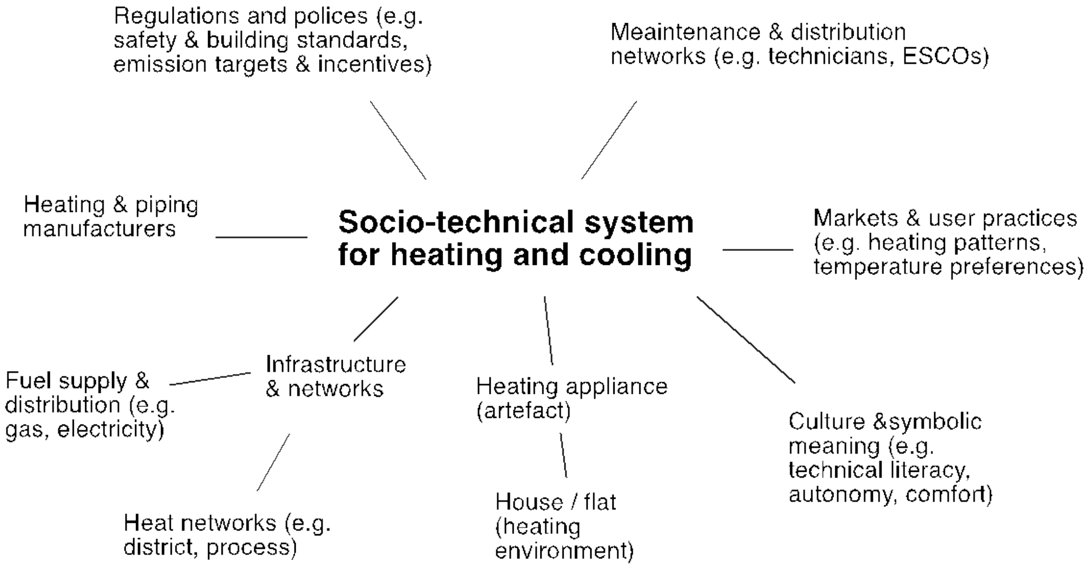

Figure 3: Schematic representation of ideal elements of a socio-technical system for heating

Figure 3 provides a rough sketch of the main components of a socio-technical system for heating in the UK, focussing mainly on domestic heating. The system is made up primarily of technical artefacts (appliance and housing), supply and distribution infrastructure (fuel and heat), manufacturing and services (system installation, maintenance, servicing, etc.), but also socio-political elements (regulations and policies, markets and practices, cultural and symbolic attributes).

Heat in households is mainly made up of space heating, water heating, and cooking applications (see Figure 4), supplied by a variety of appliances and their combinations. Figure 5 provides an overview of the main technical elements involved in domestic heating in the UK.

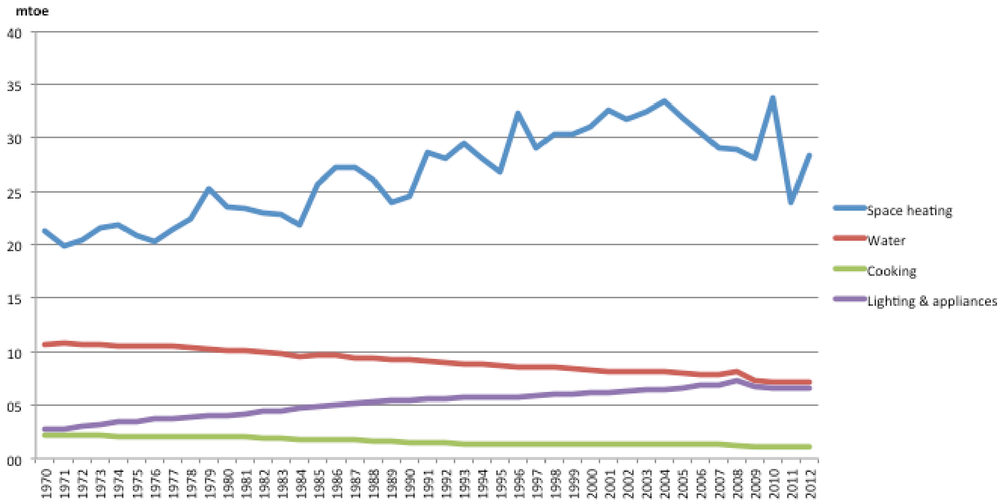

Figure 4: Domestic energy consumption by end use in the UK (1970-2012) (Data: DUKES 2013)

The demand for heat within the home is influenced by a number of factors, including the desired temperature (thermal comfort preferences, occupancy etc.), the heating pattern management (individual room heating, thermostat controls, etc.), the efficiency of heating appliance (including synergies with parallel appliance or distributed networks), the nature of the heat delivery system (radiator, underfloor heating, etc.), and the energy performance of housing (insulation, air-tightness, ventilation, etc.).[2]

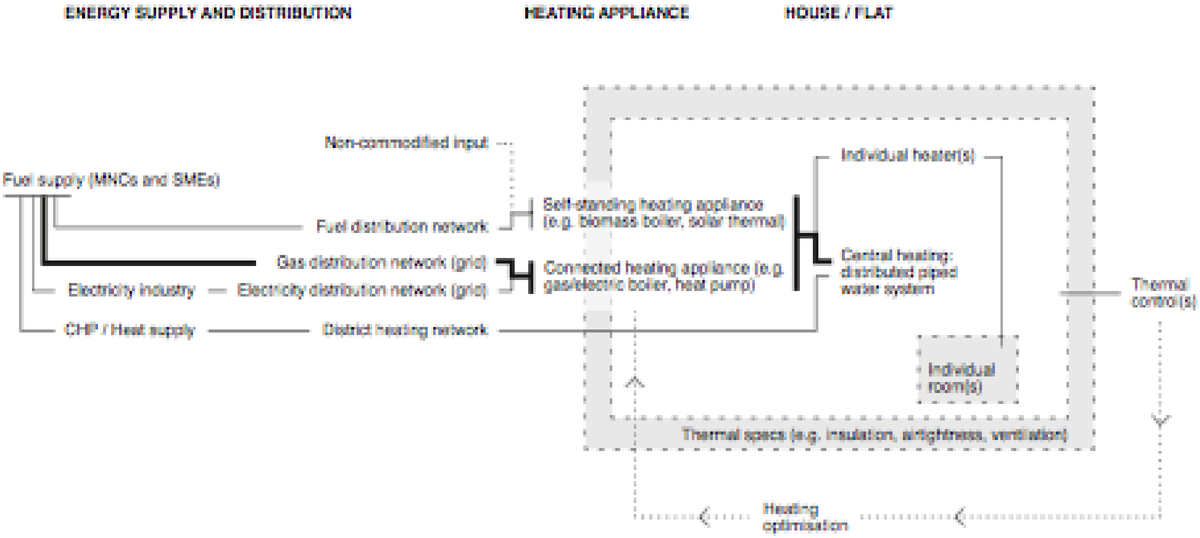

Figure 5: Schematic overview of technical components and options in domestic heating in the UK (bold lines represent dominant configuration)

Heat in the UK is a highly decentralised matter, with most heat production located at the point of consumption, i.e. in individual appliance for the domestic sector. This is reflected by the relative low proportion of energy sold as heat in total energy consumption, and particularly in the domestic sector. Most households can be considered self-contained heating generation and consumption units. Central heating systems have been installed in 90% of homes. Domestic heating in the UK is largely dominated by boilers (95% of homes), of which 80% are connected to the gas grid (DECC 2013a). Around 1.5 million condensing boilers are sold yearly in the UK (DECC 2013a:74).

Operating a domestic heating system is a rather seamless process, as daily use requires very little effort (e.g. flicking a switch or relying on thermostat-controlled heating) when compared to other socio-technical practices such as driving (where user involvement is critical). However, following a similar trend as in electricity or automotive mobility, the main user of heating appliances is usually not autonomous in terms of installation, tuning and maintenance, relying instead on manufacturer and/or fuel supplier servicing. The average user is also relatively non-expert (and hence disempowered) in the technical aspects of heating and cooling, and how such processes can be optimised. Current heating habits are thus mainly determined by installation specifications and routines. The increasing relative cost of fuel and the development of detailed billing are somehow changing this pattern, with stronger user involvement.

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[2] The UK building stock is relatively old (Victorian), with a large proportion of semi-detached and terraced houses (DECC 2012a), which suggests a high potential for energy efficiency improvements.

A number of long-term dynamics are affecting the development of heating regimes. Such dynamics can influence established socio-technical trajectories both negatively (destabilise) and positively (stabilise). They will be analysed more fully in D2.2. We here provide an overview:

- Main destabilising pressures include pressures for environmental change (cutting back on GHG emissions), gas and energy prices, energy poverty, the search for more self-sufficiency, and greater consumer awareness of heat and energy efficiency. These issues are challenging the (socio-cultural and policy) legitimacy, practical efficiency and economic viability of established heating arrangements. They are likely to contribute to shaping the future of heating.
- On the other hand, a number of landscape developments are contributing to stabilise the current gas-fired heating regime, as well as to make it more difficult for alternatives to break through. These include: high sunk costs in (gas) infrastructure, reduced funding capacity since the economic downturn, an old building stock, the fact that heat has until now been a low visibility issue.
- The existing heating regime is further stabilised by reinforcing initiatives and institutions that contribute to existing lock-in. These include: a powerful energy industry, continued technical improvements and sophistication, and supporting policies, as well as the current lack of capabilities and skills to support innovative change.
- Despite inherent stability, the heating regime in the UK is also showing 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 energy production and distribution, the development of a dedicated heat policy strategy.

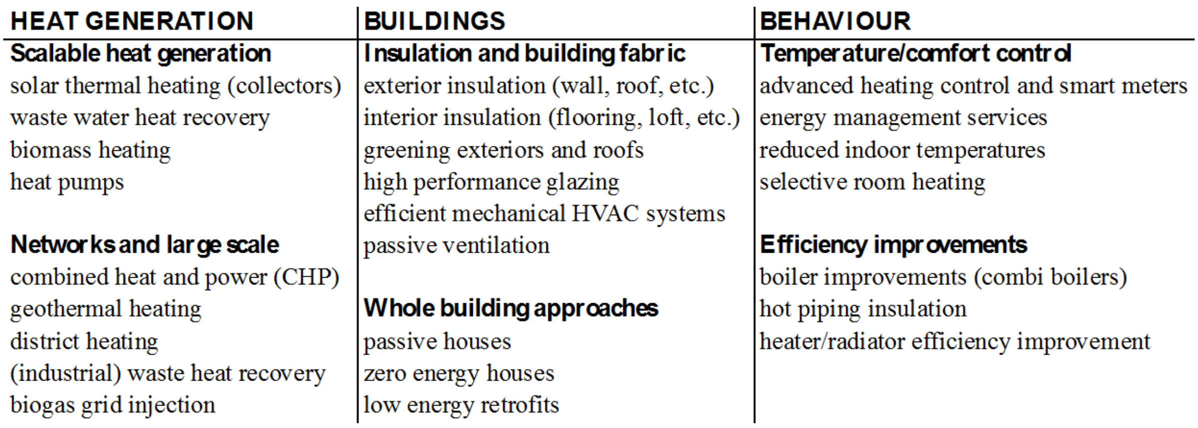
2 Case selection

We first compiled an extensive list of potential niche innovations in the heating and cooling domain, screening from policy documents and existing literature on emerging (sustainable) heating technology and energy transitions research. We then selected a smaller number of these niche innovations on the basis of criteria tailored to our research objectives.

2.1 Potential green niche-innovations

A long list of interesting niches was generated in collaboration with other project partners, on the basis of policy and industry documents. In line with PATHWAYS analytical focus, we were looking for technologies with a potential to contribute to a prospective transition of heating within the coming decades. Table 1 presents a structured long list of potential cases.

Table 1: Long list of potential domestic heat cases



HEAT GENERATION	BUILDINGS	BEHAVIOUR
Scalable heat generation	**Insulation and building fabric**	**Temperature/comfort control**
solar thermal heating (collectors)	exterior insulation (wall, roof, etc.)	advanced heating control and smart meters
waste water heat recovery	interior insulation (flooring, loft, etc.)	energy management services
biomass heating	greening exteriors and roofs	reduced indoor temperatures
heat pumps	high performance glazing	selective room heating
	efficient mechanical HVAC systems	
Networks and large scale	passive ventilation	**Efficiency improvements**
combined heat and power (CHP)		boiler improvements (combi boilers)
geothermal heating	**Whole building approaches**	hot piping insulation
district heating	passive houses	heater/radiator efficiency improvement
(industrial) waste heat recovery	zero energy houses	
biogas grid injection	low energy retrofits	

2.2 Niche-innovation selection

The selection of interesting and relevant green niche-innovations for domestic heating in the UK is based on a preliminary screening according to considerations related to niche development, regime interactions, and transition pathways.

Niche considerations include a preliminary assessment of their transition potential (momentum, growth potential, support, credibility, etc.), the main actors involved, the time horizon and current stage of development, a consideration of development pattern in a transition context, and their decarbonisation potential. Regime considerations include the niche-innovations' reliance on current regime elements, the involvement of regime actors, and departure from the existing regime.

A smaller number of cases was selected. The result of this selection for the UK is presented in Table 2.

Table 2: Selected niche-innovations and selection considerations

	Niche	Niche considerations	Regime and pathway considerations
1.	Small biomass	Developed in other countries and small UK pockets Policy support Some new players Long-term option, available today High decarbonisation	Limited regime actor involvement (only equipment suppliers/installers) Regime departure: - Decentralised technology - Alternative fuel (and supply) - new (charging) infrastructure to link with electricity domain - needs user involvement/maintenance

2.	District heating	Developed in other countries but little in UK Requires new actor coalitions Available today Decarbonisation depends on generation option	Limited regime actor involvement (no longer individual boilers) Regime departure: - heat network and coordination - new business models - long-term contracts - heat as commodity
3.	Heat pumps	Some development Policy support New players Long-term horizon (2030) Decarbonisation depends on power generation	Limited regime involvement, bust still individualised heating solution Regime departure: - heat transfer - depends on power generation - important capital investment
4.	Solar thermal	Developed in other countries and developed UK pockets Policy support Some new players (link with PV) Available today High decarbonisation	Limited regime actor involvement Usually as back-up Regime departure: - Decentralised technology - Alternative (free) energy carrier
5.	Low energy retrofits	Developed in other countries (with higher standards) Policy support Some new players, linked to development in passive houses, new techniques Long-term option, available today Multiple options Variable decarbonisation	Most regime elements unchallenged: working around existing buildings to improve efficiency Regime departure: - new refurbishment skills and standards, new materials - reflection on comfort, system, etc.
6.	Smart heating controls and meters	Developed in non energy applications Policy support through rollout Some new players (devices and infrastructure) Promises to become enabling infrastructure Mid-term option, available today Unknown decarbonisation	Most regime elements unchallenged: infrastructure improvement pushed by regime actors Regime departure: - new forms of control/management - towards energy management as service - enables more flexible heat systems

We come back to these considerations in greater detail in the concluding sections following the analysis of each niche-innovation separately.

3 Niche-innovation momentum analysis

3.1 Niche 1: small biomass

3.1.1 Innovation and market trajectory

Historical overview. Biomass burning for heat and other household energy process has been around for thousands of years (Fouquet and Pearson 1998), and is still the primary energy source in many places in the world, especially in poorer countries. In Europe, colder climates with extensive forestry resources such as Sweden, Finland, Germany and Austria have more developed markets for biomass boilers, and therefore also more extensive appliance supply. While domestic biomass burning is used in remote rural areas in the UK, it remains relatively marginal across the country.

Technical distinctions. Domestic biomass appliances provide space and/or water heating for single rooms or entire home (via central heating system). Wood stoves heat a single room and can be fitted with a back boiler for water heating. Wood boilers are usually connected to a central heating and hot water system. Small wood boilers usually refer to boilers under 50kW, but domestic boilers are usually only a few kW (Palmer et al 2011).

Motivations. Biomass use is usually advocated as an energy option that can contribute to low-carbon and self-sufficiency objectives, with a potential contribution to up to just under a third of the UK 2020 renewable energy target (IIED 2010). Biomass burning releases carbon emissions that are offset by the carbon sequestration from growing the organic matter. Net carbon emissions hence only arise from harvesting, transport, processing and boiler manufacture. So, the overall net carbon balance of biomass use depends on supply-chain specifications, and particularly on burning efficiency, distribution options and land-use change. This has attracted substantial debate from civil society and is being addressed at EU and UK policy levels.

There are potential self-sufficiency benefits from using a plentiful local resource, such as reliability of supply and fuel cost. However, the UK is also importing some of its biomass. Small-scale domestic biomass systems can also contribute to user empowerment if considered within the frame of ‘decentralised micro-generation of energy’,[3] with intrinsic motivations related to “a cultural–behavioural shift towards users’ control and responsibility, linked with knowledge of renewable energy sources” (Levidow et al 2013:215)

Technical components. Biomass boilers and heaters can be considered mature heat production technologies (Jablonski et al 2008), despite less experience with manufacturing in the UK, compared to Germany and Scandinavia. Modern biomass combustion systems can offer net efficiencies over 90%, which is substantially higher than their gas counterparts. Typical costs for a pellet stove is just over £4000, while an automatically fed pellet boiler and a log boiler would cost £14-19000 and £11-23000, respectively.[4] Log stoves and boilers, the most common technology for small-scale domestic applications, remain a relatively low-tech bioenergy option compared to biofuels, biogas, or biohydrogen, or even pellet boilers and stoves with high degrees of automation and control (and emission reduction potential).

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[3] Micro-generation refers to the “small-scale production of heat and/or electricity from a low carbon source” (Energy Act 2004).

[4] http://www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Wood-fuelled-heating, accessed May 26, 2014.

Like any kind of central heating system, biomass heating requires heat a distribution network laid out in the house. There are also different kinds of thermal storage options, ranging from basic water tanks to more elaborate systems with substantial heat loss reduction potential (e.g. accumulator tanks) requiring more dedicated space. Fuel storage can also take up quite some space if fuel is bought in bulk for cost savings. Small biomass boilers can burn different fuel forms, including wood chips, wood pellets (compressed sawdust), logwood, or energy crops (straw, miscanthus, etc.), but logs are the most commonly used fuel at this scale. Smaller fuel types (e.g. chips and pellets) tend to be more responsive to dynamic heating requirements controlled by thermostat, especially if the boiler is automatically fed.

In addition to other heating alternatives, biomass heating involves quite some maintenance (daily ash removal, monthly boiler clean, yearly servicing, etc.). Fuel storage is a substantial component, which tends to rule this option out in dense urban areas.

Fuel supply and distribution. Different fuels provide options for local sourcing, potential (positive) interaction with woodland management and biodiversity, and intelligent waste use as “the UK generates more than six million tonnes of non-recyclable waste wood annually, with much of this ending up in landfill” (IIED 2010:18). However, the increasing development of medium and large-scale biomass power plants is raising concerns about the possibility for local sourcing, and the need to rely on increasing biomass import. In a step towards greater control of fuel supply, NGOs have been advocating for raising sustainability standards, including emissions from distribution trucks, and indirect emissions from land use change, which is leading to fuel supply requirements and greater consumer education.

Markets. The UK has one of the smallest biomass heating markets in Europe (Carbon Trust 2009), with less than 10,000 micro biomass heating installations in 2008 (Palmer and Cooper 2013:78). One of the major problems for the penetration of renewable heat is the current existence of a low-cost incumbent option heat (gas), with a well-developed gas main grid. Comparatively, biomass boilers are still an expensive option, with substantial upfront investment costs and long payback periods (HM Government 2011).

Government biomass rollout support has until now mainly focussed on medium- to large-scale biomass (for commercial and industrial applications), although this market is also one of the smallest in Europe due to the poor development of CHP and heat networks, which are prime candidates for biomass. In the domestic sector, there are small market niches, such as off gas network rural areas – where biomass is mainly displacing oil. Although small, the market for biomass boilers is developing and attracting suppliers:

> “the market for biomass heating boilers is becoming well established and there are approximately 50 plus suppliers of boilers in the range 6kWth to 12MWth” (Carbon Trust 2012:19)

The total population of domestic stoves (including biomass, or multi-fuel stoves that may be run on coal only) in the UK has been estimated at around 1 to 1.5 million, with yearly sales under 200,000, while the market for biomass stoves with back boilers is estimated at under 20,000 yearly (AEA 2012:26-7).[5] There is however limited diffusion potential in urban setting because of the CAA and smokeless zones (1956), and fuel storage options.

Research and innovation. Technological innovation in the area of biomass boilers has mostly focussed on emissions, efficient and controlled burning, convenience and automation, and versatility of fuel source. The introduction of electronics and automation (sensors, automatic feeding, firing, automated ash removal, etc.) has greatly improved overall control

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[5] However, it is likely that most biomass stoves are used in combination with a secondary heat source. So, domestic biomass use is only marginally self-sufficient.

of combustion conditions, which are crucial to emission abatement. Improvements in insulation and heat exchange have contributed to combustion efficiencies nearing 90%. Miniaturisation has allowed high performances within reasonable sizes (not much larger than a standard fridge). The current areas of innovation are 1) efficiency and emission improvements for existing and new log-fired stoves, and 2) ultra-low emissions with advanced pellet boilers using a combination of primary and secondary combustion techniques (which present miniaturisation challenges). An important obstacle to improved performance of small-scale biomass combustion is the instability of use patterns, which may require integration with other devices (renewable or not).

Consumers and legitimacy. Micro-generation technologies require ‘active’ social acceptance of technologies (Sauter and Watson 2007), which is a particularly important hurdle in the case of heat technologies, given the current low public visibility and interest in heat. Contrary to electricity for instance, “heating systems are an integral part of people’s lives, used on a daily basis and fundamental to comfort” (Element Energy and NERA 2011:1), but mostly operating seamlessly and effortlessly. 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 change over to more efficient and less polluting technologies if the economics are right.

3.1.2 Actors and networks

Domestic biomass heat supply is not very well developed in the UK. A number of pioneering European countries have developed significant supply capacity, building on existing skills with larger scale biomass burning but also the development of domestic markets. The UK biomass heating industry is very small in contrast:

> “A major wood heating industry has grown up, in advance of the UK, in response to fast growing markets in the Scandinavian countries, Germany and Austria. As a result the majority of boilers sold in the UK are manufactured in these countries, but with a sizeable minority produced in the UK.” (Carbon Trust 2012:19)

While boiler and heating installation remains a highly localized activity, with a number of UK players competing, they tend to import their boilers from multinational companies such as the Swiss Hoval or the German Vaillant. Euroheat is a leading installation distributor in the UK. It has set up a wood biomass training centre since 2006.

Biomass fuel is available throughout the country from a range of suppliers. Fuel distributors and solid fuel heating suppliers are gathered in a number of associations to defend common interests, centralise market information for consumers, and generally raise awareness among the general public about the benefits and technicalities of domestic biomass heating. These associations include the Solid Fuel Association and the Stove Industry Alliance. Consumer information can also be sought through the Energy Saving Trust or the Renewable Energy Association. The UK government developed a dedicated information source for biomass energy use: www.biomassenergycentre.org.uk.

3.1.3 Governance and policy

The European Directive 2009/28/EC has called for increasing shares of renewables in heat generation (RES-H supply), which has been translated in a target of 12% heat from renewable sources by 2020 (HM Government 2011).

Historically, there has been a relatively low level of support for biomass heat in the UK (IIED 2010). 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. When biomass heat is considered, again, the main policy emphasis is 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. Specifically for domestic biomass, the RHI provides financial support for the purchase of boilers and stoves, along with stronger sustainable requirements applied to verified biomass suppliers[6] in a move to address the address concerns about fuel sourcing and transportation. Additionally, the Microgeneration Certification Scheme (MCS) certifies products and installers of appliances, as required for Feed-in Tariffs (electricity) and the RHI (heat).

In response to sustainability concerns, fuel and equipment certification has been developed. The Biomass Suppliers List is a government certified sustainable biomass suppliers registry, from which recipients of the Renewable Heat Incentive are to purchase their fuel. HETAS (www.hetas.co.uk) is a certification body recognised by the government for the testing and approval of biomass and solid fuel domestic heating appliances, fuels and services, including the registration of competent stove installers and servicing businesses.

3.1.4 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.

3.2 Niche 2: district heating

3.2.1 Innovation and market trajectory

District heating (DH) refers to “the supply of heat to a number of buildings or dwellings from a centralised heat production facility by means of a pipe network carrying hot water or steam” (DECC 2012b:104). DH systems configurations are comparable to electricity generation and distribution networks, with the exception that they are contained in a local geographical area (Figure 6), as heat can difficultly be transported over long distances without major energy losses. DH systems allow for substantial energy savings from greater efficiencies and heat conservation, in particular when considered in conjunction with Combined Heat and Power (CHP).

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[6] See http://www.biomassenergycentre.org.uk/portal/page?_pageid=77,363178&_dad=portal&_schema=PORTAL

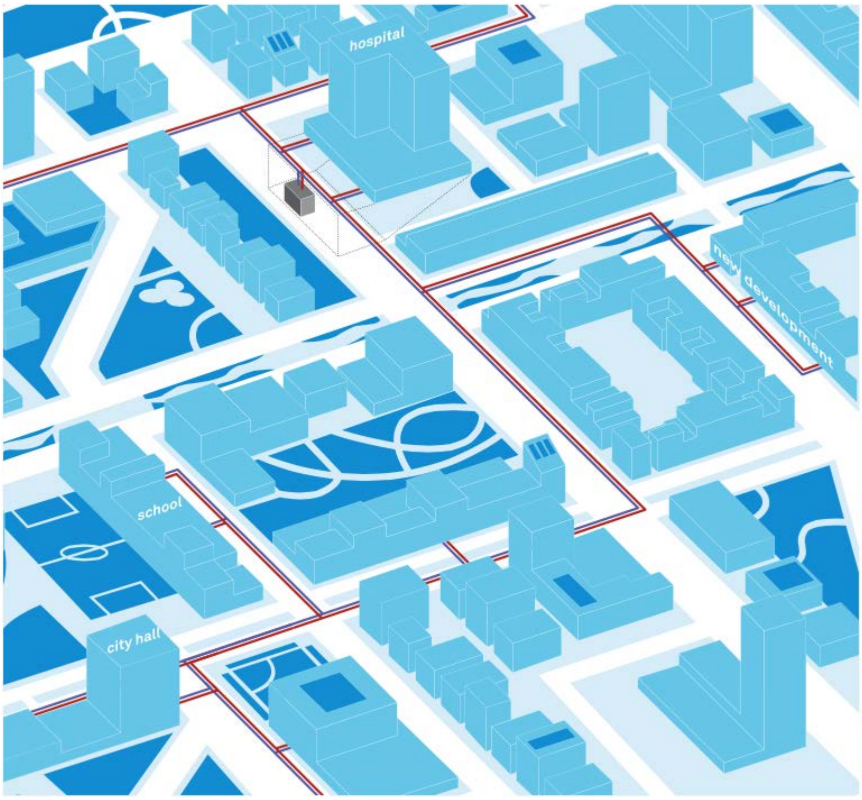

Figure 6: Schematic representation of a district heating network (Greater London Authority 2013)

Historical overview. DH has been considered as a more integrated alternative for the provision of heat from central sources to entire buildings, neighbourhoods and cities since the first large-scale CHP-DH systems was installed in Manchester in 1911 (Kelly and Pollitt 2010).[7] Enthusiasm around this heating option developed from the 1950s through the 1970s, particularly in developing cities like Milton Keynes or urban neighbourhoods (e.g. Pimlico Community Heating established 1950, using waste heat from the Battersea power station), seen as ideal contexts for rollout. However, DH in the UK remained a small niche led by local authorities in conjunction with social housing developments. While DH has been substantially developed in Scandinavia, it has achieved only anecdotal penetration in the UK, in large part due to the structure of housing and the replacement of individual coal heating with the breakthrough of gas in the 1980s, as well as the inability to develop a market for heat. This situation may however be changing, with the emergence of a number of local schemes that could pave the way to wider diffusion (Kelly and Pollitt 2010).

Technical distinctions. Heating networks supplying multiple domestic units come at different scales: at the level of a whole building (or development), multiple sites (e.g. a street or neighbourhood) or a whole district (e.g. a borough, town or city). They respectively referred to as central, communal and district heating, but also small, medium and large scale.

Motivations. The main motivation for DH is the potential for energy savings and related carbon emission reductions, and fuel poverty reduction (i.e. by supplying heat to social housing and tower blocks), as well as the utilisation of otherwise wasted heat (e.g. from power stations or industrial process heat). DH can lead to reduced and more stable long-term energy costs, and increased energy independence at the local level as they can be operated independently from national energy systems and networks. Additionally, DH systems

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[7] The original Crystal Palace provided an early demonstration of DH technology in 1851.

(whether DH/CHP or not) can be run on a variety of (local) alternative fuels, including biomass and waste. Other benefits include reduced maintenance and operating costs from centralised heat production.

Technical components. District heating systems are composed of one (or more) central heat production (boilers) or co-production (CHP) source(s), a heat distribution network (piping, heating and pressurisation pumps managing flows and pressure differences between connections), heat exchangers and thermal stores (accumulators), radiators and controls in each heating unit, as well as a hot water network (often cycling back to the heat source to improve efficiency) and water treatment (to limit pipeline corrosion). Interestingly, heat production can be from a range (or combination) of sources, including combustion boilers (biomass, coal, gas, etc.), CHP, renewable heat sources (solar, geothermal, heat pumps, etc.), or waste heat. These technical components are relatively mature (Hawkey 2012), individually and integrated in DH systems, especially considering the long and successful history of DH in Scandinavia. Additionally, there are options for interconnections *between* DH networks to increase their scale and versatility.

Infrastructure. DH relies heavily on *local* infrastructure rollout, "requiring innovative organisational, contractual and commercial solutions" (Hawkey 2012:20). The main obstacle to the diffusion of DH is the substantial investment cost and the time involved with heat distribution infrastructure: insulated piping networks that can cost up to £1000 per metre in the UK (DECC 2012b). This means that DH requires long-term policy commitment to infrastructure change. In the case of CHP systems, disproportionately high cost of connection to the power grid is an additional barrier. Limiting supply to local grids in private wire networks (PWNs) provides an alternative (Kelly and Pollitt 2010).

Markets. DH currently supplying less than 2% of total UK heat demand,[8] and the 172,000 domestic buildings supplied in the residential sector predominantly consist of social housing, tower blocks and public buildings (DECC 2012b). Of the 1765 DH networks currently recorded in the UK, the bulk supplies less than 100 residential properties, is fuelled by gas, and is located in the region of London (DECC 2013b). It has however been suggested that DH could supply up to 14% of heat requirements for buildings (Pöyry Energy 2009) and even around 50% (DECC 2011a).

City-wide DH in the UK has been initiated in the 1970-80s, including schemes in Nottingham, Southampton, Leicester, Sheffield, and a number of schemes across London (Bolton 2011). More recent DH schemes include developments in Aberdeen, Birmingham, Milton Keynes, Woking, London, etc. Sheffield, Leeds, Derby, Bradford, have all announced plans for DH development. London examples include the Cranston Estate regeneration project (Hackney), the Olympic Park and Stratford City project, and the proposed London Thames Gateway Heat Network (Greater London Authority 2013).

Research and innovation. Considering the maturity of DH technology, the main locus of innovation is at the organisational and institutional level. A major aspect for the development of creative solutions is financing, because of the large upfront costs with slow payback period in a context of unstable energy prices and conservative accounting. Policy (in)stability directly affects the perceived long-term viability of such investments, and has so far encouraged short-term profit-oriented decision-making in the energy sectors (e.g. CCGT in the 1990s). Because they require long-term commitment of multiple actors, the set-up of DH

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[8] These figures are to be compared with over 50% penetration rate in Northern European countries, with nearly 90% in urban concentrations such as Helsinki and Copenhagen.

schemes also generates major coordination difficulties. Innovative Local Energy Governance and Organisation (LEGO) models, as coined by Hawkey et al (2013) play a significant role in generating momentum and overcoming the typical barriers for the establishment of a DH scheme (e.g. risk-aversion, conservative accounting, coordinated management conflicts, etc.). The core initial subscribers typically determine LEGO models by shaping a scheme's configuration, organisation, governance, and operation.

Consumers and legitimacy. 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 of communal form of heating. Important consumer benefits of DH systems include the externalisation of heat provision and management (without losing the ability for control), and affordable cost and long-term price stability (Greater London Authority 2013).

Considering the systemic nature of DH, it is relevant to realise that 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:

> "perceptions of risk among potential subscribers leads to often protracted negotiation between system developers and subscribers around price, service level guarantees, and redress procedures. Strategies employed to build legitimacy at a local level include connection of well regarded businesses (such as national supermarket stores), open book accounting, demonstration of previous experience and performance (particularly in the UK), and local authority involvement in system governance." (Hawkey 2102:26)

3.2.2 Actors and networks

DH requires the "participation and long term commitment [of] network builders and subscribers" (Hawkey 2021:24). An initial coalition of core actors (large or bundled users) can stabilise an emerging scheme by committing to stable long-term demand for 'anchor loads' that critically allow for the set-up of and eventual subsequent expansion. It is important to have a limited number of actors to maximise coordination and consensus. Long-term contracts are sought to reduce the high risks, which means that DH developers are targeting customers such as the public sector and social housing administrators in priority. Securing a core customer base then allows further developing the network at its margins, once the main infrastructure is up and running.

Most large energy equipment suppliers (Alstom, Siemens, Bosch, etc.) have developed adjusted products and services for DH. In addition, DH involves more specialised manufacturers offering insulated piping for DH applications (including established CPV Ltd, Vital Energi, but also newcomers such as Amco Pipe, Mibec, etc.), tailored automated controls, heat exchangers (e.g. Alfa Laval), etc., as well as project management and financial and engineering consultancy services (e.g. Pöyry, Cofely – GD Suez, Dalkia Solutions, etc.). However, this nascent industry still lacks vitality and critical mass of suppliers:

> "The small scale of DH industry in the UK means equipment (particularly insulated pipes) is imported, and other factor costs are high relative to other European countries (Pöyry Energy, 2009)." (Hawkey 2012:27)

Developers setting up DH schemes as part of their (old or new) construction plans in the UK are pioneers whose strong entrepreneurial spirit allows them to navigate and overcome the numerous regulatory, coordination, and local governance difficulties. Most DH networks developed in the UK have seen the creation of an ESCO to manage the networks, namely in order to reduce risks and serve as an intermediary to achieve objectives and distribution of ownership (Kelly and Pollitt 2010). ESCO ownership can be any combination of public, private and community-owned, and the chosen form of partnership is dependent on the types of contracts and end purposes of a DH scheme. Dedicated ESCOs can also provide specialised expertise and experience with the management of heating networks, relationships with suppliers and customers, etc.

Municipalities have a major role to play in the deployment of DH systems, as they are the main decision-makers concerning new developments and planning arrangements, particularly in the UK where DH is not developed enough to have yet attracted nationally coordinated actors (Hawkey 2012). Municipalities are in a position to locally support and push for the development of DH, facilitating the connection of buildings and the rollout of heat pipelines, providing long-term guarantees, weighing in planning permission decisions, and negotiating agreements with ESCOs (leasing, contracts, etc.). Municipalities and organisation such as hospitals can reduce the risks associated with DH investments by connecting their own buildings. In practice, however, “UK local authorities have had very limited roles in energy services for almost a century” (Hawkey et al 2013:22), their involvement in service provision has been largely privatised since the 1980s, and coordination between municipalities and other public sector organisation is proving challenging.

Local DH governance regimes tend to be set-up in a context and purpose-specific frame in the UK, with only limited national coordination or knowledge and expertise sharing. Dedicated associations such as the UK District Energy Association (www.ukdea.org.uk) and the Combined Heat and Power Association (www.chpa.co.uk) offer opportunities for practitioner interaction for coordinated learning, lobbying, and standard setting. The District Heating Vanguards Networks brings together local authorities involved with District Heating for greater coordination and mutual learning. In a more geographically focussed initiative, the Decentralised Energy Programme Delivery Unit (DEPDU) in London boroughs, is seeks to generate a framework supporting and harmonising DH development in Greater London.

3.2.3 Governance and policy

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.[9] Similarly, public funding for DH schemes has so far been possible via non specialised grants and subsidies:

> “One route by which financial resources have been mobilised for DH is via national grant programmes: the Community Energy Programme (2002–2005), the Low Carbon Infrastructure Fund (2009–2010), and the Community Energy Saving Programme (2009–2012).” (Hawkey 2012:27)

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

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[9] There are also issues with power generation regulation that make it difficult for CHP to compete in the UK. A city-wide DH-CHP scheme in Leicester was abandoned following the inability to secure contracts for the generated power.

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). 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 the greater diffusion of DH networks, it is also necessary to break the mould of the established preference for centralised 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. DECC recently commissioned a national heat map[10] in order to facilitate the identification of lead markets for DH development.

DECC has recently recognised the need for the UK to catch up with other countries. A number of priority action points have been proposed in the heat strategy (DECC 2013a), including:

- to support local authorities in developing heat networks via a dedicated DECC team: the Heat Networks Delivery Unit (HNDU)
- to make funding available to local authorities to contribute to initial development costs
- to explore the need for additional financial support, e.g. via the RHI

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) (Bolton and Foxon 2014). These pioneering local authorities are generating innovative organisational forms and can provide an important source of momentum for future developments.

3.2.4 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 we 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 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. Critically, what is needed is the development of business models and institutional forms that reward long-term infrastructure commitments.

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 2014). Recent

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[10] See http://chp.decc.gov.uk/developmentmap/, accessed June 2, 2014.

support in the scope of the Heat Strategy however provides hope that existing barriers may eventually be lifted.

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.

3.3 Niche 3: heat pumps

3.3.1 Innovation and market trajectory

Heat pumps are electrical or gas-powered devices that extract low-temperature heat from the ground, the ambient air, or even water (e.g. pond) to the desired heat sink, following similar principles as fridges or air-conditioner:

> “Heat pumps work by extracting low-grade heat from a source (air, ground or water) and converting it into high-grade heat” (Greening and Azapagic 2012:206)

Historical overview. The thermodynamic principles behind heat pumps date back to the 18th century, with very early prototypes in the 19th century. Practical applications have multiplied since the mid-20th century, with particular development in Scandinavia following the energy crises of the 1970s.

Technical distinctions. Typical technical distinctions between heat pumps include air source heat pumps (ASHP), ground source heat pumps (GSHP), and water source heat pumps (WSHP).[11] In domestic heating and cooling applications, heat pumps either directly heat ambient air or piped water. Their operating efficiencies are commonly measured by their coefficient of performance (CoP): the ratio between effective heat output to work input (electric or gas engine).

Motivations. The main motivation for installing heat pumps is potential increased energy efficiency of heating and related carbon emission reductions. Heat pumps are projected to play a major role in providing renewable heat (Skea 2012). However, their environmental benefit is questionable in the current UK context, because of 1) highly variable efficiencies in practice, 2) a relatively high-carbon electricity mix, and 3) the widespread use of gas boilers.

Heating efficiency of heat pumps currently installed in the UK range from 130 to 330%. There are concerns that high efficiencies (over 250%) should be reached in practice in order for heat pumps to save carbon over gas heating (Caird et al 2012). Furthermore, for electrically powered heat pump to be considered a ‘renewable energy source’ under the EU Renewable Energy Sources Directive (2009/28/EC), it should reach a minimum 290% efficiency given the current UK electricity mix. Electrically powered heat pumps tend to be an environmentally sounder option when there is a high proportion of renewables in the electricity mix (Greening and Azapagic 2012), which is not currently the case in the UK. Combining heat pumps with other renewable technologies (e.g. micro-power) can raise their sustainability profile

Technical components. The main components of a heat pump are an evaporator, a compressor, a condenser, and piping (in the case of GSHP). Heat pumps can be powered by electricity or gas engines. While the most widespread configuration involves using electricity from the grid, they can potentially be used in combination with e.g. distributed power generation options. Heat pumps are best suited to energy efficient buildings with efficient

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[11] Also commonly referred to as aerothermal, geothermal and hydrothermal energy options respectively.

heat distribution (e.g. underfloor heating) (Allen et al 2008), and may hence make more sense in new builds, or in retrofit situations (Roy and Caird 2013).

GSHP are considered more efficient due to greater temperature stability of the heat source, but are particularly complicated to install, as they involve field pipes that need to be dug in trenches in addition to the heat pump unit and heat distribution system. Optimising heat pump efficiency requires active control of the heating pattern (programming heat pump controls to match specific requirements), with greater performance achieved when uninterrupted gentle heating is considered – which is counterintuitive in the light of conventional heating system operation. Because of the important planning and installation considerations (cost and size), GSHP are mostly fitted to new buildings, or in conjunction with DH. ASHPs, though generally less efficient, have greater short term potential in the domestic market (as potential replacement for gas boilers), given that they are less reliant on heavy infrastructure or construction, and are more easily retrofitted.

Markets. France and Scandinavia have stable markets for heat pumps. In general, markets tend to be more developed where electricity is relatively cheap and electric heating plays an important role. Heat pumps involve important capital costs:

> “a heat pump system costs two to three times that of a gas central heating system (Müller et al., 2009) and is not likely to be cheaper to run” (Roy and Caird 2013:21)

The current UK market is fairly small, but growing. While a few thousands of domestic heat pumps were installed in 2008, this figure increased to around 30,000 in 2010 (Greening and Azapagic 2012). The market is further expected to grow with increased awareness and the availability of the domestic RHI (DECC 2011b). The early market potential for heat pumps in the UK is primarily made of domestic users off the mains gas grid and hence replacing oil-fuelled boilers (Caird et al 2012), in a similar fashion as domestic biomass boilers, because of space and noise restrictions (Fritsch 2011), but also the carbon-intensity of UK electricity which reduce the environmental benefits of switching over to electric heat pumps. However, for greater deployment, “it is important that heat pumps penetrate the retrofit or boiler replacement market […] where most conventional boilers are sold.” (Fritsch 2011:5).

The current small size of the UK market means that there is scope for learning, but also that the small cohort of early ASHP adopters consisting of ‘pioneering housebuilders and developers’ (Pan and Cooper 2011) is facing limitations due to poorly developed installation capabilities and technological familiarity:

> “application in the UK is not so developed and we are therefore still learning about the installation of heat pumps (…) We need to invest in up-skilling our existing heating engineers and designers in this important technology.” (DECC 2011b:31)

Consumers and legitimacy. 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 (DECC 2013a):

> “Probably the biggest challenge is to make heat pumps better known among end-users and the general public.” (Fritsch 2011:6)

Greater information, marketing and communication could go a long way towards addressing these deficiencies.

Research and innovation. Heat pump technology is considered mature. The main scope for innovation in the UK context concerns efficiency improvements and cost reductions (Lohrenz 2011). Heat pumps are relatively complex in comparison to conventional domestic heating systems, which means that technical support and advice are important (Caird et al 2012), both for installation and operation.

Satisfactorily operating heat pumps requires user training and assistance, which is an important obstacle to their wider diffusion. Streamlining and improving the user-friendliness of controls and interface are important areas for innovation.

Despite a relatively poorly developed market, the UK has hosted a number of field trials and schemes, which provide a substantial base for learning and optimisation. The official preferred direction of search are summarised below:

> "Areas such as developments in compressors and absorption chillers, operation and maintenance could lead to significant savings up to 2050." (DECC 2011b:31)

3.3.2 Actors and networks

Dedicated industry. There are over 1,000 certified heat pump installers in the UK listed on the MCS website.[12] The European Heat Pump Association (www.ehpa.org) brings together installer and manufacturers at the European level. The UK Heat Pump Association (www.heatpumps.org.uk) is a trade association representing manufacturers and distributors. Its membership includes dedicated specialists (installer, designers, consulting engineers, etc.), large incumbent actors from the energy sector who are involved via dedicated energy services branches (e.g. E.ON Energy Solutions) and global actors in the electronics and engine businesses with dedicated products (Hitachi Air Conditioning, Mitsubishi Electric, Samsung Electronics, Toshiba Carrier, etc.). The Ground Source Heat Pump Association (www.gshp.org.uk) also brings together relevant actors in the field to promote the development and deployment of heat pumps.

Dedicated heat pump installers can act as promotional actors to raise awareness about and legitimate the technology, especially given the ambitions to compete with boilers – a nation-wide market.

Electricity industry. A large-scale shift to heat pumps would lead to increased electricity demand. This is potentially a massive challenge for power generation and distribution companies, in terms of strategic foresight and investment in generation capacity to meet load increases for which it has no prior experience. There are also potential economic gains from increased electricity demand.

Construction sector. As heat pumps are more likely to be installed during retrofits or new constructions, actors in the construction business (developers, builders, architects, engineers, local planning authorities, etc.) have an important role to play in their diffusion and optimal installation. This crucial sector is however not highly familiar with heat pumps and currently lacks the kind of training that would lead to greater efficiencies in practices.

3.3.3 Governance and policy

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:

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[12] www.microgenerationcertification.org

> “We want to see the heat pump industry investing in research and development so that the UK economy can benefit from innovations in this technology.” (DECC 2011b:31)

DECC has been undertaking field trials to gather greater information on the performance of domestic heat pumps and possible improvements (DECC 2013a). More recently, the RHI has put a strong emphasis on supporting heat pumps through financial means:

> “[The RHI] aims to promote the rapid uptake of low carbon and renewable heating systems, and especially heat pumps, which are viewed across Europe as an increasingly important technology as the proportion of renewable grid electricity to power them grows.” (Caird et al 2012:284)

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 2011c).

3.3.4 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 2013a: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.

3.4 Niche 4: solar thermal

3.4.1 Innovation and market trajectory

Solar technologies are interesting in that they tap into a virtually unlimited source of energy. The relative simplicity and maturity of the technology has made it one of the most attractive renewable heating options so far. It is also worthwhile noting that solar thermal technology is currently considered an ‘additional’ technology (rather than substitutional) (Elmes 2013), which means that it is facing lesser systemic barriers than other systems.

Historical overview. The collection and storage of solar thermal energy is common throughout the world. Modern solar thermal collection and storage designs have been developed more recently, including numerous innovations to improve system efficiency since the 1970s (Brinkworth 2001). There has been some market development throughout the 2000s (See Figure 7).

Technical distinctions. Solar thermal energy collection can be done for space or water heating purposes, or both (dual systems). We here focus on the main domestic solar thermal application: solar hot water (SHW).

Motivations. The main motivations for SHW are its low carbon potential, energy independence and energy price stability resulting from a freely available energy resource. There are however concerns that in the UK context (replacement of gas boilers, and relatively low solar irradiation levels) the widespread diffusion of solar thermal storage would only lead to limited environmental benefits (Greening and Azapagic 2014).

Technical components. Solar thermal collection is a relatively simple and mature technology. The most common and developed form of solar heat storage is referred to as ‘sensible storage’, via a liquid or solid medium. It is “well demonstrated, clearly understood, reliable and widely used” (Pinel et al 2011:3347). Options for storage include water, rock beds, solid rock, and other solutions (oil, salt solution, etc.), with water being the predominant choice because of its high heat capacity and wide availability. A basic solar thermal system comprises of a solar collector, eventual reflectors, an insulated (pressurised) hot water storage tank, electric pump(s), controller(s), and piping to connect to hot water supply (and central heating systems in the case of dual systems). The insulation of the storage tank and pipes is critical to higher efficiencies (Marsh 2013). Solar collectors are typically installed on South-facing rooftops, the most common designs being ‘flat plate collectors’ (solar absorbers contained in an insulated and glazed box), ‘evacuated tube collectors’ (reclined rows of vacuum glass tubes with inner metal absorber tubes) and ‘unglazed plastic absorbers’ (Hossain et al 2011, Mills and Schleich 2009). A basic system is a 4m2 south facing rooftop collector connected to a hot water tank and ‘evacuated tubes’.

In the UK, solar thermal water heating is usually not enough to supply hot water use throughout the year, especially in the winter, and is often complemented by a back-up (gas) boiler. Most current solar thermal applications store heat in a short-term mode (e.g. daily). Interesting innovation opportunities with greater potential environmental benefits concern seasonal storage options, where thermal energy is stored in a long-term fashion.

Markets. Solar thermal technology is one of the most developed microgeneration technologies in the UK, with 80,000 systems installed by 2005 (Allen et al 2008), and over 200,000 units in use today,[13] but remains one of the smallest markets (RAE 2012), representing only around 2% of the 40 Mm2 European installed capacity. Solar thermal capacity has grown steadily since the early 2000s, with a notable installation peak in 2008 (ESTIF 2014), but sales have declined since 2010, and industry actors see the current market as “disappointingly small”[14]. Delays with the implementation of the RHI are considered within the solar industry to have negatively affected sales.

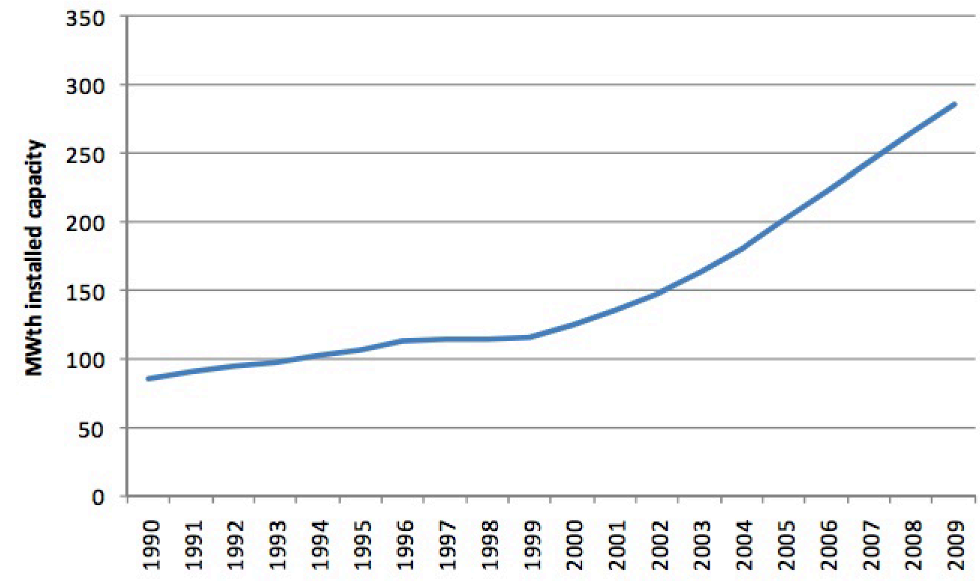

Figure 7: Installed capacity of UK domestic hot water systems (MWth) 1990-2009 (AEA 2010:83)

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[13] www.solar-trade.org.uk

[14] http://www.solarpowerportal.co.uk

Germany is the most developed market for solar thermal systems in Europe, with nearly 8Mm2 installed capacity. Austria, Spain, France, Greece, Italy and Poland each represent between 1500km2 and 300km2 yearly new installed capacity (RAE 2012, Mills and Schleich 2009, ESTIF 2014), which make Austria and Greece clear leaders in per-capita installed capacity.

Installation costs are estimated at around £3-5000,[15] but payback times are considered relatively rapid (Roy et al 2008). Solar thermal technologies currently enjoy a greater market potential than other options in the UK, as they attract a more mainstream kind of customer:

> "Solar hot water has a wider appeal [amongst microgeneration heat options], with [adopters] living in smaller, suburban or urban properties. This in part reflects the fact that the lower cost and smaller size of this technology makes it more widely suitable." (Roy et al 2008:5)

While installation may present some difficulties that favour integration in retrofit, solar thermal technology requires very little maintenance. Solar thermal does not seem to be the preferred renewable option in the case of new builds, but is (along with PV systems), "among the most convenient ways to reduce energy consumptions and bills in existing buildings" (Fiorentini 2013:10). Solar thermal heating systems competes for space with other roof-based systems: PVs and the emerging PV-T (combined systems).

Research and innovation. Solar thermal systems can be considered mature technologies. Current innovation efforts within solar thermal water storage is mainly incremental in nature, including:

- cost reduction via greater volumes and standardised components,
- efficiency improvements, through the use of materials and coatings increasing heat absorption and transmission, or the minimisation of heat loss,
- optimised seasonal heating configurations,
- integration to the built environment, with the development of less noticeable collectors and integration with roofing, but also walls and windows (Marsh 2013). The development of prefabricated façade systems could generate some opportunities.

Innovation efforts are also directed at different thermal storage models, such as:

- the use of different heat transfer mediums (e.g. air, rock, etc.),
- integration with other renewable energy technologies (e.g. heat pumps, solar PV, and even micro-wind)

More forward-looking innovation avenues focus on other storage mechanisms, including chemical reactions, thermo-chemical processes, and latent storage, for which no residential application has yet been developed (Pinel et al 2011). These options present high potentials in terms of seasonal storage, but have not yet been generated economically viable propositions.

Consumers and legitimacy. 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 2013a:44).

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[15] www.energysavingtrust.org.uk

3.4.2 Actors and networks

The Solar Trade Association (www.solar-trade.org.uk) is the main federation of industry interests in solar technologies in the UK. It is a member of the European Solar Thermal Industry Federation (ESTIF, www.estif.org). These associations are central actors in terms of influencing decision-making and lobbying for policy support (e.g. market and R&D initiatives), developing demonstration projects, and raising awareness through campaigns directed at consumers and installers (e.g. by releasing documentation). The main strategy is to establish solar thermal technology as the main option for renewable heating in off-grid homes, and to push for their adoption in larger residential and commercial buildings. Industry organisations, web-based knowledge platforms (e.g. solarthermalworld.org) and meeting points (e.g. Solar Energy UK, Estec, Solar Industry Summit, European Solar Days, and the Heating & Renewables Roadshow) allow for knowledge sharing within the professional community, communication about of new innovative applications, and the consolidation of the solar thermal proposition. The Solar Trade Association, the Global Solar Thermal Energy Council, and the Energy Saving Trust have contributed to raising consumer and installer awareness.

Roof-top solar thermal collectors are specialised devices, with some similarity with PV technologies and related skills.[16] 24 flat plate collectors, and 19 evacuated tube collectors suppliers operate in the UK (AEA 2010) under the Energy Technology List and the MCS. Except for a few longstanding solar dedicated companies such as AES, energy suppliers such as Grant UK, and more recent players like Viridian, solar thermal supplies tends to be distributed by more diversified energy and heating equipment suppliers (Vokera, Baxi, Ariston, Viessmann, etc.), or imported from by installers from market leading countries such as Germany.

Besides solar plates and pipes, most of the components making up solar thermal systems are widely available and rely on well-established trades. It is their assembly, installation and optimisation that are so crucial for the successful implementation of solar thermal systems. Heating equipment installers can act as ‘multipliers’ because 1) they can suggest (and push for) the solar thermal option if it is part of their portfolio, 2) their ability to install and service high-performance installations is crucial to user experience and satisfaction, and ultimately the reputation of the technology.

3.4.3 Governance and policy

SWH is not put forward as one of the major technological promise for heating in policy documents (DECC 2013a). 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.

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.

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[16] The build-up of a PV dedicated service industry and specialised technicians in recent years is an asset for the development of rooftop solar thermal systems.

3.4.4 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. This may be changing with the launch of the dRHI. Solar thermal heating is available from most renewable heating installers, as well as large boiler equipment manufacturer catalogues.

3.5 Niche 5: low energy retrofits

3.5.1 Innovation and market trajectory

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 building sector has seen a lot of innovation in terms of sustainable construction and passive houses in the last decades, particularly in Germany. It is now possible to build new houses that virtually don’t require any heating at all, including in the coldest winter months. However, we here focus on the retrofitting existing homes to improve their energy efficiency, with particular emphasis on the building fabric (and hence insulation). Low energy retrofitting is not a technology in the conventional sense, but rather a systemic improvement strategy involving a number of techniques and site-specific considerations.

Motivations. The main motivations behind retrofits are energy performance improvements to reduce energy use and carbon emissions. Retrofits can also reduce individual energy bills, increase energy independence, contribute to addressing fuel poverty and excess winter deaths (UK Green Building Council 2014). Retrofitting can develop (or generate new advanced skills for) a large industry, and stimulate economy by revitalising the building sector.

Technical components. Retrofitting a home is more difficult than building an energy efficient home from scratch. It requires assessing opportunities for improvement, adapting existing design and building features, negotiating space and systemic constraints, as well as juggling building and conservation regulations. The main strategies seek improved insulation, air tightness, and ventilation. Depending on each house, conventional technical measures may include solid wall insulation,[17] cavity wall insulation, loft insulation, floor insulation, glazing upgrades (double or triple), draught proofing, as well as heating measures (boiler improvement, heating controls, hot water tank insulation), and energy efficient lights and appliances, etc. Further measures include the replacement of heating and ventilation systems, and renewable energy technologies. Different strategies can be pursued:

- Punctual insulation is the most common strategy for retrofits in the UK

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[17] Opportunities for external insulation are restricted in the UK because they alter historical façades.

- Passive design has a “tight performance specification” (Lowe et al 2012:6), see Table 3, particularly in terms of insulation, fabric and component U-values, which means that mechanical ventilation with heat recovery (MVHR) is enough to provide basic heating throughout the year.
- A zero energy house strategy builds on passive design by adding active techniques and renewable technologies to meet energy requirements.

Markets. 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 (Figure 8). The potential market for retrofits is massive, provided there are the right incentives. Retrofitting remains a voluntary measure, however bad a building’s performance, as “there is currently no strategy to ensure a minimum level of efficiency for all occupied dwellings” (Roberts 2008:4485).

Spontaneous customer demand for energy efficient retrofits in the UK is low, because of high upfront costs, little certainty about economic gains and payback periods, technical difficulties and the disruptive nature of refurbishments. The cost-effectiveness of energy saving retrofit measures varies greatly across measures and from house to house (Shorrock et al 2005). However, there is some interest, particularly from homeowners, and this has the potential to develop into a healthy market.

There are further barriers to the diffusion of retrofitting, as an estimated 40% of the existing housing stock is considered ‘hard-to-treat’ as they “possess solid walls, no loft space to insulate, no connection to the gas network or are high-rise” (Dowson et al 2012:296) and can therefore difficultly be retrofitted using conventional techniques.

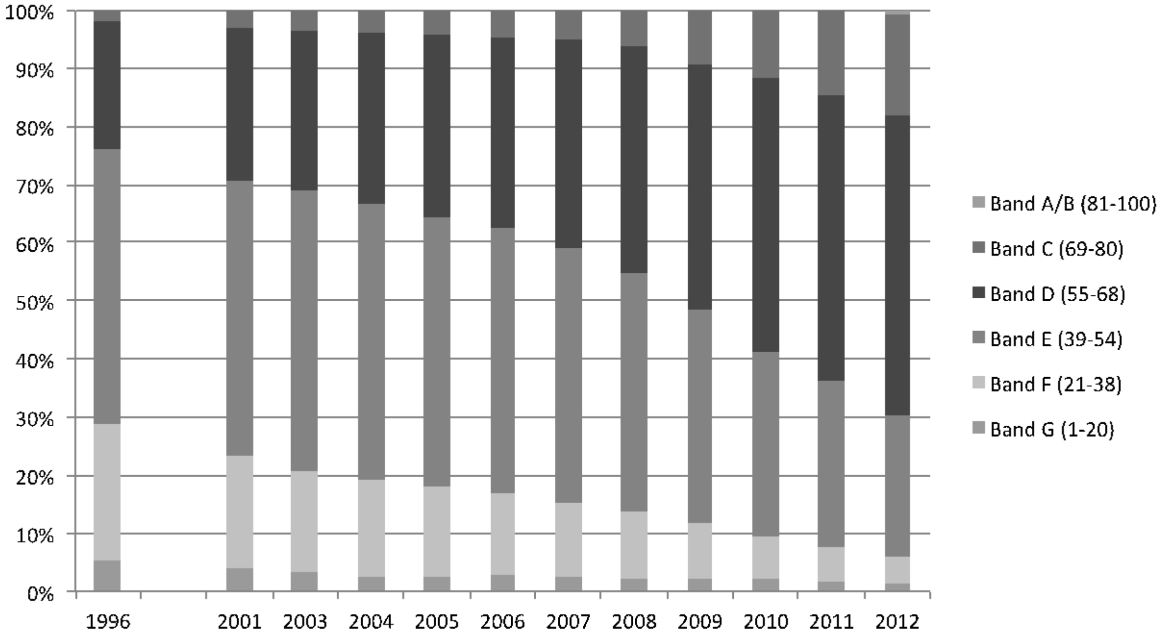

Figure 8: Energy efficiency rating bands across a sample of English dwellings, 1996 to 2012 (Data: English Housing Survey)

Supply side. In the UK, the appropriate construction skills required for high performance retrofits are rare and the supply of high efficiency standard components is underdeveloped:

> “The relatively small scale and short history of the UK retrofit market means that many components and systems need to be sourced from overseas” (Lowe et al 2012:32)

Furthermore, the immaturity of the supply chain may lead to unnecessary delays, inexperience, mistakes, and cost increases – potentially discouraging a readily small customer base.

Research and innovation. Current cutting edge technologies for retrofits through insulation include insulating paints and coatings, triple glazing windows (already common in Northern countries), vacuum glazing and insulation panels, etc. In terms of building design, there have been major developments with passive houses and underlying principles. Retrofitting British houses to passive house standards remains a challenge for which it is important to multiply demonstration projects and proper evaluation and data collection. In an effort in that direction, the Technology Strategy Board launched the ‘Retrofit for the Future’ competition in 2009, funding over 100 high energy standard retrofit demonstrations in the UK, encouraging collaborations between housing providers, designers, contractors and researchers. It has helped stimulate new business opportunities in the UK retrofit market.[18] Recently, the low impact buildings innovation platform secured £60m to support innovation in buildings over 2014-2019.

Consumers and legitimacy. 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.

3.5.2 Actors and networks

Energy efficient retrofits may involve a range of actors, including homeowners, architects, engineers, project managers, builders, materials and products suppliers, insulation installers, etc.

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. While it is possible to find builders and contractors for refurbishments, these are far from standard, come at high expenses, and mistakes are common due to inexperience. Individual components, such as double- or triple-glazed windows or high performance coating, are difficult to get by and often sourced abroad.

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

A number of organisations promote the development of low energy skills in the building sector. The UK Green Buildings Council is a not for profit organisation aiming to “facilitate dialogue between industry and Government to promote greener approaches in the construction sector” (http://www.ukgbc.org/). There are a number of information sources

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[18] See retrofit.innovateuk.org

about low emission retrofitting standards and practice. The UK Passive house organisation (www.passivhaustrust.org.uk) promotes and offers guidance about the Passivhaus low energy design standard. 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.

3.5.3 Governance and policy

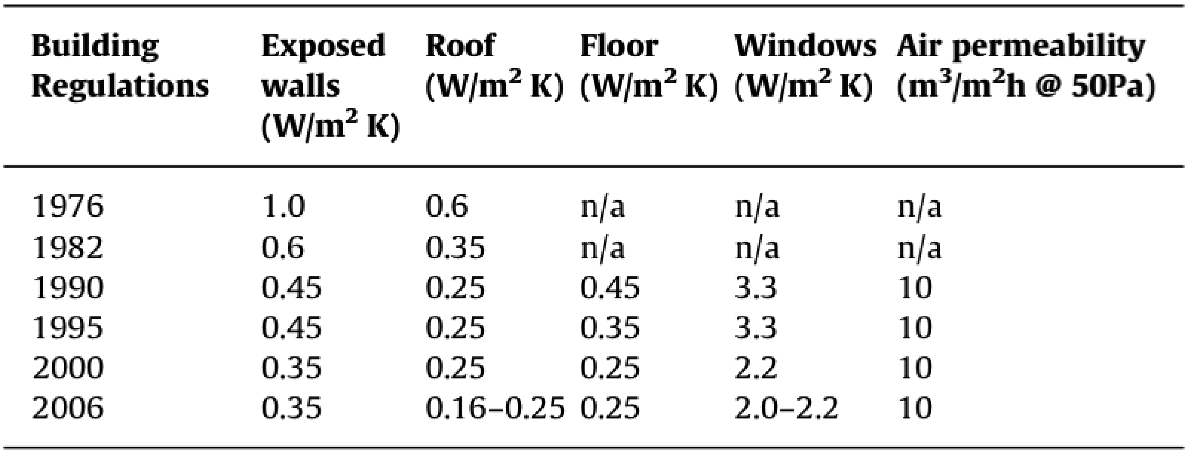
The main issue with the energy performance of the built environment in the UK is linked to the existing building stock, and remains to be addressed properly:

> "The energy efficiency of new homes has been covered by Building Regulations and, from 2016, will be covered by the Zero Carbon Homes initiative. However, the biggest challenge facing the UK is improving the energy efficiency of the existing building stock, much of which will still be in place by 2050." (Skea 2012:437)

The performance of buildings is regulated through the Building Regulations. The first efficiency regulations appeared in 1976 after the oil crisis, setting minimum U-value standards for *new* buildings to minimise heat loss (Table 3). These values are not highly ambitious, and concern new buildings. Similarly, a number of policy statement have referred to ambitious targets concerning new developments. "Building a Greener Future" (2006) proposed that all new homes should aim at being zero carbon by 2016.

Standards provide systematic metrics and benchmarks for building performance. The Energy Performance Certificates (EPC), introduced in 2007, provide information on energy performance to potential tenants or buyers, without introducing any specific requirements. Discussions are currently underway about introducing minimum performance standards for existing rented properties, to a minimum EPC rating E, by 2018.

Table 3: Historic minimum U-values & air permeability targets in the building regulations (Dowson et al 2012)



Building Regulations	Exposed walls ($W/m^2 K$)	Roof ($W/m^2 K$)	Floor ($W/m^2 K$)	Windows ($W/m^2 K$)	Air permeability (m^3/m^2h @ 50Pa)
1976	1.0	0.6	n/a	n/a	n/a
1982	0.6	0.35	n/a	n/a	n/a
1990	0.45	0.25	0.45	3.3	10
1995	0.45	0.25	0.35	3.3	10
2000	0.35	0.25	0.25	2.2	10
2006	0.35	0.16–0.25	0.25	2.0–2.2	10

In terms of new construction, a number of sustainable design standards exist worldwide, specifying criteria and evaluation methods to achieve high-energy efficiency or zero energy objectives, including PassivHaus (Germany), and LEED (USA). In the UK, the EcoHomes standard became mandatory for new social housing in 2003 (www.breeam.org). The Association for Environmentally Conscious Builders (AECB) initiated a 'Gold Standard' for new homes with high performance standards. The Government launched the Code for Sustainable Homes in 2007. These design standards usually start out as voluntary initiatives to push the boundaries beyond what is required by regulations alone. They can be extended to refurbishment to some extent.

The Green Deal, initiated 2013, addresses 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 instalments 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.

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 (www.ofgem.gov.uk). 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.

The Green Deal Home Improvement Fund was launched in 2014, making £120m available for private energy efficiency improvements.

3.5.4 Momentum

There is 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.).

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 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. There is however a large potential for economies of scale, supply chain and skills development if substantial demand can be generated, through e.g. mandatory performance requirements on *existing* buildings.

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.

3.6 Niche 6: smart heating controls and meters

3.6.1 Innovation and market trajectory

Controls are the interface between heat users and their heating system. They provide a gateway to heating performance management, and hence potential energy use and cost savings. Smart meters may also potentially pave the way for heating system improvements by better-informed users and more automated forms of use optimisation. They cannot, however, make up for inefficient heating systems or poorly insulated homes. Evaluating efficiency and cost savings form such devices is inherently tricky and contested.

Historical overview. Basic control technology (e.g. timer, room thermostats, radiator valves) are a standard feature of heating systems but 70% of British do not have the full set (DECC 2011d). The miniaturisation of consumer electronics has expanded their features (e.g. heating programmers, timed settings, etc.). The generalised use of smart phones and the ‘Internet of Things’ are promising new, more convenient forms of domestic environment control – addressing functions such as energy management, safety and lifestyle support (Balta-Ozkan et al 2013). Recently, the first generation of smart thermostats has made its appearance on the UK market.

Motivations. The main arguments in favour of smart meters are consumer-oriented: expected energy savings (from optimisation in use), increased wellbeing and comfort. Smart meters are expected to deliver energy efficiency improvements automation and behavioural change. An observed lack of user interest in household energy management is both a challenge and an opportunity for smart meters to fill a gap. A less publicly acclaimed argument relates to the potential for energy suppliers to acquire priceless real-time data on demand patterns, and the possibility for third party remote control – arguably the main motivation behind the smart meter rollout agenda (Pullinger et al 2014).

Technical components. Smart meters combine basic control components and features (sensors, thermostat, timing, etc.) with the opportunities offered by ubiquitous electronics and the ‘Internet of Things’. Home technology is inscribed in a larger data-intensive infrastructure (e.g. ‘smart grid’) comprising a number of technologies, actors and services (Figure 9). The main elements, as far as heating is concerned, include:

- within a ‘Home Area Network’:
    - an in-home display unit (IHD) with advanced data visualisation options: real-time feedback and historical data on energy usage and spending
    - a smart gas meter and other environmental sensors
    - a communication hub enabling wireless data exchange
    - smart appliances
- extending to the ‘wide area network’:
    - a data and communication infrastructure (network, regulations, service provision)
    - third-party service provision (e.g. energy management, data mining, etc.)

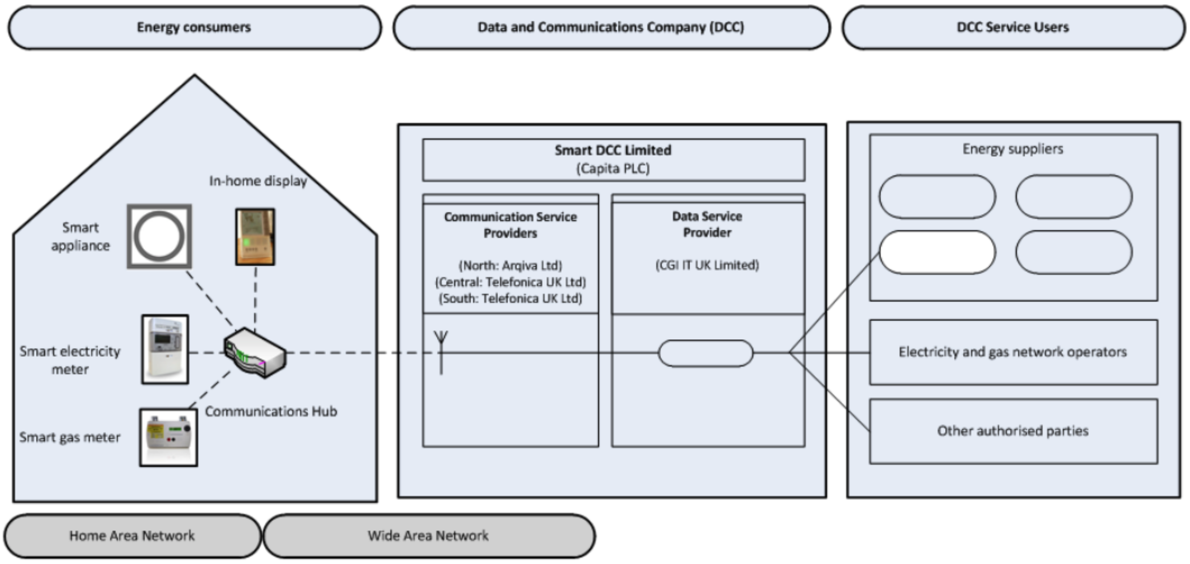


Figure 9: The smart metering system (DECC 2013d)

Markets. The market for smart meters is currently relatively small in the UK. However, the potential market is large, as recent policy commitments were made towards the rollout of 53 million devices by 2020, requiring ambitious yearly installation rates, in excess of 10 millions for some years (see Figure 10). Such commitments to basic infrastructure and metering may open up a potentially large and profitable market in energy-related smart devices and services.

However, there are currently no market incentives for heating appliance manufacturers to improve their controls (Consumer Focus 2012), which means that energy suppliers are most likely to deploy basic (cheaper) smart meters serving their needs (energy usage data access) rather than more sophisticated (and promising) meters. At any rate, given the relative novelty of smart meters, related products, services and business models remain to be invented, trialled and negotiated with users.

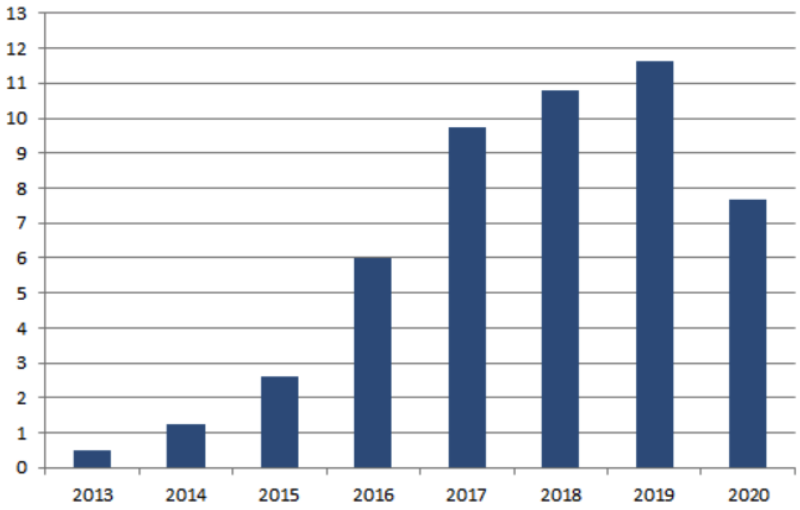


Figure 10: Projected yearly smart and advanced meter installations, millions (DECC 2013d)

Research and innovation. Continuing ICT developments present important prospects in the field of energy management. While current smart meters offer user feedback through real-time data, a number of more advanced applications are possible, including:

- predictive display of expected energy use
- self-adapting controls learning from previous behaviour patterns
- energy data related services and energy management systems
- the multiplication of sensors (e.g. wireless-enabled appliances) and disaggregated feedback on energy use
- playful interaction and game-oriented user involvement

Issues meriting further investigation include user behaviour, response to, and acceptability of smart meters, privacy and security of energy data. In advance of the planned mainstream national rollout of smart meters, academic and industry-led field trials have been initiated. The Smarter Heating Controls Research Programme has been developed by DECC in 2012 to generate robust evidence “that either standard or more advanced heating controls actually save energy”[19] to support the Government’s rollout programme on the basis of previous research evidence and the results of field trials.

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[19] https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smarter-heating-controls-research-programme

Consumers and legitimacy. The main consumer issues 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.

Concerning the recent rollout policy programme, a number of issues have arisen, including the lack of public debate and consumer involvement, and ambiguities about who, from the consumer or the energy suppliers, really is to benefit from this scheme. There are concerns (truly) smart technology is costly and only for an affluent minority (Balta-Ozkan et al 2013).

3.6.2 Actors and networks

Smart metering and smart energy networks involve traditional energy actors (suppliers, regulators, installers, etc.), major new opportunities for component suppliers (e.g. meters), as well as emerging data-oriented actors developing new products and services.

Actors and strategies. Energy suppliers are keen on smart meter rollout, as it will allow them to monitor real-time energy demand with a high level of detail, instead of relying on estimates and 'manual' meter readings. This is likely to translate into savings through energy supply and personnel adjustments. In the deployment phase, however, energy companies will have to arrange for meter installation by subcontracting or employing meter operatives (Jennings 2013). At any rate, meeting projected deployment ambitions will require the training and skilling of a large workforce dedicated to installation and maintenance, troubleshooting, and advice on energy efficiency and smart meter usage.

In the frame of the planned smart meter rollout, energy utilities signed contracts with meter manufacturers:

> "British Gas's agreement with Landis+Gyr to provide smart meters, First Utility's appointment of Siemens to deliver, install and maintain domestic meters and the Siemens and Green Energy Options (GEO) project to bring smart metering into multi-dwelling and high-rise buildings" (DECC 2013d:32-3).

A number of companies have positioned themselves on the in-home energy display and heating control market, including Nest (owned by Google), Hive (owned by British Gas), Tado, Green Energy Options (Geo), and more established companies such as Siemens. The deployment of smart metering and energy management could open up a market for a wide range of products and services, from consumer electronics to energy management apps. Interoperability between devices and platforms will require cooperation or regulation through standards – something for which the ICT industry has a mixed track record.

At a network level, a wide area smart energy network relies on intensive data and communication infrastructure (a grid) and supporting regulations and management. Smart

DCC has been granted a license to "establish and manage the smart metering communications infrastructure, governed by the Smart Energy Code".[20] As such, it will oversee issues such as data provision, access and permissions.

Visions and expectations. Smart metering is inscribed in visions of smart grid developments and active demand-side network management, an agenda pushed for by the main energy trade associations, particularly in the electricity sector (Connor et al 2014). The main argument is that 'smart' devices, systems and networks can deliver energy savings where behavioural change has so far failed to:

> "[Smart] homes can provide a means of shifting and reducing energy demand independent of the need for behaviour change." (Balta-Ozkan et al 2013:361)

Advanced controls are also advocated as crucial 'infrastructure-type' investment enabling efficient delivery of energy savings at system and appliance level, e.g. with heat pumps.

The UK government has taken a strong interest in smart meters, and is leading an ambitious rollout programme (see below). There is a perspective according to which smart meters (and the data communication and processing systems underlying them) consist in an infrastructure investment that is crucial for the future development of smart grids, smart homes, etc., together unlocking network level demand-side response energy savings potential (Balta-Ozkan et al 2013)

3.6.3 Governance and policy

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.

The smart meter rollout is largely a top-down venture to deploy what is seen as the necessary infrastructure for a technology that will unlock a largely untapped potential for energy savings and greater system efficiency. At European level, the Smart Meter Rollout Directive (2009/72/EC) requires at least 80% rollout of smart meters by 2020 from Member States. The UK is currently leading the way in Europe with mandated smart meter, along with Ireland, the Netherlands, and Italy.

A Government proposal for smart meter rollout was published in 2010. Following a consultation in 2011, it was concluded that

> "energy suppliers should install smart metering equipment meeting defined technical specifications. At a minimum, this will involve a completion target and mandatory reporting of progress by suppliers. The Government's intention is to consult on an obligation on suppliers to effectively complete the rollout in 2019"[21]

The scale of this programme is impressive and unprecedented, as it seeks the installation of 53 million devices by 2020. The cost is estimated at £11bn, or roughly £200 per household. These costs have been justified by the potential future savings, as evidenced by an impact assessment estimating the net present value of this programme at over £6bn.

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[20] www.smartdcc.co.uk

[21] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42735/1479-rollout-strategy-smart-metering.pdf

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 to start in late 2015, in relation to lack of preparedness. The minister for energy and climate change was reported stating:

> "I want to ensure that consumers have a good experience of smart metering from day one [and] that's why we are allowing additional time for the energy suppliers to complete the rollout, so industry has the time to get it right for consumers."[22]

In November 2014, 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.[23]

3.6.4 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. As with most infrastructure development, 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.

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.

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:

> “[it] has been designed to minimise disruption to the existing market-based energy regime and incumbent actors: existing suppliers are obligated to ‘deliver the rollout’ of smart meters, including the design or procurement of equipment, with Ofgem continuing its monitoring and regulatory role” (Pullinger et al 2014:9)

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[22] http://www.theguardian.com/environment/2013/may/10/smart-meter-rollout-delay-year

[23] http://www.telegraph.co.uk/earth/energy/11242115/11bn-energy-smart-meter-roll-out-suffers-fresh-delay.html

4 Conclusion

4.1 Momentum analysis

In this section, we provide an assessment of momentum for each niche-innovation, based on the consideration of innovation and market trajectory, supporting actors and networks, and policy and governance. The results are presented in Table 4, which also tries to assess momentum by using a rating.

Table 4: Momentum analysis of 6 niche-innovations in the heat domain in the UK

Niche and ranking	Momentum	Main drivers of momentum	Pathway
1. Smart heating controls and meters	Moderate	- market currently poorly developed - large market potential – virtually all homes connected in a large infrastructure rollout - innovation challenge resides in widespread rollout and effective management, rather than technological issues - supporting visions of smart grids. Potential downstream technological application and market development (accelerating feedback) - important plans and support for deployment. The national plans represent a massive infrastructure investment that should materialise to 2020. BUT delays. Hype/disappointment? Probably not, but lowered ambitions likely.	A but could enable B
2. Solar thermal	Low	- solar thermal (water) heating technology is a relatively mature proposition - UK market is quite small, but the largest compared to alternatives and steadily growing - well-developed markets in specific European countries, widespread availability of basic systems, promising innovation avenues, and standardisation - promising capability spillovers form PV installation - the domestic Renewable Heat Incentive may provide strong incentive for mainstream growth	B
3. Small biomass	Very low	- mature technology - poorly developed market (besides small market pocket off-grid housing) - few British manufacturers and suppliers involved - technological development abroad (e.g. Scandinavia)	B
4. District heating	Very low	- UK market for heat networks is currently poorly developed - early UK experiments (1960s-1980s) not followed through - technological and commercial success elsewhere (e.g. Sweden and Germany) - institutional, regulatory, infrastructural and market barriers in the UK - need for new business models and institutional forms rewarding long-term infrastructure commitments - current hopes for a new expansion phase (e.g. council housing and public utility) - some local momentum (local authorities driven) - recent Heat Strategy provide support BUT need to transform local authorities initiatives into strengthening of knowledge networks, skills and supply chains for greater momentum and legitimation	B with elements of A

5. Heat pumps	Very low	- heat pump technology is considered mature - not much skill and experience in the UK - current UK market for heat pumps is fairly small and niche (marginal off-grid pockets) - commercial distribution and promotion networks are poorly developed - lack of installation expertise on the ground. - high expectations about future deployment - within UK heating policy, heat pumps are seen as the main long-term option for domestic heating, especially from 2030 and onwards BUT deployment of heat pumps in the UK likely depend on the decarbonisation of the electricity system and efficiency improvements in the housing sector.	B
6. Low energy retrofits	Very low	- currently small market - large potential market, of old and poorly insulated building stock - 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.) - publicly funded demonstrations are accumulating experimental knowledge on the ground BUT Important barriers to deployment include costs, building conservation requirements, a lack of skills and knowledge in the building industry, and poor material supply	A with elements of B

4.2 Conclusion about transition pathways

In this section, we provide an assessment of the niches-innovations in terms of their fit to the ideal-types Pathways A and B, ‘technical component substitution’ and ‘broader regime transformation’, respectively. For most cases, we find a dominant leaning towards one of the ideal Pathways, but also some elements of the other.

Small biomass has many elements of a Pathway B development insofar as it is driven by new entrants (fuel supply and dedicated appliance manufacturers), is currently framed as a decentralised option, is relatively independent of the existing gas distribution infrastructure and related agencies, and requires a cultural-cognitive shift towards greater user involvement in heating practices. However, it also has elements of a Pathway A development insofar as it is compatible with a heating regime based on individual appliances with point-source heating.

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 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.

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 power supply and distribution network, and depend on decarbonisation in that domain.

Solar thermal heating has many elements of a Pathway B development insofar as it is currently an ‘off-grid’ or back-up energy proposition, disconnected from centralised energy systems or boiler-based heating, seeks to make the most of widely and freely available solar radiation, and rests on relatively new entrants and skills (that partly build on PV development).

Low energy retrofits have many elements of a Pathway A development insofar as they aim to improve the existing building infrastructure by implementing a number of known measures (replacing or upgrading conventional insulation materials, etc.) with an obvious role for the construction/refurbishment sector (albeit with the adoption of new skills and ways of doing). However, a number of elements point toward a Pathway B development, and particularly the relationship with major innovations occurring in the area of passive and zero-energy houses, which promise to fundamentally revisit the way we conceive of domestic heating, and how the construction sector operates (new actors, principles, and skills base).

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.

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