British gas central heating as a rapid socio-technical transition

Abstract
The UK government has signed up to the 2015 Paris Agreement of the UNFCC, to reduce carbon emissions by 80% on 1990 levels by 2050, but to achieve this will require a radical shift in domestic heating practices, which are currently dominated by gas central heating, installed in 82% of UK homes (Palmer and Cooper 2014).

Using a socio-technical systems analysis, based on Actor Network Theory, this paper examines what can be learned from previous transitions in heating, in particular the series of changes which led from the majority of UK homes being heated by open coal fires in the middle of the twentieth century, to a very high proportion of whole-house gas heating by the end of the century. How did a new technology (small bore central heating systems) spread rapidly and effectively, and how was a fundamental change to a natural gas fuel infrastructure achieved? What does this tell us about the implementation of technological change across society?

Keywords: Actor network theory, central heating, gas industry, historical energy transitions.

1. Introduction

Recent agreements to reduce carbon emissions made in the 2015 Paris Agreement of the UNFCC have been welcomed, but the question of how to achieve significant reductions in fossil fuel use remains open. In the UK, a commitment to reduce carbon emissions by 80% from 1990 levels by 2050 has intensified the focus on the main uses of fossil fuels in the country. Domestic space heating fuelled by natural gas is responsible for 11% of the UK's CO_2 emissions (DECC 2012). Britain's low-quality housing stock and reliance on natural gas are a clear focus for efforts to reduce emissions, with increasing pressure to achieve a "transition" to new forms of domestic heating that are less reliant on fossil fuels. Even though social historians of energy have been at the forefront of recasting our understanding of human energy use as socio-technical systems (e.g. Hughes 1983, Nye 1990, Hecht 1998) analysis of previous experiences of domestic heating transitions in the UK remain limited. Historical analysis can provide insight "by identifying often-overlooked considerations among practitioners who propose and implement energy policies" (Hirsch and Jones 2014: 106) even if, as Hirsh and Jones make clear, history does not "offer powers of prediction". With this in mind, we argue it is pertinent to consider the remarkably rapid and far-reaching introduction of gas central heating to UK households in the 1960s and 70s as a particular instance of rapid transition.

According to Sovacool, mainstream views of energy transitions imagine them, as "long, protracted affairs" such as the "switch from wood to coal or coal to oil" (2016:202), yet few, if any of these transitions could be seen as either definitive, complete or temporally finite. Araújo (2014) has elaborated on the lack of coherence in discussions of energy transitions, and the many competing trends and approaches to defining and understanding what a transition is. Sovacool (2016) points out the importance of defining the scope and starting points of transitions and acknowledges that what may appear retrospectively to be radical transitions may be the culmination of a cohort of smaller changes. Understanding such transformations requires both the over-arching view of the sweep of history but also the detailed analysis of particular changes, the circumstances under which they occurred, their vulnerabilities and critical factors. Hence Mitchell's (2011) Carbon Democracy gives us a broad picture of global energy geopolitics, while Lorkowski's fascinating account of the 20th century Berlin rental business for storage water heaters (2012) shows us how socially-embedded technologies brought about widespread changes in domestic practice through planned as well as unexpected alignments between technological development, economic interests, domestic practices and political governance.

Given the now general consensus that energy systems, or elements of an energy system cannot be properly understood through a focus on technology or society alone, we focus in this article on a socio-technical approach to the dramatic transition in domestic heating seen in Britain[1] in the second part of the twentieth century[2]. This involved both a change from single room heating to central heating of the whole house and from coal to gas as the predominant heating fuel (Fouquet 2008: 88).

To analyse this transition, we use socio-technical methods that fall under the general banner of Actor Network Theory (ANT) and associated approaches. In a communication in this journal Wong (2016: 106) advocates ANT as "a frame and mode of thinking about inter-disciplinary energy research". As we outline below, ANT represents an established approach in the social sciences that is designed to evade the dichotomies and hierarchical explanations between the social and the material, the technical and the political, between structure and agency, and between the human and the non-human. It is one of few methodologies that allows us to conceptualise, describe and understand a whole system, or rather to understand a system holistically. In highlighting the interactions and links between diverse entities, it enables us to demonstrate how apparently stable systems come about, how they are maintained and how they might become unstable, in other words, to understand what a transition might be and how it might come about.

ANT is neither a restricted methodology, nor the only possible approach to understanding socio-technical change and stability (see Bijker 1995, Geels 2002), but as a particular interpretation within Science and Technology Studies, it offers a useful approach for conducting historiographic research in this area. In this article, we consider an often overlooked moment in the history of British domestic heating when a large scale technological and social change was enacted. This work is complementary to Arapostathis et al's (2013) analysis of historical transitions in the UK gas industry, which takes a multi-level perspective (MLP) on transition pathways and focuses on governance and institutions. It expands on the mention of the new markets offered by central heating in Turnheim and Geels' (2013) discussion of the destabilisation of the British coal industry in the period to 1967. ANT is a loose grouping of analytical and methodological approaches that has developed since the 1980s (Sismondo 2004) whose over-riding central concern is with how people, non-humans and materials interact to do things in the world. It aims to go beyond institutional or social analysis, laying aside the primacy of either technological, material or social relations and give them equal significance in our explanations of the world.

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1 The focus is on Britain since the situation in Northern Ireland, where natural gas was only introduced in 1996 (Utilities Regulator NI 2015) is rather different

2 Fouquet (2008: 433) shows an increase in effective domestic heating in the UK from 17.3Mtoe in 1950 to 47.9 Mtoe in 2000

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2. Understanding Heating Systems using ANT

In order to understand the transition in systems, we trace the relations between the diverse actors, including human and non-human actors (sometimes referred to as 'actants') using an approach inspired by Actor Network Theory (ANT). Our approach to heating systems starts with the identification of key actors, both human and technical, and of the links between them. Heating systems are complex networks including material objects, persons, institutions and organisations. They contain all the material connections between fuel source and heat delivery in the home, from power stations and gas drilling rigs, gas mains and electricity cables, through to heating pipework in buildings. The infrastructure linking fuel supply to heating equipment in the home is owned and managed by energy companies and agencies. Human actors associated with heating equipment thus include installers, manufacturers, designers, retailers, builders' merchants, regulators, etc. These people are linked together by professional networks and relationships of trust between buyers and suppliers, as well as by further technological infrastructures (transport, communication, regulation, etc.).

A heating system does not spontaneously develop and find itself in a house. A long chain of events and relationships have to be enacted for a heating system to emerge. In this article, we are concerned to understand the emergence of gas central heating as the dominant form of domestic heating in the UK in the 1960s and 70s. Which were the elements that enabled this transition from coal-fires to gas central heating with small diameter water pipework, how was the transition facilitated, and what are the insights that might be relevant for future transitions away from fossil-fuelled domestic heating?

The concepts of **translation** and **alignment**, as they are used in ANT, are important for this investigation. Callon (1991) describes the process of translation taking part between the actors in a network. This involves one actor translating a network element for another actor in terms that are meaningful to the second actor (an example in the heating field might be a 1960s advertisement for central heating seeking to persuade householders that it is both desirable and affordable for their homes). The process of translation involves aligns the interests of a variety of actors, enrolling and mobilising allies so that they work together, strengthening the network (Callon 1986).

An important influence on our analysis is the concept of the **heterogeneous engineer**, who "seek[s] to associate entities that range from people, through skills, to artefacts and natural phenomena" (Law 1987: 129), a figure that stands for the operation of translating between different elements of a multi-dimensional network. Because the notion of the heterogeneous engineer tends to conjure up an individual person, in our analysis, we coin the notion of a **translation hub**, to characterise a concentration of translation activities in one organisation which aligns the interests of a constellation of actors and creates stability in the network, in a similar way to the activities of an individual heterogeneous engineer. Another important concept used by ANT writers is of the **black box**. This indicates a part of the network with predictable behaviour, so that it can be taken for granted without understanding its inner workings (Sismondo 2004).

Callon describes how **intermediaries** circulate between actors in a network and provide the means by which "actors define one another in interaction" (Callon 1991: 135). Fuel supplies and information in the form of texts (e.g. instruction manuals, energy bills) are examples of significant intermediaries in heating networks, as are payments for equipment and fuel. Similarly, infrastructure and equipment afford specific practices and relations. Such objects materialise the relations between elements that can pre-empt the potential for future uses, as particular pieces of equipment or relations between consumers and providers afford restricted options for change. We should be alert to the relations that are fixed through the particularities of a heating system in different contexts, and the forms of path-dependency implicated in the system (Walker 2000). Such materials help to stabilise the network, whose practices and procedures can be described and imagined as a stable state.

ANT examines why some networks are more stable than others by examining the alignments between actors and sees stability as based on a process of **enrolment** into the network rather than coming from the state, markets or social institutions (Wong 2016: 107). We use ANT methods to describe the relatively stable states for domestic heating before and after the transition to gas-fuelled central heating, and the transition from one to another, asking: how have stable networks been achieved in the historical transition? What were the differences between the stable configurations actually achieved and other options that were available but did not become widely established? How were the interests of different actors aligned, and are there actors playing the role of “heterogeneous engineer” to achieve this? Can we see a collection of such “engineers” working together as a kind of “translation hub”?

3. Methods

The heterogeneous networks associated with home heating are reflected in the varied evidence we use to trace them. The focus of the investigation is on primary sources which show how heating networks appeared to actors at particular points in time, and the uncertainties they faced. Table 1 shows the main primary sources consulted.

The starting point was a search of electronic newspaper archives for references to central heating. This brought up both informative articles on technical developments and a wealth of advertisements, which suggested further avenues for investigation. Articles on central heating displays at the Ideal Home Exhibition led to *Ideal Home* magazine. With its dedicated annual heating supplement, this monthly magazine is a valuable source for identifying the heating system choices offered to the aspirational consumer from the 1950s through to the 1970s. A search for gas industry periodicals brought to light *Gas Showroom* magazine, a monthly magazine for gas sales staff.

As discussed below, a number of sources pointed to the key role of the British Coal Utilization Research Association (BCURA) and the records of this organisation (annual reports and technical circulars) stored at the North of England Institute of Mining were consulted.

The UK National Gas Archive at Warrington was a valuable source of official gas industry records and the section of the archive containing personal accounts included the reflections on conversion by two area gas board managers which provided individual perspectives on how the industry faced the challenge of conversion.

A range of secondary sources providing an overview of the history of the UK gas industry (e.g. Williams 1981, Arapostathis et al 2012, Elliott 1988) and of the evolution of energy demand (Fouquet 2008) provided context for the primary sources.

Table 1 Primary sources

Source type	Key references
Government publications	1967 Fuel Policy White Paper (Ministry of Power 1967) "Parker Morris" report (Ministry of Housing 1961)
Professional and industry guidance	British Coal Utilisation Research Association (BCURA) circulars and annual reports Plumbing and heating design textbooks (Penn and Soley 1960, Barton 1970) Journal of the Institute of Heating and Ventilation Engineers (Purkis and Wills 1966)
Newspapers and Magazines	Daily Mail Ideal Home Magazine Gas Showroom magazine
Personal accounts (unpublished)	Heslop (1979) Mercer (n.d.)

4. British central heating before natural gas

Prior to the 1960s, the majority of housing in Britain was heated by open coal fires. Typically only a few rooms in each home were heated (Carlsson-Hyslop 2016). The preparation of fires, transfer of coal and cleaning of the resulting grime and dust involved significant labour. Before the late 1950s, central heating hot water circulation systems had been gravity-based with large bore pipework (internal diameter 50mm or above), and were only installed, at considerable cost, in large buildings (Barton 1970). Yet by the mid-1960s, and before the conversion to North Sea Gas the uptake of central heating was accelerating with the number of homes with whole house heating increasing from less than one million in 1960 to more than 2.5 million by the end of 1965 (Purkis and Wills 1966). What lay behind this?

The heating profession in the 1960 and 70s had no hesitation in identifying a key driver of the trend to central heating: the development by the British Coal Utilization Research Association (BCURA) of "small-bore" hot water pipework systems for central heating using pressurised pipework with an internal diameter of 30mm or less. A striking example of the many references in text books and the trade press of the time can be found in a 1970 textbook for heating engineers. In a section that stands out from the equations and graphs in the rest of the book, Barton (1970) interrupts his description of the calculations for designing a heating system with a text-only section headed "A Historical Note" in which he describes the introduction of small-bore central heating systems. He explains that this followed the introduction of a small, silent pump suitable for circulating hot water in smaller houses and credits BCURA with "the original development of modern small-bore hot water central heating" (Barton 1970: 121). He describes the advantages of a pumped system that was cheaper and easier to fit in both existing and new-build houses, and suitable for smaller homes, for which large bore systems were particularly ill-suited.

This development can be seen as an alignment (Callon 1986) between housing and heating equipment; here was a heating system that fitted very well with the typical smaller home (semi-detached or terraced) in which so much of the population lived. A change in heating technology made central heating for ordinary houses cheaper and more convenient. Textbooks such as Barton's also demonstrate the significance of the role of heating engineers and installers, described by Wade et al (2016) as “missing middlemen” of domestic heating. Installers across the nation had to be both persuaded of the efficacy of the new technology and of their interest in installing it – another alignment that binds technological, social, professional and economic spheres.

As well as matching the housing stock, small-bore central heating aligned with changes in social attitudes, in particular growing expectations of whole house heating. Evidence for this change can be seen in the influential “Parker Morris” report of 1961 *Homes for Today and Tomorrow* which demonstrates how expectations for decent housing for all were rising, and taken seriously by government. The report sets out a need for new housing standards to meet changing lifestyles and expectations and states “after more floor space, the first priority in the evidence was for better heating” (Ministry of Housing 1961: 3).

4.1 Industry and professional networks

Why did BCURA develop and promote small bore central heating? BCURA was the coal industry research association with the objective “to promote research and other scientific work in connection with the utilization of coal and its derivatives” (BCURA 1949). Its members included appliance manufacturers and major coal users as well as coal producers. It seems ironic now that work funded by the coal industry can be seen to underpin the growth of oil and natural gas heating systems, but when the development work was carried out in the mid 1950s, at a time of fuel shortages and rationing, the most effective use of coal was a priority. If the equipment was fuelled by gas, the expectation at the time would be that the gas would be manufactured from coal.

BCURA published a series of “information circulars” for its members and a wider audience and two of these published in 1957 outline the small-bore system and set out its benefits. Circular 181 states the objective as “reducing the cost of a full central heating system to a level within the reach of a much larger section of the population, and at the same time, to produce a system with an improved efficiency of operation” (Brook 1957: 1). In describing the disadvantages of the large bore pipework that was standard at the time, Brook stresses the less obtrusive pipework and more efficient, lower cost operation. A pumped system allowed the used of heating control valves and much of the BCURA work focused on system control, developing features now taken for granted such as control valves linked to room thermostats.

As the Research Association (funded by member subscriptions) of the coal industry, focusing on coal utilization, BCURA acted as an industry “translation hub”, making links among equipment manufacturers and heating system designers and pulling together people, equipment and texts in support of this new way of designing central heating. The account of the small-bore work in the BCURA Gazette (BCURA 1956:27) describes how member firms were working on control devices, silent pumps and other heating equipment suitable for the new systems. The new concept was publicised among heating design professionals (for example in a paper to the Institute of Heating and Ventilating Engineers) and the heating supply chain (BCURA 1956: 16) and to potential customers and the wider public in newspaper articles (Hall 1956).

4.2 A choice of fuels

Unfortunately for the coal industry, although the BCURA system aligned well with the housing stock and social attitudes, there was no clear alignment of central heating with one particular fuel. Heating supplements of *Ideal Home* in 1957 and 1962 show a wide range of central heating systems being marketed to the magazine's aspirational middle class readers. Articles outline the advantages and disadvantages of room heaters and central heating (covering warm air systems as well as hot water radiators) and consider coal, oil, electricity and gas. The calculations of costs for particular situations shows there was no clear leading fuel choice for all situations. A 1960 textbook on heating systems (Penn and Soley 1960), which contains information on a range of types of central and local heating systems, reinforces the impression that many heating system and fuel options were available and various factors had to be weighed up to select the most appropriate for a particular building.

Additional factors contirbuted to moving coal out of this new convergence. The Clean Air Act of 1956 gave local authorities the power to designate "smokeless areas" in which only authorised smokeless fuels (types of coke) could be burnt (Scarrow 1972) and after 1962 grants for conversion to gas or electric heaters were available. Scarrow reports that councils found a significant proportion of "voluntary conversions" had occurred before an area was scheduled to become smokeless, and he links this to increasing affluence and demand for higher heating standards.

Advertisements are revealing about manufacturers' views of consumer priorities and an increased emphasis on whole house central heating, rather than individual room heaters, is evident through the 1960s. In adverts for boilers, a shift away from the physical labour involved in coal systems is a clear theme. For example a 1957 advert for a coal boiler describes it as "the truly automatic boiler for the small house" which needs stoking with fuel "not more than once in 24 hours" (Ideal Home 1957: 15). The oil industry carried out significant advertising campaigns around central heating in this period, with advertisements stressing the lack of work to run the system "a boiler that never needs stoking" (Ideal Home 1957: 15). Williams describes how "in the early 1960s Shell made a determined bid to promote central heating in Britain with their "Mrs 1970" campaign, "designed to persuade the public that this was no longer a luxury but a normal domestic amenity" (Williams 1981: 136). Oil and coal were not the only fuels being promoted: Carlsson-Hyslop (2016) describes the activities of the Electricity Development Association (financed by the industry to develop sales material) which aimed to increase electricity demand and promote off-peak storage heating in the 1950s and 1960s. CF Claxon, Commercial Manager SE Gas Board is quoted as saying: "we as an industry must strongly attack the whole-house heating market. If we do not capture this essential load then our competitors will" (Gas Showroom 1969: 14).

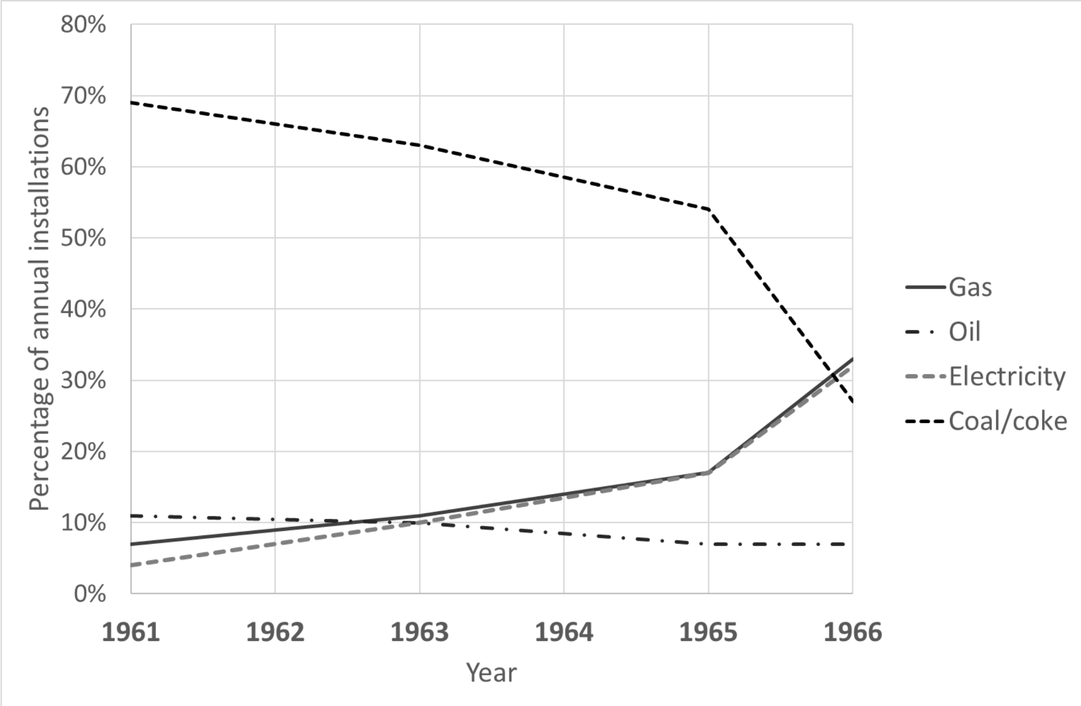

Figure 1 Central heating sales by fuel 1961-1966 (based on data from Newby 1967)

Figure 1 above shows the decline of coal as the fuel for new heating installations and the rise of gas and electricity as alternatives. It is based on figures given in an article in *Gas Showroom Magazine* by the managing director of a boiler manufacturer[3]. A dramatic change occurred between 1963, when oil, gas and electric had about 10% of the market while coal had over 60% and 1966 when coal, gas and electric installations were all running at about 30% of new installations that year. The decline of coal was clear but the future supremacy of gas was not obvious at this point. However by 1972 three quarters of all new housing had gas central heating (Mercer n.d.). In the next section we trace the factors that lead to gas becoming so dominant, linking this to the major infrastructure changes that occurred with the conversion to North Sea gas.

5. Transition to natural gas

The 1967 Fuel Policy White Paper (Ministry of Power 1967) outlines the challenges and opportunities for moving from a two fuel (coal and oil) to a four fuel (coal, oil, natural gas and nuclear) system and stated that "the discovery of natural gas in the North Sea is a major event in the evolution of Britain's energy supplies"(Ministry of Power 1967: 1). In retrospect it can also be seen as the trigger for a major change in patterns of energy demand as well as supply.

The national conversion from town gas (manufactured from coal or oil) to methane from the North Sea over the period 1967 to 1977 was a "centrally coordinated and state-led transition" (Arapostathis et al 2012:41) in contrast to the gradual, sales-led process that had

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[3] No source is quoted for these annual percentages although figures given for total number of installations elsewhere in the article agree with those in Purkis and Wills (1967). Although they cannot be considered definitive, they nevertheless provide an interesting snapshot of the shifts in fuel use as they appeared to a senior industry figure at the time.

led to the expansion of central heating up to then. It was a major centralised undertaking; Williams (1981 p295) compares the scale and complexity of exploration for, production of, and conversion to North Sea gas (NSG) with the Apollo space programme in the US. The financing of this very significant infrastructure change was effectively a state decision. The nationalised gas industry's spending plans were approved by the Ministry of Power and the Treasury and justified based on the future expansion in gas demand expected, and the avoided costs of new town gas production plants at a time when substantial investment would have been required to maintain town gas supplies (Elliott 1980: 8).

The massive organisation responsible for conversion can itself be visualised as a parallel actor-network, in which gas board staff, contractors, appliance manufacturers and gas consumers are linked together by information campaigns, gas pipelines, contractual arrangements, industrial relations agreements and millions of conversion kits. This is not to under-acknowledge the significant financial or political interests involved in the process, but to highlight the diversity of actors that had to be brought together to achieve such a dramatic change, and its far-reaching consequences. Elliott (1980: 1) tells us that 40 million appliances and 14 million customers were converted and that one appliance manufacturer, the Radiation Group of companies, provided conversion sets for over three million cookers, two million water heaters, 1.7 million fires and 52,000 central heating units (ibid p69). From the local Gas Board perspective the prospect was daunting: Mercer of South Eastern Board explains that each domestic customer (there were 1.6 million in his region) had to be visited at least five times (Mercer n.d.).

One gas company manager looking back to the conversion remembered a challenging period: "to those carrying out and managing the work it represented seven years of working to tight deadlines with often unreasonable demands from both customers and management under the constant glare of publicity" (Mercer n.d.). In his official account of the conversion Elliot stresses the leadership skills of Desmond Ellis who headed the Conversion Executive and recounts how long term planning, and co-ordinated central purchasing of equipment, brought stability for those involved. His sums up the conversion as: "a major technical triumph, but also a managerial one. Its very success has contrived to obscure its complexity" (Elliot 1980 p1). This simplifying of the historical narrative to reflect the overwhelmingly positive outcome rather than the many stresses and uncertainties faced during the process is an example of the process described by Callon in which "a translation that is generally accepted tends to shed its history. It becomes self-evident, a matter on which everyone can agree" (Callon 1991: 145). This makes it all the more important to uncover the uncertainties and difficulties in the process, in assessing how such change was achieved.

Before nationalisation the gas industry had been made up of a multitude of small companies, (there were 716 statutory gas undertakings reporting to the Board of Trade in 1935 (Williams 1981:73)) and afterwards these were consolidated into twelve Area Boards. The requirements of co-ordinating a nationwide conversion programme and developing a transmission system across Britain led to a re-organisation to centralise the industry further. A Conversion Executive was set up in 1966 to coordinate nationally and the Gas Act of 1972 led to the formation of a single organisation responsible for gas supply across the whole country, the British Gas Corporation, on 1 Jan 1973. Arapostathis et al (2013: 37) describe the changes in industry governance, with roles and power networks of existing actors altering as technology changed. An ANT perspective highlights how changes in the physical infrastructure were reflected by changes in social organisation.

5.1 1966 uncertainties

Looking back, the conversion to natural gas seems straightforward and uncontroversial, but at the time it was being planned, things seemed far less clear. A paper titled *Trends in gas utilization* published in the December 1966 edition of the Journal of the Institute of Heating and Ventilation Engineers (JIHVE) demonstrates the many challenges faced by those planning for the changeover from town gas to natural gas. The authors, C H Purkis and D R Wills, both employees at Watson House, the central research and information facility of the Gas Council, are giving their peers, professional engineers and members of the IHVE, an overview of the information available at the time, asking "what is likely to be the effect of all this on the work of the heating engineer?" (Purkis and Wills 1966 p270) and describing the many unknowns, including the effect on their own profession. The paper covers a wide range of issues relating to use of gas and how to match supply and demand. In combination with another paper in the same journal which discusses production and transmission of natural gas, it indicates the breadth of the exercise and shows clear evidence of overall systems visualisation and planning, similar to the work of electricity "systems builders" such as Edison and Insull described by Hughes (1983), albeit one that seems to have been very much a collaborative exercise by an organisation rather than by "heroic" individuals (c.f. Nye 1999).

The first uncertainty discussed is likely future demand for gas, an important factor in the planning for the new transmission systems for natural gas. At the time less than 10% of "total energy for heat services" in the UK was supplied by gas, and the authors mention a study that "suggests that natural gas may represent some 20% to 25% of this country's energy requirements in about 15 years' time" (Purkis and Wills 1966: 270). (In fact this proved be an underestimate, with gas providing more than 30% of total UK energy supply and more than half of domestic customers' total energy needs in 1980 (Elliott 1980: ix)).

Next they describe the uncertainty over chemical composition of NSG: "it is not possible, at the present time, precisely to define 'North Sea natural gas' because there are variations between some of the present drillings and although they are relatively small a large area remains to be explored" (Purkis and Wills 1966: 272) – a variation in the proportion of methane and other gases, which is invisible to consumers now, was a cause of concern at the time. They move on to describe the changes needed to gas appliances to allow NSG to be burnt: burners designed for town gas will need "modification or, in most cases, complete change" (ibid p271) and go on to describe how these changes affect a range of typical gas appliances, describing changes in design required for the different burner configurations for natural gas.

The JIHVE article finishes with a description of the function and activities of Watson House which included development and field trials on behalf of industry, approval of appliances and equipment and distribution of technical information to regional gas boards. In a similar way to BCURA's work with the heating supply chain, Watson House can be seen as a "translation hub" for the industry, taking on many of the roles of a "heterogeneous engineer", in this case aligning the gas industry and appliance supply chain with the requirements of a new fuel. The work at Watson House aimed to overcome misalignments, for instance by ensuring appliances were safe and could be operated on NSG, and by supplying information to professional networks affected by the conversion. The role of Watson House in approving new appliances and conversion kits established its central position in the conversion process.

5.2 Co-operative and less co-operative actors

Callon describes how "strongly convergent networks only develop after long periods of investment, intense effort and co-ordination" (Callon 1991: 148). In retrospect it can be seen that some elements of the gas supply actor-network were more co-operative and easier to bring into alignment than others.

The North Sea gas itself can be seen as a crucial actor, available in large quantities in a convenient location and under the auspices of the state, and, as it had double the heat content per unit volume to the town gas it was replacing, effectively allowed for a doubling of the capacity of existing pipework (Elliott 1980: 7). Some consumers, however, complained that the gas was hard to ignite, triggering work by Watson House on new ignition systems.

Gas-using appliances were less co-operative. The new fuel required modifications to the burners in many thousands of different types of appliances, some of which were found to be obsolete and unsafe. Elliot recounts how fish fryers were perhaps the most troublesome to convert, a problem perhaps compounded by the additional demand for fish and chips from the conversion teams (Elliott 1980: 93). Falkus (1988: 11) tells us that in the North Thames region "an 1884 farm milk heater resisted all attempts [at conversion] and the programme turned up many other appliances dating from before the First World War". This also illustrates how those elements that could not be aligned to the new network were, effectively, made obsolete by it.

The conversion programme involved inspecting every gas appliance in the country. Safety concerns meant that some appliances (e.g. gas fires without flues) were not converted, leading to customers feeling they had been harshly treated. Professor Frank Morton's 1970 inquiry into the safety of natural gas emphasises the contribution to safety made by the conversion and fed into the codification of the 1972 Gas Safety Regulations (Williams 1981 p193-4).

Goodall (1999) describes how the conversion shook up working practices in the industry. The successful completion of much of the work by contractors who went through a short training course, but did not have the traditional gas apprenticeship, destroyed the mystique of this apprenticeship. Appliances which had largely been retailed through gas showrooms could now be obtained from other sources, and the market was now open to European suppliers of natural gas equipment.

Falkus (1988) describes customer concerns and complaints. He recounts the saga of "Mrs Levin's geyser" when North Thames' problems with the conversion at the home of the mother of a prominent journalist were played out in the pages of The Times in 1973. Mercer's unpublished account describes how, during conversion, "complaints passed to the Board by the Consultative Council were to reach record levels" and how the local press fastened on to stories of poor workmanship. He quotes one unhappy consumer complaining to their local newspaper "if they hadn't made gas non-toxic I would have stuck my head in the oven by now" (Mercer n.d.).

5.3 Expanding the market for central heating

The gas industry was not content with simply converting existing appliances. Gas board sales staff were tasked with increasing sales of gas in line with the increasing supply available from the North Sea. It was clear that central heating was an area with major potential for growth. Articles in Gas Showroom Magazine (a publication aimed at gas sales staff) in 1969 give an indication of sales priorities part way through conversion. A sales manager rallied sales staff to achieve targets and explained that central heating, rather than individual room heaters, was the key application to build up demand. He explains how the campaign was targeted on C1 and C2 social groups (who previously had not been able to afford central heating) in "between the wars" semi-detached houses (Middleton 1969).

As central heating became an affordable option for a wider proportion of the population, Gas Council figures show a rapid rise in central heating installations in the late 1960s and early 1970s (Arapostathis et al: 34). Heslop describes the 1969 "Guaranteed Warmth" marketing campaign as "in my opinion the greatest single event to influence the development of central heating since its inceptions" (Heslop 1979 p26). He recounts how a fixed price "pack" of boilers, radiators and installation was offered together with guarantees for the materials, workmanship and for the temperature that would be achieved in the house. The price of a system was standardised based on the volume of the property. This "removed the fears of the customer ... simplified into understandable terms, heat losses, BTU[4], temperature gradients all resumed their rightful place, i.e. in the minds of the engineers, not in the minds of the customers or … the salesman"(ibid p26). A complex engineering exercise had become a black box "whose behaviour is known and predicted independently of its context" (Callon 1991: 152).

5.4 Closing down the options

The plethora of adverts for boilers and complete heating systems in the annual heating supplement of *Ideal Home* magazine in 1957 and 1967 show the many different options available to a homeowner (or developer) choosing a central heating system. It could be based on either hot air or radiators, and there are competing advertisements for gas, electric, oil and coal fired equipment. In 1972 the equivalent issue has no separate heating supplement and just a few adverts for complete central heating systems (but none for boilers). The availability of cheap, convenient and abundant fuel, aligned with trained fitters and secure supply chains meant that gas boilers (or oil for those off the gas grid) packaged together with radiators becoming the obvious choice, with little need for persuasion. In effect the network was stabilised, and the "black box" system which is still assumed to be the default heating system for British homes had been established. For those with a gas grid connection (91.8% of the UK population Baker REF) the fuel, heating system and building were so strongly aligned that other options were very rarely considered.

A more recent move to make domestic gas central heating more efficient through the introduction of condensing gas boilers relied on a different process. Given that the rest of the stable black-box of heating system needed no alternations, and the new boilers had similar dimensions and connections to the old, the change to a different boiler could be legislated for – a date was imposed by which all new installations had to be of this type, older types were withdrawn from the market, and since boilers have to be replaced relatively frequently (usually every 10 to 20 years), the transition was effected relatively swiftly (Palmer and Cooper 2014) although it did present challenges in terms of skill levels in the supply chain (Mallaburn and Eyre 2013) . This transition did little to destabilise the networks that maintain domestic gas-fired central heating as the primary heating technology in British homes, and indeed it relied on those networks to ensure that one type of boiler

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[4] British Thermal Unit, the heat unit in use at the time.

could replace another. Only in recent years, with the increasing urgency to find renewable energy sources has this network-system come into question, without having yet been significantly destabilised.

6. Discussion – lessons for future heating transitions in the UK

This section discusses how the lessons learned from the historic transitions described can be applied to potential future British heating transitions. Many scenarios for UK decarbonisation[5] show a major role for two particular types of heating system. District heating is seen as the most suitable low carbon option for densely populated areas and electric heat pumps for suburban and rural locations, so the implications for these two technologies are considered in this section.

The history of the introduction of small-bore central heating systems shows how novel heating systems can rapidly become popular and widespread. For small-bore gas-fuelled central heating, this was facilitated by the improvement in heating service and reduction in operating costs offered by the BCURA design, backed up by BCURA's ability to market the concept widely and effectively. The challenge faced today by low carbon heating technologies such as district heating and air source heat pumps is that they provide a similar, rather than improved, service with an investment cost that is significantly higher than the equivalent gas boiler (Delta-ee 2012). The benefits, that is, are largely in controlling the externalities of the system, rather than offering significant mateiral or financial improvements for the consumer. Fouquet (2016) points out that whether or not an energy service offers new characteristics has an impact on speed and scale of transition.

An important aspect of the adoption of new systems is how easily heating systems can be incorporated into building fabric, as can be seen in the rapid deployment of small-bore systems, which were easily and cheaply fitted in both new and existing buildings. The space available and amount of disruption required for the installation of new equipment are key considerations when selecting new heating equipment. For a transition to low carbon heating in existing buildings there is a need to modify the built environment to find extra space for heat pumps and to install hot water supply pipework for district heating, and this is likely to create barriers to change in terms of the cost and disruption to the householder (Delta-ee 2012). But ANT tells us that beyond the cost and space requirements, new technologies must also be aligned with the social, legislative, political and economic infrastructures around them, and the failure of just one dimension can stop the whole network. Hence, the failure of government fiscal policy to support wholescale introduction of either air-source heat-pumps or domestic solar heating or PV poses a critical threat to developing supply-chains.

The infrastructure that supplies the fuel to the home is essential to the operation of the heating system. A move to electric heat pumps will significantly increase overall electricity demand and require significant network reinforcement REF. District heating requires investment in a local infrastructure of heat distribution pipework as well as associated connections to individual dwellings, and the relevant control systems, here again drawing in a range of commercial, state and private actors, as well as heterogenous materials.

The history of the North Sea gas conversion demonstrates that major infrastructure changes and switches in fuel supply can be made in a relatively short timescale, but in this case there was a state-controlled, centrally directed programme with strong co-ordination to maintain alignment of all the actors involved. There are thus also significant political and social

[5] see for instance the six scenarios compared by Leveque and Robertson (2014)

differences between the historical changes we document here and the situation today. Watson House, which played such a key role in NSG conversion was the Gas Council's national research centre, able to operate on a large scale and draw other parties into alignment with its interests in the success of the conversion programme. Today there is no obvious UK organisation with the scope or authority to effect major changes at a system level, as there was in the days of nationalised energy industries. Instead, a new set of alliances and alignments must be built if any such transformation is to be effective.

7. The benefits of the Actor Network Theory approach

This study has used ANT as a framing device for discussing historical energy transitions. While this is by no means the only method for analysing transitions, we believe the approach brings valuable insights to the complex factors involved in changing home heating technologies. The technique recognises the heterogeneity of networks made up of components at many different scales (from national infrastructure to equipment in individual homes).

The focus on alignment allows us to identify the actors playing a key role in change at a particular point in space and time and trace their connections to one another and to different technological elements. By identifying groupings of people and technology, which, when aligned, reinforce one another, forming a strong and stable structure linking through from fuel to heating consumer, we can examine how different aspects of networks have been important at different times.

The catalysing activities of the organisations we have described as "translation hubs" occurred at different points in the network, and ANT offers the flexibility to investigate which actors are particularly significant in creating alignments without any preconceptions about where in the network they will occur. As Wong (2016: 106) points out the flexible approach of ANT "has the potential to become a messy, chaotic and complicated exercise, but the reward is … a wider angle on what constitutes the problem and a larger pool of possible solutions and actions."

ANT has been criticised as concentrating too much on the specifics of micro-scale case studies and not dealing with macro scale political forces (e.g. Russell 1993 p50), but our experience is that it has proved a flexible technique that is helpful for investigating links between energy systems and political structures at national scale as well as household and local levels. The ANT approach can also be criticised for its lack of focus on economic factors which clearly influence uptake of new technology. However, if money is considered as key "intermediary" circulating in the network it can be seen that it is included as one of the "inscriptions" used to convey information about networks (Latour 1987). As one of ANT's key proponents points out "money is used to code all states of affairs " (Latour 1990 p58).

8. Conclusion

The initial expansion of central heating in the UK was based on alignment of new heating systems with the type of building in which many people lived, supported by changing expectations of thermal comfort. New, convenient technology which improved comfort and saved labour developed at a time of rising incomes and expectations of higher living standards, encouraged by consumer advertising campaigns. The introduction of a new fuel infrastructure for natural gas led to alignment across equipment, fuel, homes and infrastructure which formed an extremely stable network around gas fired central heating and underpinned its rapid uptake.

To achieve this kind and scale of change, different parts of the network must be linked together, requiring communication of expertise and information. This study highlights the value of "translation hubs" at times of transition; organisations such as BCURA and Watson House had a particularly important role in co-ordinating and communicating technical changes through this period.

In the gradual sales-led initial phase of the central heating transition, BCURA promoted a new central heating technology and assisted the heating industry in offering a new service. Watson House's approval of appliances gave it a more formal, regulatory role in the rapid natural gas conversion process, supporting a government-mandated programme affecting all gas consumers. One area for further research would be to identify organisations which played a similar catalysing role in other energy transitions (including those which may not have been so successful in meeting their objectives) and to identify common characteristics and themes.

In 1960s Britain there were many different fuel and equipment options for central heating available, but most were high cost, not affordable by all. Today central heating is nearly universal but those on the gas grid are effectively locked in to one type of system, a gas boiler with hot-water-fed radiators. At present, fuel and buildings infrastructure, the heating equipment supply chain and associated institutions remain aligned in a strong and stable system around this option. Gas central heating is thus by far the cheapest and most convenient option for the vast majority of homes on the gas grid. For those wishing to change to lower carbon options, this network becomes a trap, from which it takes a great deal of effort and expense to escape, creating the kind of path dependency described by Callon, in which:

> markets and institutions become more irreversible as they evolve, choices and decisions made in earlier periods play a part in limiting the range of possible choices and decisions during the second period ... The agents have no choice but to renew the decision they made earlier. They are prisoners, trapped in networks from which they have neither the resources nor the desire to escape ... the chosen technology becomes increasingly attractive and profitable because substantial investments have been devoted to its improvement. (Callon 1998: 48)

Discussions about alternative heating options are often framed in economic terms, but it should be recognised that barriers identified are not simply about cost. High costs reflect the major reconfiguration of both social and physical networks needed to align with new heating options. Resistance to new network configurations has deep roots that have been "built in" to the energy infrastructure, roots and relations that are highlighted in our account of the transition to gas central heating in the UK.

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