PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

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

<u>Country report 5</u>: The UK heat system

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Executive summary

The purpose of this document is to develop a forward-looking, qualitative scenario describing a socio-technical pathway for the UK heat domain. Unlike other D2.5. PATHWAYS reports, we build this analysis not on quantitative scenarios created in WP1, but on a more commonly used scenario mobilised in UK policy discussions: The RESOM core run for residential heat use. This scenario figures centrally in support of the recent Heat Strategy (DECC 2012; 2013) and covers the period and constraints required for our analysis.

We use this quantitative scenario as starting point and develop an imaginative, yet plausible storyline of what (socio-technical) changes would need to occur in order for this scenario to happen. We hence offer *endogenous* underpinnings of the quantitative patterns and emphasise, for instance, the role of different actor groups, struggles and conflicts, or lock-ins. To do this, we build on empirical data generated in PATHWAYS D2.1, D2.2 and D2.3, mobilising the same analytical categories.

To analyse tensions between the future model scenario and our earlier WP2 findings on niche momentum within the heat domain in the UK, we identify so-called 'transition challenges' (the constraints and possibilities) faced in trying to achieve the low-carbon pathway:

Innovation /Challenge	RESOM core run / Pathway	Constraints
Heat pumps (Hybrid, ASHP and GSHP)	This pathway suggests a very important role for heat pumps, from virtually 0% of heat provision in 2011, to around 85% by 2050. Disregarding the distinction between air- and ground-source HPs, this scenario suggests 2 HP dynamics: - a very rapid roll out of hybrids (gas-HP) (from 0% in 2011 to nearly 60% of requirements by 2030). It is assumed that these hybrids would shift from mainly gas to mainly electric over the long run, and be nearly phased out by 2050 - a more gradual but long-lived roll out of HPs (from 0% in 2011 to around 85% in 2030) Hybrids are seen as a more flexible, transitional technology. The main issues here are: - whilst technically possible (relatively mature technology deployed elsewhere), there are currently no real signs of these emerging trends, and policy signals point in the wrong direction - the 'outsourcing' of decarbonisation to the electricity sector - the dependence of HPs on well-insulated houses to function efficiently (and hence lead to overall energy reduction) - there is a 'single bullet' perspective on addressing the heating challenge	Technical and economic feasibility (of deployment) Inexistent supply, installation and maintenance chains (important barriers to adoption, in terms of skills and capabilities) Lack of policy and political will (from discourse to substance) Economics (how to finance) Domain integration, and strong prerequisite of electricity supply decarbonisation
Conventional boilers (predominantly gas but also fuel oil and electric)	This pathway suggests a simple story for conventional boilers (including gas, fuel oil, and electric): complete phase-out by 2030, from around 85%, 8%, and 8%, respectively. This is a very rapid phase-out that is compensated to some extent by the deployment of hybrid boilers (first using predominantly gas and then predominantly electric HP), although in terms of appliance renewal rates may be feasible. The main challenges are:	Technical and economic feasibility (of phase out) Lack of policy and political will (from discourse to substance) Potential political resistance by energy suppliers and distributors

	- the current absence of credible alternatives on the ground - the absence of (dis)incentives or regulations - potential stranded assets in the gas grid	
Heat networks (district heating – DH)	This pathway assumes a gradual but shy rise in the significance of heat networks, from virtually 0% in 2011 up to about 10% of heating output by 2050. This trend is a credible one, as the potential for more ambitious roll out would be constrained by the rates and costs of housing stock renewal (or major refurbishment) required. There are difficulties with establishing the kinds of stable long-term consortiums, business and pricing models required, but the devolution agenda may be beneficial by granting more power to local authorities.	Not many Needs stable policy frame and polity High infrastructure costs
Efficiency improvements / Demand reduction	This pathway assumes a gradual but significant role for efficiency improvements and demand reductions in curbing the heating demand rise that would be expected by 2050, corresponding to just over 20% reduction on projected demand. While this may be technically feasible, there are serious concerns in terms of financing these refurbishments, changing building regulations and practices, establishing low-carbon refurbishment competences, and ownership structures in the housing domain. Furthermore, it is unclear whether the efficiency improvements required to achieve expected decarbonisation from the roll out of HPs has been computed.	Technical and economic feasibility (of phase out) Lack of policy and political will (from discourse to substance) Economics (how to finance)

This brief analytical summary allows us to link the quantitative CO2 reduction scenario with the qualitative socio-technical scenarios developed in this document.

For our scenario, we divide our storyline into two main periods (2015-2030 and 2030-2050). Our methodical approach is to 'tell the history of the future', meaning that our detailed scenario descriptions are written in past tense.

Scenario: RESOM core run – all-electric heating

Modelling outcomes within PATHWAYS were missing at the time of writing and we are hence not creating storylines following our usual pathway A and B distinction but a single pathway attuned to the quantitative scenario at hand. For this reason, unlike other D2.5 PATHWAYS reports, we build this analysis not on quantitative scenarios created in WP1, but on a more commonly used scenario mobilised in UK low-carbon heat policy discussions: The RESOM core run for residential heat use. This scenario figures centrally in support of the recent Heat Strategy (DECC 2012; 2013) and covers the period and constraints required for our analysis. Modelling outcomes within PATHWAYS were missing at the time of writing and we are hence not creating storylines following our usual pathway A and B distinction, but a singular pathway attuned to the quantitative scenario. The overall picture of this scenario is largely comparable to earlier models informing decarbonisation policy, such as MARKAL modelling runs DECC-1A-IAB-2A as put forward in the Carbon Plan (2011).

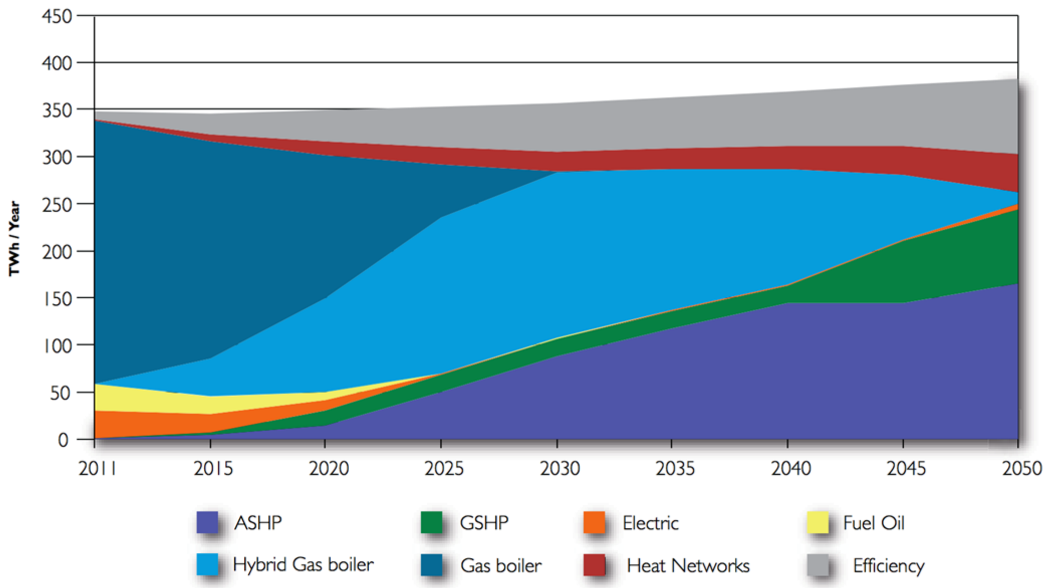

Figure 1: RESOM core run – domestic space heat and hot water output (DECC 2013:78)

This core run, achieving significant greenhouse gas reductions from ca. 80 MtCO2/yr in 2010 to ca. 10 MtCO2/yr by 2050, relies mainly on the rapid phase-out of gas boilers and the massive deployment of different forms of heat pumps (HPs), hence largely 'outsourcing' carbon reductions to the electricity sector. Demand reductions from efficiency improvements also play a significant role over the long run, along with district heating (DH) in denser areas – largely supplied by gas CHP until 2030, and by large-scale HPs and nuclear power stations thereafter.

2015 – 2030: Hybridisation of residential heating

This period started just after the 'discovery' of heat as a pressing policy area for decarbonisation towards the end of the first decade of the century. It had become clear that reaching the binding targets of 80% GHG emission reductions by 2050 would require considerable efforts in the heat domain. The UK Government had ambitions to fully reconfigure the residential heat supply system. This ambition was supported by the so-called 'Heat Strategy', which relied mainly on 1) encouraging energy efficiency in buildings, and 2) moving towards low-carbon heat (for which electrification of heat via HPs was a promising prospect). However, in these early years of ambitious plans, renewable heat was struggling to generate any significant momentum and none of the many options (biomass, heat pumps, solar thermal, etc.) managed to get off the ground – with the exception of small market pockets in mainly off-grid locations. More structural options such as low-energy retrofits and district heating were proving even more difficult – in large part due to the inertia and poor energy performance of the housing stock. The general background was influenced by soaring energy prices, and gas in particular, which was raising concerns in terms of energy security as the UK was increasingly relying on imports.

Successive governments had introduced incentives schemes under different names (RHPP, DHI, Green Deal, etc.), but these were characterised by a general tendency to the regular scaling back of funding and inconsistent long-term signals as well as very little overall effectiveness. In 2018, the Heat Strategy was scrutinised by a number of expert reviews ranging from Whitehall and academics to NGOs, all pointing to the lack of progress, inconsistency, and the need for a clear and feasible strategy. Such a strategy was to be oriented towards a feasible transition trajectory making the most of existing opportunities for green industry development. The recommendations were overwhelmingly in favour of pursuing a narrow portfolio of technologies with great intensity and strong direction, rather than supporting up an open and competitive innovation race for a wide range of options through non-prescriptive market incentives. A case was built under the banner of 'electrifying heat' – largely based on the positive achievements in early decarbonisation of the electricity sector, and the sense of hope that this generated.

The 'electrifying heat' strategy was initially resisted collectively by the industry, in large part due to the tacit coordination between the main energy suppliers (the 'Big Six'), and the vested interest that the National Grid had in maintaining the status quo. The destabilisation of gas demand, which would result from a move towards non gas-based, lower carbon heat supply, faced substantial resistance. However, this picture started to change as a result of increasing pressure on gas supplies and price which was eroding the relative cost advantage argument; opportunities in heat pump technologies and demand shifts; and increasing pressure from smaller electricity supply and distribution companies not involved in gas and increasingly differentiating themselves by projecting an attractive green and progressive image. Electricity suppliers saw a competitive advantage in getting involved with HP technology, understanding related opportunities in terms of electricity demand patterns, and getting involved early in shaping what increasingly seemed like a clear policy commitment. Whilst Centrica, which had retained the largest share of the market, remained firmly reactive, Edf and E.On sought to demarcate themselves by making the first bold pledges to support this policy – promising to drastically reduce their stakes in gas supply by 2030.

Meanwhile, an embryonic HP industry was in strong need for support, as it had not developed significantly since 2010. On the up-side, a renewable heat industry had built up internationally, providing a number of options to be implemented in the UK (with potential co-benefits in terms of job creation, etc.). The main challenge for low carbon heat in the UK was to generate the conditions and capability for the uptake of effective solutions. The UK government wanted to support the development of HPs for domestic heating and the underlying industry, by backing research and development as well as by coordinating field trials to gather information on the performance of domestic heat pumps and possible improvements. Much was learnt, particularly about the scale and scope of the challenge. Clear future directions were set out to address specific challenges: 1) integrating HP development with insulation measures, 2) training and skilling key actors of the building sector (plumbers and technicians, developers, customers, building regulations legislators, etc.), 3) rethinking heat governance, including responsibilities, incentive structures, and building regulations, and 4) establishing strong and vibrant supply-chains with the longer-term objective for the UK to become a leader on the global market.

In 2018, the Department for Business, Innovation and Skills set up the 'Future heat jobs' programme, in coordination with the Department for Education, and under direct advice from the Council for Science and Technology (CST). This programme was tasked with supplying the HP roll out projected ambitions with the skills and expertise on the ground to deliver them, by geographical area, and over time – an exercise largely motivated by the massive expected shortage of skilled labour in this sector. An expected 100,000 newly skilled technicians were needed on a yearly basis to kick-start the industry, stabilising towards 50,000 after 5 years. These jobs included drillers, plumbers, electricians, low-energy building workers, and assembly-line workers. Further training and skilling was required in terms of engineering, planning authorities, and salesmanship. This ambitious training and skilling programme relied on the set up of 25 technical academies and research centres throughout the country.

Between 2016 and 2020, electricity corporations also became strongly committed to heat pump technology, strengthening their research capabilities and investing in supply capacity in moves towards vertical coordination. Commercially, this enabled the set-up of innovative new types of contracts that included appliances (HPs) and a baseline supply contract – following a model pioneered in previous decades by telecommunications companies. Electricity companies also played a leading role in co-financing industry skilling programmes and scouting talent through grant schemes.

In terms of policy interventions oriented towards users and appliance conversion, the 'electrifying heat' policy widely drew from experience accumulated with product conversions elsewhere: light bulbs and CFCs (although heat appliances were more challenging due to their greater costs and lifetime), and from successful HP deployment schemes. Since the technology was relatively mature, and notwithstanding the challenge of building supply, installation and maintenance chains, the main market deployment strategy focussed on a ban on conventional boilers, lowering HP costs, and staged conversion in priority segments. By 2018, the installation of new conventional gas boilers was fully banned, which was nonetheless a very bold policy move. Naturally, installation subsidies (in particular, for households faced with energy poverty) played a significant role in making heat pumps and hybrid boilers more attractive relative to gas boilers, and enabling the implementation of the ban. The increasingly unpredictable price of gas – which hit lower incomes the hardest – also contributed to a general acceptance of the need for alternatives to boilers.

On the legitimacy front, there was an uphill battle to familiarise the public with this new technology, lifting barriers to adoption and raising the profile of HPs. At the time, only a limited number of proactive consumers were familiar with HPs, which were still perceived as quite complicated and new. Increasing the interest and awareness of HPs – which was small compared also to other heat sources – through better information, marketing, and communication became a priority. Crucial for constructing a positive narrative was the generation of alliances between electricity suppliers, the nascent HP industry, and consumer and citizen-oriented actors (e.g. NGOs and energy awareness advocates) – who aptly articulated the promise of heat electrification with issues of energy affordability. The Energy Saving Trust played a leading role in framing this narrative of change, simplifying and standardising offers, and making it accessible to homeowners by providing simple financial models and installation procedures that highlighted the undisruptive nature of change and its high cost saving potential. This coalition of actors also collectively addressed supply-side deficiencies – aligning development strategies to create a more coherent and stable offer for an emerging consumer.

However, the main obstacle was related to user reticence with a technology that required greater engagement with heat as a practice. Indeed, heat pumps supply low-temperature heat, and are most efficient when very gradually heating spaces over a number of hours, which is in stark contrast with the user experience of hot radiators and real-time heat feedback. There was a genuine demand for knowledge about heat and managing energy use, for which the knowledge and capacity of the Energy Saving Trust was actively mobilised. The Government recognised the need for this 'home economics' training and financed its expansion. Demonstrations and information campaigns were important to convince potential users, but there was a strong need for a marketing mechanism that would convert the apparent convenience loss into a benefit elsewhere: heat pumps needed to be either cheaper or more flexible, or the user herself would have to change. It is this very realisation that was behind the 'making heat pumps happen' market development strategy, led by the emerging support coalition and led by heat pump associations: 1) in the short term, hybrid heat pumps would allow heat practices to go virtually unchanged, yet enable 2) the development of a market for HPs and hence the reduction of production, installation, and maintenance costs, and 3) exposure to HPs, and the economic benefits arising from their optimal use will convert users to step out of gas. The relative ease for HP installers to get certification generated a positive dynamic by which HP marketing contributed to 'push' for early conversions as sales professionals consistently brought commercial arguments forward. The widespread dissemination of arguments for energy saving processes also contributed to shaping the collective mind towards the consideration of long-term annuitized costs of energy investments that included appliance and life-time usage costs. Such a new perspective largely favoured the more efficient heat pumps.

By 2022 nearly half of gas boilers had been replaced by hybrids, a significant number of households had adopted full HPs (mostly in newer and better insulated buildings). This positive dynamic was contributing to greater familiarity and exposure to HPs, which also made the benefits more apparent. Hybrid boilers had become commonplace. Heat pumps in well-insulated homes had become desirable. An unintended effect of this cultural shift was the raised importance of insulation and energy efficiency of buildings.

Improving the energy efficiency of buildings was a much more challenging issue than the hybridisation and conversion of gas boilers to heat pumps. The main challenges concerned the financing of refurbishments, the improvement of building regulations and practices, the establishment of low-carbon refurbishment competences, and the issue of ownership structures in the housing domain. Rising energy prices and the structural inequality in housing conditions had generated serious concerns about energy poverty. Whilst these had been largely unattended since the late 1990s, the changed policy mindset, characterised government new inclination to significantly invest in infrastructure and long-term industrial development, offered significant new opportunities. Energy poverty provided a further justification of such investments, which was aptly mobilised to further legitimise official policy. The government communicated widely on its proactive steps towards energy efficiency conversions of the building stock, which was supported by and further stimulated the 'Future heat jobs' programme. This enabled the acceleration of demolitions and the building of new developments focussing on efficiency that benefitted substantial from a relaxing of building codes despite protest of the National Trust against the emergence of an architectural 'Wild West' where engineering criteria prevailed over aesthetic and planning considerations. In smaller housing units, the 'warm home right' for tenants inverted the burden of proof that had so long worked in landlords' favour. Supported by increasing number of inspections and simplification of tenant complaining procedure, prohibitive fines were applied to poorly insulated rental houses to jump-start rapid conversion of out-dated building stock. To support conversions, cheap loans and tax credits were set up for refurbishments, targeted at homeowners, and supported by increasingly reasonable cost saving cases.

A similar long-term strategy was devised to support the development of District Heating (DH) where conditions lent themselves to it. Any new large-scale housing development was mandated to adopt DH by 2023 – in practice this meant in most cases in combination with CHP plant. This initiated a shift in building practices, starting in new high-end developments and conversions, then inscribed within a majority of regeneration plans and 'new towns' – implemented in stages towards 2050. Energy supply for these heat networks was supported by the deployment of CHP (often linked to waste management following the trialled and tested Swedish model) and large HPs. The early retirement of poor performance buildings also stimulated the construction sector and further generated market for high-efficiency housing and DH. Incidentally, the set-up of large-scale heat networks opened up scope for a new wave of local authority involvement with social and collective housing, inverting a trend that had established itself since the early 1980s.

The UK policy context had been revived by a general change of governance leaving behind nearly a decade of austerity policies (2008-2017) and moving on with substantial long-term investments in the spirit of an entrepreneurial state cultivating a strategic portfolio of industrial growth areas. By shifting to long-term strategic coherence and integration with industrial and innovation policy, energy governance had finally become exposed to the realities of win-wins and positive feedback loops. This had been enabled by a more ‘hands-on’ approach to innovation policy and technological choice in the energy sector, but also the search for systemic solutions that could overcome initial industry reticence by seeking long-term opportunities. The substantial squeeze from gas price hikes was also an important factor in providing a clear direction signal for change.

2030-2050: from hybrid to all-electric heating

By the late 2020s, gas had become relatively expensive and unpredictable as the UK mainly relied on international exports. Pursuing the heat electrification agenda, the government had resisted the pressure to subsidise residential gas prices (as it had done in the industrial sector), and instead further supported conversions to alternatives. Rising energy prices had generally led to greater engagement of individuals with energy practices, which had also evolved with greater exposure with hybrid HPs and HPs. Energy awareness, gaining new knowledge and adopting saving practices, had become a necessary part of life for householders – a shift that had been actively supported by grassroots initiatives and NGOs involvement.

The efforts and long-term policies set out from 2018 were starting to generate significant momentum, very healthy markets, and functional supply chains. By 2030, hybrid boilers had become very well developed in the UK, representing over 60% of residential heating appliances. Conventional boilers were fully phased out, and virtually absent of residential use. Hybrid users were also increasingly relying on an electric-only heating mode. Gradually, the gas supply infrastructure shrank and retreated to a minimum, largely related to strategic industrial areas. This offered opportunities for recycling.

Full HPs had broken through and captured nearly one third of the market for heating appliances. HPs were no longer seen as inconvenient and heating practices had adapted to this decidedly more modern form of heat. Insulated homes, with under floor heating had largely contributed to the appeal of greater heating control. The cooling function of HPs was also seen as an advantage in a climate with increasingly warm summers.

In terms of supply chains, HPs has become widespread, and no longer technically challenging. ‘Future heat jobs’ had been critical in this major success, as all installers and heat engineers had become experts and enthusiastic ambassadors of this revolution in heating technology and practices. The further development and integration of supply chains contributed to bringing the cost of HPs and their installation down.

However, there was also a sense that full HPs had enjoyed the low-hanging fruits of market expansion in households that were well insulated, characterised by high incomes, high energy literacy, and often in privately owned detached houses. The next challenge would be to expand beyond this segment, and to further improve insulation to reap the benefits of a generalised market for HPs. While the economic barriers were no longer too high given substantial cost reductions and supply chains were eager to further expand, the main obstacle was related to poor quality building stock in need for low-energy retrofits. The gradual tightening of minimum performance standards for existing properties since the late 2010s had gone a long way, and so did the ‘warm home right’ campaign targeted at poorest households.

Building on the experience of trained technicians and engineers, a systematic evaluation of the building stock carried out in 2032 identified that 15% of the building stock was still not fit for life in an energy efficient world – despite tremendous efforts to improve efficiencies or demolish poor performance buildings. These buildings would require substantial low-energy refurbishments or face demolition. Conversions were supported by financial incentives and zero-interest loans, and demolitions were encouraged for buildings presenting lesser heritage value. There, the building industry experimented with ultra-low energy prefabricated houses which proved a great success.

During this period, DH expanded substantially in urban areas, which also presented opportunities in terms of integration in inter-regional networks, particularly in and around high-density suburbs.

The retreat of gas use had also followed a more strategically planned territorial pattern. Following recognition that gas supply was becoming unviable, it was realised that gas infrastructure would have to be abandoned in the long term, unless options for the development of new uses are seriously considered. The 'hollowing' out of entire areas from gas use meant that gas distribution had become irrelevant. The National Grid had pushed for support in implementing a geographically-determined phase-out plan, whereby high-pressure distribution would eventually remain only around strategic terminals and storage facilities, as well as linked to industrial activity clusters. In denser areas, the distribution infrastructure was dismantled (often in conjunction with the installation of heat networks) and recycled. The recycling of carbon steel became an important activity for the British steel industry.

Conclusions

We here make a few concluding comments about future-oriented transitions pathways storylines.

Challenging pathways. Our socio-technical scenario, informed primarily by existing modelling work, is constrained by ambitious decarbonisation objectives. As a consequence, the transition efforts required are substantial in terms of the speed, scale, and scope of change of individual practices and socio-technical configurations. The scenario presented here relies mainly on a deliberate innovation and industrial strategy that focuses almost exclusively on heat pumps, and recognises the need for stepping up capabilities and developing supply chains.

Most striking is how rapidly the phase-out of gas boilers has to occur for this pathway to materialise – although this is partly offset by the deployment of a hybrid technology – which is an extremely ambitious appliance replacement rate. Additionally, the decarbonisation of heating through electrification to some extent only displaces the problem top electricity generation, which becomes under higher pressure to decarbonise at the same time as to absorb higher demand levels.

Policymakers, in particular, play an important role in recognising and accelerating the momentum of relevant niche innovations. They also rely on constructive relationships with other actor groups and civil society for the legitimation of action or the break-up of specific resistances. Strict policies can only be introduced successfully with the right backing and actor coalitions in place.

Forcing through socio-political dimensions and the role of deliberate strategies. Realising this transitions pathway, i.e. shifting away from prevailing trends and in many cases fundamentally reverting them, requires a fair amount of 'forcing'. This can occur in different ways (including relying on external shocks and dramatic events, or futuristic high-technology assumptions), but we have focussed on socio-political agency. Thus, our storyline relies on consistent and deliberate policymaking strategies to support path-breaking innovation and reduce commitment to established regimes while increasing consumers' awareness of and familiarity with HPs. We also envision more political interactions within the energy industry in relation to stepping out of gas – with frontrunners and laggards amongst the established players. The value of this is to highlight the role of governance in bringing about and making sense of change (as opposed to purely techno-economic rationales). Our storyline further highlights the importance of decision-making – at different levels and by different factions of society (government, industry, users, etc.), most effectively in alliances.

Instruments and interventions. In order to realise transitions objectives, besides the need for consistent and legitimate strategies discussed above, a number of governance instruments and interventions are required. These can correspond to 'traditional' policy instruments such as financial (dis)incentives and regulations, but also more creative or systemic interventions, e.g. industry capacity-building, phase-out of appliances.

Two aspects come to the fore when attempting to complement modelling strategies with governance considerations: 1) interventions are required well beyond the 'blanket' macro-instruments considered by modellers, and 2) no single instrument is sufficient; instead, what is needed is policy instrument mixes within specific areas and a substantial degree of integration across policy areas.

Methodological issues. This exercise entails some methodological issues, which we briefly want to reflect upon. Quantitative models, like the one we used as basis for our analysis here, often neglect important (socio-technical) developments related to, for example, different actor groups and their interactions; policies; beliefs, decisions, struggles and conflicts; or lock-ins. Moreover, they lack a degree of imagination and hence do not in detail show how prospective pathways may unfold. These shortcomings were our main motivations for this exercise of developing qualitative socio-technical scenarios. In performing this exercise, we were constrained by modelling outputs as a guide to conform to. This is a formative exercise that can shed light on specific tensions and incoherencies, enables us to look at potential and conditional hurdles, and go beyond a simple distinction between 'now' and, say, 2050 by offering a number of hypothetical branching points to focus our socio-technical narratives. Importantly, however, the story we tell is speculative and must not be taken literally. Rather, they provide socio-technical texture to a future pathway and thereby offer further opportunities to evaluate transitions challenges within reasonable expectations.

A particular limitation in this case was the fact that no PATHWAYS models for two separate pathway A and pathway B scenarios were available. We had to base our analysis on an existing model, which prevented us from distinguishing different pathways, as well as from upstream engagement with the modelisation effort.

Multiple time horizons and branching points. Starting from model projections enables narrative storytelling to focus on significant prospective events that appear necessary to break the mould of established trends. In practice, these have been taken to be inflection points and the crossing of significant thresholds. They have informed the temporal bounding of storylines in two time periods, each characterised by a few dominant techno-economic developments to be explained by socio-technical change processes.

From an analytical standpoint, much more can be said about earlier periods, and uncertainties significantly increase the further we move away from the present. That being said, the importance of rapidly shifting away from conventional heat (which is a significant departure form current trends) further underlines the importance and urgency of strong policy priority shifts in the immediate future. What we have seen in our model and scenario is that the next five years already are absolutely fundamental for ‘bending the curve’. This is further underscored by the likelihood of resistance from established actors with vested interests in the current configuration.

Contents

1 Introduction

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In the next section, we briefly introduce the quantitative scenario.

Building on earlier WP2 work, section 3 subsequently provides an overview of main developments in the UK heat domain over the last 10-15 years (niche innovations, regime developments, and landscape trends).

In Section 4, we identify the main transition challenges, i.e. the degree of departure from current trends that is needed to achieve future scenario and the main related challenges.

Section 5, then, describes our qualitative scenario. We divide our storyline into two main periods (2015-2030 and 2030-2050). Our methodical approach is to 'tell the history of the future', meaning that our detailed scenario descriptions are written in past tense.

We conclude with some reflections on methodology and the value and limitations of such an exercise.

2 Quantitative scenario

Modelling outcomes within PATHWAYS were missing at the time of writing and we are hence not creating storylines following our usual pathway A and B distinction but a single pathway attuned to the quantitative scenario at hand. For this reason, unlike other D2.5 PATHWAYS reports, we build this analysis not on quantitative scenarios created in WP1, but on a more commonly used scenario mobilised in UK low-carbon heat policy discussions: The RESOM (Redpoint Energy System Optimisation Model) core run for residential heat use.[1] This scenario figures centrally in support of the recent Heat Strategy (DECC 2012; 2013) and covers the period and constraints required for our analysis. The overall picture of this scenario (Figure 1) is largely comparable to earlier models informing decarbonisation policy, such as MARKAL modelling runs DECC-1A-IAB-2A as put forward in the Carbon Plan (2011).

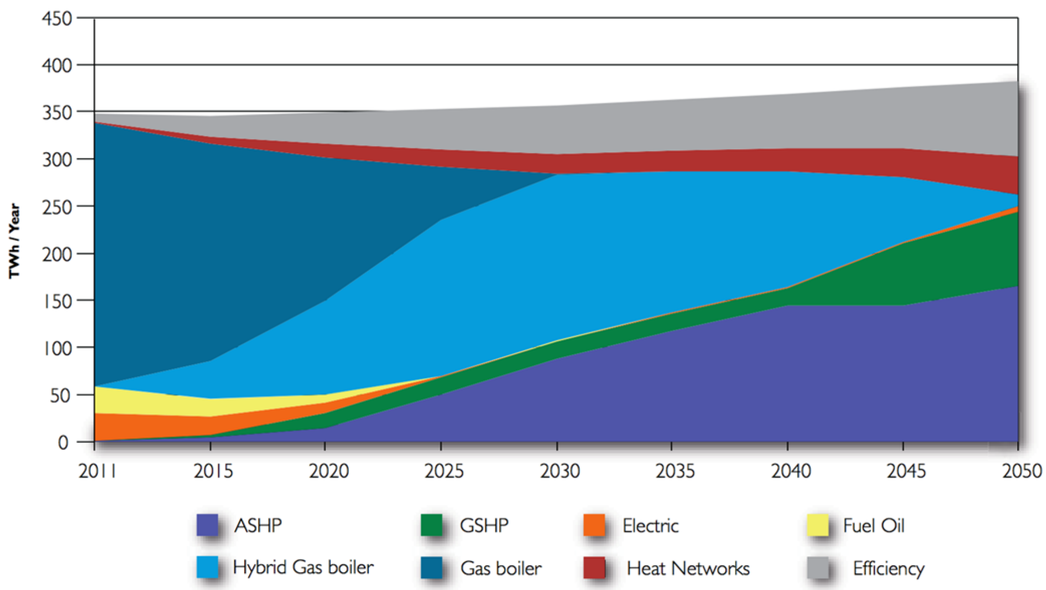

Figure 1: RESOM core run – domestic space heat and hot water output (DECC 2013:78)

This core run, achieving significant greenhouse gas reductions from ca. 80 MtCO2/yr in 2010 to ca. 10 MtCO2/yr by 2050, relies mainly on the rapid phase-out of gas boilers and the massive deployment of different forms of heat pumps (HPs), hence largely 'outsourcing' carbon reductions to the electricity sector, along a near full decarbonisation of power generation by 2050. Demand reductions from efficiency improvements also play a significant role over the long run, along with district heating (DH) in more densely populated areas – largely supplied by gas CHP until 2030, and by large-scale HPs and nuclear power thereafter.

Furthermore, this scenario relies strongly on the mobilisation of 'hybrid gas boilers' - where gas boilers are used in conjunction with heat pumps (see DECC 2013) - for a transitional period, with a rapid and immediate rollout to replace gas boilers by 2030, and a phase-out

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[1] See https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/197562/baringa_heat_paper_analytical_support.pdf for a brief overview of the RESOM model.

thereafter. It is also assumed that these hybrid systems would gradually shift from a predominant reliance on gas towards a predominant reliance on electricity.

3 Socio-technical developments in the recent past and present

3.1 Momentum of niche-innovations

In D2.1, we have analysed the momentum of a selection of niche-innovations over the last 10-15 years, systematically reviewing dynamics in 3 dimensions (techno-economic momentum, socio-cognitive momentum, and governance and policy momentum). We present these results in Table 1. In short, there is currently not much momentum for any of these niche-innovations in the British context, except for smart heating controls and meters. This is not to say that there is no *potential* for their development and deployment, but that currently the *conditions* are not conducive or supportive to such development. In particular, there is a lack of consistent and long-term visible support from the government; markets and supply-chains are underdeveloped; and small-scale demonstrations and trials are struggling to lift off the ground under such circumstances. Some of these technologies remain very marginal in off-grid locations, with limited further deployment potential.

Table 1: 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

3.2 Tensions in the prevailing heating and building regimes

In D2.2, we have analysed the sources of stability and tension both in the heating regime (see Table 2) and building regime. We summarise these findings in the following paragraphs:

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

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

Table 2: Summary findings from D2.2 of regime lock-in and tensions in the UK heating regime

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	Low cultural significance of 'heat' Low policy salience of 'heat' Financial crisis Neoliberal ideology and policy	Climate change and awareness of sustainability matters Gas and energy prices (related to resource availability and geopolitical change) Self-sufficiency and energy independence agenda Fuel poverty
Heating equipment supply	STRONG/MODERATE Gas boiler efficiency improvements over the years (incremental change) Gas assumes dominant market position No strong alternative in UK context Industry characterised by slow rate of change in skills and practice bases with preference for established solutions	WEAK/MODERATE Plans to rapidly phase out of existing gas boiler by 2030 (Heat strategy) (are these credible?) Many leadership and best practice examples in different European countries. Awareness of UK as laggard in comparative perspective
Gas supply and distribution infrastructure	STRONG Strong infrastructural lock-in (sunk costs, etc.), well functioning network. Competitive advantage from past network investments. Organisational linkages with electricity supply 'Unconventional' gas may attenuate supply squeeze. Gas grid could in a distant future be adjusted to distribute other energy carriers.	MODERATE Rising price of gas is major concern Opening to competition beyond Big Six (though weak) Gas supply under increasing criticism and dissatisfaction
Users /consumers	STRONG/MODERATE Consumers do not actively pursue heat-related choices. Individual users do not interact much with this kind of technology. Heating equipment purchases are often not planned but follow from breakdown. Awareness and interest about different heating and energy efficiency options are relatively low.	WEAK Gas prices lead to greater interest in more efficient options Low levels of engagement, trust and consumer satisfaction with gas suppliers Increasing sources of information about heating alternatives for interested consumers (e.g. Energy Saving Trust)
Policy-makers	MODERATE 'Unknown territory' for policy, as low-carbon heat has only recently been put on the agenda. History of support for micro-generation measures, but highly criticised in their effectiveness and scope Historic instability of energy policy in the UK not conducive to long-term financial commitments (of consumers and investors)	<u>POTENTIALLY</u> STRONG (but uncertain) New phase of low-carbon heat policy programme (Heat Strategy): - ambitious technological rollout vision (mainly energy efficiency and electrification via heat pumps) - specific instruments that follow from that (Renewable Heat Incentive) *but how effective and realistic is this? Difficult to distinguish symbolic discourse from substantial action at this early stage*
Public debate and opinion	MODERATE/STRONG Gas framed as relatively clean heating option (compared to coal and oil) Lack of salience of heating as issue not conducive	MODERATE Potential alignment of climate change, energy price and security concerns in favour of destabilisation

	to change	
Pressure from social movements, NGOs, scientists	MODERATE Low cultural visibility and salience of heat makes social mobilisation difficult.	MODERATE NGOs and energy researchers have contributed to put Low-carbon Heat on the policy map (e.g. Green Alliance 2007). NGOs and scientists critically evaluate policy progress to date as relatively poor, and roadmaps ahead (high uncertainties) but with little leverage.
Overall assessment	MODERATE/STRONG	MODERATE

Table 2 focuses on characteristics of the heating regime: the majority of listed points do, however, account also for the following table on the **building regime** (Table 3). This is due to the highly interconnected nature of these regimes. The overall assessment is largely congruent.

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

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

Table 3: Summary findings from D2.2 of regime lock-in and tensions in the UK building regime

	Lock-in, stabilising forces	Cracks, tensions, problems
External landscape pressures	Inertia of the building stock Low policy salience of ‘heat’ Neoliberal ideology and policy	Climate change and awareness of sustainability matters Gas and energy prices (related to resource availability and geopolitical change) Fuel poverty
Construction sector	STRONG/MODERATE Diffusion of basic insulation options and techniques (loft insulation, wall insulation, etc.) but not always integrated, leading to only minor improvements on average Low awareness and proficiency of advanced energy efficiency refurbishment skills and techniques There is a need for skills and supply chain improvements in the building industry, e.g. improved training, professionalisation, and greater standard requirements.	WEAK Development of specialised companies catering for a niche market of high efficiency retrofits. Emerging markets elsewhere in Europe, developing supply chains, skills, markets.
Housing stock	STRONG Strong infrastructural lock-in in exiting housing stock, which is on average old and energy inefficient. Replacement rates are very low.	WEAK The energy performance of newly built houses has much improved, but replacement rates are low.
Users /consumers	STRONG/MODERATE Retrofitting remains a voluntary measure and can	WEAK Rising gas prices lead to greater interest in

	lead to partial solutions (caused by structure of financial incentives) Spontaneous customer demand for retrofitting is low due to high upfront costs, uncertainty about economic gains, and technical difficulties Insulation and energy efficiency improvements are disruptive and often coincide with major refurbishments Awareness and interest about different heating and energy efficiency options are relatively low	efficiency matters Increasing interest among house owners to retrofit but not in private tenancies due to principal-agent problem Emergence of 'greener' homeowners Energy efficient refurbishing increasingly recognised as growing market Increasing sources of information for interested consumers (e.g. Energy Saving Trust)
Policy-makers	MODERATE 'Unknown territory' for policy, as low-carbon heat has only recently been put on the agenda. Energy efficiency improvements have largely been instigated by home owners with only limited government support Historic instability of energy policy in the UK not conducive to long-term financial commitments (of consumers and investors)	POTENTIALLY STRONG (but uncertain) New phase of low-carbon heat policy programme (Heat Strategy): - ambitious technological rollout vision (mainly energy efficiency and electrification via heat pumps) - specific instruments that follow from that (Renewable Heat Incentive) but how effective and realistic is this?
Public debate and opinion	MODERATE/STRONG Gas framed as relatively clean heating option (compared to coal and oil) Lack of salience of heating as issue not conducive to change	MODERATE Potential alignment of climate change, energy price and security concerns in favour of destabilisation
Pressure from social movements, NGOs, scientists	MODERATE Low cultural visibility and salience of heat makes social mobilisation difficult.	MODERATE A number of organisations promote the development of low-energy skills in the building sector (e.g. UK Green Buildings Council lobbies for energy efficiency in buildings to become an infrastructure priority) NGOs and energy researchers have contributed to put Low-carbon Heat on the policy map (e.g. Green Alliance 2007). NGOs and scientists critically evaluate policy progress to date as relatively poor, and roadmaps ahead (high uncertainties) but with little leverage.

3.3 Potential emerging transitions dynamics

Based on D2.4, we here provide an evaluation of the foreseeable fate of niche-innovations, their potential for contributing to transitions dynamics (and qualification thereof), and reflect on transitions dynamics in the heat domain in the UK.

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

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

4 Specifying 'transition challenges'

In this section, we are concerned with identifying the main transition challenges, i.e. the extent of departure from current trends (section 3) that is needed to achieve future scenario (section 2).

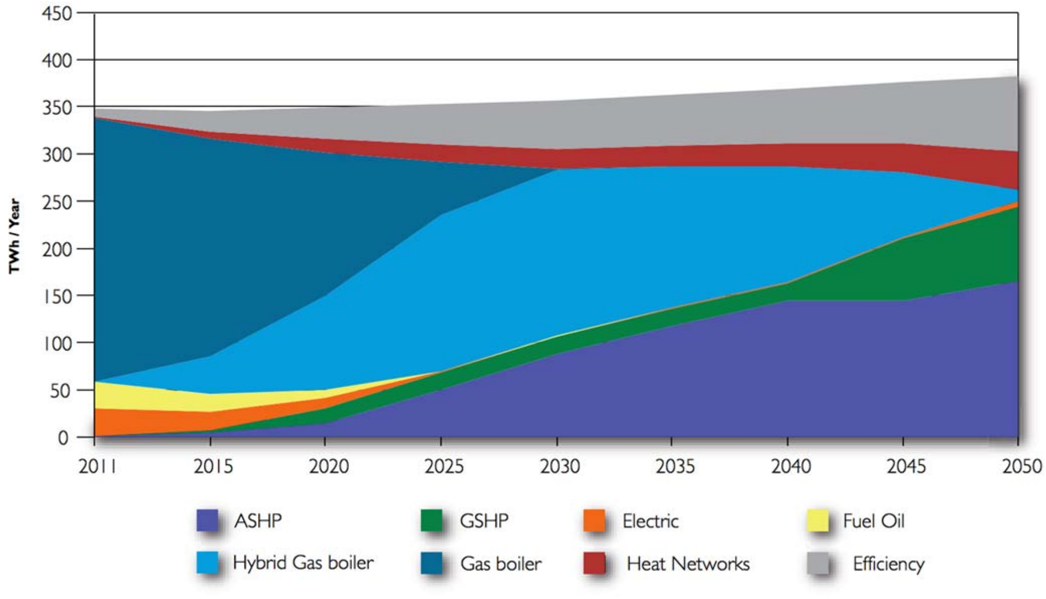
Innovation /Challenge	RESOM core run / Pathway	Constraints
Heat pumps (Hybrid, ASHP and GSHP)	This pathway suggests a very important role for heat pumps, from virtually 0% of heat provision in 2011, to around 85% by 2050. Disregarding the distinction between air- and ground-source HPs, this scenario suggests 2 HP dynamics: - a very rapid roll out of hybrids (gas-HP) (from 0% in 2011 to nearly 60% of requirements by 2030). It is assumed that these hybrids would shift from mainly gas to mainly electric over the long run, and be nearly phased out by 2050 - a more gradual but long-lived roll out of HPs (from 0% in 2011 to around 85% in 2030) Hybrids are seen as a more flexible, transitional technology. The main issues here are: - whilst technically possible (relatively mature technology deployed elsewhere), there are currently no real signs of these emerging trends, and policy signals point in the wrong direction - the 'outsourcing' of decarbonisation to the electricity sector - the dependence of HPs on well-insulated houses to function efficiently (and hence lead to overall energy reduction) - there is a 'single bullet' perspective on addressing the heating challenge	Technical and economic feasibility (of deployment) Inexistent supply, installation and maintenance chains (important barriers to adoption, in terms of skills and capabilities) Lack of policy and political will (from discourse to substance) Economics (how to finance) Domain integration, and strong prerequisite of electricity supply decarbonisation
Conventional boilers (predominantly gas but also fuel oil and electric)	This pathway suggests a simple story for conventional boilers (including gas, fuel oil, and electric): complete phase-out by 2030, from around 85%, 8%, and 8%, respectively. This is a very rapid phase-out that is compensated to some extent by the deployment of hybrid boilers (first using predominantly gas and then predominantly electric), although in terms of appliance renewal rates may be feasible. The main challenges are: - the current absence of credible alternatives on the ground - the absence of (dis)incentives ore regulations - potential stranded assets in the gas grid	Technical and economic feasibility (of phase out) Lack of policy and political will (from discourse to substance) Potential political resistance by energy suppliers and distributors
Heat networks (district heating – DH)	This pathway assumes a gradual but shy rise in the significance of heat networks, from virtually 0% in 2011 up to about 10% of heating output by 2050. This trend is a credible one, as the potential for more ambitious roll out would be constrained by the rates and costs of housing stock renewal (or major refurbishment) required. There are difficulties with establishing the kinds of stable long-term consortiums, business and pricing models required, but the devolution agenda may be beneficial by granting more power to local authorities.	Not many Needs stable policy frame and polity High infrastructure costs
Efficiency improvements / Demand reduction	This pathway assumes a gradual but significant role for efficiency improvements and demand reductions in curbing the heating demand rise that would be expected by 2050, corresponding to just over 20% reduction on projected	Technical and economic feasibility (of phase out) Lack of policy and political will (from discourse to substance)

	demand. While this may be technically feasible, there are serious concerns in terms of financing these refurbishments, changing building regulations and practices, establishing low-carbon refurbishment competences, and ownership structures in the housing domain. Furthermore, it is unclear whether the efficiency improvements required to achieve expected decarbonisation from the roll out of HPs has been computed.	Economics (how to finance)

5 Scenario: RESOM core run – all-electric heating

In this section, we describe our qualitative scenario. We divide our storyline into two main periods (2015-2030 and 2030-2050). Our methodical approach is to 'tell the history of the future', meaning that our detailed scenario descriptions are written in past tense.

Chart A1: Domestic space heat and hot water output by technology[6]



Source: RESOM core run

5.1 <u>2015-2030: hybridisation of residential heat</u>

This period started just after the 'discovery' of heat as a pressing policy area for decarbonisation towards the end of the first decade of the century. It had become clear that reaching the binding targets of 80% GHG emission reductions by 2050 would require considerable efforts in the heat domain. The UK Government had ambitions to fully reconfigure the residential heat supply system. This ambition was supported by the so-called 'Heat Strategy', which relied mainly on 1) encouraging energy efficiency in buildings, and 2) moving towards low-carbon heat (for which electrification of heat via HPs was a promising prospect). However, in these early years of ambitious plans, renewable heat was struggling to generate any significant momentum and none of the many options (biomass, heat pumps, solar thermal, etc.) managed to get off the ground – with the exception of small market pockets in mainly off-grid locations. More structural options such as low-energy retrofits and district heating were proving even more difficult – in large part due to the inertia and poor energy performance of the housing stock. The general background was influenced by soaring energy prices, and gas in particular, which was raising concerns in terms of energy security as the UK was increasingly relying on imports.

Successive governments had introduced incentives schemes under different names (RHPP, DHI, Green Deal, etc.), but these were characterised by a general tendency to the regular scaling back of funding and inconsistent long-term signals as well as very little overall effectiveness. In 2018, the Heat Strategy was scrutinised by a number of expert reviews ranging from Whitehall and academics to NGOs, all pointing to the lack of progress, inconsistency, and the need for a clear and feasible strategy. Such a strategy was to be oriented towards a feasible transition trajectory making the most of existing opportunities for green industry development. The recommendations were overwhelmingly in favour of pursuing a narrow portfolio of technologies with great intensity and strong direction, rather than supporting up an open and competitive innovation race for a wide range of options through non-prescriptive market incentives. A case was built under the banner of 'electrifying heat' – largely based on the positive achievements in early decarbonisation of the electricity sector, and the sense of hope that this generated.

The 'electrifying heat' strategy was initially resisted collectively by the industry, in large part due to the tacit coordination between the main energy suppliers (the 'Big Six'), and the vested interest that the National Grid had in maintaining the status quo. The destabilisation of gas demand, which would result from a move towards non gas-based, lower carbon heat supply, faced substantial resistance. However, this picture started to change as a result of increasing pressure on gas supplies and price which was eroding the relative cost advantage argument; opportunities in heat pump technologies and demand shifts; and increasing pressure from smaller electricity supply and distribution companies not involved in gas and increasingly differentiating themselves by projecting an attractive green and progressive image. Electricity suppliers saw a competitive advantage in getting involved with HP technology, understanding related opportunities in terms of electricity demand patterns, and getting involved early in shaping what increasingly seemed like a clear policy commitment. Whilst Centrica, which had retained the largest share of the market, remained firmly reactive, Edf and E.On sought to demarcate themselves by making the first bold pledges to support this policy – promising to drastically reduce their stakes in gas supply by 2030.

Meanwhile, an embryonic HP industry was in strong need for support, as it had not developed significantly since 2010. On the up-side, a renewable heat industry had built up internationally, providing a number of options to be implemented in the UK (with potential co-benefits in terms of job creation, etc.). The main challenge for low carbon heat in the UK was to generate the conditions and capability for the uptake of effective solutions. The UK government wanted to support the development of HPs for domestic heating and the underlying industry, by backing research and development as well as by coordinating field trials to gather information on the performance of domestic heat pumps and possible improvements. Much was learnt, particularly about the scale and scope of the challenge. Clear future directions were set out to address specific challenges: 1) integrating HP development with insulation measures, 2) training and skilling key actors of the building sector (plumbers and technicians, developers, customers, building regulations legislators, etc.), 3) rethinking heat governance, including responsibilities, incentive structures, and building regulations, and 4) establishing strong and vibrant supply-chains with the longer-term objective for the UK to become a leader on the global market.

In 2018, the Department for Business, Innovation and Skills set up the 'Future heat jobs' programme, in coordination with the Department for Education, and under direct advice from the Council for Science and Technology (CST). This programme was tasked with supplying the HP roll out projected ambitions with the skills and expertise on the ground to deliver them, by geographical area, and over time – an exercise largely motivated by the massive expected shortage of skilled labour in this sector. An expected 100,000 newly skilled technicians were needed on a yearly basis to kick-start the industry, stabilising towards 50,000 after 5 years. These jobs included drillers, plumbers, electricians, low-energy building workers, and assembly-line workers. Further training and skilling was required in terms of engineering, planning authorities, and salesmanship. This ambitious training and skilling programme relied on the set up of 25 technical academies and research centres throughout the country.

Between 2016 and 2020, electricity corporations also became strongly committed to heat pump technology, strengthening their research capabilities and investing in supply capacity in moves towards vertical coordination. Commercially, this enabled the set-up of innovative new types of contracts that included appliances (HPs) and a baseline supply contract – following a model pioneered in previous decades by telecommunications companies. Electricity companies also played a leading role in co-financing industry skilling programmes and scouting talent through grant schemes.

In terms of policy interventions oriented towards users and appliance conversion, the 'electrifying heat' policy widely drew from experience accumulated with product conversions elsewhere: light bulbs and CFCs (although heat appliances were more challenging due to their greater costs and lifetime), and from successful HP deployment schemes. Since the technology was relatively mature, and notwithstanding the challenge of building supply, installation and maintenance chains, the main market deployment strategy focussed on a ban on conventional boilers, lowering HP costs, and staged conversion in priority segments. By 2018, the installation of new conventional gas boilers was fully banned, which was nonetheless a very bold policy move. Naturally, installation subsidies (in particular, for households faced with energy poverty) played a significant role in making heat pumps and hybrid boilers more attractive relative to gas boilers, and enabling the implementation of the ban. The increasingly unpredictable price of gas – which hit lower incomes the hardest – also contributed to a general acceptance of the need for alternatives to boilers.

On the legitimacy front, there was an uphill battle to familiarise the public with this new technology, lifting barriers to adoption and raising the profile of HPs. At the time, only a limited number of proactive consumers were familiar with HPs, which were still perceived as quite complicated and new. Increasing the interest and awareness of HPs – which was small compared also to other heat sources – through better information, marketing, and communication became a priority. Crucial for constructing a positive narrative was the generation of alliances between electricity suppliers, the nascent HP industry, and consumer and citizen-oriented actors (e.g. NGOs and energy awareness advocates) – who aptly articulated the promise of heat electrification with issues of energy affordability. The Energy Saving Trust played a leading role in framing this narrative of change, simplifying and standardising offers, and making it accessible to homeowners by providing simple financial models and installation procedures that highlighted the undisruptive nature of change and its high cost saving potential. This coalition of actors also collectively addressed supply-side deficiencies – aligning development strategies to create a more coherent and stable offer for an emerging consumer.

However, the main obstacle was related to user reticence with a technology that required greater engagement with heat as a practice. Indeed, heat pumps supply low-temperature heat, and are most efficient when very gradually heating spaces over a number of hours, which is in stark contrast with the user experience of hot radiators and real-time heat feedback. There was a genuine demand for knowledge about heat and managing energy use, for which the knowledge and capacity of the Energy Saving Trust was actively mobilised. The Government recognised the need for this 'home economics' training and financed its expansion. Demonstrations and information campaigns were important to convince potential users, but there was a strong need for a marketing mechanism that would convert the apparent convenience loss into a benefit elsewhere: heat pumps needed to be either cheaper or more flexible, or the user herself would have to change. It is this very realisation that was behind the 'making heat pumps happen' market development strategy, led by the emerging support coalition and led by heat pump associations: 1) in the short term, hybrid heat pumps would allow heat practices to go virtually unchanged, yet enable 2) the development of a market for HPs and hence the reduction of production, installation, and maintenance costs, and 3) exposure to HPs, and the economic benefits arising from their optimal use will convert users to step out of gas. The relative ease for HP installers to get certification generated a positive dynamic by which HP marketing contributed to 'push' for early conversions as sales professionals consistently brought commercial arguments forward. The widespread dissemination of arguments for energy saving processes also contributed to shaping the collective mind towards the consideration of long-term annuitized costs of energy investments that included appliance and life-time usage costs. Such a new perspective largely favoured the more efficient heat pumps.

By 2022 nearly half of gas boilers had been replaced by hybrids, a significant number of households had adopted full HPs (mostly in newer and better insulated buildings). This positive dynamic was contributing to greater familiarity and exposure to HPs, which also made the benefits more apparent. Hybrid boilers had become commonplace. Heat pumps in well-insulated homes had become desirable. An unintended effect of this cultural shift was the raised importance of insulation and energy efficiency of buildings.

Improving the energy efficiency of buildings was a much more challenging issue than the hybridisation and conversion of gas boilers to heat pumps. The main challenges concerned the financing of refurbishments, the improvement of building regulations and practices, the establishment of low-carbon refurbishment competences, and the issue of ownership structures in the housing domain. Rising energy prices and the structural inequality in housing conditions had generated serious concerns about energy poverty. Whilst these had been largely unattended since the late 1990s, the changed policy mindset, characterised government new inclination to significantly invest in infrastructure and long-term industrial development, offered significant new opportunities. Energy poverty provided a further justification of such investments, which was aptly mobilised to further legitimise official policy. The government communicated widely on its proactive steps towards energy efficiency conversions of the building stock, which was supported by and further stimulated the 'Future heat jobs' programme. This enabled the acceleration of demolitions and the building of new developments focussing on efficiency that benefitted substantial from a relaxing of building codes despite protest of the National Trust against the emergence of an architectural 'Wild West' where engineering criteria prevailed over aesthetic and planning considerations. In smaller housing units, the 'warm home right' for tenants inverted the burden of proof that had so long worked in landlords' favour. Supported by increasing number of inspections and simplification of tenant complaining procedure, prohibitive fines were applied to poorly insulated rental houses to jump-start rapid conversion of out-dated building stock. To support conversions, cheap loans and tax credits were set up for refurbishments, targeted at homeowners, and supported by increasingly reasonable cost saving cases.

A similar long-term strategy was devised to support the development of District Heating (DH) where conditions lent themselves to it. Any new large-scale housing development was mandated to adopt DH by 2023 – in practice this meant in most cases in combination with CHP plant. This initiated a shift in building practices, starting in new high-end developments and conversions, then inscribed within a majority of regeneration plans and 'new towns' – implemented in stages towards 2050. Energy supply for these heat networks was supported by the deployment of CHP (often linked to waste management following the trialled and tested Swedish model) and large HPs. The early retirement of poor performance buildings also stimulated the construction sector and further generated market for high-efficiency housing and DH. Incidentally, the set-up of large-scale heat networks opened up scope for a new wave of local authority involvement with social and collective housing, inverting a trend that had established itself since the early 1980s.

The UK policy context had been revived by a general change of governance leaving behind nearly a decade of austerity policies (2008-2017) and moving on with substantial long-term investments in the spirit of an entrepreneurial state cultivating a strategic portfolio of industrial growth areas. By shifting to long-term strategic coherence and integration with industrial and innovation policy, energy governance had finally become exposed to the realities of win-wins and positive feedback loops. This had been enabled by a more 'hands-on' approach to innovation policy and technological choice in the energy sector, but also the search for systemic solutions that could overcome initial industry reticence by seeking long-term opportunities. The substantial squeeze from gas price hikes was also an important factor in providing a clear direction signal for change.

5.2 2030-2050: from hybrid to all-electric heating

By the late 2020s, gas had become relatively expensive and unpredictable as the UK mainly relied on international exports. Pursuing the heat electrification agenda, the government had resisted the pressure to subsidise residential gas prices (as it had done in the industrial sector), and instead further supported conversions to alternatives. Rising energy prices had generally led to greater engagement of individuals with energy practices, which had also evolved with greater exposure with hybrid HPs and HPs. Energy awareness, gaining new knowledge and adopting saving practices, had become a necessary part of life for householders – a shift that had been actively supported by grassroots initiatives and NGOs involvement.

The efforts and long-term policies set out from 2018 were starting to generate significant momentum, very healthy markets, and functional supply chains. By 2030, hybrid boilers had become very well developed in the UK, representing over 60% of residential heating appliances. Conventional boilers were fully phased out, and virtually absent of residential use. Hybrid users were also increasingly relying on an electric-only heating mode. Gradually, the gas supply infrastructure shrank and retreated to a minimum, largely related to strategic industrial areas. This offered opportunities for recycling.

Full HPs had broken through and captured nearly one third of the market for heating appliances. HPs were no longer seen as inconvenient and heating practices had adapted to this decidedly more modern form of heat. Insulated homes, with under floor heating had largely contributed to the appeal of greater heating control. The cooling function of HPs was also seen as an advantage in a climate with increasingly warm summers.

In terms of supply chains, HPs has become widespread, and no longer technically challenging. 'Future heat jobs' had been critical in this major success, as all installers and heat engineers had become experts and enthusiastic ambassadors of this revolution in heating technology and practices. The further development and integration of supply chains contributed to bringing the cost of HPs and their installation down.

However, there was also a sense that full HPs had enjoyed the low-hanging fruits of market expansion in households that were well insulated, characterised by high incomes, high energy literacy, and often in privately owned detached houses. The next challenge would be to expand beyond this segment, and to further improve insulation to reap the benefits of a generalised market for HPs. While the economic barriers were no longer too high given substantial cost reductions and supply chains were eager to further expand, the main obstacle was related to poor quality building stock in need for low-energy retrofits. The gradual tightening of minimum performance standards for existing properties since the late 2010s had gone a long way, and so did the ‘warm home right’ campaign targeted at poorest households. Building on the experience of trained technicians and engineers, a systematic evaluation of the building stock carried out in 2032 identified that 15% of the building stock was still not fit for life in an energy efficient world – despite tremendous efforts to improve efficiencies or demolish poor performance buildings. These buildings would require substantial low-energy refurbishments or face demolition. Conversions were supported by financial incentives and zero-interest loans, and demolitions were encouraged for buildings presenting lesser heritage value. There, the building industry experimented with ultra-low energy prefabricated houses which proved a great success.

During this period, DH expanded substantially in urban areas, which also presented opportunities in terms of integration in inter-regional networks, particularly in and around high-density suburbs.

The retreat of gas use had also followed a more strategically planned territorial pattern. Following recognition that gas supply was becoming unviable, it was realised that gas infrastructure would have to be abandoned in the long term, unless options for the development of new uses are seriously considered. The ‘hollowing’ out of entire areas from gas use meant that gas distribution had become irrelevant. The National Grid had pushed for support in implementing a geographically-determined phase-out plan, whereby high-pressure distribution would eventually remain only around strategic terminals and storage facilities, as well as linked to industrial activity clusters. In denser areas, the distribution infrastructure was dismantled (often in conjunction with the installation of heat networks) and recycled. The recycling of carbon steel became an important activity for the British steel industry.

Conclusions

We here make a few concluding comments about future-oriented transitions pathways storylines.

Challenging pathways. Our socio-technical scenario, informed primarily by existing modelling work, is constrained by ambitious decarbonisation objectives. As a consequence, the transition efforts required are substantial in terms of the speed, scale, and scope of change of individual practices and socio-technical configurations. The scenario presented here relies mainly on a deliberate innovation and industrial strategy that focuses almost exclusively on heat pumps, and recognises the need for stepping up capabilities and developing supply chains.

Most striking is how rapidly the phase-out of gas boilers has to occur for this pathway to materialise – although this is partly offset by the deployment of a hybrid technology – which is an extremely ambitious appliance replacement rate. Additionally, the decarbonisation of heating through electrification to some extent only displaces the problem top electricity generation, which becomes under higher pressure to decarbonise at the same time as to absorb higher demand levels.

Policymakers, in particular, play an important role in recognising and accelerating the momentum of relevant niche innovations. They also rely on constructive relationships with other actor groups and civil society for the legitimation of action or the break-up of specific resistances. Strict policies can only be introduced successfully with the right backing and actor coalitions in place.

Forcing through socio-political dimensions and the role of deliberate strategies. Realising this transitions pathway, i.e. shifting away from prevailing trends and in many cases fundamentally reverting them, requires a fair amount of ‘forcing’. This can occur in different ways (including relying on external shocks and dramatic events, or futuristic high-technology assumptions), but we have focussed on socio-political agency. Thus, our storyline relies on consistent and deliberate policymaking strategies to support path-breaking innovation and reduce commitment to established regimes while increasing consumers’ awareness of and familiarity with HPs. We also envision more political interactions within the energy industry in relation to stepping out of gas – with frontrunners and laggards amongst the established players. The value of this is to highlight the role of governance in bringing about and making sense of change (as opposed to purely techno-economic rationales). Our storyline further highlights the importance of decision-making – at different levels and by different factions of society (government, industry, users, etc.), most effectively in alliances.

Instruments and interventions. In order to realise transitions objectives, besides the need for consistent and legitimate strategies discussed above, a number of governance instruments and interventions are required. These can correspond to ‘traditional’ policy instruments such as financial (dis)incentives and regulations, but also more creative or systemic interventions, e.g. industry capacity-building, phase-out of appliances.

Two aspects come to the fore when attempting to complement modelling strategies with governance considerations: 1) interventions are required well beyond the ‘blanket’ macro-instruments considered by modellers, and 2) no single instrument is sufficient; instead, what is needed is policy instrument mixes within specific areas and a substantial degree of integration across policy areas.

Methodological issues. This exercise entails some methodological issues, which we briefly want to reflect upon. Quantitative models, like the one we used as basis for our analysis here, often neglect important (socio-technical) developments related to, for example, different actor groups and their interactions; policies; beliefs, decisions, struggles and conflicts; or lock-ins. Moreover, they lack a degree of imagination and hence do not in detail show how prospective pathways may unfold. These shortcomings were our main motivations for this exercise of developing qualitative socio-technical scenarios. In performing this exercise, we were constrained by modelling outputs as a guide to conform to. This is a formative exercise that can shed light on specific tensions and incoherencies, enables us to look at potential and conditional hurdles, and go beyond a simple distinction between 'now' and, say, 2050 by offering a number of hypothetical branching points to focus our socio-technical narratives. Importantly, however, the story we tell is speculative and must not be taken literally. Rather, they provide socio-technical texture to a future pathway and thereby offer further opportunities to evaluate transitions challenges within reasonable expectations.

A particular limitation in this case was the fact that no PATHWAYS models for two separate pathway A and pathway B scenarios were available. We had to base our analysis on an existing model, which prevented us from distinguishing different pathways, as well as from upstream engagement with the modelisation effort.

Multiple time horizons and branching points. Starting from model projections enables narrative storytelling to focus on significant prospective events that appear necessary to break the mould of established trends. In practice, these have been taken to be inflection points and the crossing of significant thresholds. They have informed the temporal bounding of storylines in two time periods, each characterised by a few dominant techno-economic developments to be explained by socio-technical change processes.

From an analytical standpoint, much more can be said about earlier periods, and uncertainties significantly increase the further we move away from the present. That being said, the importance of rapidly shifting away from conventional heat (which is a significant departure form current trends) further underlines the importance and urgency of strong policy priority shifts in the immediate future. What we have seen in our model and scenario is that the next five years already are absolutely fundamental for 'bending the curve'. This is further underscored by the likelihood of resistance from established actors with vested interests in the current configuration.