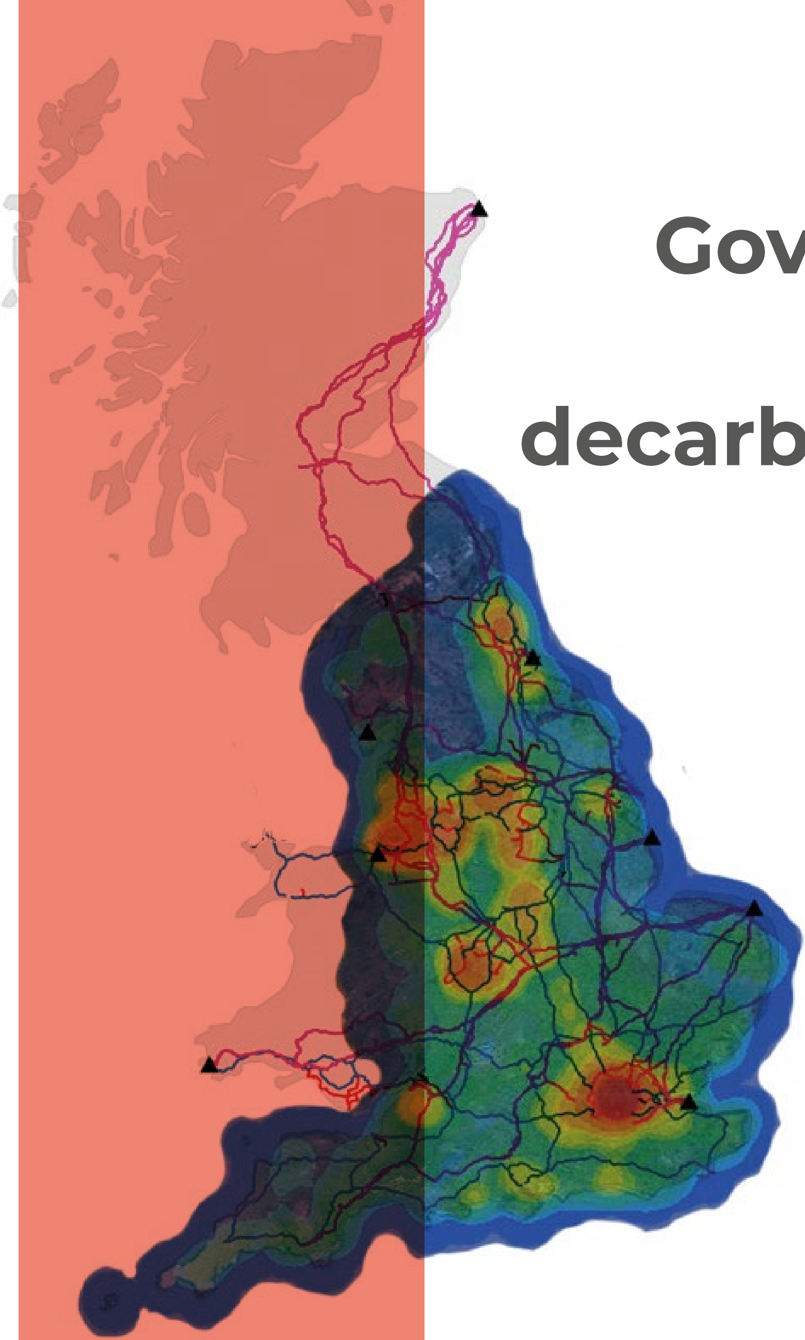
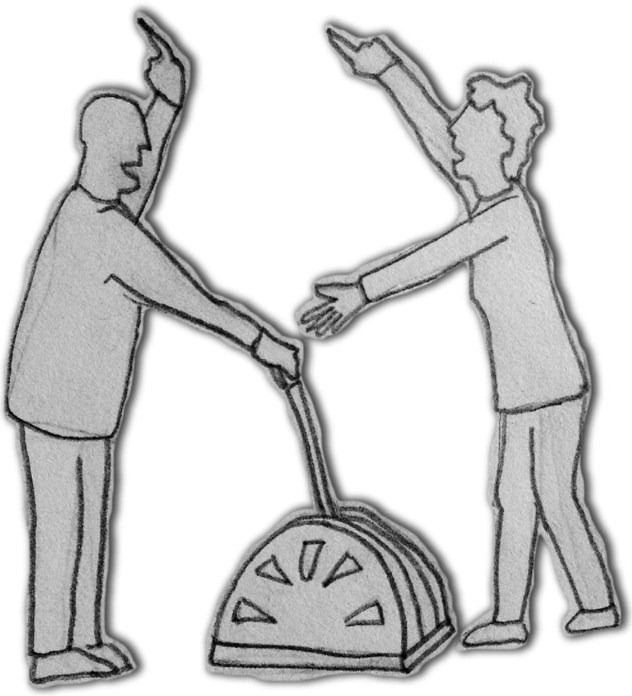


Governing the UK's transition to decarbonised heating:

Lessons from a systematic review of past and ongoing heat transitions



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Governing the UK's transition to decarbonised heating: Lessons from a systematic review of past and ongoing heat transitions

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Executive summary

In the summer of 2019, the UK Government revised its 2008 Climate Change Act, becoming the first country in the world to commit to net zero greenhouse gas emissions by 2050. With heat accounting for around one third of *accounted* greenhouse gas emissions, full decarbonisation of the sector is high on Government's agenda (BEIS, 2017). Its pledged commitment, however, stands in sharp contrast with Government's inaction on heat decarbonisation to date. Under pressure to progress this agenda, Government has charged the Clean Heat Directorate with the task of outlining *the process* for determining the UK's long-term heat policy framework, to be published in the 'Roadmap for policy on heat decarbonisation' in the summer of 2020 (BEIS, 2017). This report, resulting from one of six EPSRC-funded secondments, is designed to support early thinking on the roadmap by answering the research question: *How can 'Transitions' research informs the roadmap for governing the UK's heating transition?*

'Transitions' research is an interdisciplinary field of study within the Social Sciences and Humanities (SSH) that investigates the co-evolution of social and technological systems (such as the UK heating system) and the dynamics by which fundamental change in these systems occur. To uncover what insights this area of research may hold for the governance of the UK's heat transition, a systematic literature review was conducted, focusing specifically on past and ongoing heat transitions in the Western context.

The Web of Science search conducted in February 2019 resulted in 126 publications. When applying the inclusion/exclusion criteria to these publications (e.g. including only publications that employed key theoretical frameworks developed in the field of Transitions Research), the total number of publications for review dropped from 126 to 49. Due to time limitations, these 49 publications were categorised as 'high', 'medium' and 'low' priority for the literature review based on their expected ability to provide *new* insights about heat transition dynamics to the UK's Department for Business, Energy and Industrial Strategy (BEIS). In the end, only the 25 'first priority' publications were systematically reviewed; there is a detailed breakdown of key messages from each of these publications in Appendix 1. Nevertheless, a much broader body of Transitions literature influenced the interpretation of these findings, as is cited and discussed throughout this report.

The core of this report is based around the main findings of this review exercise. Specifically, literature in this area has focused on the role of: complexity and uncertainty; path dependency; power and politics; intermediaries; and governance frameworks (e.g. adaptive and multi-level governance frameworks) in shaping past and ongoing transitions towards renewable heat. In discussing these themes and related lessons from the literature, we draw upon a range of empirical examples across (predominantly European) case studies.

On the basis of this literature review exercise, six sets of recommendations were produced:

Recommendations for building an evidence base to steer transition

- It is highly recommended that Government adopts a systems approach to the analysis of development pathways and the analysis of policy interventions, meaning linear econometric methods are employed within a systems approach.
- In light of emergence, it would be beneficial to commission research with adaptable outputs, e.g. models that can be adapted in-house when new dynamics emerge.
- When building the evidence base, Government should **give greater weight to social and ecological aspects of the heat transition** which, together with material and financial aspects, determine outcomes of policy intervention. Practically, this could be achieved via the commissioning of interdisciplinary research that applies a 'mixed methods' approach to data collection and analysis.
- SSH should also be used to explore the 'logic(s)', framing, and conceptual/theoretical underpinnings of any transition.
- **Physical interactions with ecological processes should be explicitly modelled** and **SSH findings should go beyond market research on technology adoption**, to include research areas such as multi-level governance and energy justice, and the role of power in mediating transition processes.
- Policy would benefit from a **consideration of cross-sector interactions.** Practically speaking, it is recommended that Government commission co-

modelling and scenario-building work with a diverse group of industry experts.[1]

- **Explicitly consider Government's development targets which impact upon – or are impacted by – various scenarios of heat decarbonisation.** The Sustainable Development Goals (SDGs) are recommended, in particular, as they are the most comprehensive, systematically reviewed set of interrelated goals, to which the UK Government also has national commitments.[2]

- Government would need to **commit to an ongoing research agenda,** constantly 'updating' learnings about the system's structure and behaviour, including changes in actors' decision-making processes.

Recommendations for establishing an *adaptive* governance framework

- **It is advised that key stakeholders be brought into the process of steering/governing the transition.**[3] Their participation is expected to improve learning by both Government and participating stakeholders. This learning includes an understanding of how stakeholders' actions interact to produce system dynamics and aids consensus-building on intervention strategies around which actions can be coordinated.

- Unlike consultation processes, which consider all affected stakeholders, the ransitions Management (TM) approach prescribes narrow selection criteria for the **inclusion of innovators and exclusion of stakeholders not committed to a transition to a sustainable heat system**.

- ***Personal selection criteria*** are also recommended to select representatives of various stakeholder groups to participate in deliberative workshops. These individuals should be/have:

    - In a position of decision-making or influence (to be able to realise transitions in partnership with Government);
    - Openness to change (as the transition requires, by definition, a major transformation to current systems);
    - Creative/innovative (to imagine innovative social, regulatory and technical solutions capable of overcoming system rigidities and complex challenges);
    - Flexible (knowing plans will need to be adapted and, perhaps abandoned, due to emergence throughout the transition process);
    - Strong interpersonal skills for effective communication and collaboration;
    - Desire to understand and empathise with the views of others (for consensus-building).

- A stakeholder analysis conducted for the selection of participants, would be enhanced by **expanding its scope beyond the heating sector** – informed by an initial investigation of cross-sector interactions.

- **The governance process should begin with a visioning exercise, where goals are co-constructed and represent a diversity of interests.**

- **Open the deliberative, visioning workshops to individuals outside technocratic communities (i.e. government and scientific communities)** is critical to (i) improve the legitimacy and equitability of the transition, and (ii) reduce the risk of flawed or overly simplistic understandings about 'the public' used in modelling/scenario work (Upham et al., 2018; Hendriks, 2009; Kenis et al., 2016).

- Although consensus is an explicit goal of TM, some authors have argued that a truly 'shared' vision is unattainable. **Consideration will need to be given to methods of conflict resolution and discourse-based valuation to resolve these conflicts** in a way that provides sufficient opportunities for inter-stakeholder learning and empathy-building.

- **Practically speaking, deliberative workshops should be led by trained facilitators and participatory modelling and scenario work by an eclectic team of energy-system modelers, environmental and social scientists** to ensure that a range of social, technical and ecological processes are considered.

- Formally support real world experimentation so that government and participating stakeholders can learn about the system through intervention.

- Ensure the participatory governance framework is iterative. In other words, devise a process of learning-by-doing and doing-by-learning. Two things can support this process:

    - A **system for monitoring developments in related sectors** that may impact upon the heat transition. Not only would this reveal potential changes in transition dynamics, it would also

1 Three types of interactions would need to be explicitly considered, as they have been shown produce unique multi-regime dynamics: (1) Interactions resulting from complementary relations (e.g. improved insulation and heat pumps); (2) competition between regimes fulfilling a similar societal function (e.g. electric and gas heating); and (3) Interactions resulting from structural similarities (e.g. regulations, organisational structures, and business concepts that cut across different utilities).

2 A participatory approach to evidence gathering would provide Government with the opportunity to educate/engage stakeholders on its broader development agenda.

3 This recommendation is based on the premise that no single actor (even Government) has the managing capacity to control a transition process in a top-down manner (Guy and Shove, 2000; Rotmans and Loorbach, 2008).

shift the selection of stakeholders invited to co-govern the transition.

- **An independent body** charged with monitoring the transition (e.g. CCC) that **recommends when participating stakeholders should reconvene** to adjust the transition vision, coordinated strategies, or develop new experiments when the heating system develops new dynamics.

Recommendations for a policy-led decentralised energy transition

Multi-level governance structure reforms to support transition towards a decentralised, renewable heat system:

- **Reverse Local Authority (LA) budgetary cuts** to support local experimentation and engagement with energy governance and reduce disruption in institutional memory and political buy-in.

- **Upskill LA officers in technical, legal, and commercial expertise rather than relying on industry consultants** to improve municipalities' long-term capacity to steer transition whilst addressing the national skills gap for conducting technical feasibility studies.

- **Government should continue and scale-up grant competitions that support the development of LA energy concepts/masterplans** to support experimentation at the local level that accounts for cross-sector interactions.

- **Affordable long-term finance or financial guarantees for non-profit or joint public-private ventures should be provided to LAs having established a promising energy concept or masterplan.** This could come from UK infrastructure funds or GIB finance structured to underwrite risks for local enterprises.

- **Institutionalise bottom-up and horizontal learning** in the Heat Network Delivery Unit (HNDU), to ensure this 'experimentation' phase helps develop case studies and Government learning regarding LA capabilities, opportunities, barriers, and needed guidance/support.

- **Integrate district heating as a funded, *statutory duty* into local planning policy** (e.g. Heat Network Partnership for Scotland, 2015). This recommendation is informed by best practice and, as well, the observed barrier that time-limited grants and unpredictable changes to UK national policy/funding opportunities pose to LA-led transition.

- **Plan for the cross-sectoral, multi-level coordination challenges that arise from the decentralisation of energy governance** (e.g. increased need for coordination between municipalities, electricity providers, OFGEM, etc.).

- **Actions to create institutions for long-term multi-stakeholder coordination may include:** extending devolved budgets to resource local liaisons/intermediaries and establishing a national body responsible for (i) actor network management; (ii) provision of external support to LAs; and (iii) institutionalised bottom-up learning processes (e.g. via annual monitoring reports) and horizontal knowledge transfer (e.g. by actively engaging with organisations such as the UK District Energy Association.

- It may be that regional governance bodies (e.g. Local Entreprise Partnerships or Combined Authorities) are better placed for vertical (up and down) and horizontal coordination activities. However, these bodies have been historically vulnerable to political cycles as compared to LA statutory duties.

Policy levers to support the scale-up of decentralised, innovations in renewable heat provision

- **Sufficient economic incentives for renewable energies over fossil fuel energy sources**, e.g. Scotland's temporary 50% rate relief for District Heating (DH) (Scottish Parliament, 2017), are needed to counterbalance built-in advantages of conventional heat systems.

- In the case of LA-owned Energy Service Companies (ESCos), ***"the benefits of the optimization and saving strategy identified in the plans should be used to procure renewable energy instead of other purposes to avoid rebound effects***" (Bickle, 2017, p.22).

- **Adopt building control regulations supporting connection of new and refurbished buildings to existing heat networks**, e.g. by raising the renewable heat quota (as proportion of final consumption) and energy efficiency standards to change market dynamics and strengthen local regulatory roles.[4]

    - Webb (2015) recommends "***more directed use of planning powers to prioritise areas for network development and anchor load connection****, as in other European countries such as Norway or Denmark*" (p.271) to reduce transaction costs, ensure carbon and energy savings, and provide secure revenues for DH.

    - "*Having identified areas of high-density demand, [supply,] and network feasibility [...]* ***producers of waste heat would need to be obliged to identify means to supply the network, in line with EU Energy Efficiency Directive requirements***" (Webb, 2015, p.271).

    - Following Webb (2015), **Government might consider what it would mean to grant electricity generated Combined-Heat-and-Power (CHP) *"the same status as large scale nuclear or offshore wind, under the new 'contracts for difference' strike prices for low carbon electricity supply*.** *This would reflect the efficiency gains from electricity*

4 E.g. Germany's energy saving ordinance (EnEV) and 'Act on the Promotion of Renewable Energies in the Heat Sector' (EEWärmeG).

generation close to its point of use. Operators would then have a risk underwriting mechanism. This is however a form of regressive taxation, because it operates as a levy on energy bills" (p.271).

- During the experimentation phase, Government may need to **invest in changing public perception towards risk and experimentation in the heating sector,** as failure and learning are necessary and productive outcomes for transition whilst negative public perceptions of innovations reduce their chance of adoption by both suppliers and consumers.

Policy levers to prevent unintended consequences/ harmful dynamics that develop mid-transition towards a decentralised, renewable heat system

- **New guidance for LAs should recommend, wherever possible, an LA-owned (arms-length) ESCo model** to improve borrowing potential, protect against LA liability, remove LA budgetary dependence on ESCo, and allows for the *strategic* delivery of DH. This will also require **retraining HNDU staff and new guidance for LAs**.

- Government may wish to consider **regulating ESCo practices to ensure energy efficiency improvements are achieved *as* buildings are connected heat networks** (not after).

- Government should **expand techno-economic viability criteria of national grant schemes to include social and environmental criteria with equal or greater weight applied in the accounting method**.[5,6]

- **LA investment decisions for heat network infrastructure should be based on a whole life cost model incorporating social and environmental benefit** to ensure that sustainable solutions are chosen. This is especially important given the path-dependencies of physical DH networks with 50-year lifespans.

- Importantly, **LAs should be required to consider energy and spatial planning *simultaneously*,** *as* DH infrastructure has to be strategically integrated with other infrastructure networks and the built environment.

- To make strategic use of heat network spatial planning, **large building owners will either need to be under an obligation to connect to local heat and cooling networks** on a timetable aligned with renovation and heating replacement schedules **or incentivised to connect,** for example by expanding the CRC energy efficiency tax to *all* commercial building owners.

- **A system for licensing and regulation is needed to prevent abuse of long-term monopoly supply contracts in DH**. For example, Government would need to establish service standards and could require tariffs be competitive with other systems of heat supply.

Recommendations applicable to multiple transition pathways

- **Sufficient economic incentives for renewable energies over fossil fuel energy sources**, e.g. Scotland's temporary 50% rate relief for DH (Scottish Parliament, 2017), are needed to counterbalance built-in advantages of conventional heat systems.

- **For renewable heat technologies that are closely coupled with natural systems (e.g. ground source heat pumps), Government should avoid prohibitive, blanket regulations at the national level** (e.g. the number and depth of downhole heat exchangers and the rate of groundwater extraction).

- Actively manage phase-outs of competing, unsustainable heating systems.

- **Consult the German federal government regarding their plan to expand the R&D funds for advanced district heating systems and their declaration of these systems as a key instrument in their national energy transition**.[7]

5 For example, by applying alternative accounting methods such as socio-economic cost-benefit analysis (Chittum and Østergaard, 2014).

6 For DH systems over 10MW, Norway's 1990 Energy Act requires that development plans include evidence regarding social, economic and environmental advantages relative to other options (Norwegian Water Resources and Energy Directorate, 2009).

7 The German heat system is also predominantly based on a centralised gas system with boilers installed in individual dwellings, DH has expanded at a slow rate, and emerging hydrogen technologies are scaling up Germany's transportation system. Although significant differences exist between the two countries (e.g. greater LA autonomy and tax raising powers in Germany) there are likely transferable lessons (BMU, 2016).

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List of acronyms and abbreviations	
BEIS	UK Government Department for Business, Energy and Industrial Strategy
BMDH	Biomass District Heating
CCC	UK Climate Change Commission
CME	Coordinated Market Economy
CHP	Combined-Heat-and-Power
CHP-DH	Combined-Heat-and-Power District Heating
DH	District Heating
EPSRC	UK Engineering and Physical Sciences Research Council
ESCo	Energy Service Company
HNDU	Heat Network Delivery Unit
LA	Local Authority
LME	Liberal Market Economy
LTS	Large Technical Systems
MLP	Multi-Level Perspective
SSH	Social Sciences and Humanities
TM	Transitions Management
UKERC	UK Energy Research Centre
WtE	Waste to Energy

1. Introduction

This report is part of the EPSRC-funded (via UKERC) Energy-PIECES project, which aims to provide energy policy experiences for PhD and early-career researchers working in the Social Sciences and Humanities (SSH). The foundation of Energy-PIECES is the argument that there is a significant wealth of untapped SSH knowledge that could meaningfully help policymakers and policy-workers fulfil and/or potentially even re-frame their policy ambitions.

In this context, this report is specifically based upon a seven-week secondment that the lead author undertook with the Energy Social Research Unit at the UK Government Department for Business, Energy and Industrial Strategy (BEIS). Its basis is a systematic literature on heat innovations, interactions, and dynamic behaviours of heat transitions across Europe. The Multi-Level Perspective (MLP) on transitions formed the theoretical boundaries for this review exercise, as led by the BEIS team's emerging interest in the academic literature and the authors' aim was to convert findings from this systematic review into tangible policy recommendations for the UK Government.

In summer 2020, the BEIS Heat Policy Team will publish a 'Roadmap for policy on heat decarbonisation', and it is hoped that this secondment/report will feed into the development of that policy framework in some way. As such, the guiding research question for this report is: *How can 'Transitions' research informs the roadmap for governing the UK's heating transition?*

This report proceeds as follows: Background context on UK energy policy and the growing need/request for Transitions thinking is provided in Section 2. The methodological approach for the systematic review is then presented, including details on what literature was included/excluded in this review (Section 3). The core of the report is then based on a discussion of this review's findings (Section 4), covering issues of: path dependency; role of power and politics; complexity and non-linearity of transitions; various types of interactions between sectors, stakeholders, systems and societal elements; as well as other relevant influences shaping energy transitions and relevant intervention/policy ideas. This report concludes by summarising key headline findings (Section 5) and also by providing tangible recommendations for UK policy (Section 6).

2. Background context

This background context section is spilt into two sub-sections. The first sub-section (2.1) details the policy context and how that has led to pressures on the UK Government to deliver a highly uncertain low-carbon energy transition in a short period of time. The consequence here is that policymakers are eager for (comprehensive) policy frameworks that could assist in the governance of such a low-carbon energy transition. The second sub-section (2.2) therefore introduces the research context by detailing the interdisciplinary Transitions Studies literatures, which has for over 10 years fundamentally concerned itself with what, why and how (energy) transitions have or should be governed.

2.1. Policy context: Creating a roadmap for long-term policy on heat decarbonisation

In the UK, heat accounts for almost half of energy consumption and around one third of overall greenhouse gas emissions (BEIS, 2017). Under the revised 2008 Climate Change Act, the UK Government committed to achieving net zero carbon emissions by 2050. The economically efficient achievement of this target will require full decarbonisation of all heat in buildings and the decarbonisation of most industrial heat (BEIS, 2018). In practical terms, this requires a transition away from natural gas heating to electricity or alternative fuel sources such as hydrogen, biogas, geothermal, and waste heat. Given the scale of change (for e.g. consumers and infrastructure), a transition to these alternative fuel sources is considered by the UK Government as its most difficult decarbonisation challenge (BEIS, 2017).

The scale of this transition is similar to the former transition from coal to natural gas heating. This former energy transition, like others, was partly enabled by the discovery of abundant fossil fuel reserves. As well, it was heavily 'managed' by the UK's central government via investments in national gas grid infrastructure that replaced a fragmented gas industry, and a major programme of boiler replacements and appliance conversion (Arapostathis et al., 2014). A similar level of central management would be required for a transition to hydrogen gas heating, e.g. refitting home heating appliances and investing in infrastructure to support carbon capture and storage to produce hydrogen from natural gas. However, the past transition to a neoliberal economy and privatisation of the gas network in the 1980s diminished the steering capacity of central government (Hawkey and Webb, 2014).

By comparison, a transition to heat pumps and Combined-Heat-and-Power District Heating (CHP-DH) networks, would require decentralised governance by local authorities (LAs). However, the aforementioned transition to a centralised heat system has historically eroded energy planning expertise and the financial capacity of UK LAs to develop low-carbon heat infrastructures compared to other European municipalities in countries such as Denmark and Sweden (Bolton and Hannon, 2016).

Although these path dependencies create barriers for a transition to decarbonised heat, that is not to say that these barriers are insurmountable. Indeed, significant barriers were overcome in the transition to a national natural gas heating system. Yet, the rate of transition *away* from natural gas will certainly need to be greater than the rate of the transition *toward* natural gas. The UK's independent advisory body, formed under the Climate Change Act (2008), has recently determined that plans to decarbonise heat are proceeding too slowly:

> *"Over ten years after the Climate Change Act was passed, there is still no serious plan for decarbonising UK heating systems and no large-scale trials have begun for either heat pumps or hydrogen"*
> (CCC, 2019, p.175)

The delay is due, in part, to the lack of consensus on the best pathway to decarbonising heat. More specifically, the techno-economic evidence base gathered by BEIS does not indicate a preferred pathway in terms of economic efficiency. As such, Government remains in the evidence-gathering phase with public consultations yet to begin (CCC, 2019, p.177). This delay is especially concerning in light of the recently released Intergovernmental Panel on Climate Change's (IPCC) Special Report on the impacts of global warming of 1.5°C, which found that limiting global warming to 1.5°C would require rapid and far-reaching transitions and the achievement of 'net zero' around 2050 and a 45% reduction in greenhouse gas emissions by 2030. Following publication of the IPCC's Special Report, the UK Committee on Climate Change (CCC) was formally requested to review Government's 80% emissions reduction target. The CCC's subsequent report concluded that the UK Government's climate targets are insufficient to meet the Paris Agreement goal of keeping temperature rises below 1.5°C. Shortly thereafter, in June, 2019, Parliament passed an amendment to the 2008 Climate Change Act, raising the emissions reduction target to net zero by 2050 (Priestley, 2019). Although world-leading in its ambition, this target falls short of the CCC's recommendation for a *just* transition.

> *"Considering both the UK's relative wealth and large historical emissions [a fair decarbonisation strategy] would require 2050 GHG emissions reductions significantly greater than 100% relative to 1990 levels (over 150% reduction relative to 1990 levels in a 1.5°C scenario). Under this allocation the UK would be removing GHGs from the atmosphere overall to compensate for its high historical emissions and would need to reach net-zero GHG emissions considerably before 2050"*
> (CCC, 2019, p.107)

Rapid and far-reaching transitions in the energy sector are rare, but not unprecedented. The transition to crude oil and electricity in Kuwait, natural gas in the Netherlands, nuclear electricity in France, CHP in Denmark, and coal retirements in Ontario (Canada), all took an extraordinary 'fast track', with some transitions unfolding in under a decade (Sovacool, 2016). Some of these transitions were 'managed' by Government, whilst others were 'naturally occurring' (i.e. driven solely by market demand). Some only required the diffusion of "*discrete artefacts*" (Geels et al., 2017, p.28), whilst others required the scale-up of entire systems. Quite a few were based on natural resource discoveries (e.g. the Groningen natural gas field in the Netherlands and wind, solar and hydro potential in Ontario). Altogether, each case has its unique specificities, meaning there is no transferable blueprint for energy transitions (c.f. Grubler et al., 2016).

The UK Government, as such, is tasked with steering a highly uncertain transition in a very short window. This requires a comprehensive policy framework for governing the transition. In the summer of 2020, the 'Heat Transformation' team of the Clean Heat Directorate at BEIS will publish a 'Roadmap for policy on heat decarbonisation', which will outline the process for determining the long-term heat policy framework. The Energy-PIECES secondment, upon which this report is based, is intended to support early thinking on the roadmap by answering the research question: *How can 'Transitions' research informs the roadmap for governing the UK's heating transition?*

2.2. Research context: Introduction to Transitions literature and theory

Transitions Research is an interdisciplinary field of study, attracting Historians, Sociologists, Political Scientists, etc. from across the Social Sciences and Humanities. Specifically, Transitions scholars investigate how "*complex societal systems […] make a structural qualitative shift from (perceived) persistent unsustainability toward a more sustainable state*" (Loorbach et al., 2017, p.605). Transitions Research adopts the prescriptive goal of achieving a more sustainable society through scientific inquiry.

Finding its origin in Science and Technology Studies, the field adopts a 'socio-technical' understanding of societal systems, whereby technologies and material infrastructures are understood as being coupled with cultural norms, formal institutions (e.g. laws), social networks, etc. in unique configurations (Figure 1).

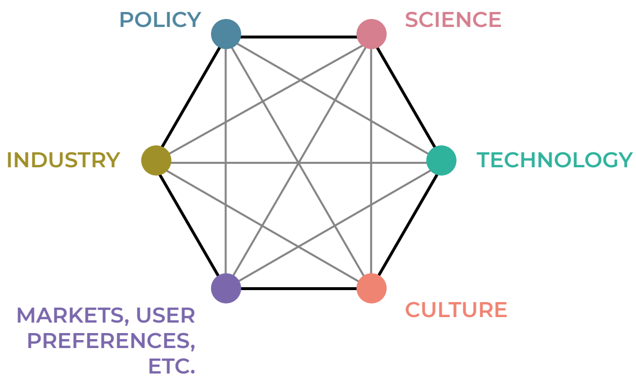

Figure 1: Socio-technical systems.

Because of these couplings, interventions in the material world produce knock-on effects on consumer practices, perceptions of technologies, supply chains, etc. These changes to *social* infrastructures in turn influence the *material* infrastructures people imagine and deliver – meaning that social and material infrastructures co-evolve. For example, the past transition to natural gas heating has produced cooking practices and preferences for gas cookers and hobs that create barriers for a transition to electric heating (see the Khalid and Foulds (2020) report published in this Energy-PIECES collection).

This notion of co-evolution is grounded in Complexity Theory – one of the core theories uniting Transitions scholars from across a diverse set of disciplines (Rotmans and Loorbach, 2009). According to Complexity Theory, complex systems have distinct properties arising at the macro level from their interconnected micro-components, such as non-linearity, emergence, spontaneous order, and adaptation (Capra, 1997). Even if the components, or 'agents' follow a small set of very simple rules, the complex web of interactions that make up the system's structure can produce unpredictable, *dynamic* behaviour – occasionally throwing the system into chaos. It is in these periods of disruption, that a complex system may transition to a new state, revert to the status quo, or collapse. If the system returns to the status quo, but pressures that triggered this event are not resolved, tensions will inevitably re-emerge, and the system be thrown back into chaos.

To make sense of this evolutionary process for socio-technical systems, a group of Transitions scholars developed the Multi-Level Perspective on transitions (Geels, 2002) – an analytical framework employed in nearly every publication analysed as part of this literature review. Applying this framework to the heat transition, the centralised, natural gas heating system is understood as the "*incumbent regime*" (Smith et al., 2005, p.1496), or dominant socio-technical system that has emerged out of

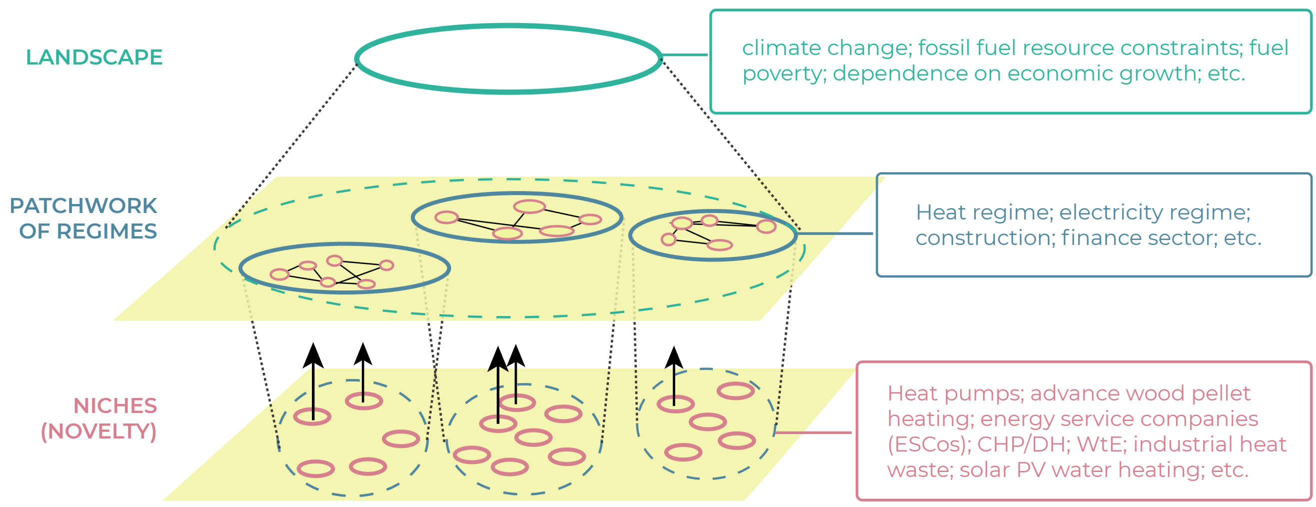

Figure 2: The Multi-Level Perspective (adapted from Geels, 2012).

past transitions. The heat regime is inter-connected with electricity, planning and finance regimes, among others (see the 'patchwork of regimes' in Figure 2). Through its interactions, this patchwork can produce internal tensions. But also, as semi-open systems, regimes can experience external pressures. Both internal tensions and external pressures are perceived at the "*landscape level*" (Geels, 2002, p.1260). Today's energy transition to renewables is driven largely by climate change – a landscape pressure that has emerged as a result of human interaction with climate and ecological systems. There are, of course, other landscape pressures (e.g. social inequality, economic dependence on continued growth, and energy security) that influence the transition in some way.

In response to landscape pressures, niche actors can develop alternative technologies (e.g. heat pumps, CHP-DH, etc.) as well as new social institutions (e.g. innovative business models or new cultural narratives). Some of these innovations enter the incumbent regime whilst others remain at the niche-level (see arrows in Figure 2). Innovations only 'breakthrough' in windows of opportunity when there is sufficient landscape pressure. Discoveries of significant and affordable forms of energy (e.g. Groningen gas fields) and scarcity conditions (e.g. 1970s oil embargos) have been important landscape pressures triggering past energy transitions (Sovacool, 2016).

In the case of climate change and the transition to renewable heat, "*niche innovations*" (Schot and Geels, 2008, p.545), both social and technological, have taken decades to emerge, to build legitimacy, and/or to scale-up. For example, the renewable heat transition in Sweden took 30 years, despite the country's rich bioenergy resource and supportive governance institutions at the local and national levels (Westholm and Lindahl, 2012).

A major cause of delay is the *rigidity* of incumbent regimes. As regimes mature and grow increasingly efficient, the number of interlinkages, sunken investments and maturity of social norms and practices result in increased rigidity or resistance to transformative change. As such, transitions are inherently disruptive (Boonstra and de Boer, 2014). An acceptance, rather than rejection, of disruption as a necessary, unavoidable feature of transition may help shift Government priorities from *minimising* disruption to *managing* disruption (Turnheim et al., 2018).

That being said, some transitions are more disruptive than others. For example, in the UK, a transition to hydrogen heating would be far less 'disruptive' than a transition to renewable district heating (DH), as the former could be delivered by incumbent actors via the national grid with minimal changes to regulatory frameworks. DH, on the other hand, would require entirely new infrastructures, actors, norms and institutions. For example, DH erodes the existing autonomy of property owners as they are bound to the new, shared heat system; places new demands on local government; involves new energy providers, such as local farmers or waste management companies; and requires new investors, such as LAs, hospitals and universities (Dütschke and Wesche, 2018). By comparison, the same transition in Sweden disrupted only the fuel regime and required some technological substitution to existing DH infrastructure (Dzebo and Nykvist, 2017). The level of disruption of the UK's heat transition will largely depend on the decarbonisation pathway pursued by Government.

Finding ways to minimise disruption for the sake of reduced short-term costs or improved public acceptance is not an explicit goal of Transitions Research. Rather, its recommendations are based on the aim of accelerating transition through positive reinforcement and mitigating transition dynamics that slow/block the diffusion of sustainable innovations. This is an important distinction, as high levels of disruption may be needed to achieve Government's targets. Once the priority of minimising disruption is let go, other previously conflicting priorities, such as accelerating transition, can come to the fore. However, the negative consequences of disruption (e.g. civil unrest or political instability), will need to be managed if they are significant enough to slow or prevent transition.

Reflecting on current governance structures, Transitions scholars have argued that a more *adaptive* governance framework is needed to manage or steer sustainability transitions (Voss et al., 2006; Newig et al., 2013). Despite the indispensable role of markets and governments in steering societal change, several Transition scholars have questioned their effectiveness in coordinating trade-offs between conflicting development goals (e.g. pursing continuous economic growth vs. observing environmental limits to growth) as well as their increasing institutional rigidity (e.g. Jessop, 1997; Mayer and Gereffi, 2010; Pierre, 2000). The coordination of trade-offs for long-term development requires more flexible, interactive and reflexive processes of debate and dialogue, which occur at the collective level of society. It is in society where people are free to consider adverse side effects of modernisation, change their beliefs and attitudes toward dominant regimes, and fundamentally reimagine pathways of development. The 'adaptive governance' approach thus *emphasises the role of society in providing much-needed reflexivity* (Newig et al., 2013; Voss et al., 2006). In effect, the adaptive governance approach implies a new governance framework that strikes a balance between state, market and society (Mintzberg, 2015).

One such framework, 'Transitions Management' (TM), was developed by a group of Dutch scholars and employed by the Dutch government in their energy transition among others (Loorbach, 2010). Practically speaking, TM utilises the steering capacities of a broad range of societal actors (e.g. interest groups, scientists, producers, consumers, government officials) by inviting them into the governing process and facilitating: (1) integrated knowledge production[8]; (2) adaptive strategies and experimentation[9]; (3) anticipation[10]; (4) iterative, participatory goal formulation[11]; and (5) interactive strategy development[12] (Voss et al., 2006).

8 *Integrated knowledge production* refers to the transdisciplinary production of knowledge between experts, scientists and various societal actors (Nowotny et al., 2001). Knowledge that results from methods of scientific inquiry (e.g. systematic modelling and laboratory research) is combined with actors' tacit knowledge gained in real-world experience.

9 *Adaptive strategies and experimentation* refer to the inclusion of experimentation, monitoring and evaluation in all governing activities. Adaptive strategies are needed to systematically address new knowledge and/or trends that emerge over time due to complex system dynamics.

10 *Anticipation* is the identification of potential development trajectories via methods of scenario construction, participatory modelling or policy exercises. Anticipation is a valuable component of reflexive governance, as it enables actors to consider what undesirable scenarios may transpire and alternative, sustainable pathways of development.

11 Because the guiding concept of 'sustainability' produces ambiguous goals and value-laden assessments of risk, *participatory goal formulation and assessment* introduces social conflict into the governance process, which is then mediated through social discourse, deliberation and political decision-making between actors.

12 *Interactive strategy development*, refers to the formulation of a collective development strategy and coordination of actions taken by a range of social actors. Coordination is critical in a world of distributed control, where society is governed in interaction rather than from a single locus of power (Voss et al., 2006).

The TM 'cycle' takes the following course (Loorbach, 2007, p.151):

- **Complex systems analysis:** First, Government and the academic community conduct a systems analysis to better understand the system's structure, its dynamic behaviour and underlying causes of unsustainability.

- **Establishment of the transition arena, problem structuring and envisioning:** Next, Government and transitions scholars/practitioners host a series of workshops to facilitate open, discursive, debate between a diverse set of stakeholders, specifically "*frontrunners*" (p.117), or innovators, in the transition. These conversations initially take a long-term view, and, from this view, actors agree on a problem definition and vision for the future.

- **Developing 'transition pathways' and 'experiments':** Through the process of back-casting from their shared vision, participants imagine a number of potential "*transition pathways*" (p.148), or development trajectories. They next design "*transition experiments*" (p.122) that could be carried out in the short-term to steer society onto one of these pathways

- **Building coalitions for the co-governance of sustainability transitions:** The transition vision, pathways, and experiments are disseminated. Those who prescribe and are able to contribute to the experiments are invited to join the newly formed "*transition network*" (p.152), increasing the group's steering capacity.

- **Monitoring, evaluation and learning:** As public-, private- and third-sector actors carry out these experiments in partnership, outcomes are monitored and evaluated to support learning about the complex system in which they are intervening. This process is meant to be recursive and ongoing, to support learning as the system evolves.

The framework, though prescriptive, can be adapted to govern local or national transitions and allows for a number of methodological approaches to stakeholder facilitation and systems analysis. Although TM is a growing sub-literature in Transitions Research, only one publication on 'transition experiments' (Kivimaa et al., 2017) was included in this review. This is likely due to search methods presented in the following section. As such, the authors are unable to comment on TM's *effectiveness* with regards to heat transition governance. However, the authors advise that BEIS follow closely the work of the Dutch Research Institute for Transitions (DRIFT), as their heat decarbonisation work with local governments[13] currently employs the TM framework.

13 The decision to work with local governments is owed, in part, to the recognised responsibility of municipalities to help govern the *decentralised* heat transition, as set out in the Government's 'Heat Vision' (Parliamentary Document 30 196, no. 305) (Dutch Ministry of Economic Affairs, 2016, p.73).

3. Systematic literature review methods

This systematic literature review for BEIS was divided into six iterative steps, the methods for which are presented in and, indeed, structure this section.

Step 1: Define search string and inclusion/exclusion criteria

Since Sustainability Transitions is an interdisciplinary field of study, it contains a number of diverse sub-literatures. A decision was taken early on to capture the breadth of findings to answer the research question, as part of showcasing to BEIS the range of insights that could be on offer to them. Similarly, the decision to include theoretical, methodological, research, and/or practice literature was taken to capture a breadth of contributions for policymaking.

Given the short timeframe in which to complete the review, however, the body of literature would have to be narrowed through other criteria. It was therefore determined that the review would be limited to studies on past and ongoing heat transitions – as indicated by '(heat OR heating)' in the topic, or 'TS', of the following Web of Science search string – in which policy, politics or governance for transition were explicitly considered:

> TS = ((heat OR heating) AND (sustainability OR sustainable OR resilience OR innovation) AND (transition OR transitions) AND (governance OR policy OR politics))

Publications lacking these search words in their title, abstract or keywords were therefore excluded from review. To save further time, the selection was limited to peer-reviewed journal articles published in English.

It was also decided to exclude articles that did not reference one of the main themes or theoretical frameworks employed in Transitions literature, namely the Multi-Level Perspective (MLP); Technological Innovations Systems (TIS); complexity theory; resilience theory/self-adaptive systems; adaptive governance; multi-level governance; or social-ecological systems). This list was compiled in a reading of five publications providing an overview to the field (Markard et al., 2012; Fischer and Newig, 2016; Sengers et al., 2016; Kivimaa et al., 2017; Loorbach et al., 2017). One of these publications (Loorbach et al., 2017) was prescribed by BEIS to indicate the themes and literature that should be reviewed by the secondee. Although these authors are very well established in the field, they admit:

> *"This overview [of Transitions Research] is by definition limited and biased. It is limited in that we cannot extensively and completely do justice to all the different concepts, ideas, and perspectives in the field or the various ways in which it relates to established disciplines. The article is also biased in that it is largely based on the authors' understanding and perception of the rapidly expanding field."*
>
> (Loorbach et al., 2017, p.601)

As such, a handful of recently published articles reviewing the field were searched on Google Scholar using the search string:

> (sustainability transitions) AND (systematic review OR systematic OR field)

These articles echoed the list of theoretical frameworks provided in Loorbach et al. (2017, p.601). Fischer and Newig (2016) added that perspectives from the field of 'multi-level governance' have also informed studies on the governance of sustainability transitions and were thus added to the 'inclusion criteria'.

Participants of the Energy-PIECES masterclass who were already familiar with Transition literature listed authors and theoretical frameworks included in this review. Those participants who were unfamiliar listed authors and theoretical frameworks from their respective fields of research that they thought were relevant to the research topic (i.e. the governance of heat decarbonisation). However, because the secondee host prescribed the literature to be reviewed, these latter contributions were considered 'out of scope'.

Step 2: Evaluation of selected literature based on exclusion/inclusion criteria

The Web of Science search conducted in February 2019 resulted in 126 publications. When applying the inclusion/exclusion criteria to these publications, the total number of publications for review dropped from 126 to 49. For reasons of expedience, the application of inclusion/exclusion criteria was limited to a review of abstracts and, when necessary, introduction and conclusion sections of the 126 publications.

Step 3: Prioritisation of selected articles

Due to time limitations, publications were categorised as 'high', 'medium' and 'low' priority for the literature review based on their expected ability to provide *new* insights about heat transition dynamics in the European context. Studies that make mention of, but do not employ the theoretical frameworks listed above, were classed as 'low' priority, and studies of European heat transitions were prioritised over non-European heat transitions. Also, if multiple publications were written by the same author(s) on a particular heat transition, the more recent publication took higher priority, based on the assumption that authors would likely cite their previous findings.

An initial table was produced to indicate priority and was subsequently used to record findings and other identifiers for the creation of a literature review summaries provided in Appendix 1.

Step 4: Inductive thematic analysis of literature

Through the iterative process of preliminary coding and categorisation, nine themes emerged from the literature:

1. Historical path dependency and the role of place-based 'selection environments'
2. The role of power and politics and the need to actively manage phase-outs
3. Heat systems as 'complex socio-technical systems' and their non-linear transitions
4. Interactions responsible for 'transition dynamics'
    a. Interactions between innovations and ecological systems
    b. Interactions between innovations
    c. Inter-sector interactions
    d. Interactions between innovations, social norms, practices, and beliefs
5. The role of uncertainty and experimentation in governing transitions
6. Key actor roles and mediating activities in heat transitions
7. Centralised vs. decentralised transition

Step 5: Combining the literature

When evaluating the findings in combination, the following questions were considered under each of the seven themes:

- What policies would support and accelerate a UK transition to decarbonised heat?
- What *policymaking processes* would support and accelerate a UK transition to decarbonised heat?
- How do the findings relate to one another? Are there any contradictions? Are there any synergies?

Step 6: Consider recommendations for energy policy(making)

In most instances, concrete policy recommendations were recorded as the journal articles were reviewed, whereas recommendations for *policymaking* were recorded during Step 5 when the findings were brought together. Recommendations can be found in Section 6 of this report. The findings are now presented in the order of the aforementioned themes.

4. Findings

4.1. The role of path dependency in heat transitions

Part of the Transitions literature is concerned specifically with how innovations diffuse across space. Part of this research looks at place-based factors that create a more or less conducive environment for the 'selection' of certain innovations. Again, this notion comes from an evolutionary understanding of societal development. In Sweden, for example, one can see how the topography of the country and lack of fossil fuel resource supported the transition to hydropower after the 1970s' oil crisis. In three alpine regions in Austria, isolation from the gas grid, a wealth of woodland, and culture of self-sufficiency and environmentalism have supported the transition to biomass-DH (Seiwald, 2014). As evidenced in these examples, social and material factors that vary between and within countries create unique "*selection environments*" (Geels, 2004, p.916) that create barriers to certain pathways of development whilst encouraging others.

As mediators and products of past transition, selection environments produce path dependency through their interaction with innovations. Path dependency is likely responsible, in part, for the lack of progress in decarbonising the UK heat sector. Many of the mature solutions for low-carbon heat (e.g. heat pumps and Combined-Heat-and-Power) require a transition to a decentralised heat system. However, nationalisation and reorganisation of the heating sector into vertically integrated structures after the Second World War, followed by the privatisation of the energy sector in the 1980s, have created significant barriers for today's heat transition toward decentralised sources of renewable heat.

Although some of these barriers are material (such as sunken investments in the national gas grid), historical studies suggest that socio-political path dependencies can be equally, if not more, powerful than material path dependencies. For example, the centralisation and then privatisation of the UK's heating system has: limited the capacity of local and national Government to plan and coordinate low-carbon transitions (Monstadt, 2009); introduced a regulatory framework geared to short-term cost efficiencies; and guaranteed return on investment to monopoly heat providers under a periodically revised price control formula, deterring private sector investment in local heat infrastructures (Webb, 2015).

Interestingly, however, DH has recently begun scaling up in the Netherlands despite its history of similar past transitions. Hawkey and Webb (2014) argue that this is due, in part, to differences in the first transition to the welfare state and centralised heat provision. Where the UK transitioned to the Anglo-Saxon model of the welfare state, the Netherlands transitioned to the continental model. As such, the neoliberal transition in the 1980s and 1990s produced a Liberal Market Economy (LME) in the UK and a Coordinated Market Economy (CME) in the Netherlands with two implications for today's heat transition – which are now discussed in turn.

First, in CMEs, deliberative problem-solving and information-sharing between public and private actors is *institutionalised*, meaning firms are prepared to invest in the costly process of coordination and generally have a better understanding of how interested parties will act. By comparison, in LMEs, investment in this social infrastructure has been discouraged on the grounds of economic inefficiency (Hawkey and Webb, 2014). This produces a barrier for DH in the UK, as it requires a *high* level of coordination and cooperation between firms, regulators, and regional business networks.

Second, countries adopting a continental welfare model underwent governance reforms after the Second World War to grant LAs the legislative and budgetary powers needed to execute welfare programmes. A legacy of this transition is that they are better suited today to deliver low-carbon transitions. For example, in Aberdeen, the council invested about £3.8m in DH – a risky investment by UK standards. By comparison, Rotterdam invested €38m *and* underwrote €150m of commercial loans (Hawkey and Webb, 2014).

What do these path dependencies imply for the UK heat transition? First, there are fewer governance barriers for a transition to hydrogen heating. Second, if a transition to a decentralised heat system is preferred on economic, environmental, or social grounds, the UK will also need to undergo a transition in its governance structures, devolving budgetary and decision-making powers to the local and/or regional level. This topic is further discussed in Section 4.10 of this report. However, it is worth noting in this section that barriers to transition are *perceived* and therefore very much susceptible to psychological constraints.

Upham et al. (2018) find that human psychology, like material factors, produces path dependency. In interviews with R&D and governance actors in Germany and the UK, the authors find that conjunctural (or situated) knowledge strongly influences individual attitudes and beliefs in relation to niche energy technologies. Knowledge is situated in the national context, whereby the realm of possibility for infrastructure provision is very much shaped by actors' knowledge of and experiences with the national heating system. Even this knowledge varies within countries, however, shaped in part by organisational logics in which people are embedded, such as the techno-promissory environments of R&D programmes that inevitably influence beliefs of policymakers in regards to underdeveloped technologies, for example, hydrogen fuel cells (Upham et al., 2018, p.172).

Beyond beliefs, organisational logics are also found to impact actors' priorities. For example, in interviews on the UK heat transition with ministerial officers, interviewees were found to share a prioritisation for the minimisation of "*physical and hence political disturbance in connection with the public at large*" (Upham et al., 2018, p.168). This position by ministry officers reflects their "*experience with UK politics and in particular past and assumed future public opinion*" (Upham et al., 2018, p.168). Compare this conjunctural knowledge with that of geothermal engineers, and one would get two very different pictures of what the 'most feasible' pathway might be for heat decarbonisation in the UK.

Although expectations and beliefs about the future (including what is possible) clearly shape technological futures, they do not do so evenly. Expectations relating to future technologies circulate and compete in arenas such as research programmes, conferences, meetings and other discussion fora, where government and scientific communities are present. These communities have the potential to influence further decision-makers to whom they are connected. Ultimately, "*those with positional authority can and do commit public and private sector resources that strengthen niche activities, bringing them into the 'regime'*" (Upham et al., 2018, p.172).

By comparison, the situated experiences of those not connected to decision makers are largely excluded from these research programmes, conferences, etc. As such, (1) assumptions by those with positional authority regarding the 'public's' attitudes toward top-down interventions may be flawed; (2) the perceptions, beliefs and preferences of those excluded from aforementioned arenas risk being discounted in discursive debate amongst technocrats. This inequity raises concerns over the legitimacy and equitability of sociotechnical transitions.

4.2. The role of power and politics and the need to actively manage phase-outs

As niche innovations scale-up, they interact with the incumbent regime in a number of social and material ways. The Transitions literature is rich in case studies in which powerful actors use their advantage to co-opt or actively block transition. One of the most controversial among them being ExxonMobil's multi-million dollar investment in a multi-decade campaign to peddle climate misinformation (Supran and Oreskes, 2017). Excluding these more ominous, and potentially criminal activities, and actions to protect incumbent industries are commonplace, and actions to protect incumbent industries are commonplace. As such, Transitions scholars advocate Government strategies that go beyond support of niche innovations and that actively manage the phase-out of unsustainable systems (Geels, 2014). The following sub-sections present three case studies that illustrate how power dynamics have mediated interactions between low-carbon innovations and incumbent heat systems.

4.2.1. Case study: Combined-Heat-and-Power District Heating (CHP-DH) in Woking, United Kingdom

Given the path dependencies cited in Section 4.1, only a small number of municipally-owned Energy Service Companies (ESCos) exist in the UK. Thameswey Energy Ltd (TEL) is arguably the most advanced among them. Woking Borough Council set up TEL in 1999 to help meet its carbon reduction targets laid out in Woking's Climate Change Strategy[14]. In 2001, a gas-powered CHP station was built to supply electricity and heat to civic offices and surrounding businesses within the town centre (ThamesWey Ltd., 2019b), and a recently approved energy centre will have the capacity to supply over 2,500 homes (Woking Borough Council 2019). In 2007, TEL expanded some 60 miles away and now supplies electricity and heat to over 900 residential and 30 retail units in Milton Keynes (ThamesWey Ltd., 2019a). These developments, however, were not without significant barriers and delays.

Because the UK electricity grid's market structure is geared towards the needs of large-scale Energy Utility companies, inhibitive transaction costs for small suppliers prevented TEL from accessing the grid. According to the Managing Director, it would have cost £500,000 minimum to transact in the national market. TEL instead chose to bypass the grid by investing in private wire networks – a highly capital-intensive solution, but one which a number of energy service companies judge to be more economically efficient (Hannon and Bolton, 2015).

This workaround is possible under the Electricity Act's Distribution and Supply Licence Exemptions, but these exemptions apply only to networks supplying a limited volume of electricity. As such TEL will need to move progressively towards sales of electricity to commercial customers only and, eventually, the grid (ThamesWey Ltd., 2016). Moreover, "*recent regulatory changes have mandated that these operators allow 3rd party access to their networks [potentially threatening] this aspect of TEL's model*" (Bolton and Hannon, 2016, p.1737).

This example shows how access to energy infrastructure becomes increasingly important as renewable energy technologies scale-up (van der Vooren et al., 2012). It also demonstrates the role of power and politics in mediating the interactions between innovations and regimes. Of course, interactions affect the incumbent regime as well. TEL has begun selling flexibility services to the national grid operator, which, if scaled up, would have a transformative effect on the incumbent energy regime. Although the regime can and does slowly change through its interactions with niche innovations, power asymmetries are known to slow this process.

14 Local climate change strategies are not statutory in England. Woking is known for having an environmentally-minded electorate and council.

4.2.2. Case study: Combined-Heat-and-Power (CHP) blockage in Sweden

Sweden's publicly-owned commercial government energy agency, Vattenfall, was historically tasked with steering the "*Transition from a locally fragmented grid powered with small- and medium-size power plants to a to a nationally integrated grid powered by large-scale power plants*" (Nciri and Miller, 2017, p.219). This transition took over four decades and resulted in the creation of the so-called 'power club' made up of 12 regional utility monopolies. Together, these 12 monopolies formed the Swedish State Power Board.

Throughout the national integration of local grids, coal and oil-fired CHP-DH systems were being adopted by municipally owned utilities. The first DH system was built in 1948, coupled with a CHP facility. In the early decades of diffusion, the two systems, DH and CHP, "*were considered two sides of the same coin* (Werner, 2010)" (Nciri and Miller, 2017, p.217). However, in the late 1970s/early 1980s, there was a sudden drop in generation from CHP-DH systems.

Behind this drop is a story of active blockage of CHP by the 'power club'. In the 1960s, forecasted growth in electricity created fear of electricity supply shortage (Kåberger, 2002). In response, the Swedish Government launched a nuclear power program, with the first nuclear reactors commissioned in the mid-1970s. Unfortunately, however, the Government had overestimated growth in electricity demand, resulting in *overcapacity* in electricity generation (Ericsson, 2009; Högselius, 2009; Werner, 2010). To prevent losses, the 'power club' colluded to block electricity generation from municipally-owned utilities. This was only possible due to the hierarchical nature of Sweden's electricity generation and distribution system which developed during the transition to a nationally integrated power grid. Because the 'power club' governed the feed-in of distributed electricity, they were able to charge exorbitant electricity rates to municipalities operating CHP units and affectively price-out local electricity, and thereby heat generation.

Dynamics changed, however, after Sweden's entrance into the European Union followed by the liberalisation of the energy sector in 1996. Liberalisation ended Sweden's regional monopoly system, initiating a process of mergers and acquisitions with three electricity generators, Vattenfall, Fortum and E.ON controlling about 90% of power generation by the end of the 2000s (Högselius and Kaijser, 2010). Municipal DH systems got caught in the merger and acquisition strategies of these large-scale utilities looking to position themselves to compete in the larger European market (Högselius and Kaijser, 2010). As a result, the share of space heat produced by municipally-owned DH companies dropped from 98% to 65% between 1990 and 2011, and private ownership increased from almost 0% to 35% (Åberg et al., 2016).

Able to participate in the integrated European energy market, Swedish energy companies suddenly shifted their position toward CHP (a now economically viable option) and began building stations where they were previously blocked. This development was largely accepted by the public, as the Chernobyl disaster of 1986 had raised public opposition to nuclear power and contributed to a consumer preference for alternative energy sources.

4.2.3. Case study: District heating (DH) vs. Passivhaus design in Freiburg, Germany

The Vauban District in Freiburg, Germany is a credited example of how energy transitions can be supported through 'good governance'. When the city was expanding in the 1990s, Forum Vauban materialised as a citizen's group tasked with facilitating a participatory planning process agreed to by the municipality. Forum Vauban belongs to a global network of citizen groups that, through "*locally owned, participatory processes*" (Global Ecovillage Network, 2019, no pagination), develop intentional communities to regenerate social and natural environments on all four dimensions of sustainability (social, culture, ecology and economy). Its success in creating a 'model district' won the city a 'best practice' award at the 1996 UN Habitat II conference in Istanbul (Metropolis, 2019).

Both supply- and demand-side strategies were adopted to improve the sustainability of the district's heat system. However, the Passivhaus design, favoured by several future homeowners, conflicted with the municipality's DH plans. To improve the economic viability of the project, the municipality planned to connect every dwelling to the heat network and charge a unified heat tariff per connection. Members of Forum Vauban argued that this would disincentivise the costlier, but more environmentally sustainable, Passivhaus standard, as the tariff would counteract most of the cost-savings. As a compromise, the municipality exempted Passivhaus connection if three very costly conditions were met by builders/developers. By effect, only a handful of Passivhaus dwellings were built in the Vauban District. So, although this innovation in design is economically more efficient than DH and local preferences support its uptake, power dynamics have relegated Passivhaus standards to a niche market in Freiburg where an expansion of the DH system is not feasible.

Although the participatory planning process provided valuable opportunities for deliberation, the role of rational arguments was, in the end, limited by authoritative decisions taken by the city council, which themselves reflected "*the interests and somewhat stabilized power balances within the city administration*" (Späth and Rohracher, 2015, p.13). The authors thus argue that "*Besides the power of argument and persuasion, it seems that we also need to appreciate the influence of interests and formal powers*" (Späth and Rohracher, 2015, p.13).

This 'appreciation' could take several forms: (1) an analysis of politics and power in addition to policy (Geels et al., 2017) – which could help tailor policy interventions throughout the transition to account for counterproductive power dynamics at the national and local level; (2) a critical reflection on disparate levels of access to

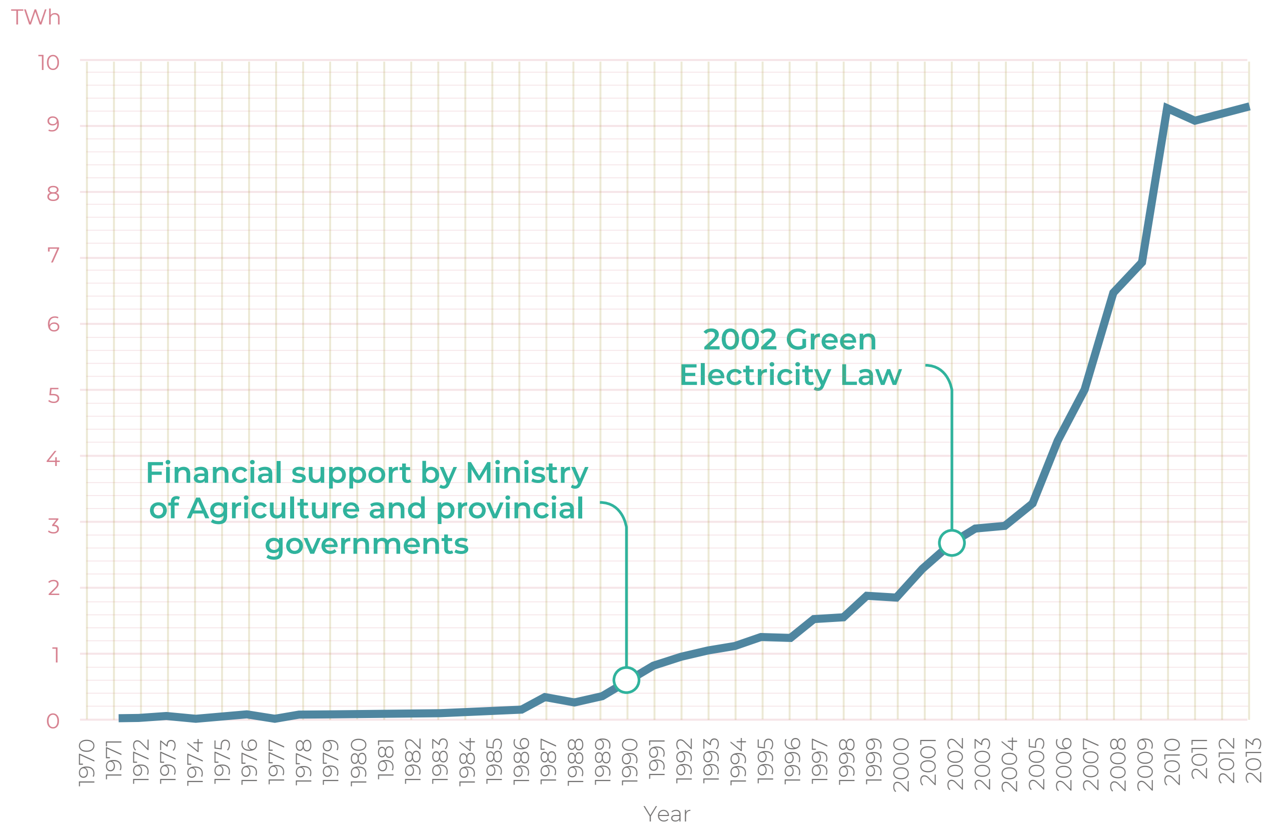

Figure 3: Annual heat production from Austrian biomass district heating in TWh (adapted from Geels and Johnson, 2018).

government officials and contributions to the national debate on heat decarbonisation; (3) introduction of a governing framework that redistributes access during the 'opening up' phase of transitions to ensure that a diversity of perspectives (e.g. organisational logics), values and priorities inform the debate on heat decarbonisation; and (4) the active management of phase-outs in addition to stimulating innovation (Geels et al., 2017).

The active management of phase-outs can take many forms. The Danish Government, for example, banned electric heat in support of municipally-owned CHP-DH and, at the same time, granted LAs the power to oblige new and existing buildings to connect to the heat network. Norway also made connection mandatory for certain categories of buildings near district energy networks, banned fuel oil boilers in new buildings, and required minimum share of renewable thermal energy (Gronli, 2016). Though these policies do raise the question of 'who pays', thus bringing into focus the role of power dynamics in mediating these debates.

4.3. Heat systems as 'complex, socio-technical systems' and their non-linear evolution

When discussing path dependencies, transitions are often conceptualised as a linear path: from the past to the present. However, historical studies show that "*Transitions often appear not as an exponential line on a graph, but as a punctuated equilibrium, which dips and rises*" (Sovacool, 2016, p.13).

This suggests the energy system switches from one equilibrium to another and that its development is nonlinear. This finding supports complexity theory, whereby the complex web of non-linear relations between micro-components create dynamic behaviour at the macro-level. It also suggests that "*energy transitions are complex, and irreducible to a single cause, factor, or blueprint*" (Sovacool, 2016, p.2), too often, explanations of the successful diffusion of niche innovations are reduced to a singular event or intervention, suggested, for example, in Figure 3.

Yet, policy interventions do not always succeed in triggering the take-off of innovations. For example, advanced wood heating in the north eastern United States have not scaled up despite generous subsidies (Edling and Danks, 2018). Similarly, Norway is heavily forested, yet advanced wood heaters have not taken off like air-to-air heat pumps, despite similar levels of Government subsidy (Sopha et al., 2011). So too, UK LAs that have established a business case, for DH "*have struggled to move forward, with projects stalling at planning stage, declining in scale, and/or taking many years to advance to construction* (*Wiltshire et al.*, 2013)" (Webb, 2015, p.267). In other words, transitions cannot be reduced to a single policy intervention such as the introduction of financial incentives.

Case studies of successfully diffused technologies reveal a number of other, equally important drivers of heat transitions. That said, not a single heat transition presented in the literature was without subsidy. Returning to Figure 3, financial subsidy by Austria's federal Ministry of Agriculture and provincial governments of Styria, Upper Austria and Lower Austria in the early 1990s (if fully utilised) could amount to up to 60% of investment costs in biomass district heating (BMDH) (Geels and Johnson, 2018). Indeed, these subsidies were critical in supporting the diffusion of this socio-technical configuration across rural alpine villages. The lesson here is that financial incentives are necessary *but insufficient* drivers of transition. Too often, when a financial incentive fails, pundits lazily argue that the subsidy was too low or the interest rates prohibitively high. These explanations may hold legitimacy, but to reduce societal transitions to techno-economic explanations prevents learning about the complex systems Government wishes to transform. In-depth, qualitative research in the Social Sciences helps to identify other critical drivers of heat transitions and how governments can support, and thereby accelerate, these processes. Two such case studies are now summarised.

4.3.1. Case study: Biomass district heating (BMDH) in Marburg-Beidenkopf, Germany

On the national scale, two regulatory frameworks have been essential in supporting the scale-up of BMDH in Germany: (1) the Renewable Energy Sources Act (EEG), which regulates the feed-in compensation for electricity produced by renewable energies; and (2) the Renewable Energies Heating Act (EEWarmeG), which established the legal framework for heat production based on renewable energy sources. Having recognised early on the role of local and regional governments for steering the energy transition, the German Government also rolled out national grant competitions and programmes such as the master plan 100% climate protection, providing county administrations with additional funds to establish a regional 'energy concept'. Before this grant scheme, there was little-to-no institutional support at the subnational level for renewable energy infrastructure development. (Roesler and Hassler, 2019)

In Marburg-Biedenkopf, the grant funded a county-wide working group on bioenergy villages. This working group within the county government recruited municipalities as cooperative members and facilitated the creation of an informed network. This network was achieved via regular meetings where guest speakers shared information on overcoming planning and financing barriers with any and all residents and farmers interesting in creating a heat cooperative. Residents experienced with heating cooperatives were also invited so as to facilitate knowledge sharing and network building. At the local level, village mayors were critical in winning the trust and political support of residents. The involvement of municipalities as cooperative members not only provided base-load consumption and investment, but also helped foster trust in the professional implementation of community projects. It also helped reduce barriers in the planning system where possible, unlocking the BMDH transition in Marburg-Biedenkopf.

Germany's systems approach to transition governance includes the funding of coordination activities by regional and local governments, helping these actors to overcome barriers in planning. Similarly, in 2018, the German Government set up an agency to promote path-breaking innovations by setting up innovation networks and clusters – fostering the horizontal 'scale-up' of innovations (BMWI, 2019).

4.3.2. Case study: Advanced wood heating in Northeast, United States

Northern Forest Centre, a non-profit in the United States, is also executing a strategic 'cluster' approach in their 'Model Neighborhood Project' to support the scale-up of advanced wood heating in four heavily forested New England states. The project focuses on one community at a time, developing highly visible models of advanced wood pellet boilers, working with industry to increase supply and distribution networks of boilers and pellets and with local community representatives to offer decision and technological support, hosting community-level meetings and workshops, and running local print media campaigns. The clusters approach is meant to improve efficiency for pellet distributors and service technicians and, as a result, improved fuel security for households adopting this new technology. Together with the Northern Forest Centre, a group of researchers are conducting a 'natural experiment' to determine the differentiated effect of state subsidies on adoption in areas with this support vs. those without. Thanks to access to installers, adopters and "*informed non-adopters*" (Edling and Danks, 2018, p.334), Social Science researchers aim to uncover a more nuanced understanding of actors' decision-making processes and, as well, the systemic barriers to scale-up.

When explaining the motivation behind this research, the authors write:

> *"System-based studies [...] have the capacity to provide more than just marketing advice about characteristics of potential adopters for new energy technologies. When done well, they can provide change agents with insights into which elements of the energy system are within their ability to influence and how to cope with shifts in elements they cannot change"*
>
> (Edling and Danks, 2018, p.338)

4.3.3. Case study: Biomass district heating (BMDH) in the alpine region of Austria

The BMDH transition began with private sawmill owners purchasing advanced wood boiler systems (often from Sweden) to make economic use of offcuts and sawdust. Despite the absence of policy support, sawmill owners began experimenting with small-scale BMDH-systems and are therefore considered the 'pioneers' of this niche innovation. From the mid-1980s, the emergence of a new market for wood products from BMDH-systems attracted Austrian farmers who own woodland and encouraged the formation of cooperatives to pull farmers' resources for small to medium-scale BMDH networks in villages.

Geels and Johnson (2018) find that the early adoption of BMDH by local residents as heat consumers was not driven by cost-savings. In fact, joining a network more often raised heat costs in this early stage of transition. The authors suggest that a strong culture of self-reliance, the desire to support local farmers, and environmental values found in rural alpine regions of Austria were critical for early adoption. So too were the positions of village opinion leaders and the influence of peer pressure. The spread of information via word-of-mouth was also critical. Visits to BMDH sites were organised by intermediaries where residents from different villages could learn about the technology, express concerns, and exchange experiences.

At some point, provincial energy agencies, chambers of agriculture and the Biomass Association centrally organised information dissemination via media campaigns, brochures, and public events. "*These organizations also provided advice for private households and enabled communication between component suppliers and BMDH-operators, [...] provided training and financial support for BMDH-developers, assisted with heat mapping exercises, and advised in BMDH-construction via 'technology introduction managers'*" (Geels and Johnson, 2018, p.148).

During the same period, the National Forestry Agency supported farmers in lobbying regional governments for BMDH subsidies. At first BMDH was being sold to policymakers as an industry to alleviate rural decline. It was not until the 1990s that BMDH became linked to climate change, green jobs and exports, and energy independence. These latter issue linkages facilitated the enrolment of more powerful policy actors at the national level, ensuring the inclusion of biomass in the feed-in tariffs under the 2002 Green Electricity Law (see second intervention in Figure 3). Multi-level governance institutions provided opportunities for interaction between local, provincial and national governments – supporting bottom-up (and in some cases, top-down) policy entrepreneurship.[15] Similarly, horizontal policy entrepreneurship was supported by inter-departmental institutions between the Ministry of Agriculture and the Ministry for Traffic, Innovation and Technology (Seiwald, 2014).

Thanks to a number of qualitative studies, there now exists a better understanding of the various 'scaling-up' activities that can be further supported by Government. But the sum of these activities does not fully explain the diffusion curve in Figure 3. In truth, the curve in Figure 3 does not represent the scale-up of one particular innovation. Because small- to medium-scale BMDH is limited by dis-economies of scale, diffusion has been confined to villages for which these systems are well suited.

A breakdown of the single diffusion curve into public and private DH and CHP plants helps to explain the dynamic transition process. Incumbent energy utilities entered the biomass energy industry following the 2002 Green Electricity Law (see the vertical line in Figure 4), as the feed-in tariff attracted the development of large-scale biomass CHP plants. These new systems varied largely from small-scale BMDH networks owned and operated by farming cooperatives. Not only were they larger in scale, in many cases, the CHP plants did not connect to DH at all. Their sudden entrance into the market rapidly drove up demand for wood pellet feedstock and, thereby, biomass prices, forcing plant operators to maximise their electricity sales to ensure profitability. Yet, many experienced losses between 2008 and 2009. Because these large, privately-owned CHP plants were not connected to DH, this period is associated with large amounts of unutilised waste heat, turning CHP plants into an ecologically unsustainable, loss-making business. (Seiwald, 2014)

15 Policy 'up-scaling' went as far as the level of EU through the strategic, early involvement of Styria's regional energy agency director, who was also involved in discussions at the EU-level on the design and management principles of European Regional Development funds (Späth and Rohracher, 2012).

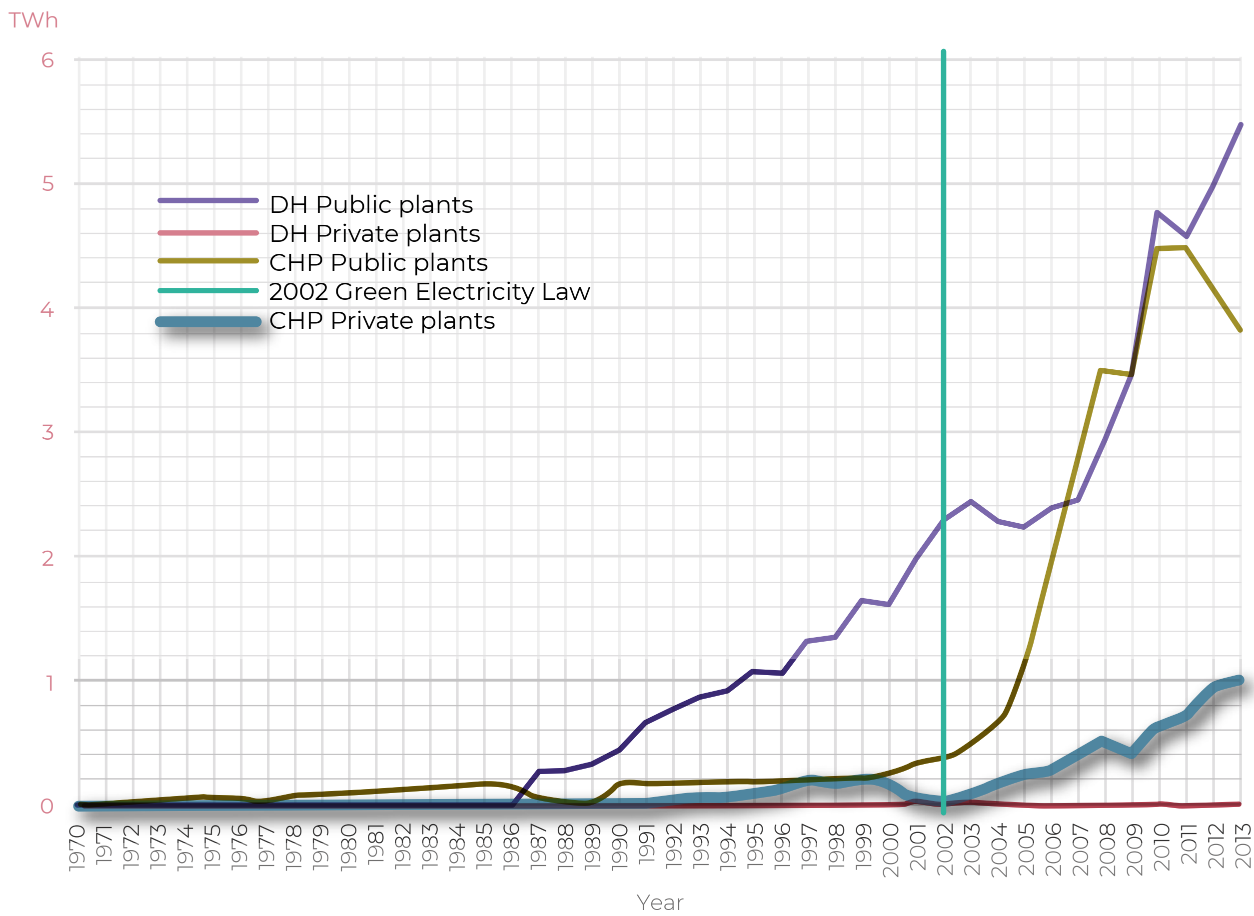

Figure 4: Diffusion curves of different biomass energy systems in TWh (adapted from Geels and Johnson, 2018).

Coupled with the business innovation of energy service contracting, the feed-in tariff triggered a transition to biomass micronets, owned and operated by Energy Service Companies (ESCos). Figure 4 shows the rapid diffusion of biomass micronets compared to the steady and slow growth of village DH. In part, the rate of growth was supported by internal reinforcement: Contributing technical, operational and planning skills, as well as expertise in subsidy applications, ESCos further professionalised the BMDH industry, thus increasing the attractiveness of micronets and reinforcing growth. The rapid rate of deployment attracted incumbent energy utilities to enter the micronet industry and compete with ESCos.

The emergence of a business model innovation (i.e. energy service contracting) that 'unlocked' the transition to biomass micro-nets, as well as the sudden price rise in biomass feedstock are both examples of how unpredictable dynamics emerge mid-transition. As the system shifted between equilibria – first from oil heating to small-scale BMDH, then to large-scale CHP and finally to micronets – different 'system builders' also 'emerged'. The initial system builders were sawmill owners. From the second period onwards, farmers and their cooperatives become system builders of village heating. In the third period energy utilities and the National Forestry Agency entered as system builders with regard to BMDH-CHP. And finally, in regard to BMDH micronets, project developers, engineering and consultancy firms have been the main system builders. Together, these emerging features of Austria's BMDH transition demonstrate how interventions in complex systems produce unpredictable developments.

4.4. How interactions between innovations and ecological systems lead to 'emergence'

As with energy service contracting in the Austrian BMDH case study, new artefacts and system dynamics emerge mid-transition, and their emergence is impossible to predict. According to complex systems theory, 'emergence' is one of the key properties of complex systems (see Section 2.2). "*Emergence is a function of synergism, whereby system-wide characteristics do not result from superposition (i.e. additive effects of system components) but instead from interactions among components (Lansing and Kremer, 1993)*" (Manson, 2001, p.410). In this and subsequent sub-sections, interactions shown to produce 'emergent' behaviour as heat systems evolve are introduced. The property of *emergence* produces great uncertainty for Government, as it implies that a linear pathway to a renewable heat system, triggered by 'the right' set of policies, is unachievable. Rather, to 'steer' transitions, an adaptive governance framework is needed to react to unforeseeable social and technological artefacts that emerge mid-transition.

The first interaction presented is that between energy technologies and the natural environment, both of which are vulnerable to negative feedbacks. Technologies that are more closely coupled with local natural systems are more susceptible to sudden changes in public opinion and policy. For example, in 2007 in the German city of Staufen, a drilling operation to provide geothermal heating to the city hall caused buildings in the city centre to rise by some 12cm, causing severe damage. One engineer called it "*the largest accident conceivable in shallow geothermal energy utilization*" (Bleicher and Gross, 2016, p.283). In response, the state government of Baden Württenberg tightened regulation of the industry by introducing limits on drilling depth and a ban on geothermal drilling in water protection areas, ultimately suppressing delivery rates of ground-source heat pumps. The creation of uniform decision criteria for drilling was criticised by practitioners, as each installation (and its related risk) is highly specific and depends on local hydrogeological conditions (Bleicher and Gross, 2016).

Although the Staufen case study provides a rather dramatic example of short-term negative feedbacks between energy and ecologic systems, other feedbacks are delayed and often require several years for system pressures to form. For example, 98% of Norway's electricity is generated by hydropower, and most heat systems are powered by electricity. However, periods of low rainfall resulting in recurring high electricity price events (Sopha et al., 2011) and an increased awareness in the 1970s and 1980s of the environmental impacts of dams have provided windows of opportunity for alternative niche developments in gas-fired power plants, DH, heat pumps and wood pellet heating (Norwegian Minsistry of Petroleum and Energy, 2018). With climate change already effecting rainfall patterns, it is expected that these windows will broaden with time. This energy-ecological system interaction impacts upon coupled systems as well. For example, the battery function Norway's steady hydropower provides neighbouring countries that are more reliant on wind and solar is under threat (Wettengel, 2018). Interactions between Norway's electricity system and the climate system therefore have knock-on effects for the scale-up of renewable energy technologies in neighbouring countries.

4.5. How interactions between innovations lead to 'emergence'

DH and heat pumps provide up to 75% of the energy demand for heating in Swedish buildings, but these systems are reaching saturation and are now in competition. DH entered in a phase of stagnation in the early 2000s due to increased energy efficiency of dwellings and market saturation: over 85% of multi-housing dwellings were already connected to DH systems (Nciri and Miller, 2017). Similarly, after 13 consecutive years of growth in the single-dwelling sector, heat pump sales declined in 2007 for the first time. Saturation has led heat pump providers to seek business in larger cities and multi-dwelling buildings. Discontent with rising heat prices associated with the DH monopolistic structure has made heat pumps a competitive alternative to DH. As such, heat pumps are expected to take away market share from DH (Dzebo et al., 2017).

If successful, the scale-up of heat pumps in urban areas of Sweden would put further pressure on DH companies, forcing them to raise heat prices. This development could trigger a downward spiral in market share. At a minimum, it could slow investments in decarbonising network heating and increase networks' dependence on unsustainable sources such as heat, such as energy from waste.

Whilst difficult to predict these system dynamics in advance, a concerted effort to analyse potential interactions between innovations would likely improve the policy mix. Though, a more adaptive governance framework is needed to monitor and respond to such developments as they emerge. Such a framework would support, as well, the monitoring of and the response to cross-sector interactions.

4.6. How cross-sector interactions lead to 'emergence'

As heat innovations scale up, not only do they interact with the incumbent heat regime, but as well, with other coupled regimes. For example, heat innovations are known to interact with demand-side innovations such as smart metering, retrofit and new-build standards; the electricity sector regarding heat network storage of intermittent energy; transport, such as the hydrogen-powered vehicles lying the groundwork for mobile hydrogen fuel cells; and even agriculture and sanitation sectors as sludge and organic waste are used for biogas production. Konrad et al. (2008) have adapted Geels' Multi-Level Perspective model to conceptualise these interactions (Figure 5). The example used in the model shows how greywater recycling, a niche innovation emerging in the water regime, has created a new functional and structural coupling between water and sanitation regimes that were previously highly separated. As water recycling systems scale-up, improvements in membrane technology enable opportunities for decentralised sanitation systems as well. If progressed, these developments would strain water and wastewater distribution networks that rely on a minimal flow for proper functioning (see 'functional problems centralised sanitation systems' interaction in Figure 5). In addition to rising maintenance costs, the decrease in network users would increase prices for remaining users, thus reinforcing the transition to decentralised water supply and sanitation systems.

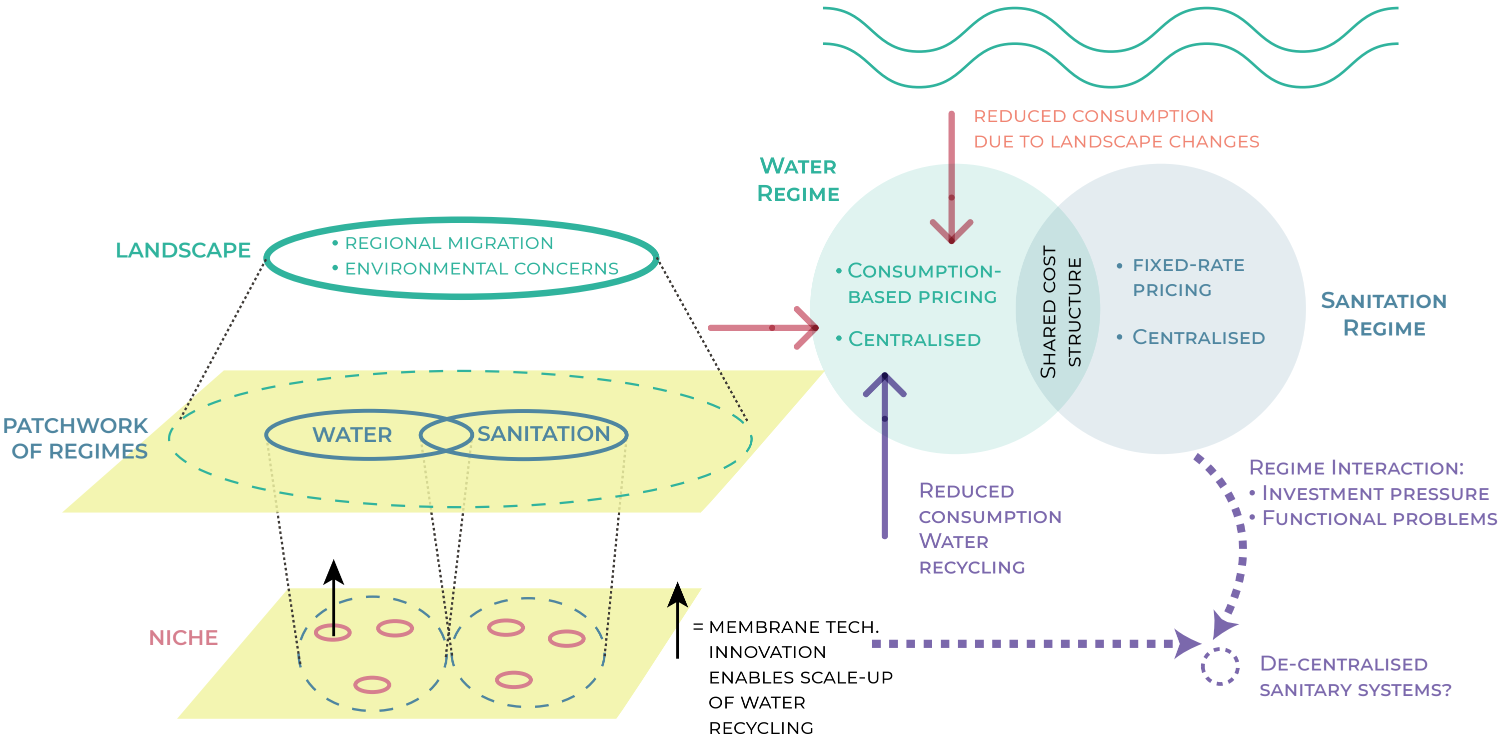

Figure 5: Multi-level, cross regime dynamic in the water and sanitation regimes (adapted from Konrad et al., 2008).

Konrad et al. (2008) recommend that these interactions, including those that are currently 'inactive' (such as the use of water recovery systems for heat recovery) be explicitly modelled when producing the evidence base for decision-making. In their article, they provide a method for mapping inter-regime (or cross-sector) interactions with key stakeholders. Such exercises with industry experts in the UK would be invaluable, as several cross-sector interactions have been found to influence national transitions to renewable heat. Some of these interactions are now discussed in the following sub-sections.

4.6.1. Interactions with the electricity sector

The heating and electricity sectors may become functionally coupled in the UK in one of two ways. As in Norway, Government may decide to pursue a pathway toward heat electrification. However, this envisaged transition is very much constrained by the lack of renewable energy capacity and the unresolved issues around network balancing and energy storage associated with the transition to renewable energy. Alternatively, DH or hydrogen heating, could provide energy storage for system balancing.

Whilst dynamics from these interactions are well understood, others have come as a surprise, such as the biomass price spike in the Austrian BMDH case study presented in Section 4.3.3 and the blockage of CHP in the Swedish case study presented in Section 4.2.2).

4.6.2. Interactions with the waste sector

Following the 2002 ban on landfill waste, Swedish municipalities began paying DH companies to incinerate their waste, resulting in very low or, in some cases, negative fuel costs. This development in the waste sector facilitated the rapid diffusion of waste incineration plants in Sweden, which have grown increasingly dependent on imported waste as domestic recycling rates have climbed to 99%. These developments have led to increased environmental concern relating to the waste hierarchy and debate on European Waste-to-Energy (WtE) overcapacity (Dzebo et al., 2017). In fact, a waste incinerator, on which a planned DH system in Rotterdam relied, was suddenly closed in 2009 due to overcapacity. Plans were stalled, and nearly cancelled, until an alternative, low-carbon energy source was found and the scheme was brought forward (Hawkey and Webb, 2014).

Recognising the adverse effects of the WtE industry for sustainable development, the European Union has urged member states to gradually phase-out public support for WtE, introduce or raise incineration taxes, and carefully consider the risk of stranded assets when supporting investment in WtE, particularly in countries such as the UK where separate collection and recycling obligations have not been met and where much-needed improvements in recycling would reduce the availability of feedstock of new incineration plants over their lifespan (Malinauskaite et al., 2017). As national governments act to increase recycling rates under existing and developing waste policy frameworks, the availability of refuse waste for fuel stock will continue to fall. As such, policy developments in the waste sector, such as the UK's recently released Resources and Waste Strategy for England (DEFRA, 2018), should be monitored and their impact upon the heat transition analysed so as to prevent unintended consequences for the waste and heat transitions.

4.6.3. Interactions with the agricultural sector

In the Austrian case study (see Section 4.3.3), the agricultural sector lobby for BMDH was strengthened by the oil crises of the 1970s and 1980s. Issue linkage with rural regeneration created an attractive symbiosis for government policy, supporting the scale-up of low-carbon heating in three alpine regions. Other symbiotic relationships include third sectors, such as in the new generation of sewage works that generate heat and electricity from sludge with fertiliser supplied as a by-product for agriculture.

However, negative relationships are well documented with the European Union recently agreeing "*conventional biofuels will be capped EU-wide at a maximum of 7%, with additional member state caps of below 7%[, and] the counting of biofuels with a high risk of indirect land use change (ILUC) will be freezed at 2019 levels and gradually phased out from 2023 towards 2030*" (European Council, 2018, no pagination).

4.6.4. Interactions with the finance sector

Studies show that lack of renewable energy infrastructure assets pose a barrier to investment, given concerns over the lack of asset liquidity (Jones, 2015; González and Lacal-Arántegui, 2016; Grüning and Moslener, 2016). The implication therefore is that unsustainable, low-hanging fruit, such as waste incineration, may support the transition by adding to the asset liquidity of renewable energy systems. However, these solutions can produce harmful lock-ins, so caution must be taken.

4.6.5. Interactions with the housing sector

Heat innovations were found to interact with both the planning system and building regulations, presented in this order. Firstly, a planning system that does not account for spatial requirements of renewable heat systems will likely produce barriers to renewable heat innovations as energy infrastructure and the built environment co-evolve (Karvonen and Guy, 2018). The example provided here is that of DH, which is highly coupled with the panning system. DH energy centres require a certain level of density, yet also a significant allocation of space in the city centre where energy centres are located, creating an interesting retrofit challenge for the built environment. DH also presents an interesting social challenge, as storage tanks are tall and narrow, provoking objections concerning the visual impact upon the landscape from local residents. Moreover, bends in pipework increase development costs and weaken the performance of heat networks. Linear pipework often faces obstructions such as bridge crossings and rail crossings. There is also the issue of mixed-use development, which is needed to for the efficient consumption of heat: "*The ideal scheme would link those adjacent buildings with differing patterns of heat demands, [...] [serving] flats predominantly in the morning and evening, but a school during the day*" (Karvonen and Guy, 2018, p.25).

This example illustrates how low-carbon transitions are very much informed by governance at the local level, regardless of whether infrastructure is owned and operated by the LA. As such, new forms of context-based governance and planning are needed. The EU's 3-year Spatial Planning and Energy for Communities in All Landscapes (SPECIAL) project addresses this need by providing "*training and capacity building; knowledge exchange; pilot projects; and the development of policy statements to train planners about the technical and policy aspects of energy infrastructure and to position them as facilitators of low-carbon energy transitions*" (Karvonen and Guy, 2018, p.31).

Interactions between the heat system and building standards highlight the role of sequence and timing in sustainability transitions. Given the long repayment timescales of capital-intensive heat systems, their economic viability is vulnerable to changes in levels of heat consumption. Uncertainty in long-term heat demand, on which business cases rest, has been cited as a major barrier to DH in the UK (Bush et al., 2016). Until Government addresses the policy vacuum on new-build standards and energy retrofitting, this uncertainty is expected to forestall capital-intensive solutions.

Because DH networks were constructed long before the rollout of energy retrofitting in Sweden, DH companies have actively obstructed measures to improve energy efficiency in their supply area. Nevertheless, a market for building upgrades has matured and is considered one of the drivers of rising DH prices and, by extension, competition with the heat pump industry (Nciri and Miller, 2017; Dzebo and Nykvist, 2017).

This interaction is not only relevant for DH. To govern a more cost-effective transition to decarbonised heat, the Swedish Government based building regulations on *energy purchased* for the property rather than overall *energy demand*. Energy purchased can be reduced through efficiency upgrades or by installing heat pump technology combined with solar panels. The latter, less environmentally sustainable option, has proven to be more cost-effective and is therefore advantaged over demand-side interventions (Dzebo and Nykvist, 2017). Considering findings presented in Section 4.5, the prioritisation of cost efficiency over environmental sustainability may very well impact negatively upon Sweden's heat transition in coming years. "*Therefore, it is of key importance to take all possible steps to reduce energy consumption before [or as] investments in district heating are made*" (Westholm and Beland Lindahl, 2012, p.333).

Yet, this coordination can be challenging in practice, as heat supply and demand solutions develop "*independently from each other in two distinct fields, and they involve different actor groups, institutions and practices; in short, they are about two distinct socio-material configurations of sustainable urban futures*" (Späth and Rohracher, 2015, p.10). The Passivhaus conflict in Freiburg (see Section 4.2.3) provides an illustrative example of this challenge. Even though both strategies (Passivhaus and DH) shared the aim of reducing the negative impacts of conventional heat provision, the isolated pursuit of these two strategies at the early stages of planning produced "*institutional and discursive inertia*" in which "*hegemonic positions*" were formed among municipal officers and corporate heads of service (Späth and Rohracher, 2015, p.13). Findings from this case study highlight the need for a truly iterative, participatory governance framework as envisaged in Transition Management that provides opportunities for future contestation, "*particularly in urban contexts where the interplay of various systems of provision often creates ambivalences, trade-offs, and opportunities for the contestation of system boundaries*" (Späth and Rohracher, 2015, p.13).

In this sub-section, cross-sector interactions that have hindered the transition toward a sustainable heat system were presented. However, positive, reinforcing relationship exist as well. For example, innovations in building insulation have enabled the scale-up of heat pumps, as a certain level of insulation is needed in winter months for the technology to meet consumer expectations (Bleicher and Gross, 2016).

4.7. The co-evolution of innovations, social norms, practices, and beliefs

This section is divided into three sub-sections. First, there is a discussion on the co-evolution of socio-technical innovations and social norms, practices and beliefs. Market research is useful for capturing consumer preferences at present and providing some insight into the short-term 'adoption' of innovations. However, studies of past heat transitions provide examples for how social norms, practices and belief affect and are affects by innovations the heat regime evolves.

The second sub-section discusses specifically the interaction between innovations and social norms, etc. at the very early stages of transition. Using examples from the heat sector, the authors show how early-established beliefs can significantly delay transition processes.

In the third sub-section, the authors discuss the need for a mixed policy approach to increase adoption amongst distinct adopter groups. An additional pitfall of market research, namely 'non-adopter bias', is reviewed and the authors recommend greater collaboration between Government, private sector actors, and the research community to improve the study of "*informed*" non-adoption (Edling and Danks, 2018, p.337).

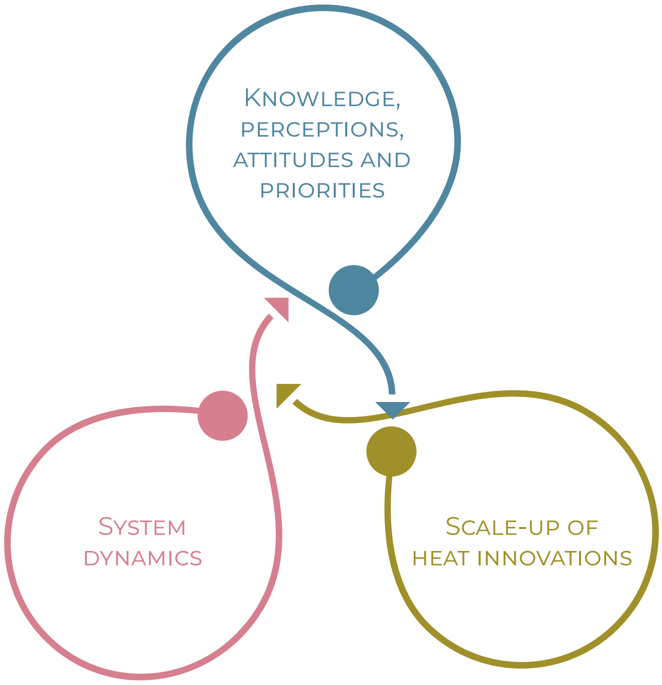

Figure 6: The co-evolution of heat systems and knowledge, perceptions, attitudes and priorities.

4.7.1. Utility functions are not static – knowledge, perceptions, attitudes and priorities undergo changes throughout the transition process

The scale-up of innovations is determined in part by existing knowledge, perceptions, attitudes and priorities of adopters (e.g. households, municipalities or landlords of residential and commercial buildings). If 'selected' for scale-up, innovations interact with the incumbent regime, coupled regimes, the environment, and each other to produce new system dynamics (Figure 6). As the public experiences these new dynamics, their practices and situated knowledge change – informing, as well, their beliefs about competing socio-technical configurations. The resulting change in knowledge, perceptions, attitudes, and priorities informs (non)adoption of socio-technical innovations moving forward. This theory of co-evolution has two implications: (1) actors' utility functions and thereby decision-making processes are not static, and thus Government's understanding of them needs updating throughout the transition process; and (2) social norms, practices and beliefs create path dependencies for co-evolving technologies and formal institutions.

For example, attitudes and perceptions of DH, a configuration which has long dominated the Swedish heating system, have shifted in recent years. Today, many households prefer heat pumps, as they are perceived to improve household energy security and reduce the risk of future price increases. They are also perceived to reduce GHG emissions relative to DH. These perceptions did not exist at the early stages of transition and have rather developed with the scale-up of heat pumps. Collectively, these perceptions have implications for the market value of homes which reinforce preferences for heat pumps. It is because of these changing perceptions that DH is expected to lose its market share (Dzebo and Nykvist, 2017).

As with energy service contracting in the Austrian BMDH case study, these new consumer preferences, or social artefacts, emerge mid-transition influencing the further evolution of Sweden's heat system.

4.7.2. Susceptibility of niche innovations to public perception at early stages of transition

In Denmark, Vattenfall pressed forward with planning a carbon capture and storage (CCS) project for its coal-fired CHP at Nordjyllandsværket without first opening the process to public debate. The plans were met by significant resistance from the local population where the storage was planned, leading to the formation of the local association 'No to CO2 Storage', whose activities have been supported by large NGOs, such as Friends of the Earth and Greenpeace. In September 2011 the Minister of Climate, Energy and Buildings issued a final refusal to Vattenfall, and the coal-fired power plant was later sold to a local energy provider and converted into a biomass-CHP plant (NOAH, 2014; Ropenus and Klinge, 2015).

Public opposition in Germany has been so strong that a law was introduced in 2012 allowing federal states the right to veto CCS developments on their land. According to a climate and energy expert at WWF, the debate leading up to the technology's earlier rejection "*did not centre on small amounts of residual emissions in industry but was essentially about saving coal-fired power generation and the fossil energy industry. That led to many misgivings which cannot be dispelled overnight*" (Wettengel, 2018; 2019).

These examples show how the early application of an innovation creates path dependencies in public opinion. Since bad news travels fast "*information dissemination [during early stages of transition could] have negative effects when news of poorly performing [heat] systems spread*" (Geels and Johnson, 2018, p.146). As such, close attention must be paid to the application of innovations at early stages, as perceptions and attitudes, once established, do not change overnight. Change they do, however.

4.7.3. Governing transitions with diverse adopter groups in mind

Although the public is not one homogenous group, narratives about (non)adoption tend to imply this. For example, the high levels of participation in the alternative, geothermal heating regime in countries such as Germany, the United States, Canada, China, Sweden, Japan, and Switzerland "*contradicts the image many technology developers have [...] of home owners who just want to have a well-heated house and are not interested in technological details*" (Bleicher and Gross, 2016, p.285). This assumption may very well hold for a large portion of households, but clearly the perceived barrier is lower for a significant subset of householders.

Social Scientists will often divide individuals, firms and households into adopter groups: innovators, early adopters, early majority, late majority and laggards (Rogers, 2003). Policy mixes, responsive to the motivations of different adopter groups, are recommended as they may help accelerate transition. To this end, investigation of the differences between these groups (e.g. differences in beliefs, attitudes and preferences) helps to build a more nuanced understanding of the opportunities for and barriers to transition. However, this research often suffers from 'early adopter' bias – the phenomenon by which the attitudes and beliefs of those with a preference for innovation are disproportionately represented in market-based research, as scientists struggle to access the relatively small population of non-adopters who have experience with and knowledge of the innovation under investigation. In effect, this bias inflates scientific confidence in innovations.

To avoid 'early adopter' bias, it is critical that the beliefs, attitudes and priorities of non-adopters are analysed. Moreover, an improved understanding of the experience of non-adopters can improve "*understanding of the levers within the system that impact adoption of [a niche innovation]*", as they can "*pinpoint aspects of the sociotechnical system that contributed to their decision to reject [the innovation]*" (Edling and Danks, 2018, p.334).

In a study of advanced wood pellet heating in the north eastern United States, Edling and Danks (2018) defined non-adopters as "*those who had gathered information about advanced wood heating technology (by attending workshops or assessing the feasibility of conversion) and then had chosen not to adopt*" (p.334). Access to these individuals required the cooperation of private firms. The involvement of state government agencies as a trustworthy intermediaries was critical for enrolling firms in the study. Without this trust, researchers would have never been granted access to non-adopters.

4.8. The role of uncertainty and experimentation in governing transitions

As presented in the theoretical background of this report (Section 2.2), emergence is a key feature of complex systems. As such, uncertainty is a necessary, unavoidable feature of analysing and intervening in complex systems. An acceptance, rather than rejection, of this uncertainty encourages a shift from 'control and command' to 'learning-by-doing'. Experimentation has been proposed as a key governance mechanism to steer sustainability transitions in the midst of uncertainty, "*notably by creating space for innovative solutions to emerge*" (Kivimaa et al., 2017, p.17). By helping to initiate learning and provide proofs of concept in a protective space, real world experiments provide *opportunities "to reconfigure existing socio-cultural, technological, regulative and institutional elements of socio-technical systems (e.g. Berkhout et al., 2010; Bulkeley et al., 2013, 2014b; Sengers and Raven, 2014)*" (Kivimaa et al., 2017, p.24).

Woking Borough Council experimentation began with a revolving fund for reducing energy use in council building use in 1992. The Success of the programme on environmental and financial criteria was considered critical for shifting perceptions of risk within the finance department and building the political legitimacy needed to tackle larger DH projects (Hawkey and Webb, 2014; ETI, 2018). A study of UK LA engagement in energy governance found that successful experimentation with *small-scale* energy innovations helped shift perceptions of risk and build political legitimacy.

Substantive outputs of experimentation range from new technologies, changes to the built environment, and market change to changed discourse, consumer or citizen practices, policy, business practices and informal institutional change. Whilst some experiments fulfil a 'deepening' function (e.g. by shifting practices and ways of thinking), others fulfil a 'broadening' function, whereby the legitimacy of innovations, and the network of advocates backing them, grows through the process of repeating experiments in different contexts. The last function is 'scaling up', whereby experiments are embedded in "*established ways of thinking, doing and organising (Grin et al., 2010)*" (Kivimaa et al., 2017, p.22).

Although there is a strong theoretical argument for the use of experiments in transition processes and evidence of their role in 'niche' and market creation, there is a clear evidence gap in the ability of experiments to disrupt the existing regime and help overcome barriers to low-carbon transitions (Bos et al., 2013; Porter et al., 2015). In their systematic review of articles published between 2009 and 2015, Kivimaa et al. (2017) found that 20 of the 27 reviewed experiments were described to have resulted in changed discourses and that the evidence of the 'deepening' function of experiments far outweighed the evidence of the 'scaling up' function. However, due to the short time periods of studies, it is not possible to determine the disruptive force of changed discourses, new business models, etc. As such, the authors argue there is an urgent need to develop and conduct in-depth post-evaluations of experiments to reveal 'success factors' or unfounded hopes placed on experiments. From their preliminary review, Kivimaa et al. (2017, p.22) do conclude, however, that "*the impact appears in many cases to be modest or incremental, questioning the role of experiments as a disruptive force*".

4.9. Key actor roles and intermediary activities in heat transitions

The case studies reviewed indicated key 'intermediary' roles of local, regional and national governments in successfully governing a transition toward low- or zero-carbon heating. These findings have implications for both policy and governance reform. Before presenting these findings, the two concepts off 'system builder' and 'boundary spanner'/'intermediary' are introduced. Since their functions are necessary in realising socio-technical transitions, these roles should be well understand and supported by Government.

4.9.1. The 'system builder'

The "*system builder*" (Geels, 2004, p.898) is a well-established concept in Transitions Research, originating from the Large Technical Systems (LTS) literature (Hughes, 1983). System builders are individuals or institutions that drive socio-technical transformation by mobilising resources to "*solve critical problems and unite divergent interests within a complex set of actors*" (Palm and Fallde, 2016, p.10). For example, LAs are system builders of DH networks even when they are privately owned, as they: introduce heat innovations into strategic planning; establish their legitimacy to increase participation of large heat consumers (e.g. arenas, hospitals and universities); and, in some cases, help secure finance (Hawkey et al., 2013).

Since different development phases require different skills, the identity of the system builder can vary throughout the transition process. The changing identity of system builders is emphasised in the Austrian case study (see Section 4.3.3), whereby each socio-technical configuration (village BMDH, large-scale electricity generation from biomass-CHP, and micronets) was 'built' by different actors (farmers and LAs, utility companies, and ESCos). In other words, transition is "*not necessarily driven by a homogenous group of niche actors*" (Seiwald, 2014, p.52).

It should also be noted that innovators often lack sufficient resource to 'system build'. In their study of the biogas transition in Linköping, Sweden, Palm and Fallde (2016) find that the energy utility's "*willingness to change was insufficient in itself to create change; rather, all the resources of the [municipal] energy company were essential to its acting as a system builder*" (Palm and Fallde, 2016, p.11). For example, close working relations between management and city councillors provided the utility company with 'agenda-setting power' to bring about a debate in council. As the incumbent energy provider, the utility company also had access to user and network data which it used to build its techno-economic case. Moreover, the utility company could mobilise the human resource, client network, and executive power to implement proposed changes. Again, power very much mediates transition processes.

This reality leaves Government with two options, either: force powerful institutions to 're-configure' themselves; or provide other actors with the resource (including access to policymakers, regulators, business associations, etc.) to 'system build'. This decision will likely depend on the expected level of disruption. As previously mentioned, Sweden's renewable heat transition disrupted energy supply, but only required technological substitution by incumbent actors, such as the Linköping municipal energy company. In the UK context, a transition to decentralised, renewable heat would likely require new system builders, as was experienced in Austria's alpine heat transition. Governing more disruptive transitions therefore requires the identification of new system builders, capacity-building, the removal of barriers to scale-up, and an understanding of how other stakeholders may react to system change, as new 'system builders' may emerge, redirecting the transition pathway for better or worse.

4.9.2. The 'boundary spanner'

A similar concept developed separately from that of system builder is the "*boundary spanner*" (Zietsma and Lawrence, 2010, p.191) or "*intermediary*" (Kivimaa et al., 2019, p.1062), who engages in strategies to manage relationships between businesses, regulators, professional bodies, etc., each with their own, unique organisational logic and interests. Their activities are especially important in mediating the interactions between niche and regime actors, where conflicting interests and logics must be skilfully addressed (Smith, 2007).

This literature review revealed six 'intermediary activities' that are said to enable socio-technical transition:

(1) **Supporting niche actors in their identification of opportunities and barriers** – e.g. "*finding out the agendas and issues of others*" (Smink et al., 2015, p.227).

(2) **Convening** – as "*coalitions of local actors are needed to create the conditions and to institute actions for low-carbon transitions*" (Karvonen and Guy, 2018, p.30).

(3) **Translation and dissemination of information** – information must be "translated" to different organisational logics before dissemination.

(4) **Consensus building –** consensus building can be pursued from the position of an 'honest broker' or policy entrepreneur, e.g. by "*convincing people of the merits of the initiative by framing the initiative to be fit with their agendas*" (Smink et al., 2015, p.227).

(5) **Mediation –** as perfect consensus is impossible to achieve between actors with competing interests, intermediaries employ methods of conflict resolution and discourse-based valuation to establish "*partial truces and settlements*" (Smink et al., 2015, p.234).

(6) **Coordination of actions –** as no single actor has the managing capacity to control transition processes (Guy and Shove, 2000).

Intermediaries (i.e. boundary spanners) can sit between organisations or be embedded within an incumbent organisation. Change agents embedded within organisations are referred to as "*boundary shakers*" (Balogun et al., 2005, p.261). Boundary shakers identify barriers and opportunities for institutional reform and, with this knowledge, change dominant perspectives, particularly within management. At the early stages of Aberdeen's CHP-DH transition, contestation arose at each stage of planning, which then required intensive research, information dissemination and policy entrepreneurship by the council's Home Energy Coordinator. The coordinator had to mediate conflict and foster political mobilisation across the multiple service domains whilst building formal alliances with executive officers from different council departments and councillors from each political party. Similarly, at Woking Borough Council, a small number of highly committed, intra-organisation advocates across both the engineering and financial departments carried out boundary work to obtain institutional commitment to CHP-DH and the publicly-owned ESCo, Thameswey Energy Ltd. Cuts to LA budgets directly threaten non-statutory, 'boundary shaking' activities.

Boundary spanners operating *between* organisations can avoid some of the aforementioned intermediary activities by developing a business case out of social and material translation. This type of activity is especially useful when material factors produce opposing logics. For example, the physical infrastructure of the Dutch natural gas system has created a dislike among network operators for small projects and diversity. So-called "*boundary organisations*" (Smith, 2007, p.227) have addressed this material mismatch by buying biogas from several farmers and caring for the upgrading process before selling to grid operators (Smink et al., 2015).

Government subsidy can create a market for biogas and the financial incentive for 'boundary organisations' to form. However, institutional logic mismatches can still prevent transition when material mismatches are resolved. The study by Smink et al. (2015) illustrates how institutional logic mismatches contributed to the low realisation (only 13% in 2014) of the Dutch Government's allocated subsidy for biomethane production. This example speaks to the earlier claim that financial incentives are a necessary, but *insufficient*, driver of transition.

4.9.3. The 'intermediary' roles of local, regional and national governments

In their study of successful DH projects in the UK, Bush et al. (2017) identify important intermediary activities performed at each level of government (Table 1).

In this literature review, the 'facilitation of horizontal knowledge sharing' by regional government (such as providing advice to private businesses and private households) was considered to be a key factor in realising renewable heat transitions; see the German and Austrian case studies in Sections 4.3.1 and 4.3.3 for further detail, for instance. Moreover, in the Dalarna region of Sweden, horizontal knowledge sharing is facilitated through the regional government's strategic network 'Building Dialogue' that connects 130 public, private and research institutions. The Dalarna regional government also provides "*advisory services to private firms on energy efficiency, ongoing dialogue with housing companies, [and] schemes for monitoring energy use in buildings* (Westholm and Lindahl, 2012, p.332).

However, 'pooling resources' and 'facilitating horizontal knowledge sharing' are not the only observed intermediary roles of regional government. In case studies outside the UK, where regional governments are empowered to play a more significant role in governing heat transitions, 'capacity-building' and 'vertical integration of policy' are also identified as important intermediary roles of regional government. 'Capacity building' refers to the support offered to LAs for the effective governance of locally-specific transitions. In the German and Austrian biomass case studies, for instance, this included LA officer training on energy planning. 'Vertical integration of policy' refers to 'plugging the gaps' (e.g. in regulatory frameworks or funding) and gathering/feeding back local experiences of national policy reform to central government so that policy can continue to evolve in support of transitions towards renewable heat. For example, the provincial states of Lower Austria and Sytria lobbied for federal and ministerial support for BMDH based on their learnings from regional farmer cooperatives and members of the National Forestry Agency (Geels and Johnson, 2018) – through discussions with the Ministry of Agriculture, appropriate levels of subsidy were determined.

There is evidence from the UK that the lack of governance structures for vertical policy integration is negatively effecting local governments' ability to effectively govern a transition toward decentralised, renewable heat systems. Although UK LAs have articulated their need for devolution and greater shielding policies to realise CHP-DH, "*there was little evidence of an intermediary providing a coordinated narrative from local authority interests on the need for regime change. Instead, individual local authorities fed their experiences through to [...] the UK Government on an ad hoc basis*" (Bush et al., 2017, p.146). Since bottom-up learning has not been institutionalised in the UK Government's Heat Network Delivery Unit, activities have been reduced to the top-down distribution of resources such as advice and funding that ultimately reflected the objectives of national government and neglected those of LAs.

Table 1: Intermediary activities in the multi-level governance of heat transition (summarised from Bush et al., 2017).

Spatial scale	Actor	Intermediary activity
Local level	Local Authorities (LAs)	• **Persuasion of the value of District Heating (DH) internally** to gain corporate buy-in from across the local authority (LA) needed to build LA capacity (creation of a multi-skilled team of planners, mapping specialists, lawyers, finance specialists, and energy managers. • **Public-private network building for project delivery:** Requires enrolling local stakeholders, the negotiation of risks and responsibilities, establishing project legitimacy, building the public's trust in the new heat configuration (Hawkey et al., 2013). • **Mediating relationship with the incumbent regime:** Engage with energy markets designed for large-scale centralised provision.
	Community energy groups	• **Exploring opportunities** to develop community owned schemes.
	Private sector District Heating (DH) companies	• **Sharing expertise and experience from previous schemes:** *"Public sector actors delivered most of the intermediary functions, but private sector actors also played intermediary roles for supporting learning processes [in the form of consultants]"* (Bush et al., 2017, p.143).
Regional level	Local Enterprise Partnership (LEP)	• **Pooling resources:** LEPs *"enabled the building of social networks required for employment of a shared specialist staff member for district heating that would not have been possible for individual authorities acting alone"* (Bush et al., 2017, p.144). • **Facilitation of horizontal knowledge sharing** between LAs involved in same project.
National level	Heat Network Delivery Unit (HNDU)	• **Facilitation of private intermediary role** at the local level by connecting LAs with consultants and co-funding technical-economic assessments of DH plans.
	Core Cities Group, Vanguards Network, Association of Decentralised Energy and the UK District Energy Association	• **Best practice sharing** between system builders.

Studies considered in this literature review (Webb, 2015; Bolton and Hannon, 2016; Bush et al., 2016; ETI, 2018) consistently found that the social and environmental objectives of UK LAs (e.g. tackling fuel poverty and achieving environmental sustainability) were at least as prominent as economic objectives. However, potential social and environmental benefits (beyond carbon reduction) are not recognised explicitly in HNDU's funding application process, despite being a major motivator for most LAs pursuing DH.

These findings suggest that the UK Government may want to consider codifying intermediary activities at the level of regional authorities (e.g. Combined Authorities) by creating new, statutory duties of LAs, if it is to pursue a transition to a decentralise renewable heat system. In fact, there is evidence in the UK that Local Enterprise Partnerships have "*enabled the building of social networks required for employment of a shared specialist staff member for district heating that would not have been possible for individual authorities acting alone. This scale of working also facilitated greater sharing of knowledge and cooperation between the neighbouring local authorities working on similar challenges*" (Bush et al., 2017, p.144). However, the creation and termination of these bodies have been historically vulnerable to political cycles. Since schemes are highly vulnerable to changes in funding (e.g. recent reduction in scale of ECO funding) and regulation (e.g. scrapping of the Code for Sustainable Homes), 'vulnerability to political cycles' has been identified as a key barrier to local heat solutions in the UK and should thus be taken into consideration when determining whether or not devolve energy governance to the regional level (Bush et al., 2016; ETI, 2018).

4.10. Decentralised: The rise and influence of district heating

This systematic literature review yielded a significant number of policy recommendations specific to decentralised and, in many cases, municipal-led heat transition – with a particular focus on DH as a promising socio-technical configuration. This section begins by discussing some of the possible practical and theoretical influences that likely underlie this outcome (Section 4.10.1), before then discussing the roles and possibilities offered by: LA leadership (4.10.2); windows of opportunities (4.10.3); barriers to local governance (4.10.4); and commercially-owned networks (4.10.5). The section then finishes by reflecting on the implications of pursuing a decentralised heat system transition pathway (4.10.6).

4.10.1. Practical and theoretical considerations leading to calls for decentralised heat transition

Both implicitly and explicitly, the literature reviewed make the case for decentralised heat transition, with municipalities playing a key role in its evolution, and with DH also being a common feature of this future pathway. The authors believe this is likely due to a combination of practical and theoretical considerations, which are now detailed in turn.

Practical considerations

- ***Nature of technologies:*** the delivery and subsequent use of most renewable heat technologies are experienced at the local level. As such, any interactions these new technologies have with conventional heat systems – interactions whose study forms the basis of much of the Transitions literature – are observed locally too.

- ***Path dependency:*** Countries and subnational regions that are further along in the transition to low- or zero-carbon heating, generally already have decentralised heat systems, which has produced a greater number of case studies regarding decentralised transitions. While this, in itself, provides some evidence that decentralised heat systems are more supportive of change processes at the *early stages of transition*, it does not suggest that decentralised transitions necessarily have a greater capacity to achieve a zero-carbon future.

Theoretical considerations

- ***Bottom-up understanding of transition:*** According to Transitions theory, innovations can 'scale-up' either from the local level (e.g. DH and heat pumps) *or* from the national level (e.g. hydrogen heating). However, because 'transition' is understood as an evolutionary function of variation and selection (Nelson and Winter, 1982), it is assumed that a greater number of innovations and experimentation will more quickly yield innovations capable of challenging, and potentially transforming, the conventional heat system. At the same time, innovators can seek out specific localities that act as less challenging testbeds in which to develop alternative systems. These are locations where a combination of material, financial, social, and political factors (e.g. being off-grid in a rural area) might increase the pressure for innovation. As the technology, business networks, user practices, consumer perceptions, and other elements of these niche developments mature over time, they may come to challenge conventional heat systems beyond the spaces in which they were developed.

- ***Limitations of incumbent-led transitions:*** The transformative capacity of the UK's gas-powered heat system is not only bound by material and technological constraints, but also by vested interests that are more deeply entrenched at the national level than the local level. Every transition is shaped by powerful actors with sunken investments in the conventional (heat, food, etc.) system. These actors "*tend to remain on their current trajectory based mainly on incremental innovations to their products, because of high profit margins and the high investments made in the past*" (Dütschke and Wesche, 2018, p.253). As a result, Transitions scholars are naturally wary of incumbent-led transitions. In fact, in their work, scholars have shown that incumbents often do not carry the capacity for the kind of radical, disruptive change necessary to achieve the goals of transition (Dütschke and Wesche, 2018). Like all stakeholders, incumbents act to promote options favourable to their own interests. They are different from other stakeholders, however, in that they have "*asymmetric capacities to control legal and material resources and to build powerful coalitions enable dominant actors to actively block or promote certain technologies based on their interests*" (Nciri and Miller, 2017; Supran and Oreskes, 2017, p.226). As a case in point, oil companies have drawn back their investments in new renewables to focus on biofuels and hydrogen, "*favouring technological trajectories most compatible with their existing infrastructure, expertise and business model*" (Meadowcroft, 2011, p.72). Such power asymmetries play an important role in transition processes and should not be ignored or underestimated. This view accounts, in part, for the greater focus on decentralised renewable heat solutions, as transitions that emerge from a local context would be more likely to break asymmetrical power relations.

4.10.2. Local authority (LA) leadership as a necessary condition for transition

In every DH case study reviewed (Seiwald, 2014; Webb, 2015; Bush et al., 2016; ETI, 2018), leadership by LAs was found to be a crucial element for success. Even in commercially-led schemes, the role of municipalities as e.g. intermediaries, planners, regulators, and project partners was critical. Having analysed six DH cases in Germany, Dütschke and Wesche (2018) for example concluded that successful transitions often relied on important "*opinion leaders*" (p.253), such as LA council members and other members of the community to initiate and convince property owners of the project. LAs were also essential in identifying and coordinating with potential heat providers and in planning the relevant infrastructure. Only in those cities where the LA became closely involved and acquired new expertise was a DH scheme successful.

Since DH systems are capital-intensive, the cost of stranded assets is substantial, and thereby deters investors. In this context, the participation of LAs is found to improve local perceptions of risk – particularly regarding the capacity to expand the system and attract new subscribers. In Norway and the Netherlands for instance, local governments were shown to influence the willingness of companies to invest in DH through their use of planning policies, e.g. by "*building control regulations supporting connection of new and refurbished buildings to the heat network*" (Hawkey and Webb, 2014, p.1239) and by granting area-wide concessions for heat centres and network infrastructure, thereby building "*business confidence in opportunities for expansion*" (ibid, p.1239).

Moreover, as owners of public buildings (e.g. town halls and schools) and council housing, LAs played an important role as 'initial adopters' in every case study. In addition to providing a substantial share of the system's base load, their role as initial adopters functions as a "*confidence building role model for private consumers*" (Dütschke and Wesche, 2018, p.253), encouraging the enrolment of additional large-scale heat consumers. Research suggests that this confidence is not only based on practical considerations, such as the achievement of a sufficient baseload, but as well on trust in local councillors or community 'opinion leaders'. Because commercial actors do not share this social capital, they very much rely on the participation of LAs.

4.10.3. UK district heating (DH) projects reliant on rare windows of opportunity

The literature suggests that successful DH projects in the UK have only come forward in rare windows of opportunity. "*Where schemes have been developed successfully, they are often the result of a convergence of local political agendas, funding opportunities, and the determination of key individuals who have challenged the traditional way of doing things* (Hawkey et al., 2013)" (Bush et al., 2016, p.86). The Chief Executive of one council claimed that 'political will' was the most important criterion for establishing the council-owned ESCo: "*There needs to be the will in place… You can buy the technical and administrative capacity but you cannot buy the will to do it…the dream, the aspiration to do something. If there is a will, there is a way*" (Hannon and Bolton, 2015, p.204). Thameswey Energy Ltd (TEL), an ESCo owned by Woking Borough Council (see Section 4.2.1) has enjoyed consistent local political support, in part, because the council's Chief Executive was one of the originators of TEL in the 1990s (Bolton and Hannon, 2016).

So long as the decarbonisation of heat is a voluntary enterprise, activity will be confined to a small number of localities where political will aligns with the many other necessary conditions – least of all, funding. All three DH schemes analysed in Hawkey and Webb (2014), including TEL, hinged on Labour's short-lived Community Energy Programme (2002-2007) that covered a share of costs for the technical feasibility assessment and provided up to 40% of capital. Plans to expand TEL's operations to Milton Keynes were formulated during the years of CEP, but hinged on access to land held by a state-owned regeneration agency that explicitly supported DH connection through its planning requirements (Hawkey and Webb, 2014). The CEP also enabled the establishment of Aberdeen Heat and Power, a non-profit company owned by the city council. Scottish government funding was later accessed for the expansion of Aberdeen's DH network via its subsidiary, District Energy Aberdeen Ltd.

Social capital was also necessary to bring schemes forward. In establishing Aberdeen's LA-owned ESCo, "*council legal advice opposed the proposal on the grounds of financial risk. The deputy council leader however chaired the key meeting, and his expertise in the oil and gas sector conferred confidence in relation to local energy*" (Webb, 2015, p.270). Those interviewed suggested that the social capital held by the council leader, as well as the courage displayed in going against legal advice, played an important role in gaining votes for the scheme's approval.

Birmingham's DH scheme equally relied on a rare window of opportunity. The council's leader and officers strongly advocated the scheme based on former experience with small-scale CHP-DH. This experience came not from past political leadership, but rather from a lawsuit brought by a group of council housing tenants in the 1980s for the excessive cost of heating their homes. In addition to council leader and officer advocacy, regeneration plans for the city centre, coincided with a much-needed boiler retrofit at national convention centre – both of which supported the introduction of new technologies and infrastructure development. In addition to accessing funding through the CEP, the council was awarded a grant by the Homes and Communities agency from its Low Carbon Infrastructure Fund. (Bolton and Hannon, 2016)

This reliance on rare windows of opportunity is due to relatively high barriers in the UK, which is now discussed in more detail in the following subsection.

4.10.4. Barriers to local governance of the UK's (decentralised) heat transition

> *"UK policy for development of low carbon and renewable energy has largely relied on a technology-driven, supply-side model of innovation (Steward, 2012). It is however increasingly recognised that transformation of energy systems also requires innovation in societal institutions"*
> (Hawkey and Webb, 2014, p.1229)

The following six selected sets of barriers are now discussed in turn: unreliable national energy policy; austerity; limited revenue raising powers of UK LAs; little-to-no LA experience with energy governance; national skills gap; and adoption of decentralised heat systems not mandatory.

These barriers to the governance of a local heat transitions emphasise that *social* innovations are desperately needed if a transition to localised sources of renewable heat is to be pursued. Indeed, the UK's lack of social innovation may explain the recent failure of (techno-economic inspired) UK Government subsidies and other financial incentives to generate significant adoption of renewable heat technologies at the local level.

Unreliable national energy policy

Time-limited grants and unpredictable changes to national policy/funding opportunities pose a barrier to LA-led transition (Hawkey and Webb, 2014; Webb, 2015; Bush et al., 2016; ETI, 2018; Karvonen and Guy, 2018; Roesler and Hassler, 2019). This is, at least in part, due to the discrepancy between short political cycles and long project implementation cycles for DH. Projects in development have consequently stalled or were reduced in scale and/or ambition to e.g. meet shorter timetables. Examples of "unreliable" energy policy (Webb et al., 2017, p.13) at the UK Government level include, to name only a selection of examples: Green Deal failure; short-notice and significant reductions in Feed-in-Tariffs; removal of zero carbon housing targets and related commitment to the Code for Sustainable Homes framework; funding reductions for Energy Company Obligation scheme for residential energy/heating improvements; and the dialling back on the Carbon Reduction Commitment.

Austerity

LA capacity to utilise grant funding has been significantly reduced by austerity (Webb, 2015; Bush et al., 2016; ETI, 2018; Roesler and Hassler, 2019). LA budget cuts have driven a reduction in staff and greater demands on officer time. As such, there is less internal capacity to invest in key intermediary activities, such as stakeholder engagement to gain buy-in for potential projects (see additional activities in Section 4.9.3). Moreover, because energy governance is a 'discretionary activity', energy and sustainability teams have been scaled back. Teams have therefore had to be created from scratch for each new project – often with support from external consultants. Not only does this disruption of institutional memory fragment knowledge and expertise, it also increases the transaction costs of energy projects that increasingly rely on commissioning and contracting. Austerity has also led to frequent restructuring, which is shown to disrupt managerial buy-in of non-statutory renewable heat projects. Lastly, austerity has raised uncertainty over the future of council building stock. This significantly impacts risks of DH development, as smaller stocks translate to smaller financial savings and profits from energy service contracting.

UK local authorities (LAs) have limited revenue raising powers

The limited financial autonomy of UK LAs significantly constrains investment in low-carbon energy projects, inhibiting capital-intensive heat projects before they start (Hawkey and Webb, 2014; Webb, 2015; Bush et al., 2016; Dütschke and Wesche, 2018; ETI, 2018; Karvonen and Guy, 2018; Roesler and Hassler, 2019). As explained in Section 4.1, LAs in coordinated market economies have greater financial autonomy and are therefore better suited to deliver low-carbon heat projects. It is therefore understandable how Aberdeen City Council invested about £3.8m in DH, whereas Rotterdam invested €38m and underwrote €150m of commercial loans (Hawkey and Webb, 2014). However in the UK more broadly though, it is certainly true that perceived (and real) financial risk is one of the main barriers to LA involvement in DH (Webb, 2015; Bolton and Hannon, 2016; Bush et al., 2016; Bush et al., 2017; ETI, 2018; Roesler and Hassler, 2019). Although this is fuelled, in part, by the unreliability of Government policy, it too is strongly informed by the limited capacity to raise council revenue, create green infrastructure bonds, etc.

Little-to-no local authority (LA) experience with energy governance

Given path dependencies described in Section 4.1, UK LAs have little-to-no experience with energy governance. When approached by domestic, or more often, foreign energy companies, this lack of experience creates a number of uncertainties and challenges that typically deter LA engagement. Although Aberdeen City Council, an outlier amongst UK LAs, succeeded in bringing forward a DH scheme, the council's own project evaluation reports reveal a number of precarities, including a lack of energy planning and finance expertise, intensive work loads, few resources, and responsibility without clear authority. (Webb, 2015, p.271).

National skills gap

One study revealed a national shortage of experienced technical consultants to conduct feasibility work, e.g. for district heating networks (Bush et al., 2016). This is highly concerning given the aforementioned lack of in-house expertise and inability for UK LAs to evaluate the technical and financial feasibility of alternative heat projects.

Adoption of decentralised heat systems not mandatory

First, energy governance is not a statutory duty in English local planning policy, although policy does seem to be changing in Scotland. Making heat mapping and other energy planning activities a funded statutory duty would likely stimulate LA action and give long-term signals to investors. However, there is still the issue of household adoption. The Danish and Norwegian governments have, for example, granted LAs the power to oblige new and existing buildings to connect to local heat networks. Dütschke and Wesche (2018) note, however, that it is not fully clear whether prescribing participation is compatible with German law. There are, however, regulatory measures that could be taken to support connection to local heat networks, such as banning oil boilers (as in Norway), electric heat (as in Denmark), or gas boilers and hobs, as proposed by the CCC (2019) for the UK.

4.10.5. Local authority (LA) vs. commercially-owned district heating (DH) networks

According to Bush et al. (2016), there are three approaches to DH delivery:

- ***Public-funded approach*** – funder stipulates criteria (e.g. fuel poverty for ECO funding).
- ***Commercial approach*** – decisions taken to maximise financial returns on investment.
- ***Strategic approach*** – decisions taken to meet competing strategic aims, such as reduction of financial risk to council; carbon reduction; eradication of fuel poverty; local job creation; regeneration; etc. with a balanced consideration of trade-offs.

The UK is said to be pursuing a hybrid of a public-funded and commercial approach, as HNDU stipulates project criteria but also encourages projects to be carried out by private-sector ESCos. This approach has three detrimental, unintended consequences for the heat transition. First, LA projects seeking social and environmental benefits beyond carbon reduction may be disqualified, as these benefits are not formally recognised in HNDU's funding application process. Second, a commercial approach to DH delivery may result in an *unjust* transition, with uneven distributional impacts across communities likely. For example, Åberg et al. (2016) estimate that 62% of municipally-owned energy utilities in Sweden apply cost-in-use based pricing, compared to only 11% of privately-owned utilities. Moreover, in the UK, there is a risk that private energy companies avoid areas of lower density or poor neighbourhoods[16] to increase returns on investment. If this phenomenon is replicated across the country, those left on the gas grid will face rising heat bills, producing an (inequitable) income gradient in energy cost per unit.

Third, if plans for network expansion are profit-driven, there is a risk of early market saturation. A demand for short-term returns on investment result in 'cherry picking' of the most profitable buildings for connection at early stages of development (i.e. those that consume more heat and are relatively cheap to connect), leaving buildings whose connections are less economically viable to be reliant on an increasingly inefficient (and expensive) natural gas grid. Not only would DH diffusion then be cut short, but inequitable outcomes regarding the price of energy per unit may emerge, with poorer households having to pay more to heat their homes. A more strategic approach to network expansion could ameliorate such risks.

Bolton and Hannon (2016) argue that LA-owned ESCos are better placed to adopt a strategic approach to DH delivery, as they are responsible to deliver on multiple public interests (e.g. supporting the local economy, tackling fuel poverty). Furthermore, LA-owned ESCos provide a number of efficiencies as well, such as the ability to bypass the costly procurement process for retrofitting and services public buildings (e.g. schools), as these buildings are contracting with another public body. Bolton and Hannon (2016) go further to recommend the promotion of arms-length ESCos, as these are able to raise finance from both private and public sectors and provide LAs with partial insulation from financial risk. Moreover, business plans of arms-length ESCos transcend the democratic cycle, adding further protection to longer-term strategic ambitions. As a separate legal entity, ESCos are protected from party politics and "*able to take losses in years going forward, which the council couldn't carry on its books*" (Hannon and Bolton, 2015, p.204). Aberdeen Heat & Power (AH&P) has adopted this model for example, as well as utilised a strategic approach to DH delivery: "*Despite the dominance of short-term cost models in UK local government, local political mobilisation around the joint principles of affordable warmth and carbon reduction had in this instance advanced a definition of best value as lowest 'cost in use' of heating for tenants*" (Webb, 2015, p.269).

Yet, even with its strategic approach, the option to insulate the social housing stock was rejected despite this being the more environmentally sustainable option. In a review of German municipal climate action plans, Bickel (2017) finds that 'strong' sustainability principles are not reflected in municipal plans. For example, municipalities do not acknowledge limitations of ecological carrying capacity in their plans, let alone pursue a strategy of setting limits. This finding is mirrored in the Vauban District case study (Section 4.2.3), with detrimental effects on the council's ability to *further* decarbonise the housing stock in coming years. For this reason, and

16 Deprived households typically have lower heat consumption rates per square metre, particularly in the case of fuel poverty where consumption rates are supressed. For this reason, plus financial barriers such as connection charges, deprived households may be excluded from commercially-owned DH networks.

to protect the council from liability, Bolton and Hannon (2016) recommend arms-lengths model of municipally-owned ESCos. This example suggests Government may have to ensure, through regulation, that social and environmental criteria are equally weighted to prevent path dependencies preventing full decarbonisation at later stage of transition.

4.10.6. Considering the implications of pursuing a pathway to a decentralised heat system

In its analysis of transition pathways, Government should consider both sides of the argument for pursuing a transition to a *decentralised* heat system (Table 2). Table 2 is not intended to be an exhaustive list of advantages and disadvantages, but does present the headline findings reported in the literature reviewed herein, and thus hopefully provides a solid basis for further reflection. Please note that these are based on the existing governance system, and that reforms could (and perhaps should) be introduced to address each disadvantage.

Table 2: Advantages and disadvantages of pursuing a decentralised heat transition.

Advantages	Disadvantages
• More opportunities for experimentation (theoretically increases rate of transition).	• Increasing complexity in decentralised transition presents coordination challenges and increases risk of lost learning.
• Mitigate risk of co-optation by incumbent regime actors.	• 'Strong' sustainability principles not typically observed by local governments, meaning social criteria are prioritised over carbon savings.
• Future adaptability of system (more conducive to technological adaptations, as CHP can apply a very wide set of fuel options.	• Risk of early saturation and unjust transition (if market-led).
• More likely to tackle social inequalities (if led by LAs).	• Potentially greater conflict with future rollout of national retrofit programme and enforcement of national building standards if transition is carried out by LA-owned ESCos.
	• In the case of early saturation, DH prices may rise, creating the added risk of competition between DH and modular heat systems.

5. Conclusions

The aim of this report is to systematically review existing research Transitions Studies literature associated with heat energy and heat decarbonisation, as part of drawing out tangible recommendations that the UK Department for Business, Energy and Industrial Strategy (BEIS) may consider in its development of a 'Roadmap for policy on heat decarbonisation'. Specifically, the guiding research question for this report is: *How can 'Transitions' research informs the roadmap for governing the UK's heating transition?*

The following section presents these recommendations in turn, but the purpose of this Conclusions section is to step back and synthesise some of the key messages that have emerged from reviewing the literature. These headline messages are grouped around six themes, which we now discuss in turn.

Complexity and uncertainty

- Rapid and far-reaching transitions in the energy sector are rare, but not unprecedented.
- Given the complexity of energy systems, transitions are not reducible to single factors, e.g. the introduction of new technologies or policy levers.
- There is no transferable blueprint for energy transitions; each case has its own specificities.
- The historical development of heat systems is non-linear, as interventions by industry disruptors, Government, and/or other actors are often followed by dynamic system behaviour that is often impossible to predict, e.g. the introduction of new energy suppliers, changes in consumption patterns, and innovations in interconnected sectors that feed back to affect the development trajectory of heat systems.
- This review identified four causes of dynamic behaviour that emerged during transitions toward low-carbon heat systems:
    - Interactions between innovations and ecological systems.
    - Interactions between innovations as they scale-up.
    - Cross-sector interactions, e.g. between the heat sector and electricity, waste, agricultural, finance and housing sectors.
    - Interactions between innovations and social norms, practices, and beliefs.
- In many cases, these interactions hindered transitions toward decarbonisation heat systems, but they can also be reinforcing, such as the interaction between energy retrofit innovations and heat pump technologies.
- Given its non-linearity, an adaptive, experimental, governance framework is needed to react to unforeseeable social and technological change that emerges mid-transition.

Adaptive governance framework

- Pro-actively mapping the aforementioned interactions with a broad range of industry representatives, technology experts, ecologists, and social scientists could help to analyse the unintended consequences that may emerge after policy intervention(s).
- Interdisciplinary co-modelling can be embedded in an adaptive, participatory governance *framework* whereby Government and industry engage in the joint endeavour of learning-by-doing and doing-by-learning. One such framework, 'Transitions Management' (TM), is presented in this report. The effectiveness of this framework, however, has not yet been evaluated over the necessary time horizons (e.g. in the Dutch contexts), as the timespan of most transitions surpasses the lifetime of the TM framework.
- TM prescribes the use of real-world 'experimentation' to learn about and affect change in complex heat systems. Although there is a strong theoretical argument for experimentation, there is a clear evidence gap in the ability of experiments to disrupt the existing regime and help overcome barriers to low-carbon transitions. This may, in part, be due to the focus on niche-innovations and lack of experimentation with deconstructing existing systems of provision.

Power and politics

- The literature is rich in case studies in which powerful actors use their advantage to co-opt or actively block transition toward sustainable heating. As such, Transitions scholars advocate Government strategies that go beyond support of sustainable innovations and that actively manage the phase-out of unsustainable heat systems. The active management of phase-outs can take many forms. The Danish Government, for example, banned electric heat in catchment areas of municipally-owned CHP-DH and granted local authorities (LAs) the power to oblige new and existing buildings to connect to the heat network. However, these policies do raise the question of 'who pays', thus bringing into focus the role of power dynamics in mediating these debates.

- Government should take stock of which actors are included in research programmes, conferences, meetings and other discussion fora, where government and scientific communities are present. In particular, the positional authority of those with greater access should be considered in terms of how they may be shaping or have previously shaped Government expectations about the future (including what is even possible). After taking stock, Government should actively seek to include the knowledge and situated experiences of those with disproportionately low access to improve the quality and legitimacy of the heat transition policy framework.

Why Transitions scholars may recommend transitions towards decentralised heat

- *Diversity in experimentation* – since 'transition' is understood as an evolutionary function of variation and selection (Nelson and Winter, 1982), it is assumed that a greater number of innovations and experimentation will more quickly yield innovations capable of challenging, and potentially transforming, the conventional heat system.

- *Limitations of incumbent-led transitions* – the UK's gas-powered heat system is not only bound by material and technological constraints, but also by vested interests. Like all stakeholders, incumbents act to promote options favourable to their own interests. They are different from other stakeholders, however, in that they have asymmetric access to policymakers and material resources to promote solutions aligned with their interests. Such power asymmetries play an important role in transition processes (see Section 4.2) and should not be ignored or underestimated. From this perspective, a transition toward a decentralised, heat system is favourable as it could help to break these asymmetrical power relations.

Governing transitions toward decentralised renewable heat systems

- Innovators typically lack sufficient resource to 'system build'. As such, Government would either need to force powerful institutions to 're-configure' themselves (as in the case of Scandinavian heat transitions) or provide other actors the resource (including access to policymakers, regulators, business associations, etc.) to 'system build'. In the UK context, a transition to decentralised, renewable heat would most certainly require new system builders and thereby capacity-building to enable this to happen.

- LA leadership was found to be a necessary condition for transitions toward decentralised, renewable heat systems, given their importance role as intermediaries and, in some cases, system builders. UK district heating case studies found that LAs are unable to take on these roles outside rare windows of opportunity and that regional governments are not fulfilling a 'capacity-building' role as in other countries.

- Barriers to local governance of UK heat transitions included unreliable national energy policy, little-to-no in-house experience with energy governance, a shortage of experienced technical consultants, austerity, limited revenue-raising powers, a complete lack of statutory duties related to energy governance, and missing intermediaries to feed LA experiences and interests into national heat strategies (here, Government was criticised for not institutionalising this role within the Heat Network Delivery Unit at BEIS).

- Regional governments were found to play a critical *intermediary role* in heat transitions. In case studies outside of the UK, this role is more robust and may account, in part for the lack of progress in the UK.

- These findings suggest that the UK Government may want to consider codifying intermediary activities at the level of regional authorities (e.g. Combined Authorities) if it is to pursue a transition to a decentralised renewable heat system. In fact, there is evidence in the UK that Local Enterprise Partnerships have enabled fruitful social networks and DH specialisations to develop and prosper in ways that would not have been possible if LAs had been working in isolation. However, the creation and termination of these bodies have been historically vulnerable to political cycles.

Path dependency

- Due to historic reasons, UK local government is not 'geared up' to deliver low-carbon transitions. If a transition to a decentralised heat system is preferred on economic, environmental, or social grounds, the UK will need to undergo a transition in its governance structures, devolving budgetary and decision-making powers to the local and/or regional level.

6. Recommendations

Three types of recommendations fell out of this systematic literature review. First, high-level recommendations for evidence gathering that would apply to the governance of any sustainability transition. Second, high-level recommendations for the steering, or governing the heat transition (again, transferable to other transitions). These two sets of recommendations refer to the governing *process*. Conversely, the final set of recommendations identifies specific policies Government should consider based on experiences in other countries and barriers to transition identified in UK studies. A large portion of these recommendations apply only to a decentralised transition toward local, decarbonised sources of heat and energy and have thus been demarcated in the policy recommendations section of this report.

6.1. Recommendations for building an evidence base to steer transition

- It is highly recommended that Government adopts a systems approach to the analysis of development pathways and the analysis of policy interventions, meaning linear econometric methods are employed within a systems approach.
- In light of emergence, it would be beneficial to commission research with adaptable outputs, e.g. models that can be adapted in-house when new dynamics emerge.
- When building the evidence base, Government should **give greater weight to social and ecological aspects of the heat transition** which, together with material and financial aspects, determine outcomes of policy intervention. Practically, this could be achieved via the commissioning of interdisciplinary research that applies a 'mixed methods' approach to data collection and analysis.
- SSH should also be used to explore the 'logic(s)', framing, and conceptual/theoretical underpinnings of any transition.
- **Physical interactions with ecological processes should be explicitly modelled** and **SSH findings should go beyond market research on technology adoption**, to include research areas such as multi-level governance and energy justice, and the role of power in mediating transition processes.
- Policy would benefit from a **consideration of cross-sector interactions.** Practically speaking, it is recommended that Government commission co-modelling and scenario-building work with a diverse group of industry experts.[17]
- **Explicitly consider Government's development targets which impact upon – or are impacted by – various scenarios of heat decarbonisation.** The Sustainable Development Goals (SDGs) are recommended, in particular, as they are the most comprehensive, systematically reviewed set of interrelated goals, to which the UK Government also has national commitments.[18]
- Government would need to **commit to an ongoing research agenda,** constantly 'updating' learnings about the system's structure and behaviour, including changes in actors' decision-making processes.

6.2. Recommendations for establishing an adaptive governance framework

- **It is advised that key stakeholders be brought into the process of steering/governing the transition.**[19] Their participation is expected to improve learning by both Government and participating stakeholders. This learning includes an understanding of how stakeholders' actions interact to produce system dynamics and aids consensus-building on intervention strategies around which actions can be coordinated.

17 Three types of interactions would need to be explicitly considered, as they have been shown produce unique multi-regime dynamics: (1) Interactions resulting from complementary relations (e.g. improved insulation and heat pumps); (2) competition between regimes fulfilling a similar societal function (e.g. electric and gas heating); and (3) Interactions resulting from structural similarities (e.g. regulations, organisational structures, and business concepts that cut across different utilities).

18 A participatory approach to evidence gathering would provide Government with the opportunity to educate/engage stakeholders on its broader development agenda.

19 This recommendation is based on the premise that no single actor (even Government) has the managing capacity to control a transition process in a top-down manner (Guy and Shove, 2000; Rotmans and Loorbach, 2008).

- Unlike consultation processes, which consider all affected stakeholders, the TM approach prescribes narrow selection criteria for the **inclusion of innovators and exclusion of stakeholders not committed to a transition to a sustainable heat system**.

- ***Personal selection criteria*** are also recommended to select representatives of various stakeholder groups to participate in deliberative workshops. These individuals should be/have:

  - In a position of decision-making or influence (to be able to realise transitions in partnership with Government);

  - Openness to change (as the transition requires, by definition, a major transformation to current systems);

  - Creative/innovative (to imagine innovative social, regulatory and technical solutions capable of overcoming system rigidities and complex challenges);

  - Flexible (knowing plans will need to be adapted and, perhaps abandoned, due to emergence throughout the transition process);

  - Strong interpersonal skills for effective communication and collaboration;

  - Desire to understand and empathise with the views of others (for consensus-building).

- A stakeholder analysis conducted for the selection of participants, would be enhanced by **expanding its scope beyond the heating sector** – informed by an initial investigation of cross-sector interactions.

- **The governance process should begin with a visioning exercise, where goals are co-constructed and represent a diversity of interests.**

- **Open the deliberative, visioning workshops to individuals outside technocratic communities (i.e. government and scientific communities)** is critical to (i) improve the legitimacy and equitability of the transition, and (ii) reduce the risk of flawed or overly simplistic understandings about 'the public' used in modelling/scenario work (Hendriks, 2009; Kenis et al., 2016; Upham et al., 2018).

- Although consensus is an explicit goal of TM, some authors have argued that a truly 'shared' vision is unattainable. **Consideration will need to be given to methods of conflict resolution and discourse-based valuation to resolve these conflicts** in a way that provides sufficient opportunities for inter-stakeholder learning and empathy-building.

- **Practically speaking, deliberative workshops should be led by trained facilitators and participatory modelling and scenario work by an eclectic team of energy-system modelers, environmental and social scientists** to ensure that a range of social, technical and ecological processes are considered.

- Formally support real world experimentation so that government and participating stakeholders can learn about the system through intervention.

- Ensure the participatory governance framework is iterative – In other words, devise a process of learning-by-doing and doing-by-learning. Two things can support this process:

  1. A **system for monitoring developments in related sectors** that may impact upon the heat transition. Not only would this reveal potential changes in transition dynamics, it would also shift the selection of stakeholders invited to co-govern the transition.

  2. **An independent body** charged with monitoring the transition (e.g. CCC) that **recommends when participating stakeholders should reconvene** to adjust the transition vision, coordinated strategies, or develop new experiments when the heating system develops new dynamics.

6.3. Recommendations for a policy-led decentralised energy transition

Multi-level governance structure reforms to support transition towards a decentralised, renewable heat system

- **Reverse LA budgetary cuts** to support local experimentation and engagement with energy governance and reduce disruption in institutional memory and political buy-in.

- **Upskill LA officers in technical, legal, and commercial expertise rather than relying on industry consultants** to improve municipalities' long-term capacity to steer transition whilst addressing the national skills gap for conducting technical feasibility studies.

- **Government should continue and scale-up grant competitions that support the development of LA energy concepts/masterplans** to support experimentation at the local level that accounts for cross-sector interactions.

- **Affordable long-term finance or financial guarantees for non-profit or joint public-private ventures should be provided to LAs having established a promising energy concept or masterplan.** This could come from UK infrastructure funds or GIB finance structured to underwrite risks for local enterprises.

- **Institutionalise bottom-up and horizontal learning** in the Heat Network Delivery Unit (HNDU), to ensure this 'experimentation' phase helps develop case studies and Government learning regarding LA capabilities, opportunities, barriers, and needed guidance/support.

- **Integrate district heating as a funded, *statutory duty* into local planning policy** (e.g. Heat Network Partnership for Scotland, 2015). This recommendation is informed by best practice and, as well, the observed barrier that time-limited grants and unpredictable changes to UK national policy/funding opportunities pose to LA-led transition.

- **Plan for the cross-sectoral, multi-level coordination challenges that arise from the decentralisation of energy governance** (e.g. increased need for coordination between municipalities, electricity providers, OFGEM, etc.).

- **Actions to create institutions for long-term multi-stakeholder coordination may include:** extending devolved budgets to resource local liaisons/ intermediaries and establishing a national body responsible for (i) actor network management; (ii) provision of external support to LAs; and (iii) institutionalised bottom-up learning processes (e.g. via annual monitoring reports) and horizontal knowledge transfer (e.g. by actively engaging with organisations such as the UK District Energy Association.

- It may be that regional governance bodies (e.g. LEPs or Combined Authorities) are better placed for vertical (up and down) and horizontal coordination activities. However, these bodies have been historically vulnerable to political cycles as compared to LA statutory duties.

Policy levers to support the scale-up of decentralised, innovations in renewable heat provision:

- **Sufficient economic incentives for renewable energies over fossil fuel energy sources**, e.g. Scotland's temporary 50% rate relief for DH (Scottish Parliament, 2017), are needed to counterbalance built-in advantages of conventional heat systems.

- In the case of LA-owned ESCos, "***the benefits of the optimization and saving strategy identified in the plans should be used to procure renewable energy instead of other purposes to avoid rebound effects***" (Bickle, 2017, p.22).

- **Adopt building control regulations supporting connection of new and refurbished buildings to existing heat networks**, e.g. by raising the renewable heat quota (as proportion of final consumption) and energy efficiency standards to change market dynamics and strengthen local regulatory roles.[20]

    - Webb (2015) recommends "***more directed use of planning powers to prioritise areas for network development and anchor load connection****, as in other European countries such as Norway or Denmark*" (p.271) to reduce transaction costs, ensure carbon and energy savings, and provide secure revenues for DH.

    - "*Having identified areas of high-density demand, [supply,] and network feasibility [...]* ***producers of waste heat would need to be obliged to identify means to supply the network, in line with EU Energy Efficiency Directive requirements***" (Webb, 2015, p.271).

    - Following Webb (2015), **Government might consider what it would mean to grant electricity generated by CHP "*the same status as large scale nuclear or offshore wind, under the new 'contracts for difference' strike prices for low carbon electricity supply*.** *This would reflect the efficiency gains from electricity generation close to its point of use. Operators would then have a risk underwriting mechanism. This is however a form of regressive taxation, because it operates as a levy on energy bills*" (p.271).

    - During the experimentation phase, Government may need to **invest in changing public perception towards risk and experimentation in the heating sector,** as failure and learning are necessary and productive outcomes for transition whilst negative public perceptions of innovations reduce their chance of adoption by both suppliers and consumers.

Policy levers to prevent unintended consequences/ harmful dynamics that develop mid-transition

- **New guidance for LAs should recommend, wherever possible, an LA-owned (arms-length) ESCo model** to improve borrowing potential, protect against LA liability, remove LA budgetary dependence on ESCo, and allows for the *strategic* delivery of DH. This will also require **retraining HNDU staff and new guidance for LAs.**

- Government may wish to consider **regulating ESCo practices to ensure energy efficiency improvements are achieved *as* buildings are connected heat networks** (not after).

- Government should **expand techno-economic viability criteria of national grant schemes to include social and environmental criteria with**

20 E.g. Germany's energy saving ordinance (EnEV) and 'Act on the Promotion of Renewable Energies in the Heat Sector' (EEWärmeG).

equal or greater weight applied in the accounting method.[21,22]

- **LA investment decisions for heat network infrastructure should be based on a whole life cost model incorporating social and environmental benefit** to ensure that sustainable solutions are chosen. This is especially important given the path-dependencies of physical DH networks with 50-year lifespans.

- Importantly, **LAs should be required to consider energy and spatial planning *simultaneously***, *as* DH infrastructure has to be strategically integrated with other infrastructure networks and the built environment.

- To make strategic use of heat network spatial planning, **large building owners will either need to be under an obligation to connect to local heat and cooling networks** on a timetable aligned with renovation and heating replacement schedules **or incentivised to connect,** for example by expanding the CRC energy efficiency tax to *all* commercial building owners.

- **A system for licensing and regulation is needed to prevent abuse of long-term monopoly supply contracts in DH**. For example, Government would need to establish service standards and could require tariffs be competitive with other systems of heat supply.

6.4. Recommendations applicable to multiple transition pathways

- **Sufficient economic incentives for renewable energies over fossil fuel energy sources**, e.g. Scotland's temporary 50% rate relief for DH (Scottish Parliament, 2017), are needed to counterbalance built-in advantages of conventional heat systems.

- **For renewable heat technologies that are closely coupled with natural systems (e.g. ground source heat pumps), Government should avoid prohibitive, blanket regulations at the national level** (e.g. the number and depth of downhole heat exchangers and the rate of groundwater extraction).

- Actively manage phase-outs of competing, unsustainable heating systems.

- **Consult the German federal government regarding their plan to expand the R&D funds for advanced district heating systems and their declaration of these systems as a key instrument in their national energy transition.**[23]

21 For example, by applying alternative accounting methods such as socio-economic cost-benefit analysis (Chittum and Østergaard, 2014).

22 For DH systems over 10MW, Norway's 1990 Energy Act requires that development plans include evidence regarding social, economic and environmental advantages relative to other options (Norwegian Water Resources and Energy Directorate, 2009).

23 The German heat system is also predominantly based on a centralised gas system with boilers installed in individual dwellings, DH has expanded at a slow rate, and emerging hydrogen technologies are scaling up Germany's transportation system. Although significant differences exist between the two countries (e.g. greater LA autonomy and tax raising powers in Germany) there are likely transferable lessons (BMU, 2016).

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9. Appendix 1 – Literature review summaries

Publication: Bickel (2017)

System: Energy - across sectors
Scale: Local
Country: Germany
Historical or ongoing transition: Ongoing

Research question:

1. What areas of the energy system do German municipal climate action plans focus on?
2. Are strong sustainability principles adequately linked to the energy system to support a transition towards sustainability?

Methods:

Network analysis (via text mining) of 16 municipal climate action plans from Lower Saxony's to reveal local transition patterns in the region.

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat system

- Governance modes 1 and 2 ('planning and regulation' and 'direct services') have seen increased activity since the national 'Energiekonzept' was released in 2010, which widened the scope for municipal climate action. Activities reported under modes 3 and 4 ('consumer and role-model' and 'facilitating and encouraging action'), however, still dominate in municipal climate actions.
- Increased national support for municipalities is found to strengthen the regulatory role of municipalities. For example, EnEV, an energy savings ordinance, is referred to in most municipal plans to legitimate new regulatory activity.
- To increase municipal action further, *"national legislation favouring markets based on renewable sources in the heat [sectors]"* (p.22) is needed, as well as closer cross-sectoral, multi-level coordination and cooperation between municipalities, local and regional grid operators, and the German Federal Network Agency (the German regulatory body for utility networks).

Interaction of innovations with ecological systems

- 'Strong' sustainability principles could not be found in municipalities' climate action plans. The strategy of setting limits could not be identified in the plans, nor did they explicitly acknowledge limitations in ecological carrying capacity.

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Publication: Bleicher and Gross (2016)

System: Geothermal heating
Scale: Subnational
Country: Germany
Historical or ongoing transition: Ongoing

Research question:

1. How does a technology that forms a tightly coupled relationship with complex local environmental conditions scale-up from a niche innovation?
2. How are human and non-human elements dealt with in situations of newly faced uncertainties?

Methods:

Thematic analysis (deductive and inductive coding) of 14 semi-structured interviews with home owners, drilling engineers, local environmental administration. Thematic codes were developed to identify concepts of experimental strategies adopted by each actor group.

Headline findings and extracts:

The role of uncertainty and experimentation

- The interactions between nature, technologies, perceptions of risk, social acceptance, and regulation are place-based, path-dependent and ongoing – resulting in high spatial diversity in these socio-technical systems.

- Socio-natural-technical systems in which technologies are closely coupled with complex natural systems (e.g. ground-source heat pumps) present many uncertainties in each new application of the technology. As such, their applications are not 'ready-made' and must be adapted to each specific social and environmental context using experimental strategies. Experimentation is thus an essential feature of technological innovation that persists past the innovation stage and can be observed in transferring a technology to the regime level.

Interaction of innovations with perceptions, attitudes, and beliefs

- Socio-technical systems that require ongoing experimentation turn passive consumers into knowledgeable, active decision-makers. It is therefore likely that such alternative regimes attract only a portion of households, i.e. the *"'pioneers' who are convinced by the technology and more open to surprise"* (p.285). Their participation in the alternative, geothermal heating regime in countries such as Germany, the United States, Canada, China, Sweden, Japan, and Switzerland *"contradicts the image many technology developers have [...] of home owners who just want to have a well-heated house and are not interested in technological details"* (p.285).

Multi-level governance for a transition towards a decentralised, decarbonised heat system

- Improved coordination is needed in decentralised systems to collate and share disaggregated learning. *"Approval processes are a key dynamic of technology development in Germany and are highly decentralized, hinging on decisions taken by local environmental administrations. This has crucial implications in terms of learning processes and knowledge transfer"* (p.285).

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Publication: Bolton and Hannon (2016)

System: District Heating (DH)
Scale: Local
Country: UK
Historical or ongoing transition: Ongoing

Research question:

1. How do innovative business models interact with evolutionary transition processes?
2. What are the implications of these interactions for the governance of sustainability transitions?
3. How do the 'activity system', LTS and MLP analytical perspectives provide different answers to question 1 based on their unique perspectives on socio-technical systems?
4. Bringing these three perspectives together, what insights can be gleamed for the governance of sustainability transitions?

Methods:

- two in-depth case studies of ESCos (one private, one public) in different parts of the country where CHP-DH has been deployed.
- 53 semi- structured stakeholder interviews were conducted between June 2010 and February 2012.

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat system

- UK DH delivery relies on rare windows of opportunity where supportive local and national factors align in brief moments of history (Birmingham example).
- LA key partner in DH delivery (e.g. by providing anchor loads).
- *"LA-owned ESCo model could help facilitate non-incumbent actors to take the lead in a transition to a low-carbon energy system"* (p.1736) with a number of co-benefits:
  - Reduced transaction costs of servicing public buildings.
  - LA more likely to take strategic approach to ensure that projects deliver on multiple public interests (e.g. tackling fuel poverty and supporting local economy).
  - Avoiding 'cherry picking' by a commercial operator.
- Arms-length model has added benefits:
  - Offers LAs partial insulation from financial risk.
  - Able to raise finance from both private and public sectors.
  - Business plans transcend the democratic cycle.
- LA's decision to establish its own ESCo depends on:
  - its willingness to expose itself to risk.
  - the level of strategic control it desires.
  - the resources it has at its disposal.

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Publication: Bush et al. (2016)

System: : District Heating (DH)
Scale: Local
Country: UK
Historical or ongoing transition: Ongoing

Research question:

1. What are the local actors' visions for DH development in the UK?
2. What decision criteria are used to prioritise activities for achieving these visions in the UK?
3. What roles do other actors play in supporting the vision for local-government led DH schemes?
4. How can UK national-level policy better support increased uptake of DH?

Methods:

Snowball sampling and thematic analysis of 14 transcribed semi-structured interviews with stakeholders involved in DH development (local government, central government and industry) and review of policy documents and government reports.

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- UK DH delivery relies on rare windows of opportunity.
- LA key partner in DH delivery (e.g. by providing anchor loads, creating institutional infrastructure to support project development, and planning authority).
- Barriers to LA involvement in DH network delivery:
  - Austerity – (a) *"no internal capacity to invest in crucial activities such as stakeholder engagement to gain buy-in for potential projects or to build the necessary institutional infrastructure to support project development"* (p.93); (b) institutional memory disrupted; (b) restructuring disrupts buy-in from senior management.
  - Unreliable policy – Schemes are highly vulnerable to changes in funding (e.g. recent reduction in scale of ECO funding).
- Three approaches to DH delivery:
  - Public-funded approach – whatever criteria were stipulated by funder (e.g. fuel poverty for ECO funding).
  - Commercial approach – financial returns (based on desire to attract private financial investment).
  - Strategic approach – ability to expand network in future; low financial risk for municipality; ability to tackle fuel poverty; local job creation; regeneration potential; carbon reduction.
- HNDU's commercial approach to the delivery of DH has a number of unintended consequences, such as disqualifying projects with social value; underutilisation of LA social capital; perpetuating skills gap in techno-economic review; and heightening risk of early market saturation 'unjust' heat transition.

Cross-sector interactions

- No clear vision of the future energy efficiency levels of build = uncertainty regarding long-term heat demands upon which DH business cases rest.

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Publication: Bush et al. (2017)

System: District Heating (DH)
Scale: Multi-level
Country: UK
Historical or ongoing transition: Ongoing

Research question:

"How do intermediary activities across different geographical scales support niche nurturing and empowering processes for district heating innovations in the UK?" (p.138)

Methods:

Decision Theatre (Bale et al., 2014; Walsh et al., 2013; White et al., 2010) to collect accounts of personal experiences of eight local stakeholders (from various regions) involved in establishing new district heating projects.

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- UK DH delivery relies on rare windows of opportunity.
- LA key partner in DH delivery (e.g. by utilisation of social capital by councillors).

- Barriers to LA engagement in DH:
  - LA officers not trained in energy governance / no previous experience with energy systems / no knowledge of what is required.
  - Austerity.
- Policy recommendation: Energy governance as statutory duty, devolved resource, and shielding policies.
- Top-down engagement between HNDU and LAs / Bottom-up learning was not institutionalised.

Interaction of innovations with perceptions, attitudes, and beliefs

- *"Development of new systems requires [...] a cultural shift in public and practitioner perceptions of the technology (Hawkey, 2012)"* (p.140).

Intermediary roles and activities

- Authors identify key intermediaries at the local (e.g. LAs and community groups), regional (e.g. LEPs) and national-level (e.g. HNDU and business associations) and their 'scaling-up' activities that support transition to DH.

The role of power and politics and the need to actively manage phase-outs

- Devolution *"will require a process of negotiation between resource-holders and local [authorities] [...]. This highlights again the question of [power dynamics] in shaping transitions"* (p.146).

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Publication: Dütschke and Wesche (2018)

System: District heating (DH)
Scale: Local
Country: Germany
Historical or ongoing transition: Ongoing

Research question:

1. Will the energy transition be disruptive at the community level?
2. What new roles and institutions and processes can we imagine in such a transition?

Methods:

Authors analysed case studies of renewable district heating as a sustainability niche at the community level. Methods of analysis were not reported in this publication but in other papers published in German.

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LA key partner in DH delivery (e.g. by utilising social capital, particularly legitimacy and trust, providing anchor loads, creating institutional infrastructure to support project development, disseminating information, providing investment, utilising planning and regulatory powers).
- Barriers to LA engagement with DH delivery – lacking expertise or political will.
- Decentralisation = increased complexity from heterogeneity of interacting actors and of those needing to coordinate actions.
- Prescribing participation in DH: *"Either the municipality has to prescribe participation - or enough property owners have to be convinced to join the scheme. It is very difficult to prescribe participation as some of the details how to do this compatible with law are not fully clear"* (p.253).

The role of power and politics and the need to actively manage phase-outs

- *"The heating market in Germany has been dominated by single-building gas and oil boilers, which are mostly supplied by domestic industrial actors. [...] Some of these industrial actors have recently acquired companies with technological knowledge about new and more sustainable heating infrastructure. However, they tend to remain on their current trajectory based mainly on incremental innovations to their products, because of high profit margins and the high investments made in the past"* (p.253).

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Publication: Dzebo and Nykvist (2017)

System: District Heating (DH) and heat pumps
Scale: National
Country: Sweden
Historical or ongoing transition: Historical and ongoing

Research question:

1. What regime change processes underpin Sweden's transition to a low-carbon heat energy system?
2. What happens after new regimes with improved environmental performance are established?
3. What determines whether a new regime becomes incumbent and locks in new problems, or it continues to adapt, reinvent itself and improve its performance?

Methods:

Literature review complemented with a policy analysis and a limited number of interviews involving researchers and policy actors, as well as technical experts in the field of Swedish heat energy.

Headline findings and extracts:

Disruption

- When the Swedish heat system reconfigured itself with some technological substitution, the transition required few deep changes in social institutions and structures.

Landscape pressures

- 1970s oil crisis and desire for energy independence; Public concern over climate change; EU energy directives.

Historical path dependency and the role of place-based 'selection environments'

- Material path dependencies: Pre-existing DH networks; abundant forest resource; high share of communal buildings; cold, dark winters (increases efficiency of CHP systems).
- Cultural path dependencies: Trust in Government; Swedes less frequently move house (allowing for solutions with longer-term returns); communal heat systems reduce impact of demand-side behaviour change.
- Financial path dependencies: cheap hydro and nuclear power.

Non-linearity

- Rules and structures introduced to change the system have unexpectantly turned into institutional barriers to further change.

Cross-sector interactions

- WtE: *"In 2002, Sweden banned the use of landfills for waste, so municipalities began to pay DH companies to incinerate waste, leading to very low or even negative costs for waste fuel. [...] Continued investment in new waste-burning CHP plants has led to a debate about over-capacity, lock-in of waste incineration, and dependency on waste imports [24]"* (p.118-120).
- Building regulations: building regs based on energy purchased, meaning less sustainable, more affordable option of HP installation, and solar is favoured over improvements in design and insulation.

Interactions between innovations

- DH and HP provide up to 75% of the energy demand for heating in Swedish buildings, but these systems are reaching saturation and are now in competition.

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LAs control and develop DH infrastructure - Planning and Building Act (2010:900).
- As a third party, Swedish Energy Agency *"mediates the negotiations between the DH companies and customers [... and] negotiations between DH companies and those wishing to gain access to DH infrastructure"* (p.118).

Role of uncertainty and experimentation

- Historically, transition to renewable energy relied on experimentation by LA-owned energy utilities and civil engineers.

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PUBLICATION: EDLING AND DANKS (2018)

SYSTEM: WOOD-PELLET HEATING
SCALE: REGIONAL
COUNTRY: NE USA
HISTORICAL OR ONGOING TRANSITION: ONGOING

RESEARCH QUESTION:

1. What methodological challenges arose when conducting participatory research on a niche innovation (advanced wood heating) in a socio-technical system (heating) under transition?
2. What insights from these challenges can be offered for energy transitions research more broadly?

METHODS:

Participatory research design starting with a preliminary analysis - inductive thematic coding of interview data with 8 purposively sampled key industry actors for insights into the advanced wood heating industry. Followed by 60 semi-structured interviews with adopters and informed non-adopters of the innovation. The sample of respondents was stratified by state, (non)adoption date (pre- or post-2015 drop in price of oil), and 'household' vs. 'small-scale institution'.

Concluding with a consumer survey with a few open-response questions to be thematically coded (not yet administered).

HEADLINE FINDINGS AND EXTRACTS::

Adopting a Systems approach to the governance of transitions

- Non-profit (Northern Forest Centre) conducts several niche-support activities, such as running print media campaigns and community-level meetings/workshops, in selected communities, as opposed to state-wide, as *"a strategic effort to create neighbourhood clusters of advanced wood pellet technology users that create not only fuel security for pellet consumers, but also efficiency for pellet distributors and service technicians"* (p.332).

Adopting a Systems approach to the analysis of transitions

The authors adopt a systems approach to the analysis of advanced wood-pellet heating in the north eastern United States. Commenting on the value of this approach, the authors write:

- *"System-based studies [...] have the capacity to provide more than just marketing advice about characteristics of potential adopters for new energy technologies. When done well, they can provide change agents with insights into which elements of the energy system are within their ability to influence and how to cope with shifts in elements they cannot change"* (p.338).
- *"The methods of this study were chosen in an attempt to capture not just the prevalence of perspectives, but also the nuanced and complex motivations of system actors as they interact with larger economic, cultural and political changes [over time as the transition unfolds]"* (p.336).
- Study of 'non-adopters', i.e. those who had "*gathered information about [the] technology (by attending workshops or assessing the feasibility of conversion) and then chosen not to adopt*" (p.334), relies on intermediary role of government (as a legitimate, trustworthy third party bringing together academic and private sector actors).

Interaction of innovations with perceptions, attitudes, and beliefs

- *"As transition proceeds, [...] the perception of niches and the size of the supporting actor groups changes [4]. Thus, in order to understand the role of developments in the landscape and regime level of the system [...], an examination of the perspective of that small network of actors [e.g. boiler installers and employees in state energy agencies] is a critical aspect of the study of an energy system transition"* (p.336).

Intermediary roles and activities

- Study reveal two key intermediaries: Boiler Installers and employees in state energy agencies.

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Publication: Geels and Johnson (2017)

System: Biomass district heating
Scale: National
Country: Austria
Historical or ongoing transition: Historical

Research question:

1. What are the core characteristics and causal mechanisms in the family of adoption models and socio-technical models?
2. How can system diffusion be understood with a modular approach that combines insights from the two analytical model families?

Methods:

Research strategy: To compare four 'adoption' models and three 'socio-technical' models, the authors apply each theoretical lens to a single case study to highlight the 'usefulness' of each theoretical model in describing the case.

Data sources: academic publications, reports from European research projects, reports from industry associations, reports from the Austrian Energy Agency, and statistical data from the Austrian statistics agency, provincial governments and Chambers of Agriculture and Forestry and eight semi-structured expert interviews w/ ten organisations involved in Austrian biomass DH

Headline findings and extracts:

Adopting a Systems approach to the analysis of transitions

- Authors find different theorisations have more or less explanatory power at different phases of transition (e.g. rational choice models have little-to-no explanatory power at early phase of transition but important to explain behaviour of large utilities mid-transition). Thus, they recommend adopting a combination of analytical approaches from across the SSH.

Non-linearity

- • *"[During transition] BMDH-systems developed and differentiated into three configurations (village-heating, BMDH-CHP, micro-grids) [...] The identity of system builders changed substantially over time: sawmill owners in the first period, farmers from the second period onwards, energy utilities and National Forestry Agency in the third period (with regard to BMDH-CHP), engineering, consultancy firms and project developers in third period (with regard to BMDH micro-grids)"* (p.149-150).

Intermediary roles and activities

- Business association (Austrian Biomass Association) - lobbied provincial and national government, organised workshops, compared local experiences, developed benchmarking and quality control contributing to performance improvements, etc.
- Provincial governments – *"launched energy agencies that provided training and financial support for BMDH-developers, assisted with heat mapping exercises, [...] provided advice for private households[,] enabled communication between component suppliers and BMDH-operators, [etc.]"* (p.148).
- Municipalities - see below bullets.

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- National Government – supportive policies included use of subsidies and feed-in tariff for biomass-CHP.
- Provincial governments (see note above).
- LA key partner in BMDH delivery (to provide baseload, lobby provincial government, provide planning support, and sometimes as project initiator).

Role of uncertainty and experimentation

- During the early 1980s, technical and operational problems of BMDH plants gradually diminished through learning-by-doing and dedicated circulation and aggregation.
- Info dissemination during this stage could negatively impact BMDH delivery, as bad news travels fast.

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Publication: Hawkey et al. (2013)

System: District heating (DH)
Scale: Local
Country: UK
Historical or ongoing transition: Ongoing

Research question:

How do the following dimensions (through their interaction) differentiate models of local energy governance and organisation?: (1) decisions about ownership and control (locally embedded vs. non-local); (2) the governance of subscriber, or customer, relationships; and (3) the level of commitment to in-house vs. outsourced techno-economic expertise.

Methods:

Semi-structured interviews and documentary analysis, conducted as part of comparative research on DHC development.

Headline findings and extracts:

Historical path dependency and the role of place-based 'selection environments'

- *"In the UK, establishing development pathways is likely to be more demanding than Scandinavian experiences suggest, due to the political-economy of centralised energy markets and global finance, matched by uncertain state commitment to regional contributions to low carbon energy. The institutions and networks of the UK DHC system are weakly developed, as indicated by lack of dedicated regulation, intermittent and unpredictable grant funding, under-developed technical standards, and knowledge held as intellectual property of consultants and contractors rather than in the public domain"* (p.24).

Intermediary roles and activity

- In light of limited access to finance, social capital is critical for the following DH intermediary activities: *"draw on non-local community energy and commercial and technical networks of expertise; [...] introduce the technology into strategic planning; establish its legitimacy and the legitimacy of a form of multi-organisation suited to numerous stakeholders; secure finance; negotiate risks and responsibilities; and engage with energy markets designed for large-scale centralised provision"* (p.22).

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LA key partner in DH delivery.
- Lack of supportive policies at national level for DH.
- Policies shouldn't be too prescriptive. Policy frameworks must be flexible and responsive to local specificities (e.g., actor knowledge and material infrastructures).

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Publication: Hawkey and Webb (2014)

System: District Heating (DH)
Scale: National
Country: UK, Netherlands and Norway
Historical or ongoing transition: Ongoing

Research question:

"Using five case studies, we ask why heat network development in the UK takes a relatively piecemeal and fragmented form in comparison with the Netherlands and Norway, countries whose heating sectors are comparable with the UK and where district heating provision is limited" (p.2).

Methods:

Analysis of data from (1) 15 semi-structures interviews with project developers; (2) local government and state policy documents; and (3) four 1-day workshops with UK LAs.

Headline findings and extracts:

Historical path dependency and the role of place-based 'selection environments'

- For various reasons, UK, Netherlands, and Norway did not follow development pathway of countries like Sweden and Denmark with mature DH networks.
- Recent progress in DH in Norway and the Netherlands, relative to the UK, is owed in part to institutions present in coordinated market economies (CMEs) and not in liberal market economies (LMEs): (1) Greater LA capacity and financial independence in CMEs due to legacy of LAs historically delivering more ambitious welfare state; and (2) The

"relationships between firms and regulators and regional business networks [in CMEs] motivated and sustained coordination to explore DH" (p.12).

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- UK DH delivery relies on rare windows of opportunity – all three UK case studies relied on the short-lived Community Energy Programme (2002-2007) and Milton Keynes CHP-DH scheme relied on access to land held by a state-owned regeneration agency that supported DH connection through planning requirements.
- Supportive national policies for DH beyond subsidy in Norway, e.g. (1) regulated utilisation of surplus heat from industry; (2) consumer protection legislation to ensure reliable service standards and fair prices; (3) planning powers to grant area-based concessions for heat centres and network infrastructure to sustain business confidence, particularly regarding opportunities for network expansion.

Cross-sector interactions

- WtE: Rotterdam LA & co. had relied on waste heat from nearby WtE plant, but then the incinerator was closed in 2009 due to national overcapacity.

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PUBLICATION: KARVONEN AND GUY (2018)

SYSTEM: DISTRICT HEATING (DH) AND SPATIAL PLANNING
SCALE: LOCAL
COUNTRY: UK
HISTORICAL OR ONGOING TRANSITION: ONGOING

RESEARCH QUESTION:

What influence do the spatial and physical aspects of heat provision have on the spatial development of cities?

What new forms of local governance (combining spatial and energy planning) can be observed and how has Government supported this development?

METHODS:

Analysis of *"16 semi-structured interviews conducted between 2011 and 2015 with a range of UK actors involved in the development of new heat networks, including trade organizations, mechanical engineers, architects, housing developers, and builders, as well as attendance at workshops and presentations for policymakers and practitioners"* (p.20).

HEADLINE FINDINGS AND EXTRACTS:

Cross-sector interactions

- Housing market: Tension between spatial attributes of heat networks and economic drivers of property markets.
- Electricity sector: DH can contribute to system balancing via heat storage of excess electricity.
- Spatial planning: Characteristics of built environment can preclude DH (several examples in study), which is why integrating energy planning into spatial planning is so critical for the success of DH.

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- *"Funding is needed by central government, as well as training, such as that provided in the EU's 3-year Spatial Planning and Energy for Communities in All Landscapes (SPECIAL) project"* (p.31).

Intermediary roles and activities

- Coalitions such as the UK District Energy Association play key role in educating Governmentt about barriers to transition and informing LAs about opportunities.

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PUBLICATION: KIVIMAA ET AL. (2017)

SYSTEM: URBAN SYSTEMS (TRANSPORT, BUILT ENVIRONMENT, ENERGY, SPATIAL PLANNING, COMMUNITY DEVELOPMENT, AND WATER MANAGEMENT)
SCALE: LOCAL
COUNTRY: GLOBAL (UK, S. AFRICA, INDIA, NETHERLANDS, SLOVENIA, DENMARK, ETC.)
HISTORICAL OR ONGOING TRANSITION: ONGOING

RESEARCH QUESTION:

1. "*What is the nature and focus of experiments that link sustainability transitions to climate governance?*" (p.18)
2. "*What kind of outputs and outcomes do these experiments generate? And what is their specific role in low carbon or climate resilience transitions?*" (p.18)

Methods:

- Systematic lit review of journal articles published in the period 2009-2015 in the Social Sciences and Humanities.
- Search words: Experiment, efficiency, low energy, energy saving, renewable energy, mobility, transport, adaptation, and transition.

Headline findings and extracts:

Role of uncertainty and experimentation

- Three roles of experimentation in facilitating transitions: (1) 'deepening' (e.g. by shifting practices and ways of thinking); 'broadening', whereby the legitimacy of innovations, and the network of advocates backing them, grows through the process of repeating experiments in different contexts; and (3) 'scaling up', whereby experiments are embedded in *"established ways of thinking, doing and organising"* (p.22).
- 20 of the 27 reviewed experiments were described to have resulted in changed discourses and that the evidence of the 'deepening' function of experiments far outweighed the evidence of the 'scaling up' function.
- Although there is a strong theoretical argumentation for the use of experiments in transition processes, and evidence of their role in 'niche' and market creation, there is a clear evidence gap in the ability of experiments to help overcome political and institutional difficulties and barriers to low-carbon transitions. *"There is a particularly urgent need to develop and conduct in-depth post-evaluations of experiments and clusters of experiments"* (p.26) to reveal 'success factors' or unfounded hopes placed on experiments.

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Publication: Konrad et al. (2008)

System: Utilities
Scale: National
Country: Germany
Historical or ongoing transition: Historical and ongoing

Research question:

1. How do transformation processes in different (utility) regimes interact and how does this interaction shift regime boundaries?
2. What is the relevance of multi-regime dynamics in future-oriented applications of the Multi-Level Perspective? / What are the implications of excluding multi-regime dynamics from transition analysis?

Methods:

Qualitative analysis of focus-group data resulting from foresight exercises and participatory scenario-building with sector experts. The analysis was conducted based on the authors' proposed conceptual framework for analysing multi-regime transformation.

Headline findings and extracts:

Cross-sector interactions

- Taking historical and theoretical transitions across German utility sectors, the authors show how transformations that emerge independently in a single domain and/or regime (e.g. the rise of electricity prosumers in the energy sector) interact across regime boundaries with functionally coupled regimes (e.g. telecom sector) and thereby contribute to larger systemic changes (e.g. smart distributed energy systems of the future). The key take-away is that an improved understanding of multi-regime dynamics can improve the theoretical grounding of development scenarios and thereby our ability to steer/manage transitions.

Adopting a Systems approach to the analysis and governance of transitions

- The authors recommend the facilitation of co-modelling workshops with industry experts to map out inter-regime (or cross-sector) interactions and to identify potential implications for various development pathways (detailed instructions on how to go about this are provided).

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Publication: Nciri and Miller (2017)

System: Combined-Heat-and-Power District Heating (CHP-DH)
Scale: National
Country: Sweden
Historical or ongoing transition: Historical (1945 until 2011)

Research question:

What are the *"socio-spatial and political processes that produced the coupling, decoupling, and recoupling of district heating systems and combined heat power in Sweden from 1945 to 2010"* (p.213) and what role did power and politics play in those processes?

Methods:

"Drawing on government and industry documents as well as the broad literature on energy systems" (p.213).

Headline findings and extracts:

Landscape factors

- (1) Liberalisation; (2) climate change agenda; (3) debate around nuclear phase-out.

The role of power and politics and the need to actively manage phase-outs

- In the context of electricity over-capacity, nuclear and hydropower energy providers blocked developments in CHP.

Non-linearity / Adopting a Systems approach to the analysis and governance of transitions

- *"Our analysis suggests that the study of technological diffusion and blockage is far from a straightforward matter. Rather, it may require examination of multi-level governance and overlapping socio-technical systems in a dynamic and spatial, rather than static and aspatial, way. Regimes are in constant evolution and actors struggle to adapt to new circumstances. This dynamic dimension is crucial. A regime is not merely the production of a material system and landscape, but an expression of dynamic socio-spatial power relations and adaptation strategies"* (p.226).

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- National policies: 1991 carbon tax and (previously blocked) exemption for CHP generation in 2013; green electricity certificate (2003) to promote renewable energy generation, including biomass-fired CHP; subsidies in 2000s to construct biomass-fired CHP plants.
- LA vs. privately owned DH: *"Åberg et al. estimate that 62 per cent of municipally owned utilities apply cost-based pricing while only 11 per cent of privately-owned utilities apply this pricing method"* (p.224).

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Publication: Pereverza el al. (2019)

System: Heating
Scale: Local
Country: Bila Tserkva, Ukraine, and Niš, Serbia.
Historical or ongoing transition: Ongoing

Research question:

What overarching design principles would allow long-term planning frameworks to adapt to (1) planning levels; (2) socio-cultural contexts (e.g. planning horizon, participatory culture); (3) project limitation (e.g. budget, time and skills available).

Methods:

Modular Participatory Backcasting

Headline findings and extracts:

Adopting a Systems approach to the analysis and governance of transitions

- Interdisciplinary, participatory scenario work/modelling recommended, as this facilitates:
    - creation of new knowledge from interdisciplinary working.
    - a 'shared' vision for transition.
    - systems learning.
    - stimulation of cross-sectoral planning.
    - recognition of trade-offs in management strategies and disputes mediation/resolution.
    - legitimisation of decision-making.
    - sense of legitimacy and ownership of decisions taken and, thereby, actors' commitment to support the implementation of new strategies.
    - buy-in and resource; (viii) trust and network building.
    - coordinated actions.

- Article lists tools for participatory modelling and alternative (adaptive) long-term planning frameworks in infrastructure sectors.

Historical path dependency and the role of place-based 'selection environments'

- *"The suitability of different [heating] solutions is highly dependent on local socio-cultural and physical conditions. [...] This diversity in possible technologies implies that scenario exploration methods [both formal and conceptual] need to be included in strategic planning frameworks"* (p.124).
- Participatory modelling may need carried out at the local level.

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Publication: Roesler and Hassler (2019)

System: Bioenergy
Scale: Regional
Country: Germany
Historical or ongoing transition: Ongoing

Research question:

What is the role of multi-level governance in the creation of niches within energy regimes?

Methods:

Data: 40 in-depth semi-structured interviews were conducted in 2011 and 2013 with representatives of ten bioenergy villages in Marburg- Biedenkopf.

Methodology: "*The data analyses followed the procedures of the qualitative content analysis by Mayring (1993): reduction of the transcribed interviews to the relevant content, structuring the material along specific topics (e.g. policy) and further filtering of the content along certain categories (e.g. local policy)*" (p.97).

Headline findings and extracts:

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LA key partner in DH delivery (e.g. by providing baseload, fostering trust in the professional implementation of community projects, etc.).
- Social capital of village mayors = key resource.
- Multi-level policy integration (i.e., complementarity national, regional, and local political support for bionenergy).
- National policy levers: EEG (Feed-in-Tariff) reformed to provide additional compensation for bio-electricity if suppliers verify the use of a certain amount of residual heat.
- In addition to feasibility studies, EU and state grants funded temporary subnational governance institutions (e.g. by funding creation of 'regional energy concept' and working group within regional government to implement it).
- Barrier to transition: Policy unreliability, in many cases, prevented or disrupted projects as they require detailed costs calculations. This would not happen if political and state budget cycles matched the much longer timescale of implementing local heat networks.

Cross-sector interactions

- Rural economy: EU rural development/regeneration funding is key.

Historical path dependency and the role of place-based 'selection environments'

- 'Multi-scalar policy processes' – *"Variations of policies on the regional and local scale, within a national policy framework, bring about different sub-national spatial regimes"* (p.100).

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Publication: Seiwald (2014)

System: Biomass District Heating (BMDH)
Scale: National
Country: Austria
Historical or ongoing transition: Historical and ongoing

Research question:

As opposed to a linear (and physical) 'scaling-up' of one socio-technical configuration, what configurations emerge and shape the diffusion dynamics of the Austrian biomass district heating niche?

Methods:

1. Secondary statistical data and primary qualitative
2. Analysis of studies and reports by federal agencies, research and lobbying organisations
3. 17 semi-structured interviews with staff of the national and provincial subsidy departments, lobbying organisations, plan operators and research organisations

Headline findings and extracts:

Landscape pressures

- Oil crises in 1970s and 1980s (during which agricultural sector lobbied for BMDH).
- Imperfect material and energy flows in sawmill industry.

Cross-sector interactions

- Interaction with sawmill industry: Example of how innovations in coupled systems can create landscape pressures and innovations in heat system (see Konrad et al., 2008).
- Interaction with utilities: *"The main rationale for [large] utilities to engage in micronets is to keep their long-standing customer relations that often resemble a local monopoly, considering that these utilities also provide electricity and telecommunication services, besides serving the heat market via natural gas and BMDH"* (p.52).
- Interaction with buildings regulations: Increase in required share of renewables for newly-constructed buildings is expected to support continued growth of micro-net industry.

Role of uncertainty and experimentation

- Introduction of Feed-in Tariff created new system dynamics: attraction of large utilities and sudden increase in biomass fuel prices and early saturation of CHP.

Lon-linearity

- Innovations can up-scale *"into several generic socio-technical configurations or dominant designs. Each dominant design […] follows its own life cycle [in interaction with the others]. The successful diffusion of the wider technology results from the aggregated implementation rates of the individual [and interacting] dominant designs"* (p.44).
- Identity of 'system builders' changed at each phase of the BMDH transition.

Interaction between innovations

- Saturation in one innovation (e.g. large-scale biomass CHP) leads to competition in another (e.g. micronets).

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LA is a key partner in DH delivery.

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Publication: Smink et al. (2015)

System: Biogas injection
Scale: National
Country: Netherlands
Historical or ongoing transition: Ongoing

Research question:

How do the different institutional logics that guide gas network operators and biomethane producers influence biomethane injection into the Dutch natural gas grid, and how do boundary spanners intervene?

Methods:

1. Stakeholder identification via review of 250 news articles on Dutch biomethane injection (2003 to 2012)
2. Analysis of policy documents, annual reports, and research reports for overview of unsolved technical and regulatory issues with regard to biomethane injection
3. 14 semi-structured interviews with network operators and producers of biomethane

Headline findings and extracts:

Landscape pressures

- Climate change.
- Sharp decline in expected gas extraction from Groningen.
- Liberalisation of gas 'sales' companies put pressure on network operators to accept new, local supply of biogas.

Intermediary roles and activities

- Previously unrelated organisations (e.g. large utility companies and farmers) with different 'organisational logics' are forced into association. Mismatching interests and logics create a number of barriers for transition, e.g. miscommunication, distrust, and disagreement. The authors show how these barriers stalled or prevented planned biogas injection
  - At the time of authoring the paper (2014) only 13% of the proposed biomethane production capacity that was allocated subsidy in 2011 had been realised.
- Room for optimism: *"Logics that people operate under have some latent flexibility and [...] people can become enthusiastic about new initiatives"* (p.234). By 'spanning' conflicting logics, skilled intermediaries help unlock innovation.
- Four spanning activities: Convening, translation, facilitating collaboration and mediation.
- Boundary spanners help *"people to get in touch with other logics, change their mind and practices, and so open up new avenues for change"* (p.234).
- Boundary spanners can work within institutions, between (as consultants/mediators).
- There's also such thing as a 'boundary organisation' (e.g. company that buys biogas from several farmers and takes care of the upgrading process to remedy hierarchical vs. pragmatic institutional logic mismatch and mismatch of scale).

Adopting a Systems approach to the analysis of transitions

- A closer study of the interactions between network operators (regime) and biogas producers (niche) is critical for an improved understanding of niche innovations and their potential for scale-up.

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PUBLICATION: SOPHA EL AL. (2011)

SYSTEM: WOOD-PELLET HEATING
SCALE: NATIONAL
COUNTRY: NORWAY
HISTORICAL OR ONGOING TRANSITION: ONGOING

RESEARCH QUESTION:

Despite shared subsidies, why hadn't *"Norwegian households chose[n] to adopt heat pumps, but not wood- pellet stoves, and what policy, technical, or social change may cause them to start using wood-pellets on a larger scale[?]"* (p.2722).

METHODS:

Agent-based modelling, with input parameters derived from an empirical survey (N=270).

HEADLINE FINDINGS AND EXTRACTS:

Landscape pressures

- Climate change and electricity crisis of 2002-2003.

Historical path dependency and the role of place-based 'selection environments'

- Wealth of wood biomass.

Interaction of innovations with perceptions, attitudes, and beliefs

- Residential heating characterised by individual heaters (vs. communal heating in Sweden) meaning (i) heterogeneity of household behavioural choice and (ii) social processes (e.g. conformity, socialisation, peer pressure) strongly affect transition process.
- Despite similar levels of subsidy air-to-air heat pumps scaled-up but wood-pellet heating did not. From surveys, the authors discovered that wood-pellet heating as perceived to be the least environmentally friendly among three low-carbon heating systems.

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Publication: Späth (2015)

System: Combined-Heat-and-Power District Heating (CHP-DH) and building standards
Scale: Local
Country: Freiburg, Germany
Historical or ongoing transition: Historical and ongoing

Research question:

1. What are the driving forces and normative content of opposing viewpoints in this local conflict between two envisioned heat futures?
2. "*What factors were fostering the outbreak of the conflict and what resources [did] actors [tap] into in order to settle the disagreement*" (p.274)?
3. What was the "*institutional setup of such decision making about energy policy priorities in a municipality*" (p.274)?
4. In what ways are "*municipal actors [...] able to deal with (and make use of) such instances where visions and strategies of sustainable development become problematic and negotiable again*" (p.274)?

Methods:

Analysis of (1) bills that were proposed to the city council, discussion papers, press articles, campaigning materials) ; and (2) 10 in-depth interviews between 2004 and 2014 with those "*who participated in or observed the conflict from a diversity of perspectives*" (p. 275).

Headline findings and extracts:

Cross-sector interactions

- Conflict between Passivhaus design and DH in masterplan for Vauban District (Freiburg).
- Result: Passivhaus exemptions from network connection highly unattractive and difficult to achieve, disincentivising Passivhaus design. Passivhaus design only supported in areas where an expansion of the DH system is not feasible.
- Cause of conflict: The two strategies *"aimed at reducing the negative impacts of conventional heat provision [...] had been developed independently from each other in two distinct fields, and they involve different actor groups, institutions and practices"* (p.277).

Emergence

- *"Such junctions, as our case shows, are often outcomes of emergent and unplanned processes"* (p.279). Each 'urban junction' requires renegotiation and therefore new opportunities for innovation, hence the need for a long-term, recursive governance framework.

The role of power and politics and the need to actively manage phase-outs

- Vested interests: *"When a heat network is operated by a municipally owned utility – as in the case of Freiburg – its economic performance (annual profits or losses) is highly relevant also for the municipal budget"* (p.277).
- Role of power in mediating transition: The authors conclude, *"the role of rational arguments in such conflicts is often [...] limited: Authoritative decisions will in the end mostly reflect the interests and somewhat stabilized power balances within the city administration"* (p.279).

Adopting a Systems approach to the governance of transitions

- Despite agreeing to re-evaluate the city's heat strategy, the network has since expanded, e.g. into a new sub-district. As such, Freiburg's framework for energy policy decision making is *"not best understood as a systematic process of visioning with regular cycles of re-orientation, as it would be considered ideal from the perspective of Transition Management"* (p.278). An iterative governance arrangement is needed to *"open up opportunities for renegotiation and successful contestation"* (p.278).

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Publication: Upham and Dütschke (2018)

System: Hydrogen
Scale: National
Country: UK, Germany, Spain
Historical or ongoing transition: Ongoing

Research question:

1. How are individual attitudes and beliefs in relation to a niche energy technology influenced by experience of national economic and innovation policy environments?
2. What are the implications of structuration for expectations of action by self and others?

Methods:

Quantitative and qualitative, deductive (with room for inductive) thematic coding of 145 semi-structured interviews of R&D and governance stakeholders involved in hydrogen and its application in heat and transportation.

HEADLINE FINDINGS AND EXTRACTS:

Interaction of innovations with perceptions, attitudes, and beliefs

- *"R&D stakeholder beliefs of the prospects for hydrogen fuel cells for stationary applications are partly conditioned by their socio-economic and innovation policy context and these beliefs in turn have consequences for sociotechnical processes"* (p.172).
- Study also finds that narratives of and lived experience with the national context is important for shaping conjunctural knowledge and beliefs of what is 'possible', with a distinction between technocratic actors in Germany, UK and Spain.

The role of power and politics and the need to actively manage phase-outs

- Conjunctural knowledge is debated and contested in *"arenas and communities in which expectations relating to future technologies circulate and compete [...]. Such arenas include conferences, other scientific and technological meetings and discussion fora, but also in association with research programmes that further develop the technologies in question"* (p.172).
- Not everyone has access to these arenas, meaning the sociotechnical beliefs and expectations of those in positions of power disproportionately shapes technological pathways. This is concerning, as:
  - Assumptions by those with positional authority regarding the 'public's' response to top-down interventions are likely flawed or overly simplistic.
  - The exclusion/discounting of conjunctural knowledge of those excluded from the arenas threatens the legitimacy and equitability of sociotechnical transitions.

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PUBLICATION: WEBB (2015)

SYSTEM: DISTRICT HEATING (DH)
SCALE: LOCAL
COUNTRY: ABERDEEN, SCOTLAND
HISTORICAL OR ONGOING TRANSITION: HISTORICAL

RESEARCH QUESTION:

What are the social and political processes which shape the actual take up of renewable heat technologies in centralised energy markets, and which govern shares of costs and benefits in use?

METHODS:

Inductive thematic analysis of qualitative data from nine semi-structured interviews and analysis of policy documents

HEADLINE FINDINGS AND EXTRACTS:

Landscape Pressures

- Public pressure to address fuel poverty and climate change.

Historical path dependency and the role of place-based 'selection environments'

- Economically viable, low-carbon heat projects *"have tended to remain marginal to dominant energy regimes, rather than initiating a process of transformation (Bulkeley et al., 2014; Rutherford and Coutard, 2014). In the UK the challenges are more pronounced, because of the structural weakness of urban authorities, with limited financial autonomy"* (p.267).

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- UK DH delivery relies on rare windows of opportunity.
- LA key partner in DH delivery (e.g. by providing baseload, utilisation of social capital by council leader, and investment).
- A near-success: Aberdeen City Council *"conferred a precarious hold on energy expertise and finance: project evaluation reports note the intensive work loads, few resources and responsibility without clear authority"* (p.271).
- National policy vacuum: There is no existing market for DH and no long-term capital for heat network infrastructure. This context *"creates systemic risks for DH and CHP investment, indicating the need for a regulatory framework"* (p.271). The authors go on to provide policy recommendations for the UK and Scottish governments to address this.

Intermediary roles and activities

- The council's Home Energy Co-ordinator: facilitated cross-sector and cross-party climate change/fuel poverty agenda formation via a number of intermediary activities.
- Scottish Government: *"During the short-lived [Community Energy Programme], the re-established Scottish government funded a cross-sector district energy network, demonstrating the significant potential for regional and inter-city networks of shared learning and knowledge formation to develop: forty per cent of projects receiving CEP capital funding were in Scotland, which has eight per cent of UK population, and Aberdeen became the lead UK recipient"* (p.271).

Interaction of innovations with ecological Systems

- The council chose to forgo insulating social housing stock when installing CHP-DH (less environmentally sustainable and creates barriers to future improvements in energy efficiency).

Adopting a Systems approach to the analysis of transitions

- *"Although UK policy is again highlighting the formal techno-economic potential of DH, those [local] authorities which have analysed technical and economic feasibility have struggled to move forward, with projects [...] declining in scale and/or taking many years to advance to construction (Wiltshire et al., 2013)"* (p.267). This is due to the political and social processes that govern the actual take up heating solutions, which are currently under-analysed.
- *"The performed, as opposed to theoretical, energy, cost and carbon saving value of CHP, DH (and indeed other energy technologies), are conditional not simply on technical capacities of generators, pipes and so on, but also on the social systemic inter-dependencies between suppliers, network operators, regulators and users"* (p.267). These are also under-analysed.

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PUBLICATION: WEBB ET AL. (2017)

SYSTEM: ENERGY
SCALE: LOCAL
COUNTRY: UK
HISTORICAL OR ONGOING TRANSITION: ONGOING

RESEARCH QUESTION:

1. What are the energy activities of UK LAs?
2. Have any patterns of activity emerged (e.g. more activity in devolved nations; more activity in retrofit vs. supply of renewable energy)?
3. Which service had lead responsibility in initiating the energy project?
4. What objectives do LA energy initiatives serve?
5. Whose investing in these energy projects?
6. What business structures are employed in the sample of energy projects?
7. What uncertainties do LAs face when leading, facilitating or engaging with these energy projects?
8. What solutions and strategies have LAs adopted to 'navigate' these risks?
9. What needs to change to accelerate LA engagement in energy?

METHODS:

1. Quantitative analysis: analysis of planning documents and budgets; LA surveys
2. Qualitative in-depth case studies of energy projects in 40 LAs: Surveys, focus groups, interviews (qualitative case

HEADLINE FINDINGS AND EXTRACTS:

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- LAs want to act:
  - 82% of LAs surveyed have energy and carbon management plans and/or projects (finding: those w/ strategies more likely to take action).
  - 3/4 of activity was in heat and energy efficiency for a low-carbon, low energy building stock.
- Energy project delivery relies on rare windows of opportunity.
- BARRIERS to LA action:
  - Capacity - unitary authorities take more actions than LAs.
  - Long pay-back period of many energy projects (most projects' payback period ranged from 5-7 years).
  - Unreliable energy policy.
  - Austerity (e.g. reduced ability to access grant funding).
  - Dwindling council housing stock (reduced baseload).

Intermediary roles and activities

- LA officers - *"make energy a prominent part of business plans, revenues and service provisions across the council [via mobilising cross-party and political leadership support, making energy prominent in local strategy, etc.]"* (p.33).

Role of uncertainty and experimentation

- LAs engaging in energy governance tend to experiment small to start, using pragmatic starting points.

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Publication: Westholm and Beland (2012)

System: Heating and cooling
Scale: National
Country: Sweden
Historical or ongoing transition: Historical (1980 - 2010)

Research question:

"What were the enabling contributions from the welfare model and from the competition model and what opportunities where created in the interaction between the two models?" (p.330)

Methods:

Application of the two analytical frameworks – 'welfare model' and 'competition model' – to the historical study of Sweden's heat transition.

Headline findings and extracts:

Historical path dependency and the role of place-based 'selection environments'

- *"The various state models in Europe provide different institutional pre-conditions for the energy transition"* (p.333), e.g. Swedish LAs had independent decision-making powers and powers of taxation – a legacy of their role in the welfare state project.

Cross-sector interactions

- Building regulation: *"Once the district heating is at place, the incentives for energy savings in the area are radically reduced"* (p.333). Authors provide evidence where DH companies have obstructed measures to improve energy efficiency of housing stock.

Multi-level governance for a transition towards a decentralised, decarbonised heat System

- National Government: recognised *"natural, social and economic resources varied over space ("regional capital") and should be developed in the regions"* (p.332).
- Regional Government: "*The role of the regions were less operational, being primarily oriented towards interpreting the national objectives and adapting them to regional [development] contexts and establishing networks and co-operation in the interest of policy promotion*" (p.332).
- Local Government: Coordinated actions with other municipalities to increase cost efficiency and economies of scale as well as to boost their development efforts through participation in regional development projects, EU programmes, lobbying other political levels, etc. *"The increased cost efficiency and economies of scale "made district heating and power production economically competitive in relation to other system solutions"* (p.333).

Intermediary roles and activities

- Regional Government disseminated knowledge via *"advisory services to private firms on energy efficiency, ongoing dialogue with housing companies, schemes for monitoring energy use in buildings, and support to local authorities regarding public procurement"* (p.332).
- Local Government: Helping establish public-private co-operation and providing a market for locally produced energy carriers.

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Energy-PIECES

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