A transformation to sustainable heating in the UK: risks and opportunities for UK heat sector businesses

Working Paper

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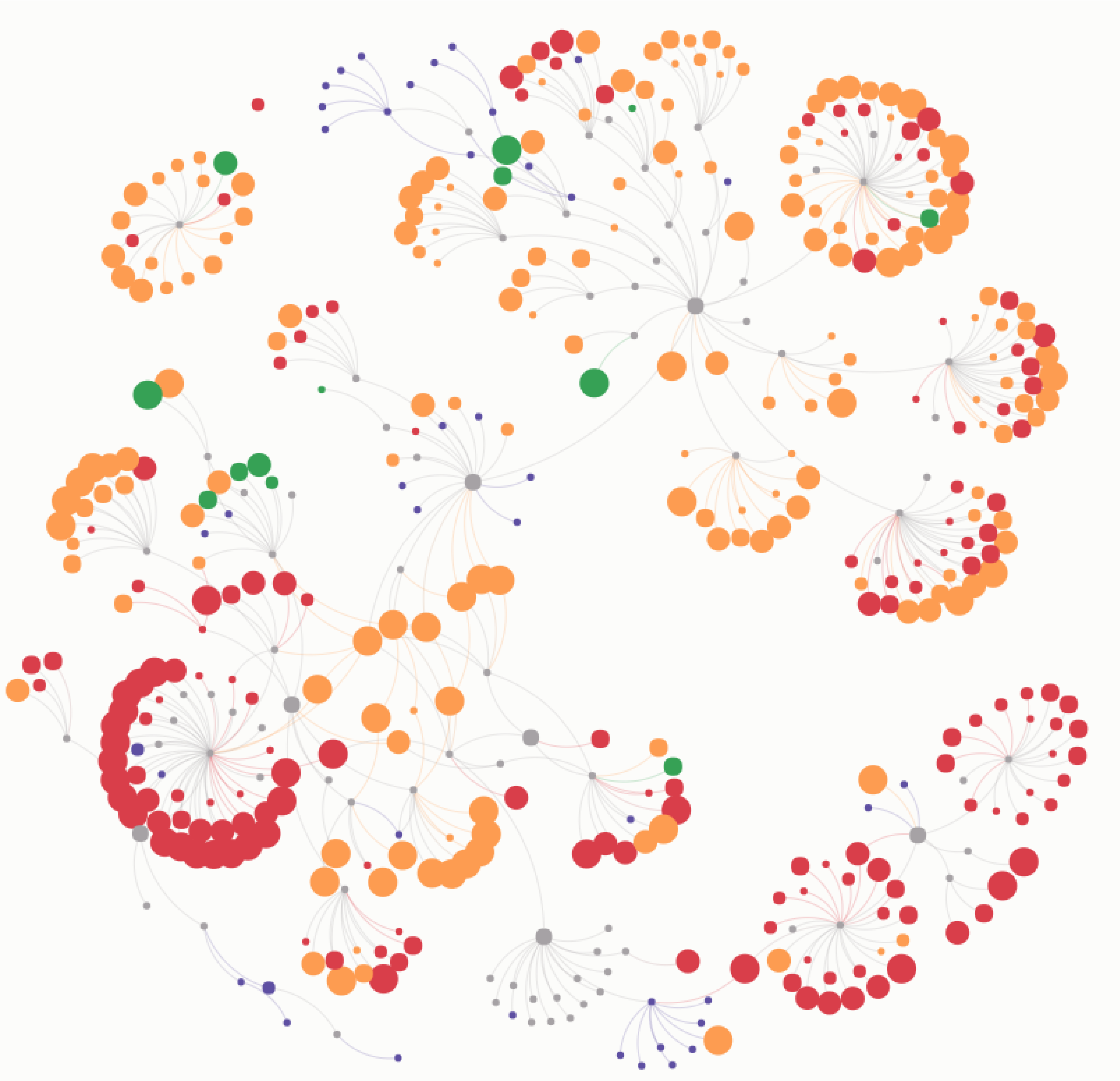

A map of UK heat sector businesses

The above image is a screenshot of the online map which has been produced alongside this working paper. The map shows the main businesses present in each sector and also contains information regarding the size of each company and whether or not the company is involved in low-carbon heat. The interactive map can be accessed using the following link: https://embed.kumu.io/122bd7e33980257722a649af7a8ec58f?settings=0

A transformation to sustainable heating in the UK: risks and opportunities for UK heat sector businesses – Executive Summary

Richard Lowes, Bridget Woodman, Matthew Clark

February 2018

Introduction

This working paper considers the risks and opportunities posed to UK heat sector businesses by a potential transformation towards a low-carbon heat system in the UK. It is an output from the Heat, Incumbency and Transformations (HIT) project which is part of the UK Energy Research Centre programme.

The HIT project is investigating the idea of incumbency, considering what the term means, how it is present in the UK's heat sector and what the implications of incumbency are for the UK's potential transformation from a high carbon heat system to a low-carbon heat system. Our previous working paper developed a working definition of incumbency (Lowes *et al.*, 2017). This working paper forms the second phase of the project exploring who the incumbents are in the UK heat system and the implications of the potential transformation for incumbents.

This executive summary provides a brief overview of each of the chapters of the working paper in order to succinctly communicate key messages from the working paper and guide readers to sections of most interest.

Behind the development of this working paper were three main tasks and each is considered in more detail:

The need for change and pathways towards low-carbon heating

In chapter 2 we consider the current shape of the UK's heat system and outline the reasons why a transformation to low-carbon heating is necessary. Following on from this, we have undertaken a desk based review of analysis considering scenarios for the UK's move towards low-carbon heating (section 3). As part of this exercise, we also investigated the potential options for the decarbonisation of industrial heating. Understanding what a low carbon heat system may look like allows analysis of how the incumbents currently present in the UK heat sector may be affected by the move to low carbon heat.

For space and hot water heating, based on the detailed analysis of UK heat decarbonisation pathways, two key scenarios were identified although it should be noted that pathway 2 is a relatively new idea in the UK heat policy debate but has become an important part of the discourse around low-carbon heat. It is also possible that a variety of different low-carbon heat options may emerge linked to geographical factors. There are also questions over the potential for bio-energy to decarbonise UK heating. However the two key pathways we have investigated are:

- Pathway 1 – **Decentralised heat** – this scenario focuses on primarily reducing heat demand with the remainder of heat requirements met through either onsite heat generation from heat pumps, electric heaters and solar thermal or with heat being provided via district heat networks themselves using low-carbon heat
- Pathway 2 – **Hydrogen conversion –** this scenario maintains the centralised heat model with hydrogen being produced from natural gas at centralised hubs where carbon is also being captured and stored from the process. Hydrogen is transported using the existing gas network then burnt in suitable boilers in each dwelling for space and hot water heating. For houses off the gas grid, primarily electric forms of heating such as heat pumps or storage heaters are used

Mapping the UK's heat sector businesses

The second task which is described in detail in chapter 4 was a mapping exercise to build a picture of the companies active within the UK's heat sector. The map was developed for a number of reasons although it is primarily to support the further stages of the project and identify the largest business actors and sectors active within the UK heat sector. It is the sectors identified in the mapping which form the basis of the risk and opportunities assessment in chapter 5. However, the map also has its own standalone value, shining a light on the business actors within heat sector in the UK which has historically been overlooked despite the importance of heat. We think that the map will be particularly useful for those working on heat decarbonisation policy and industrial strategy but will also be of use to those working on the move towards low-carbon heating such as trade associations and private firms.

This task involved a number of stages described briefly below:

1. A rough list of sectors and associated companies active in the UK's heat sector was developed from our prior knowledge of the sector. This list was expanded significantly as membership data from the key trade associations was added.
2. The data-base was then populated with data regarding the size of the companies where available such as turnover, company value and number of employees.
3. Companies were then allocated to a particular heat business sector and also attributed a ranking on their interest in low-carbon heat based on information from their websites.
4. This data was then imported into online stakeholder mapping software and modified to visually display relationships, company size and interest in sustainability.

The map can be accessed here:
https://embed.kumu.io/122bd7e33980257722a649af7a8ec58f?settings=0

While the map has some limits in that it may not have covered every company in the heat sector and there are some issues with allocating companies to specific sectors, the mapping exercise highlighted the key sectors of the UK heat market and has given an indication of the relative size of the key sectors. The relative sizes of each sector is shown below in Figure 1.

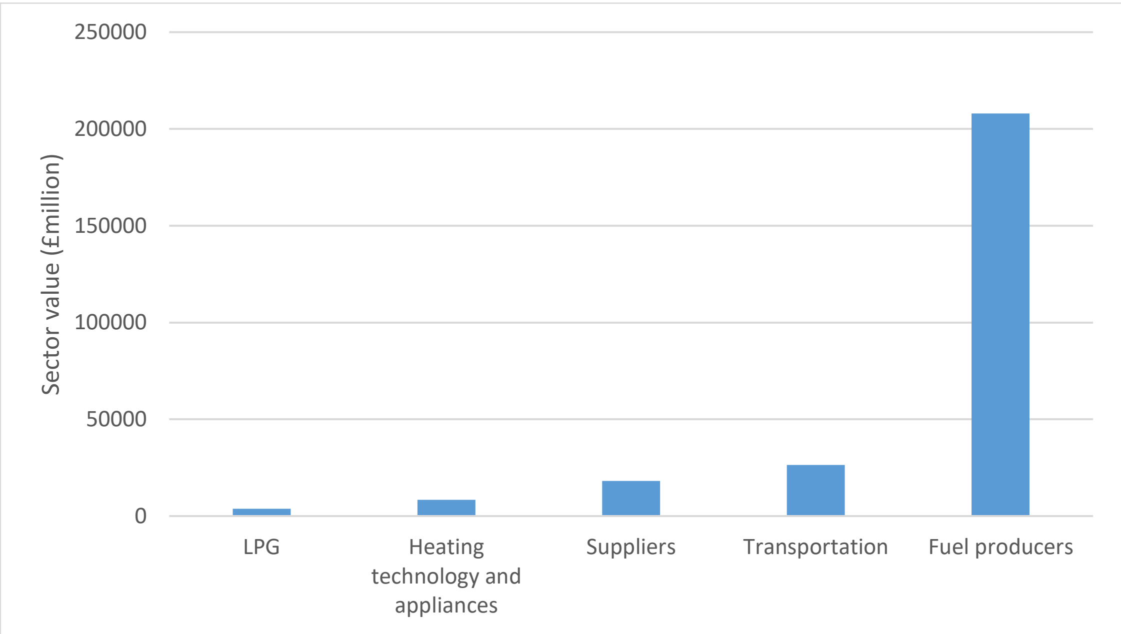

Figure 1. The value of businesses active in the UK heat market split by sector. Based on financial data for year 2015/2016. Some data points are missing. Data displayed in the graph does not include consultancies active in the sector or any information regarding industrial heat users. For this analysis, while recognised as being important, the heating engineer/installer industry has not been considered as data on this sector is limited as the sector is formed of a large number of small businesses for which no aggregated size data is known to be available. Fuel producers includes UK companies who produce coal or gas and electricity and other fuels are not included.

Risks (and opportunities) of heat decarbonisation to UK heat sector businesses

The final task carried out for this part of the project was a risk analysis exercise which, building on the previous sections, considered primarily the risks but also some opportunities posed to each business sub-sector identified in the mapping exercise, under each of the heat decarbonisation pathways.

The risk analysis exercise discussed the potential risks for each sector based on our understanding of the decarbonisation pathways. As well as discussing what the potential risks were, we also allocated a level of risk to each sub-sector under each pathway. The full analysis and associated methodology is contained in section 5 but the table below includes allocated levels of risk for each sub-sector under the two pathways.

[green]	Heat decarbonisation pathway is low-risk offering significant opportunities for this sector/sub-sector
[amber]	Heat decarbonisation pathway is medium-risk offering some opportunities for this sector/sub-sector
[red]	Heat decarbonisation pathway is high-risk with limited opportunities for this sector/sub-sector

Sector	Sub-sector	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
Consultancy	N/A	[green]	[green]
Fuel producers	Biomass producers	[green]	[green]
	Coal producers	[red]	[red]
	Electricity generators	[green]	[amber]
	Oil producers	[red]	[red]
	Upstream gas and gas storage	[red]	[green]
Heating appliances and technology	Biomass boilers	[red]	[red]
	Cookers/kitchen appliances	[amber]	[amber]
	Controls	[green]	[amber]
	Cylinders	[green]	[amber]
	Data and communications	[green]	[green]
	Demand reduction	[green]	[green]
	Electric heaters	[amber]	[red]
	Fire places and stoves	[red]	[amber]
	Gas boilers	[red]	[amber]
	Heat pumps	[green]	[green]

	Metering		
	Micro-CHP		
	Non-domestic heating products		
	Oil boilers		
	Plumbing and heating supplies		
	Radiators		
	Solar thermal		
	Water heaters		
Installation and maintenance	Low-carbon heat installers		
	Plumbers and engineers		
LPG	N/A		
Suppliers	Domestic supply including Big 6		
	Non-domestic supply		
	Oil supply		
Transportation	District heating and district heat generation		
	Electricity networks		
	Electricity network products		
	Engineering and construction		
	Gas networks		
	Pipeline products		

Conclusions

For the development of this working paper we have carried out three main tasks which we hope will inform the debate around the UK's move towards low-carbon heating.

We have firstly considered the reasons why change in the UK heat sector is needed and shown that there are two key pathways currently seen to be important for delivering a low-carbon heat system in the UK, one based around a decentralised, low-demand, primarily electrically powered heat system (pathway 1) and another currently novel idea for a pathway based around decarbonising the gas grid using low-carbon hydrogen while using electric forms of heat off the gas grid (pathway 2). We have also considered the potential changes required for industrial energy and heat demand in the UK.

Secondly, we have developed a sectoral map of the businesses active in the UK's heat sector. This map shines light on a very important but often neglected aspect of the energy system in the UK giving an idea not just of the shape of the sector and the companies present but also an idea of the size and value of the sector. This map should be of value to those working in the sector, particularly those involved in the regulatory, policy and economic aspects of decarbonisation policy.

Finally, based on the development of the company and sectoral map, we have carried out a risk analysis of each of the sub-sectors under the two identified decarbonisation pathways to consider the risks and opportunities for business sectors operating in the UK heat sector.

This analysis has shown that there are major differences in the levels of risk posed by the two potential decarbonisation pathways for each sub-sector. For companies heavily invested in gas such a gas networks and appliance manufacturers, pathway 1 represents a high risk pathway but pathway 2 is a lower risk pathway for the gas incumbents. There are also companies which would see increased risk as a result of both pathways such as energy suppliers and those involved in oil, coal and LPG heating. Finally, some sectors identified from the mapping are not seen to be at risk by either pathway. As a result, we have developed a number of hypotheses.

H1: Incumbents put at risk by pathway 1 are expected to be opposed to this pathway

H2: Incumbents who see reduced risk as a result of pathway 2 are expected to be supportive of this pathway

H3: Incumbents put at risk by both pathways are expected to be opposed to both pathways

H4: The largest sectors put at risk by decarbonisation are expected to be the most active in their engagement around heat decarbonisation policy, innovation and investment

Building on this analysis and the associated conclusions and hypotheses, the next and final stage of the project will consider the behaviour of the incumbent interests in the sectors identified in the mapping exercise in light of the risks posed to them by decarbonisation. We expect the final working paper of the project to be released in May 2018.

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1. Introduction

This is the second working paper from the Heat, Incumbency and Transformations project. The previous working paper attempted to develop a definition of incumbency in the context of sustainability transformations (Lowes *et al.*, 2017). In that working paper, we define incumbency in the context of sustainable transformations as the presence of existing actors within a specific socio-technical system. An incumbent will be currently active in the socio-technical system or a part thereof and therefore likely to be or have been involved in unsustainable[1] practices. Incumbents have the economic, social or technological capacity to influence system change.

This working paper builds on the first working paper and considers incumbent businesses currently in the UK heat sector and how they may be affected by a transformation to sustainable heating. To do this, firstly, we briefly consider why a transformation to sustainable heating is needed and then suggest the key scenarios of what a transformation may look like. We then introduce our interactive map of the UK's heat sector businesses which shows the main businesses currently involved in heating in the UK. Building on the understanding of scenarios of the map of the UK's heat sector, we go on to consider how each sector identified in our map may be affected by the previously identified low-carbon heating pathways and what the risks and opportunities may be for each sector as a result of a transformation to low carbon heating.

[1] In light of the various conceptions of sustainability, for the purpose of this project we focus on decarbonisation as our key sustainability issue and therefore for this project unsustainable generally refers to heating practices which are carbon intensive

2. The need for a transformation of the UK heat system

2.1. Current UK heat use

Heat use makes up just under half of total UK energy consumption (DECC, 2013a). Heating is responsible for around a third of the UK's total greenhouse gas emissions (DECC, 2013c).

Of the 2.68 EJ annually used for heat in the UK (DECC, 2013a) the majority of heat is provided by gas with significant shares also being produced from electricity and oil. The proportion of the UK's heat provided by different fuels is shown in Figure 2.

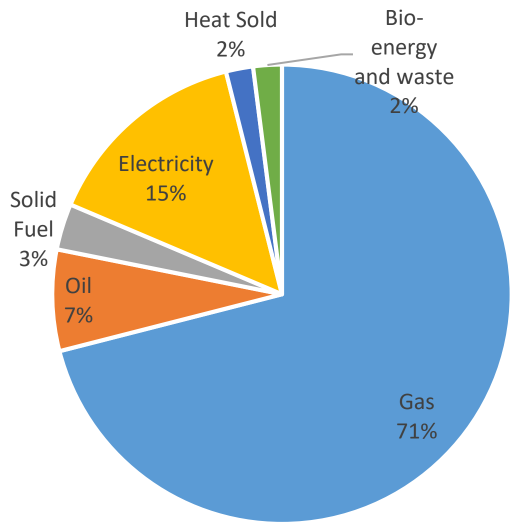


Figure 2. Fuels used for estimated total UK heat use in 2012 based on DECC (2013) data[2]

Heat use has been broken down in Government data into three main sectors. Domestic, comprising households is responsible for the majority of heat demand use (57%); industrial which includes manufacturing and heavy industry is responsible for 24% of heat demand; the service sector which includes education, retail and hospitality is responsible for 19% of heat demand (DECC, 2013a). Figure 3 shows the breakdown of different fuels used for heat in the domestic, service and industrial sectors respectively.

[2] Data for 2012 has been used as neither Government nor anyone else routinely produces data on UK heat consumption and this data provides the most recent estimate. We see no reason why the split shown in figure 2 should have changed significantly since 2012.

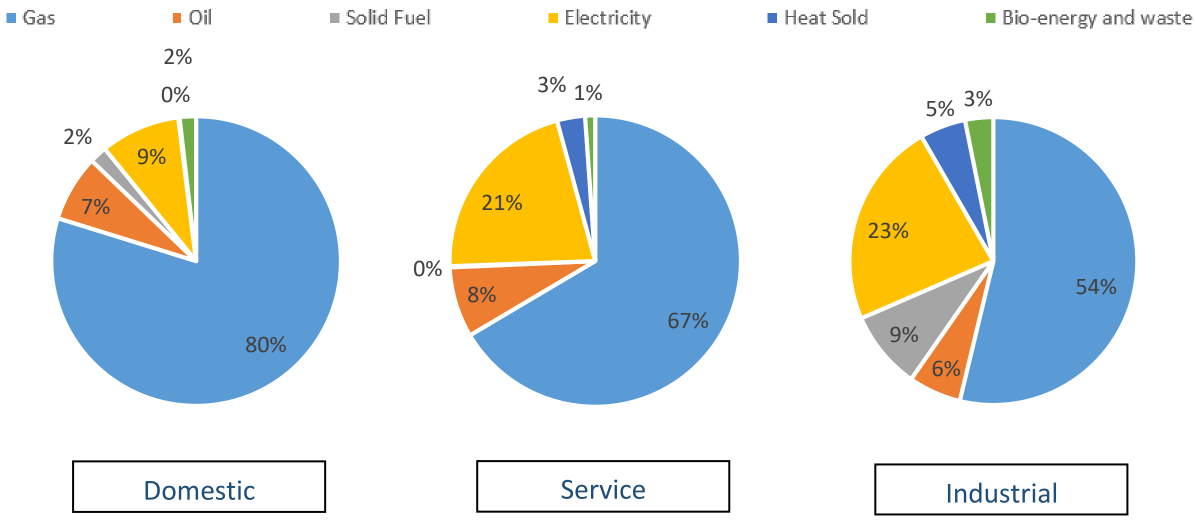


Figure 3. Sectoral heat use based on DECC (2013) *data*

Gas provides the majority of heat for the domestic sector. Of the houses not using gas for heating which are primarily houses without access to the gas grid, the next largest source of heating is electricity (9%) followed by heating oil (7%). Smaller proportions of heat are supplied through solid fuels (coal) and bio-energy (wood) and some homes are connected to district heat networks.

The development of the UK's gas based heating system is also reflected in the high proportion of service sector buildings which use gas for heating. The service sector has a slightly lower penetration of gas heating than the domestic sector, with electricity providing a much higher proportion of heat in this sector. This is possibly due to the wider use of electric air-conditioning systems and the suitability of the types of premises being heated. In this sector some heat is also provided by oil, heat sold (though heat networks) and bio-energy.

Gas provides the majority of heat for the industrial sector but higher proportions of electricity and solid fuel are used than the other sectors alongside small levels of heat sold (through heat networks), bio-energy and oil. The split in industrial heat use is due to the fact that the production of certain products requires certain heat sources, for example iron (and steel) normally requires coal (to produce coke) and high quantities of electricity are needed for aluminium smelting. 80% of the energy used in industry is for heating and the sector has been broken down into six main sectors which cover the majority of industrial energy use (DECC, 2012b); these are shown below in Figure 4.

Box 15: Heat demand for the "Big Six" industrial sectors

Coke and Refined Petroleum Products: primarily energy use for coke production from coal in coke ovens. 1000°C (high temperature) ovens are fired by a mixture of natural gas and also the gases produced by the ovens themselves and blast furnaces. Refineries use natural gas, refinery gas, fuel oil and petroleum coke residues from the refining process. CHP is used extensively.

Food and Drink: use of hot water and steam for the production, processing, drying and separation of food and drink products, also refrigeration (e.g. for frozen foods). Gas-fired CHP is also a feature in this sector.

Pulp and Paper: large amounts of hot water and steam used for the production and evaporation of pulp and drying of paper product.

Basic Metals: the production of iron and steel, through blast furnaces (which are generally very efficient) and electric arc furnaces, electrolytic production of aluminium and copper. Solid fuels and gas are used for high temperature primary production and electricity for electric arc furnace steel, plus aluminium.

Non-Metallics: includes production of glass, ceramics, bricks, lime and concrete, using a high proportion of gas use but also solid fuels (including waste) within high temperature kilns and furnaces.

Chemicals: highly diverse range of products from industrial gases, fertilisers, plastics, paints, pharmaceuticals and detergents. Majority of processes between 100-500°C for hot water and steam using a large proportion of gas (for which this sector is biggest consumer across industry) but also electricity (e.g. for chilling). There is some CHP in this sector.

Figure 4. Heat demand for the big six industrial sectors (DECC, 2012, p80)

2.2. The imperative for change

The major growth in the use of gas for heating during the second half of the 20th century has given UK heat consumers a reliable and relatively cost-effective source of heating. For those not on the gas grid who are primarily using oil or electricity for heating, a connection to the gas grid is seen as beneficial in that it can reduce heating costs and alleviate fuel poverty (Consumer Focus, 2013).

UK gas distribution network companies are required by energy regulator Ofgem to connect certain numbers of fuel poor homes to the gas grid (Ofgem, 2012) and gas network operators cannot refuse requests for new connections. However, despite the fact that connections to the UK gas network are growing due to the connection of fuel poor homes and new build homes, a transformation in the generation and consumption of heat away from gas and fossil fuels is required. This is for a number of reasons.

Firstly the UK's Climate Change Act has a required target of an 80% reduction in greenhouse gas emissions by 2050 (HM Government, 2008). Under a number of models and scenarios this implies the almost complete decarbonisation of heat use in the UK (e.g UKERC, 2009, DECC, 2012, Dodds and McDowall, 2013, Committee on Climate Change, 2015) which means in practice little or no fossil fuels used for heat generation in 2050 (unless carbon capture and storage (CCS) technologies can be used). The potential goal of post-2050 net-zero greenhouse gas emissions in the UK suggested by the UK Government last year as a result of the Paris agreement on climate change (Parliament, 2016) tightens the decarbonisation requirement further and would clearly require full decarbonisation of the heat sector.

As well as the carbon challenge, the geo-political context of the UK's gas supplies has changed radically. The UK reached peak gas production in the year 2000 and production has reduced significantly since, to the point where in 2013 the UK was importing around half of all gas; in 2014 and 2015, production of UK natural gas increased slightly (BEIS, 2016, see figure 3).

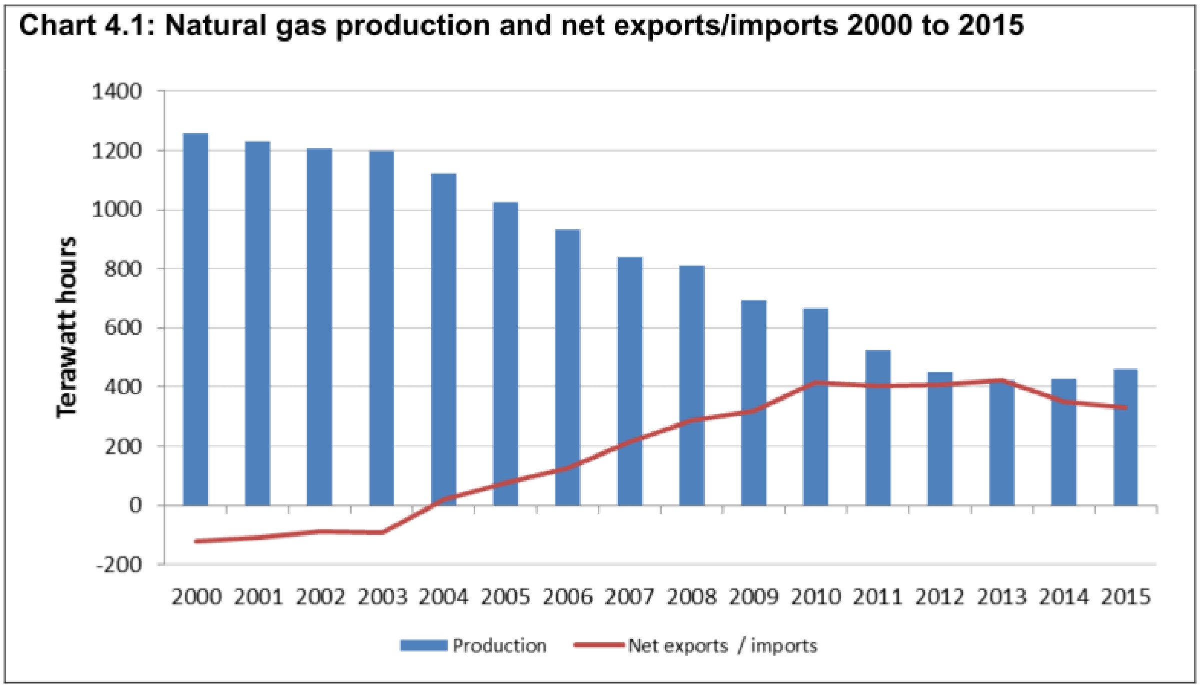


Figure 5. UK gas production and net imports 2000-2015 (BEIS, 2016) p97

This shift to a heat sector and energy system reliant on imports has potential implications for UK energy security although recent Government analysis has concluded that the UK gas supply situation 'is well placed to continue to be secure and robust in a range of supply and demand outcomes over the next two decades' (BEIS, 2017c, p3). The shift also implies structural economic changes for the UK which has historically relied on tax revenue from gas production to fund public services (HM Revenue and Customs, 2014). In fact, rather than simply providing less tax revenue to the UK, it has been reported that the projected income from the North Sea natural gas will not even cover Government liabilities for decommissioning the oil and gas assets suggesting that the UK oil and gas sector now represents a net cost to the UK Government (Financial Times, 2016).

Finally, as well as the energy security and carbon reduction challenges, the UK's current heat system is associated with major energy affordability issues. Analysis has shown that compared to other similar EU countries[3], despite the UK having the cheapest domestic gas bills and average electricity prices, the UK has some of the most unaffordable energy and highest levels of fuel poverty in Europe, even when compared to much colder Scandinavian countries (Association for the Conservation of Energy, 2015).

As a result of the combination of these issues, a transformation of the UK heat system is required in order to decarbonise the system and provide secure, equitable and cost effective heating for businesses and households.

[3] In this analysis, similar countries were those who has full heating seasons and levels of prosperity close to that in the UK

3. Considering a future UK heat system

As a result of the need for change, various actors have developed pathways and scenarios of future heat systems for the UK. This section considers the various pathways and scenarios with a primary focus on the technologies seen as required for the decarbonisation of heating. It firstly focuses on space and hot water heating which is primarily the domestic and service sectors and then considers options for industrial heat use. The chapter is then concluded, considering the key pathways seen as required for the transformation to low-carbon heat.

Understanding the scenarios for low-carbon heat options in the UK is vital for the following stages of this paper which consider the impacts of a heating transformation on incumbents in the UK heat sector. Winskel (2016) carried out a review of future scenarios for low-carbon heat in the UK in the context of the role and purpose of scenario planning. This section builds on that work and also considers more recent discussions around options to decarbonise heating using, rather than decommissioning the gas grid.

It should be noted that the various pathways generally consider carbon emissions as their key constraint and aim to show how carbon targets could be met at least cost. It may be the case that decarbonising heat costs more in terms of energy bills than continuing with business-as-usual approaches to producing heat. Our view is that the climate change imperative of decarbonisation is the key driver for system change and the low-carbon transformation must be managed to deliver an equitable energy system which provides affordable warmth. Some of the issues associated with equity, fuel poverty and heat decarbonisation have been considered elsewhere (Frerk and Maclean, 2017).

3.1. Scenarios for low-carbon space and hot water heating

This first section considers the development of low-carbon scenarios for hot water and heating or heat in buildings. It considers those scenarios developed in line with the carbon targets and presents them in a chronological order based on when they were released.

3.1.1. UKERC 2050 scenarios

Some of the earliest work which considered the long term future of heat (although not specifically heat but the long term future of the energy system under carbon targets) was carried out by UKERC. Since 2006, UKERC had been working on energy system modelling which was considering the UK energy system in 2050. In 2009, it released results from this modelling work which considered potential energy systems subject to various levels of carbon constraint using an updated version of the MARKAL model (UKERC, 2009). The modelling showed that under 80% emission reduction scenarios, both reductions in heat demand and the shift to electric heating using heat pumps would be important for the domestic and services sector.

Energy demand would need to be reduced by around 10-15% in the service sector and by between 20-25% in the residential sector. The report adds 'when looking at the decarbonisation of end-use technologies, in general, the residential sector is decarbonised by shifting to electricity (from gas) as well as technology switching from boilers to heat pumps for space heating and hot water heating' (p45). Decarbonising heat in the service sector involves switching to electricity alongside an increase in the use of biomass (UKERC, 2009, p45). The UK's first long term scenario for a decarbonised space and hot water heating consisted of reductions in the demand for heat alongside an almost complete switch to electric heat. The idea of the electrification of heating was born.

3.1.2. Early Heat Strategy development

Following the UKERC work, in mid-2010, DECC (The Department of Energy and Climate Change) released '2050 pathways analysis' carried out within the department which considered various technological pathways which were seen to be able to meet the 80% carbon reduction (DECC, 2010). Much like with the previous UKERC research, the DECC analysis suggested that across all pathways considered, a significant move to electricity for space and hot water heating (using heat pumps) would be required with a potential role for the use of waste heat and solar thermal.

Later in 2010, the same version of the MARKAL model used by UKERC for the 2050 analysis was then used to underpin the advice from the Committee on Climate Change (CCC) for the 4th Carbon Budget (2023-2027) (Committee on Climate Change, 2010). The CCC explained: '*Direct emissions from heat in buildings are reduced significantly by 2030, as a result of major improvements in energy efficiency and roll-out of low-carbon heat, especially heat pumps. Beyond 2030, further reductions are required, through energy efficiency improvement, further deployment of heat pumps where suitable (e.g. to cover around 60% of homes and the large majority of non-residential buildings), possibly combined with conventional electric heat and a potentially important role for district heating in those built-up urban areas for which heat pumps are not suitable. A feasible pace of deployment could almost fully decarbonise heat in buildings by 2050'* (p29). The Committee on Climate Change's scenario for a decarbonised heat system again suggested high levels of demand reduction and high levels of electrification but it also included a significant level of district heating using low-carbon heat in urban areas where heat demand is the highest and so heat networks are the most cost effective.

In March 2012, DECC released ' The Future of Heat: A strategic framework for low-carbon heat' which for the first time outlined the Government's view specifically on the long term future of heat in the UK (DECC, 2012b). This view was based on various sources of empirical research and energy system modelling including DECC's own pathway analysis, outputs from MARKAL modelling, analysis conducted by Nera and AEA to support the Government's renewable heat incentive scheme ((NERA/AEA, 2009) and the Energy Technology Institute's ESME model (DECC, 2012b). DECC drew out some common messages from all of the research explaining that all scenarios eliminated fossil gas from the heat energy mix, showed a major role for electric heat pumps at a building level and phased out the use of oil, coal and resistive heating. Much like with the Committee on Climate Change's previous advice in 2010, DECC's 2012 scenario for heat consisted primarily of reduced demand for heating, heat networks providing building level heat and individual heat pumps in areas where heat networks don't make economic sense (DECC, 2012b). As shown in Figure 6, the Government's strategic framework for low-carbon heat in buildings showed that as demand for heat was driven down, the use of gas for space and hot water heating would be squeezed out by electrically driven heat pumps in more rural areas and district heat networks in urban areas. The 2012 DECC heat strategy work was released as a consultation exercise as it was recognised that the proposed changes would have major social and technological implications for the UK.

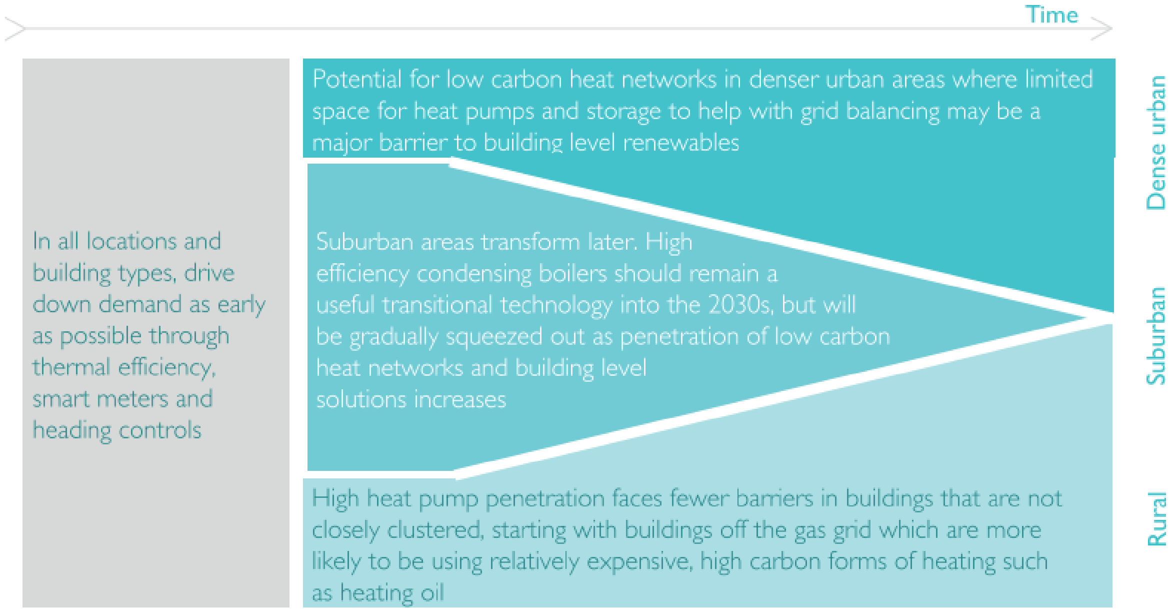


Figure 6. Government's strategic framework for low carbon heat in buildings(DECC, 2012, p97)

In April 2012, The Committee on Climate Change released the results of heat system modelling carried out by AEA and Element Energy produced in the context of the CCC's international aviation and shipping review (Committee on Climate Change, 2012). This analysis suggested that a 2050 low-carbon heat system would primarily be using heat provided by heat pumps and through district heating although the split between the two different technologies was a major uncertainty (Element Energy/AEA, 2012).

3.1.3. A potential role for gas?

Later in 2012, consultancy Delta EE released scenario analysis focusing on the UK's domestic heat sector out to 2050 funded by the Energy Networks Association Gas Futures Group (Delta-ee, 2012). This bottom up modelling suggested that if some gas heating was maintained through both the supply of biogas as well as the more efficient use of gas in appliances including gas boiler/heat pump hybrids, it would be much more acceptable to energy consumers because not all consumers would need to switch away from gas; it also suggested this approach would have much lower system impacts. The study suggested that there would be major energy system costs as a result of moving the peak heat demand currently provided by the gas system onto the electricity system due to an increase in both generation and network capacity. Therefore, suggested the authors, maintaining the gas system and using gas to provide peak heat through hybridised appliances may be a more sensible option.

It's important to note that as a result of the continued gas use, the carbon reduction of this scenario (90%) is lower than the fully non-gas scenario (96% potential carbon reduction). It also requires the maintenance of two sets of networks (gas and electricity) and required customers in many situations to have two appliances, a gas boiler and an electric heat pump. However, even in this 'balanced' scenario which has some role for gas appliances, there is still a major role for electrification and heat networks – in 2050, under this scenario, a quarter of households use district heating, half use electric heat pumps and the final quarter use a lower carbon gas appliance of some variety.

In March 2013, DECC released 'The Future of Heating: Meeting the Challenge', an updated heat strategy document which had been produced in light of responses to the 2012 DECC heat strategy document and further research and energy system modelling (DECC, 2013c). This updated modelling used Redpoint's (now Baringa) RESOM model and also used the Energy Technology Institute's ESME model. These models included a greater number of technologies for heat and also used a higher temporal resolution than the previous modelling. This temporal aspect of the models was recognised as being important for the high short-term variability of current heat demand or 'peak heat' but which had not been considered in enough detail in previous heat modelling work (DECC, 2013d). The updated modelling suggested for space and hot water heating that in 2050 there would be no role for gas boilers, but up to 2050 there may be a greater role for fossil gas used for heating, albeit in smaller volumes in different appliances such as gas absorption heat pumps and hybrid systems using an electric heat pump with a gas boiler; this was because the continued use of gas to provide heat peaking ability reduced the impact on demand on the electricity grid (DECC, 2013c). DECC's framework for heat was therefore updated to show this slight shift away from full electrification and district heating to a scenario where in the time before 2050 a higher level of gas was used (see Figure 7). It is however important to note that even after this change, in DECC's scenarios, in line with the 80% carbon target, at 2050 the vast majority of heat was expected to be provided through heat networks or by using electric heat pumps with some reduction in heat demand, much like in the previous framework.

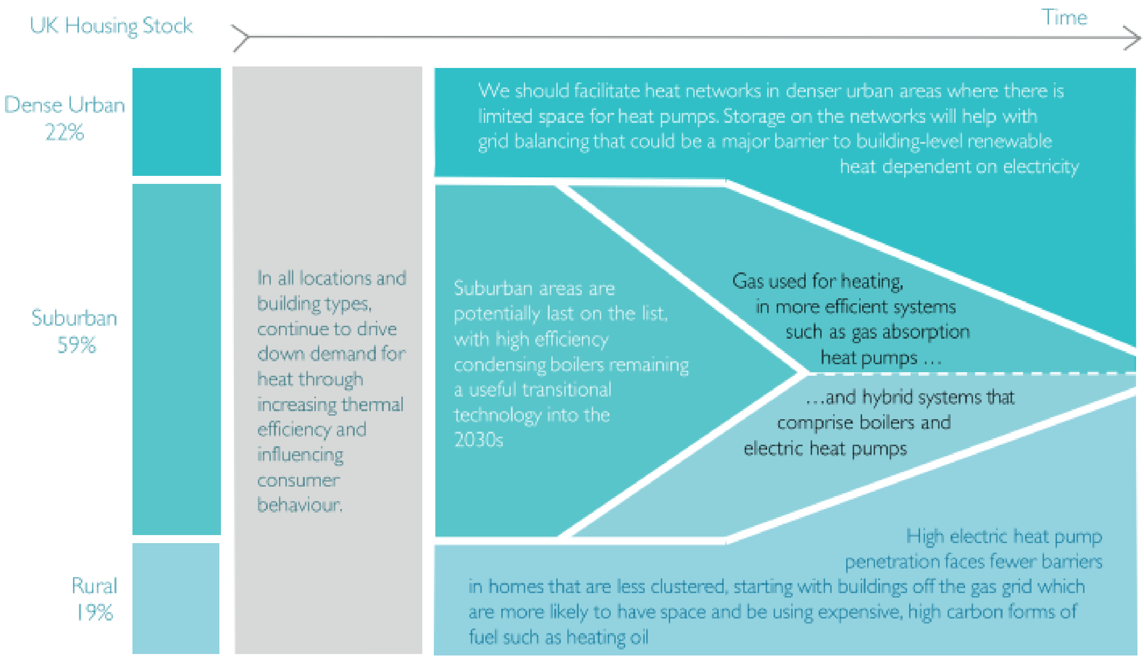


Figure 7. DECC's updated strategic framework for low-carbon heat in buildings over time

3.1.4. Ongoing heat in buildings analysis

Since DECC released its updated heat strategy in 2013, there have been no major policy or political announcements on the future of heating in the UK. Other actors have however been releasing their own scenarios and thoughts around low carbon heat futures.

The Committee on Climate Change produces annual progress reports in terms of reducing carbon as well as advice on how future carbon budget reductions can be met. Specifically on heat, for its 2013 review of the 4th carbon budget (the period from 2023 – 2027), The Committee on Climate Change commissioned new analysis through Frontier Economics and Element Energy to consider the future of the heat sector (Committee on Climate Change, 2013). This review did not propose any major changes to the long term low-carbon heat solution but suggested that in the shorter term i.e. for the 4th carbon budget, there should be a lower level of heat pump uptake than had been suggested previously because of a higher potential for district heating (Committee on Climate Change, 2013). In their own words:

- 'We have revised our uptake down from 7 million heat pumps in homes to 4 million by 2030 (i.e. 13% of homes have heat pumps in 2030, rather than 21%), along with lower deployment in non-residential and industrial buildings.
- This is offset to a degree by higher uptake of district heating – increased from 10 TWh to 30 TWh (i.e. from 2% to 6% of buildings heat) in 2030.'

(Committee on Climate Change, 2013, p45)

So central to the Committee on Climate Change's scenario for low-carbon heat in buildings are heat pumps and district heating, that the numbers of installations of heat pumps are tracked on an ongoing basis and the committee has called for greater efforts to collate data on the number of heat network connections (Committee on Climate Change, 2016a).

Another piece of analysis which considers the future of the UK energy system (including heat) is National Grid's 'Future Energy Scenarios' which consider various scenarios for how the UK energy system could develop. The most recent scenarios consider primarily to 2040 but also look forward to 2050. For space and hot water heating the scenarios suggest that by 2040, if the UK climate change act target is to be met, 12 million homes will use heat pumps for heating and 1.5 million households will be connected to district heat schemes with further growth in these areas by 2050 (National Grid, 2016). The National Grid scenarios are based on the Baringa energy system model which was previously used by DECC for their heat strategy publications.

3.1.5. Consensus on a low-carbon heat future?

As described in the previous sections, between 2006 to the present day, there has been a significant body of work undertaken in order to consider and produce scenarios for low-carbon heat in buildings in the future. In all of the work which considers carbon reduction at least in line with the UK's climate change target, significant changes in the provision of heat are seen to be necessary with all studies suggesting a greater role for electrification of heating using heat pumps and increases in the use of district heating. Much of the work also suggests a significantly smaller of even potentially non-existent role for natural gas in heating.

Chaudry *et al.* (2015) have neatly summed up the conclusions of much of the work on future UK heat scenarios suggesting that while a number of uncertainties existed, there are common messages for the future of heating: (Chaudry *et al.*, 2015, p628); these messages are:

- 'Energy demand reduction is essential for meeting emission targets'
- 'A substantial level of electrification of heating (via heat pumps) is expected'
- 'District heating will play an important role in heat supply decarbonisation'

3.1.6. Dissent from the electrification and district heat vision

While there has been a strong consensus on what a low-carbon heat future looks like for buildings, not all actors' views align with that consensus. For example, in section 3.1.3 we discussed modelling produced for the Energy Networks Association's Gas Future Group by Delta EE which suggested a higher role for gas in the future but this scenario didn't reduce carbon emissions from heating to such a high level as many of the other scenarios (Delta-ee, 2012).

Scenario analysis by Delta EE was also used by trade body The Heating and Hot Water Industry Council (HHIC), a trade association which represents the UK hot water and heating industry and is a member of the larger Energy and Utilities Alliance group of trade bodies. Much like with the previous Energy Networks Association scenarios, the HHIC scenarios suggested a more 'balanced' rollout of technologies to 2030 which included lower carbon gas appliances such micro-CHO, gas powered heat pumps and hybrid systems using a gas boiler plus a heat pump (HHIC and Delta Energy & Environment, 2013). This more balanced scenario was expected to provide more flexibility, better choices for consumers and reduced impacts on the electricity system (HHIC and Delta Energy & Environment, 2013). However, as this scenario analysis relied on the same modelling used by the ENA, this scenario does not put the UK on a path to fully decarbonised heating which is recognised as being vital for the UK's wider decarbonisation goals in line with the Climate Change Act.

Eyre and Baruah (2015) focus on the uncertainties of decarbonising (specifically domestic) heat in the UK; they explain that there may be a much more significant role for reducing heat demand than Government models have suggested and in light of this, bio-energy which could be transported as bio-energy in the gas grid may be able to play a bigger role in domestic heat.

While there has been some dissent from the consensus on the decarbonisation of heat, the two examples described above which propose higher levels of gas use have been developed and promoted by the incumbent heat actors, via the trade association which represents gas network companies (The Energy Networks Association) and trade association which represents existing heat interests such as appliance manufacturers (Heating and Hot Water Industry Council). These attempts to shape the scenarios of a low-carbon heat future seem to have only had a limited effect as still, the long term view from both Government and researchers has been that high levels of electrification combined with district heat networks are the key options for decarbonising heat. For example, in 2015, the Energy Technologies Institute, a research partnership between industry and Government suggested that alongside reducing demand for heat, 'There are two key solutions for low carbon home heating – local area schemes using heat networks and individual home systems using electric heat' (ETI, 2015, p3).

3.1.7. Decarbonising the gas grid – pipe dreams?

While a general consensus has developed that the decarbonisation of space and hot water heating should primarily consist of developing low-carbon district heating and by using heat pumps, it has been suggested by some incumbent actors that there is potential to decarbonise heating by producing low-carbon gas and maintaining use of the gas grid and gas appliances.

For example, Cadent (previously National Grid Gas Distribution) explain: 'we believe that renewable gas is a realistic option to meet this [2050 gas] demand while making a significant contribution to emission reduction targets' (Cadent, 2017, p1). In their 'Future of Gas' document, Cadent consider biomethane, synthetic natural gas and hydrogen as key low-carbon gas options (Cadent, 2017). Similarly, the Energy and Utilities Alliance, a trade body representing much of the heat sector including appliance manufacturers and gas networks also considers the three 'low-carbon gases' suggested by Cadent as the key options to decarbonise heating (EUA, 2016).

Cadent have very recently published analysis by consultants Anthesis and E4Tech considering the potential for 'renewable' gas in the UK. This suggests that around 68-183 terawatt hours of gas could be produced using renewable (bio) sources in 2050 (Anthesis and E4tech, 2017). This is equivalent to 9 to 35% of the UK's total heat demand. It should be noted that these levels of renewable gas require an expansion of the use of energy crops to produce biomethane which is known to only create limited carbon savings and rely on the development of unproven bio synthetic natural gas (both considered below in more detail). This analysis also does not consider the associated carbon savings with the different sources of gas.

There is a clear (and understandable) drive by the incumbent gas companies to promote a future which uses high levels of gas and this is likely to be in response to much of the analysis which has shown a limited role for gas in a low-carbon heat future. However, when considering existing evidence, the idea of transforming the UK's heat system to a low-carbon heat system by using low(er)-carbon forms of gas looks at best very unlikely and at worst, appears to be the active promotion of options which clearly cannot deliver a transformation to low-carbon heat by incumbents as a means to progress their own financial agenda.

The following sub-sections consider these low(er)-carbon gas options in some more detail.

3.1.7.1. Biomethane

Biogas can be produced from the anaerobic digestion of certain organic materials and this biogas can then be treated and converted to biomethane which can be injected into the existing gas grid. This gas can offset the use of fossil gas and, if lower carbon than fossil gas, can reduce emissions from gas and heat use. Because of the renewable nature of organic materials, the idea is that the carbon emissions released during the combustion of the gas are reabsorbed when further organic material is grown. It is however recognised that while biogas may be lower-carbon than natural gas, it is not carbon neutral due to the emissions released throughout the production of biogas (DECC, 2013b).

Biomethane has experienced significant growth as a result of the UK RHI policy with 82 operating plants (at 05/02/18, BEIS, 2018). The production of biogas using anaerobic digestion is limited to using only certain feedstocks including purpose grown energy crops and wastes. Of the biomethane facilities operating in the UK, the majority of these are using purpose grown energy crops such as maize (DECC, 2016a) meaning that arable farmland is being used for growing energy crops rather than food. This is at odds with general UK Government policy which supports using farm land for food production rather than energy generation (DECC, 2016c).

The use of energy crops for the production of biogas and biomethane also appears to be an extremely expensive way to reduce emissions from heating as indicated by a carbon price estimated by DECC between £350 to £600/tCO^2 saved when using agricultural crops (DECC, 2016a). This is higher than the expected 2050 carbon price of £220/tCO^2 (Committee on Climate Change, 2015b) making the use of energy crops for biomethane look expensive even in the long term. It also compares to a carbon price of £25 to £60/tCO^2 for using food waste to produce biomethane (DECC, 2016a) suggesting that using wastes for biomethane production should be prioritised.

There are also wider concerns over the availability of biomass resources in the UK. While estimates of the availability of biomass resource vary widely and depend on various assumptions, a review in 2010 suggested that bio-energy could provide 4-11% of the UK's 2008 primary energy demand (higher levels require the removal of all constraints which including increasing deforestation) (Slade and Gross, 2010).

As noted by Eyre and Baruah (2015), while biomass may be able to provide a more significant share of heat than it does currently, 'The optimum use of biomass in carbon constrained economies is a complex topic' (p650). In a low carbon energy system which has limited biomass resource, using these bio-resources for high grade heat processes, i.e. processes which require high temperatures such as industrial processes is generally seen as a better use than for domestic and hot water heating which requires lower grade heat (lower temperature heat) (The Committee on Climate Change (2010), Committee on Climate Change (2011)). It is also the case that only certain types of bio-resources are suitable for the production of biogas, primarily wastes and also energy crops.

The UK based Anaerobic Digestion and Bio-resources Association (ADBA) suggest that using all of the available feedstocks of food waste, sewage, manures and some energy crops, the UK could produce just over 40 TWh/year of biomethane (ADBA, 2017) which equates to around 5% of the UK's total heat consumption. ADBA suggest that if new (currently unused) feedstocks were used such as algae and if hydrogen was added to the biomethane production process, 80TWh of biomethane (around 10% of the total UK heat demand) could be produced each year (ADBA, 2017). This analysis however ignores the issues around land use change and carbon costs by doubling the amount of biomethane coming from purpose grown energy crops and also does not consider the optimal use of biogas in the energy system which, as described previously, is often considered to be in the industrial sector.

As such, while there is some potential for biogas or biomethane use, its actual potential to decarbonise space and hot water appears limited due to the fact that there are limited quantities available, it has a high cost of carbon and it is often considered to be most useful for industrial use in high temperature processes. We do not therefore consider biomethane to be a key technology that will transform the UK's heat system, particularly for space and hot water heating.

3.1.7.2. Synthetic Gas

There has been some limited interest in the role the synthetic natural gas may be able to play in a low-carbon UK heat system again as a route to reduce the carbon intensity of gas in the gas grid. In 2010, DECC commissioned research into synthetic natural gas through consultants NNFCC (NNFCC and E4tech, 2010). To produce synthetic natural gas, waste material or biomass is gasified using a high temperature thermo-chemical process and then this gas is converted into methane which can potentially then be injected into the gas grid (NNFCC and E4tech, 2010).

However, as yet no projects are currently producing synthetic natural gas and injecting it into the UK gas network. Cadent (previously National Grid Gas Distribution) is the key actor involved in this technology and is using Ofgem Innovation funding to support a test project in Swindon (Cadent, 2017). Cadent suggests that in the longer term, a 'plausible renewable gas production' level which included both biomethane and bio synthetic natural gas would be around 100TWh/year, which is slightly higher that that proposed by ADBA discussed in the previous section.

For synthetic natural gas to be low-carbon it is reliant on bioenergy feedstocks and as such is limited by the same bio-resource constraints considered in the previous section. As such, we have seen no scenarios or evidence which suggest that synthetic natural gas is likely to play a significant role for future low-carbon heating in the UK and if significant volumes are produced, these are likely to be of most value in the industrial heat sector.

3.1.7.3. Hydrogen

The idea of converting the natural gas grid to transport hydrogen has increasingly appeared in the discourse around scenarios for a low-carbon heat future. While DECC's 2013 heat strategy framework contained some limited recognition of the potential for the use of hydrogen (DECC, 2013c) more recently hydrogen has been suggested by ministers as a serious low-carbon heat option:

'As we know, there are a wide variety of technologies which can deliver low carbon heat – ranging from the electric heat pumps and district heating networks I have already mentioned, to perhaps a more radical possibility; replacing natural gas with hydrogen in the gas grid'

Baroness Neville-Rolf, Policy Exchange Heat Summit, 14th December 2016

There has been wide ranging academic research into the technical characteristics of hydrogen, its use in appliances such as fuel cells and for its storage; the UK Hydrogen Supergen Hub consortium has been the epicentre of most of this work. However, there has only been limited research considering the use of hydrogen at a systemic level for the UK as not all energy system models consider hydrogen technologies; when hydrogen is included, some model outputs show a potentially important role whereas others show little or no role (Dodds and Hawkes, 2014).

There are two main options for how low-carbon hydrogen could be produced; either by using low-carbon electricity as the energy source and producing hydrogen by electrolysing water or by producing hydrogen from natural gas through the process of 'steam methane reformation' (Staffell and Dodds, 2017). Both processes suffer from conversion losses and also have their own distinct issues for the production of low-carbon hydrogen; electrolysis requires low-carbon electricity, an expensive form of energy and 'steam methane reformation' requires the use of CCS for the hydrogen to be low-carbon and CCS is not operational at scale and has unknown costs (Leung *et al.*, 2014).

There are then, two main ways for how hydrogen could be transported and used for heat. Firstly, hydrogen could be added to the gas network so that it blends with natural gas and is used in existing appliances, however appliance limits due to how hydrogen burns mean that there is a limit to the amount of hydrogen which could be blended, identified as up to 20% hydrogen by volume or 7% hydrogen by energy content (Dodds and McDowall, 2013). Because this blending option has this limit which will not deliver anywhere near a full decarbonisation of heating, we dismiss this option as a long term transformative solution.

The other option available is to convert the natural gas network to a pure hydrogen network (Dodds and McDowall, 2013) and this approach has been supported by the industry who have produced research proposing this as an option to decarbonise heating (Northern Gas Networks *et al.*, 2016). The research has shown that the use of low-carbon hydrogen to decarbonise heat has the potential to both reduce consumer impacts and also reduce the need for upgrades to the electricity networks and the development of district heat networks and this is why the option seems to have become popular with policy makers.

The Northern Gas Network's project mentioned previously investigated the prospect of converting the whole of the Leeds, UK gas system to hydrogen, producing the gas via steam methane reformation, capturing and storing the CO_2 from the process, injecting the hydrogen into the grid and converting all appliances in Leeds to boilers suitable to use hydrogen. It was one of the largest scale hydrogen conversion studies ever commissioned although it is worth noting this was a desk based study. While the research was generally supportive of hydrogen conversion, it highlighted a number of major issues.

- Firstly on cost, the study suggests that the capital expenditure for this conversion would be £2,054 million with ongoing annual operational expenditure of £139 million. Despite the claim that the project is cost effective, that equates to around £7800 per connection (household or business) of capex plus £525 extra per year per connection of operational costs. This is in reality a very large cost to consumers. The solution in the report is to socialise this project cost across all UK gas consumers through distribution charges resulting in an increase of 7.2% for gas distribution charges in the RIIO GD2 period. This cost smearing idea raises significant equitability issues and would not be possible if much of the UK was to be converted.
- On carbon reduction, the report suggests that the gas will effectively be decarbonised. However, whilst the project suggests reductions in carbon, these are not an elimination of carbon, something which is generally seen as

a requirement for the heating sector in order to allow emissions from other sectors. The table below shows the percentage reduction compared to business as usual and the important number is 59% reduction which is the full life-cycle based (real world) emission reduction for the project and while still significant doesn't reach near to the zero carbon aspiration. Figure 8 show the potential emission reductions by different scopes of emissions and Figure 9 compares emissions from hydrogen in the Leeds project compared to those of natural gas.

	gm/kWh NG	gm/kWh H_2	% Reduction
UK Carbon budget basis (Scope 1)	184.0	27.0	85%
Including electricity for sequestration (Scope 1+2)	184.0	49.5	73%
Including embodied CO_2 from the production and importation of natural gas (Scope 1+2+3)	209.3	85.8	59%

Figure 8. Carbon emissions reductions estimated for the Leeds City Gate project (Northern Gas Networks et al., 2016, p5)

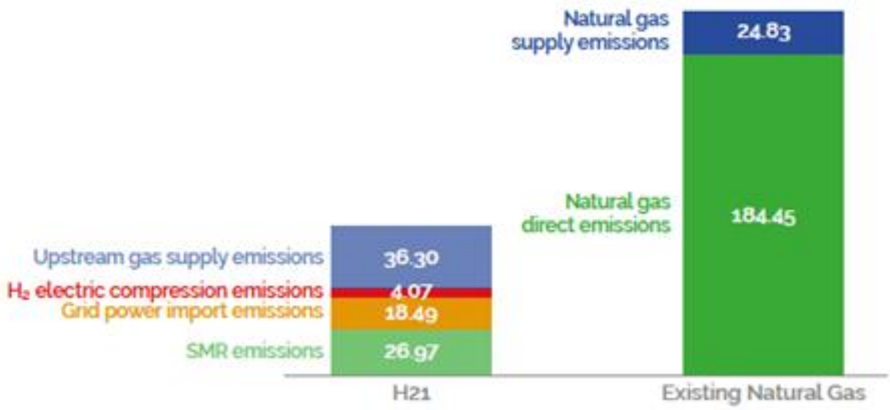


Figure 9. A comparison of scope 1, 2 and 3 emissions between hydrogen in the Leeds project and natural gas (Northern Gas Networks et al., 2016, p223)

- With regards to energy security and import dependence, the UK is currently a net gas importer and this is likely to continue and the country is expected to become increasingly dependent on imports (National Grid, 2016). Because the H21 project uses methane as a fuel to produce hydrogen, this continues the reliance on gas imports. However, it actually compounds the issue as the

H21 project explains that because of the inefficiency of the hydrogen formation process, 47% more natural gas than is currently used by Leeds would be required to produce sufficient levels of hydrogen.

In spite of these issues, as mentioned previously some of the current discourse around UK heat policy does see a potential role for hydrogen to provide space and hot water heating in the future, however the technical, cost and carbon performance of hydrogen is very uncertain. The Committee on Climate Change suggests with regards to hydrogen that: '*To understand how best to proceed, it will be vital to undertake pilots and demonstrations in the next decade* (Committee on Climate Change, 2016b, p32)'.

3.1.8. Space and hot water scenarios overview

An increasing body of evidence and a number of scenarios have emerged over the past decade considering the future of heat in the UK in light of carbon reduction requirements. Across all scenarios, reducing the demand for heat is seen as centrally important in order to both protect the most vulnerable energy users and to reduce overall heat system costs.

Top down analytical approaches to consider the heat system under carbon constraints have generally shown that as well as reducing demand for heat, much of the heat which is still required is provided by either electric appliances such as heat pumps at a building level or provided through district heat networks (these district heat networks may themselves use large heat pumps which rely on electricity). This pathway is clearly technologically challenging and also relies on significant decarbonisation and growth of the electricity system; it will also require significant consumer engagement but appears to be a pathway which can allow the UK to meet its climate targets and decarbonise heating. It has also been recognised that there may be a role for some bio-energy to decarbonise UK heat either in the form of biomass or biogas however, how and where this should be used and the availability of bio-energy resource are uncertain (Eyre and Baruah, 2015).

More recently, scenarios of a low-carbon heat system have emerged, primarily pushed by incumbent gas businesses which continue to use gaseous energy vectors for heat. Because of the requirement to fully decarbonise the heat sector rapidly, we discount technological options which have only limited potential to decarbonise heat due to availability and provide only short term benefits such as hybridisation. Therefore, we discount options which blend natural gas with lower carbon substitutes including biomethane blending (as the biomethane may be of more value elsewhere), hydrogen blending and synthetic natural gas blending. We also discount the hybridisation option as this delivers only limited carbon savings.

This leaves one final option for decarbonising space heating using the gas system, converting the natural gas grid to hydrogen. However, as we discussed in section 3.1.7.3, this option for low-carbon heat has major technical, cost and carbon reduction. It is also primarily being suggested by incumbent heat actors in the UK heat sector and has received little scrutiny. However, hydrogen grid conversion is seen by some as a potential solution and has been recognised as having potential by the Committee on Climate Change and the UK Government including in the recent Clean Growth Strategy (HM Government, 2017)

As such, our decision to consider hydrogen conversion as a potential option for low-carbon space and water heating in the UK reflects its current position in the UK future of heat discourse and does not reflect a belief of the authors that it necessarily represents a realistic low carbon heat scenario.

In light of this, in considering a transformed role for UK heat sector businesses we consider two pathways or scenarios for low-carbon heat:

- Pathway 1 – **Decentralised heat** – this scenario focuses on primarily reducing heat demand with the remainder of heat requirements met through either onsite heat generation from heat pumps, electric heaters and solar thermal or with heat being provided via district heat networks themselves using low-carbon heat
- Pathway 2 – **Hydrogen conversion –** this scenario maintains the centralised heat model with hydrogen being produced from natural gas at centralised hubs where carbon is also being captured and stored from the process. Hydrogen is then burnt in suitable boilers in each dwelling for space and hot water heating. For houses off the gas grid, electric forms of heating such as heat pumps or storage heaters are used.

3.2. Visons for industrial low-carbon heat

There has been less focus on industrial heat than on the use of heat for space and hot water heating in domestic and non-domestic settings. This may be due to the fact that industrial heat use represents only around 24% of heat use compared to the 76% used for space and hot water heating (DECC, 2013a) and 32% of greenhouse gas emissions from heat compared to the 69% from other heat uses (DECC, 2012a). It is also the case that the Government has been trying to reduce the energy costs for energy intensive industries through various exemptions and allowances (see HM Government, 2016) and so the Government may not want to be seen to be placing additional regulatory pressure on energy intensive industries.

The most recent Government data on heat use based on 2012 numbers explained that industrial energy demand made up 16% of the UK's total energy use and 71.6% of this energy was for heating (either space heating or as part of the industrial process) (DECC, 2013a).

Greenhouse gas emissions from industrial energy use have been falling since the 1970s although this is primarily attributed to a reduction of the size of heavy industry in the UK (Skea *et al.*, 2013). However, between 1990 and 2016, the energy intensity of industry dropped by 39% which will clearly have had a significant impact on the reduction in industrial energy demand over time (BEIS, 2017a). Figure 10 gives a breakdown of the changing energy demand across different industry sectors from 1990 to 2016 and Figure 11 shows how the emissions, clearly linked to energy demand, have reduce over the same time period.

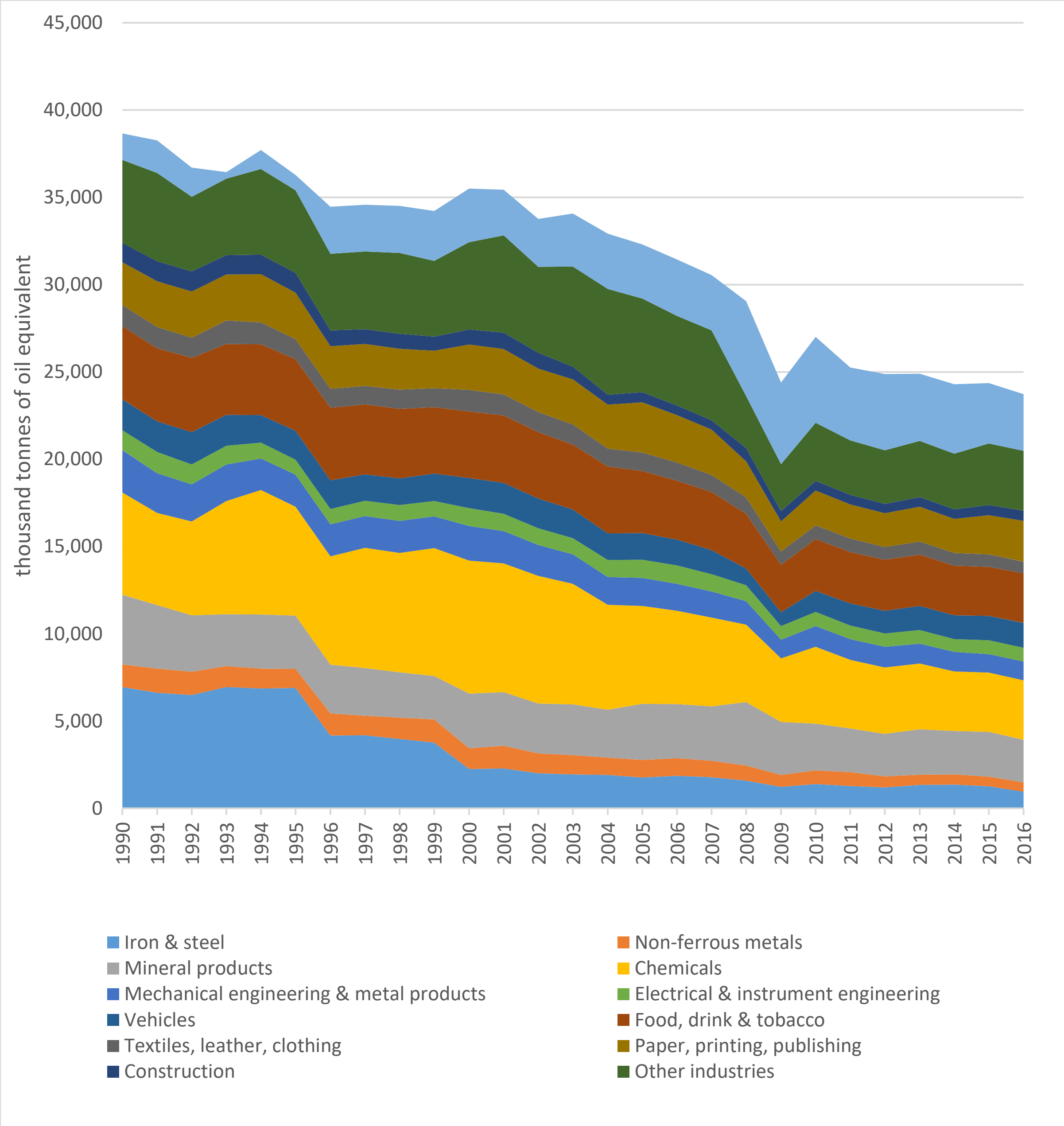
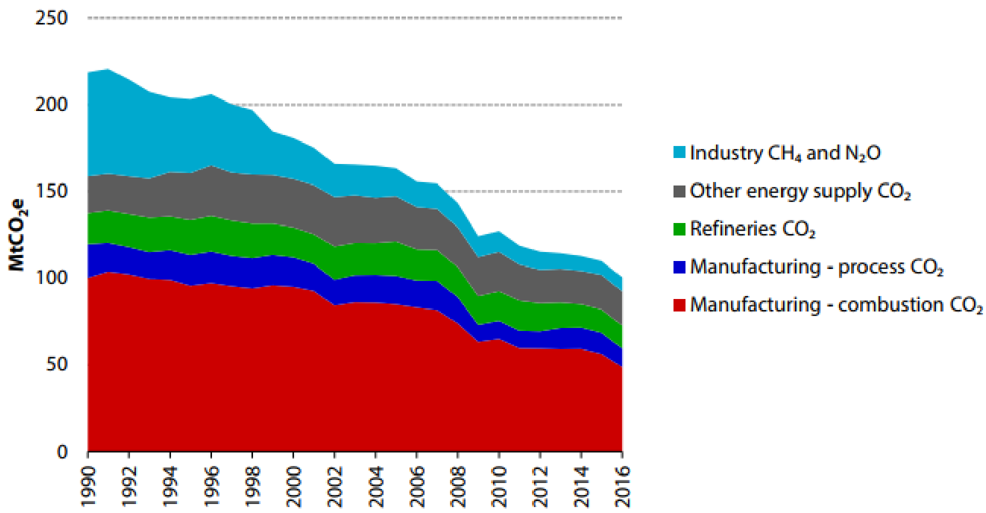


Figure 10. UK industrial energy demand by sector based on data from BEIS Energy Consumption in the UK (BEIS, 2017b)



Source: BEIS (2017) *Provisional UK GHG national statistics*, BEIS (2017) *Final UK GHG national statistics*, National Atmospheric Emissions Inventory, CCC analysis.
Notes: 2016 emission estimates are provisional. The 2016 provisional estimate for non-CO_2 emissions assumes no change from final 2015 emissions.

Figure 11. Greenhouse gas emissions from industry (Committee on Climate Change, 2017)

Total industrial energy demand is responsible for around a quarter of the UK's total greenhouse gas emissions (DECC, 2013c). Because of the scale of these emissions, it is clear that if the UK's decarbonisation targets are to be met, then significant changes to industrial heat are required and both the 2011 UK Carbon Plan (HM Government, 2011) and the more recent Meeting the Challenge heat white paper in 2013 (DECC, 2013d) suggested that the greenhouse gas emissions from industrial heat would need to be reduced by around 70% for the UK's overall carbon targets to be met.

The Committee on Climate Change has suggested that across industrial energy use, there are 4 main methods to reduce industrial emissions:

- Increasing the energy efficiency of industrial processes
- Using bio-energy for space and process heat
- Using low-carbon electricity for space and process heat
- Utilising CCS technologies (Committee on Climate Change, 2017)

The 2015 Fifth Carbon Budget Report from the CCC also suggested that using low-carbon hydrogen to fuel some industrial processes may be another way of reducing emissions from industry (Committee on Climate Change, 2015b).

There has been only little academic research focused on reducing emissions from UK industry. Skea et al. (2013) considered the UK research base around industrial energy and described it as 'small and fragmented' (pii). They identified that there was some research taking place into reducing emissions from material manufacture at Cambridge University[4], that Cambridge University was also engaged on research considering 'Business Models for Sustainable Industrial Systems'[5], that UKERC had previously carried out a 'landscape assessment' of the industrial energy research in the UK[6] and that Low Carbon Innovation Coordination Group had carried out a technology needs and impact assessment around industrial decarbonisation (Low Carbon Innovation Coordination Group, 2012). None of this work however provided a systemic overview of what a transformed low-carbon industry in the UK might look like but provided some limited knowledge on specific sectors or issues associated with decarbonising industrial processes.

Figure 10 from Skea et al. (2013) shows the energy demand from 1990 to 2013 for each of the largest energy using sectors. It shows that in 2013, chemicals, food and drink, minerals and paper were the largest industrial energy use sectors.

Taking a slightly different approach, focusing specifically on industrial heat use and splitting this by final product sector, DECC, (2013b) showed that the largest heat demand sector is coke and refined petroleum products (absent from the Skea et al., (2013) analysis), with food and drink, minerals, chemicals, basic metals and pulp and paper all having slightly smaller shares.

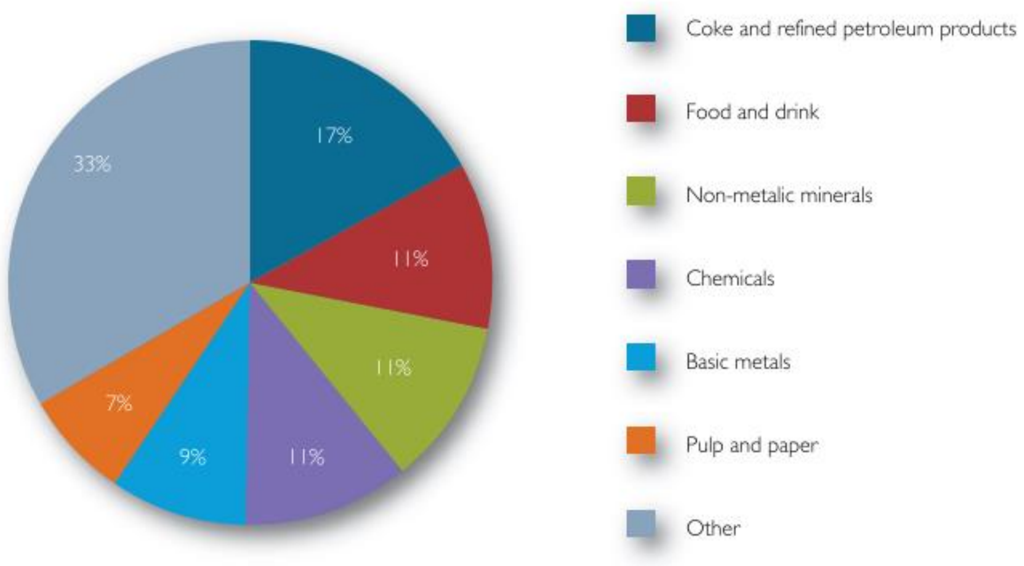


Figure 12. Industrial heat demand by sector (DECC, 2013b, p12)

DECC committed to developing low-carbon roadmaps for the most carbon intensive and largest heat using industrial sectors as part of its heat strategy work in 2013 to

[4] http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K011774/1
[5] http://www.ifm.eng.cam.ac.uk/research/industrial-sustainability/industrial-sustainability-projects/
[6] http://ukerc.rl.ac.uk/Landscapes/Industry.pdf

investigate how a 70% reduction in greenhouse gas emissions from the sector could be achieved (DECC, 2013c). These roadmaps covered two thirds of industrial emissions and were carried out by external consultants Parsons Brinckerhoff and DNV GL working with each respective industrial sector and were released in 2015. Table 1 shows the 2012 carbon emissions for each of the sectors.

Table 1. Energy intensive industry total direct and indirect carbon emissions in 2012 (Parsons Brinckerhoff and DNV GL, 2015i)

Sector	Total annual carbon emissions 2012 (million tonnes CO_2
Iron and Steel	22.8
Chemicals	18.4
Oil Refining	16.3
Food and Drink	9.5
Cement	7.5
Pulp and Paper	3.3
Glass	2.2
Ceramic	1.3

The roadmaps contain the most detailed investigation into the future pathways for each of the UK industrial sectors and so the following sections consider each of the sector roadmaps in more detail describing current industries, associated emissions and pathways for emissions reductions. While it would be preferable for us to use a variety of sources to consider industrial energy and emissions, there is such a limited literature available that the Industrial Roadmaps provide the most recent and thorough assessment available.

The limited literature associated with decarbonising industry/industrial heat use highlights a significant gap around decarbonisation showing a need for much greater research and development in this area. Because of the limited knowledge base, clearly the capacity to develop policy and regulation to drive change in this sector is also restricted.

Since the publication of the roadmaps, the Government's Clean Growth Strategy recognised the importance of major reductions in the carbon intensity of UK industry but didn't introduce any new policy or regulatory measures (HM Government, 2017). It was explained that the Government's '…goal is to enable businesses and industry to improve energy efficiency by at least 20 percent by 2030' (p63) but that beyond energy efficiency, fuel switching from high carbon fuels to low carbon fuels would be a required and the Government will develop a ‘framework to support the decarbonisation of heavy industry’ (HM Government, 2017).

3.2.1. Iron and Steel – Based on *Parsons Brinckerhoff and DNV GL (2015d)*

At 22.8 million tonnes of CO_2 emissions in 2012, the iron and steel sector had the highest annual carbon emissions of the industrial sectors in that year. This is due to both the size of the sector and also the use of coal as a reductant in the iron production process. In 2012, over 90% of UK steel manufacturing and processing took place at seven sites. Since then the Redcar steelworks at Teeside has closed, reducing both the size of the industry and energy demand and emissions (Committee on Climate Change, 2015b).

There are two main processes used in the iron and steel industry. The first process is for the production of iron and steel from iron ore. Firstly coal is converted to coke by heating it over 12-36 hours in the absence of oxygen. Coke and crushed iron ore are added to a blast furnace and blasted with very hot pressurised air. This process produces liquid iron which can be then treated with oxygen and other additives to produce the required grade of iron or steel or other iron based products such as stainless steel. The steel is then cooled depending on the type of product being manufactured and then rolled into the required shape.

The second process uses electric arc furnaces which produce plasma between two electrodes creating high temperatures. This technique is primarily used to melt scrap steel during the recycling of steel.

The iron and steel road map suggests that a 60% reduction of emissions from the sector was technically possible whilst maintaining steel output. The key technologies or options to reduce emissions from the sector are

- Decarbonising the electricity grid on which some processes rely
- Using greater levels of electricity for processes (reliant on lower carbon electricity)
- Using biomass for some processes
- Increasing the efficiency of processes and using heat recovery
- Clustering sites together in order to gain efficiency benefits
- Using CCS technologies to capture emissions

The iron and steel roadmap highlighted a number of key issues for the move towards low carbon. It suggested that strong leadership and strategic direction would be needed and showed that there were financial barriers towards the move and significant costs were likely. The roadmap also highlighted issues around industrial competitiveness, the potential lack of availability of people and skills and the need for much greater levels of research and development.

3.2.2. Chemicals – Based on *Parsons Brinckerhoff and DNV GL (2015b)*

After iron and steel, the industrial sector with the next highest level of emissions is chemicals. Energy use in the sector comprises primarily of the use of natural gas for the production of steam and direct heat and the use of electricity for services such as pumping, compression, chilling and lighting. The chemical sectors uses 16.5% of total industrial energy use in the UK as a result of the size of the sector and the required high temperatures and energy inputs used for certain processes. It is a highly competitive sector where product prices and investment decisions are closely linked to feedstock and energy prices.

The roadmap explains that in the chemicals sector, the cost of decarbonising is particularly unclear with various emissions reductions pathways estimated to cost between £600 million and £4 billion. It does however identify pathways where this sector can technically reach an 80% reduction in emissions by 2050 and potentially 90% if biomass is used as a heating fuel.

The roadmap concludes by explaining that the sector has a good approach to strategy through the 'Chemical Growth Partnership' which allows the industry and Government to work together. It explains that key barriers to decarbonisation in the chemicals sector are the extra cost of low carbon energy technologies and the associated risks to competitiveness but suggest greater levels of policy certainty may be beneficial to the industry. The roadmap also identified that a greater understanding of life cycle carbon emissions in the sector and greater value along the chemicals value chain would benefit the sector in terms of decarbonisation.

The roadmap also identified the need for research and development and greater low-carbon skills in the sector alongside commercial trials and deployment of already available technologies.

The key technologies identified for decarbonising the sector were firstly to continue decarbonising the electricity grid in order to reduce the carbon associated with electricity already being used in the chemicals sector. It was also identified that biomass could play an important role in decarbonising the chemicals sector but it was not clear where in the energy system, this biomass would have the most benefit. Energy efficiency and heat recovery technologies were seen as being vital alongside industrial clustering, which could create further efficiencies, selling products and by-products locally. CCS was also seen as potentially important although because of the scale of plants this would need to be at a larger scale with shared assets. Finally, electrifying certain processes away from natural gas was seen as a potential option and the use of hydrogen and synthetic gases were seen as possible options in need of more research and development.

3.2.3. Oil Refining – Based on *Parsons Brinckerhoff and DNV GL, (2015e)*

Following chemicals, the industrial sector with the next highest level of emissions at 16.3 million tonnes CO_2 in 2012 is the oil refining sector. In order to refine oil into various products, the sector employs distillation, conversion, reforming, desulphurisation and hydrogen production in order to convert crude oil into various products. These products may be end-products or intermediate products which are often blended to produce the end products.

The fuels used for the refining process are generally produced as part of the process itself and in 2012 the main fuels were refinery fuel gas (50.1%), catalyst coke (25.7%), natural gas (17.3%) and fuel oil (6.9%). 6.5% to 7% of the calorific value of the crude intake is consumed at the refineries.

Three of the refineries in the UK have recently closed leaving six operating refineries. As can be seen in Figure 13, the UK produces more petrol than it consumes and imports significantly more jet fuel and diesel than it consumes. This has changed over time with petroleum demand falling and diesel demand increasing as more people have chosen diesels alongside an increasing demand for aviation fuel as the numbers of flights from the UK has increased. As a result, because the existing refinery industry cannot easily switch to produce more diesel and jet fuel, overall throughput of crude oil in UK refineries has decreased. Over the medium to long term, it is also expected that as demand for fossil fuels for transport falls and transport is decarbonised, there is the threat of further refinery closures.

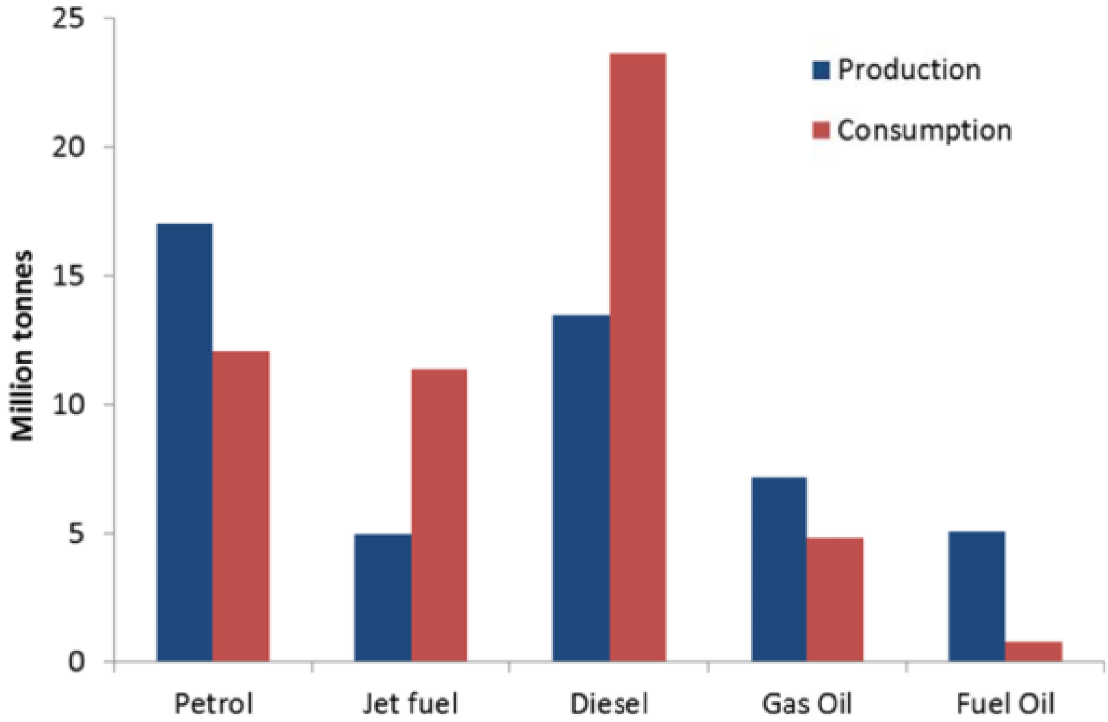


Figure 13. Production and consumption of key petroleum products in 2014 (BEIS, 2016, p69)

The roadmap for the oil refining sector suggests that the UK refining industry is at risk of further closures and consolidation alongside the potential for carbon leakage as the UK imports increasing volumes of oil based fuels. As a result, because of the expected reduction of the size of the industry, the reference pathway for the sector in the roadmap which didn't consider explicit carbon reduction options suggested that CO_2 emissions from the sector may reduce in size by 35% by 2050 from 2012 levels. With greater efforts to decarbonise the sector, the roadmap suggests that it would be possible to reduce carbon emissions from the sector by around 65% from 2012 levels if CCS technologies are employed.

There are four key options recognised that could help reduce emissions from the sector. Firstly, using biomass to replace gas in some situations is seen as being a potential option although it is recognised that the limited biomass resource may be of more use in other sectors. The second option is to increase the use of energy efficiency and heat recovery in the sector although the roadmap recognises major cost and technical issues with this option. It was suggested that overall industrial efficiency could also be increased from greater clustering of industrial sites to share assets and waste energy but also recognised that it would be unlikely that oil refineries themselves would be able to relocate. The final option to decarbonise the refining sector was suggested to be CCS which was seen to be able to deliver the greatest levels of emissions reductions from the sector.

3.2.4. Food and Drink – Based on *Parsons Brinckerhoff and DNV GL (2015c)*

The food and drink sector is a very diverse sector when it comes to energy uses as it has many subsectors such as dairy, brewing, distilling, sugar, confectionery, bakery, rendering, meat processing, fish and seafood, poultry, malting, soft drinks, animal feed, oil and fat, glucose, canned food, ice cream and pet food. Each of these sub-sectors has various operations and processes. Across the industry, most energy is used in boilers, with direct heating, motors and refrigeration all having significant shares.

Fuels used in the food and drink industry are primarily natural gas which is approximately two thirds of energy use with most of the rest coming from electricity with small shares of oil and coal use. The UK food and drink sector produces around 9.5 million tonnes of CO_2 per year. 86% of companies in the sector have fewer than 20 employees making the sector highly heterogeneous and making it potentially difficult to achieve coordinated industry wide carbon reduction.

Since 1990, the food and drink industry in the UK has reduced emissions by around 41%. The roadmap for the sector proposes a number of pathways which suggest that carbon emissions from the sector would reduce naturally from 2012 levels by around 40% under a business as usual scenario. The roadmap shows that much more significant cuts of emissions in the sector could be achieved using specific low-carbon technologies and the deepest cuts of up to 80% reductions would require electrification of much of the heat demand in the sector.

The key options to reduce emissions from the sector would be to continue using electricity from the grid as that decarbonises further, to electrify greater levels of heat, reserving fossil fuels for processes where high-value heat is required or to potentially use biomass for high-value heat. Finally it is recognised that energy efficiency and heat recovery technologies would be particularly important to help this sector reduce its emissions.

3.2.5. Cement – Based on *Parsons Brinckerhoff and DNV GL, (2015a)*

In 2012, the cement sector emitted 7.5 million tonnes of CO_2 making it the 5^{th} largest emitting industrial sector. Cement is a product which is central to the construction industry where it is most often used to produce concrete.

The first stage of the cement production process is the production of clinker. The raw materials, often primarily limestone and some clay are mixed and ground up and poured into a large kiln where it is heated to 1,450 °C. The high temperature drives CO_2 away from the calcium carbonate (the limestone) to produce calcium oxide which then reacts with other materials in the kiln, producing clinker. Once the clinker is cooled, it is ground with gypsum and other materials to produce cement powder.

The vast majority of carbon dioxide emissions associated with the production of cement are as a result of the calcination process. There are two aspects to this, firstly, CO_2 is driven from the limestone during the process and secondly, emissions result from the combustion of fossil fuels, primarily coal, to produce the heat which is used in the kilns as part of calcination. Some emissions also result from the processes which crush and transport materials and products. It is worth noting that because of goals to use waste and reduce emissions, around 40% of fuel used by the cement industry is either waste based or bio-waste.

Energy is one of the largest operational costs in cement making and the reliance on high temperatures for the calcination process makes decarbonising cement particularly difficult. Emissions from the UK cement industry have reduced by 56% between 1990 and 2013 and it is recognised that the fall in cement output has been the biggest driver of this reduction although decarbonisation drivers and energy efficiency improvements have driven this further.

The cement decarbonisation roadmap explains that there are a number of key options available to reduce emissions in the sector. Firstly, the wider decarbonisation of the UK electricity system would reduce emissions from the processes which use electricity. It is recognised that greater levels of bio-energy could be used to produce heat but as with other sectors, the availability of bio-energy feedstocks will limit total available energy from biomass and its use in other sectors may be more valuable. The sector already uses a large volume of bio-energy and waste and so while further increases in its use are possible, there are limits to how much more can be used due to technical reasons.

The roadmap recognised that there was potential to reduce emissions through energy efficiency technologies as well as through using combined heat and power however, the paybacks on these types of projects were longer than company thresholds. It was also recognised in the roadmap that CCS technology could significantly reduce emissions in the cement industry but because of the relatively small size of cement plants, CCS infrastructure would need to be shared across various industrial sites. Without CCS, reductions in CO_2 emissions would be limited to around 30% from 2013 levels however with CCS, 60% reductions would be possible.

3.2.6. Pulp and Paper – Based on *Parsons Brinckerhoff and DNV GL, (2015f)*

Following cement, the pulp and paper industry is the industrial sector with the next highest level of emissions, emitting 3.3 million tonnes of CO_2 in 2012. In this sector, either recycled paper or virgin wood is pulped, then dewatered and dried at which point it can be treated to produce various products. These include products for packaging, printing and writing paper and tissue and hygiene paper.

The key energy requirement in the paper production process is for the drying of the paper which uses around two thirds of the total energy requirement in the sector. This heat is normally generated as steam using either natural gas or biomass.

Because the UK is a net importer of paper, producing 50% of its own paper requirement, there was a recognition that extra costs on the paper and pulp industry could reduce UK production of paper further effectively causing carbon leakage.

The UK pulp and paper industry has already reduced emissions by 50% from 1990 levels however, the roadmap suggested that much greater levels of emissions reductions were technically possible. In fact, the pulp and paper roadmap showed that if a business as usual approach was taken to the sector, emissions would fall by around 30% compared to 2012 levels but, it would be technically possible for emissions from the sector to reach near zero carbon levels. The roadmap highlighted that there was only limited research and development around pulp and paper in the UK and this could cause the UK to fall behind expertise, knowledge and skills in the sector.

There were a number of key technologies expected to play a role in decarbonising the pulp and paper industry suggested by the roadmap. Firstly, the decarbonisation of the national electricity grid would reduce emissions from processes already using electricity. In order to reach the very high levels of emissions reduction, switching to electricity for all heating was seen as a key option although it was recognised that this could have cost and competitiveness implications. Biomass is already an important source of heat for the sector but the roadmap suggested that greater levels of biomass could reduce emissions further particularly if used to produce combined heat and power. However, biomass was seen to have limited availability and as with the roadmaps was suggested to be of more value where high grade heat is required. Finally, the roadmap suggested that energy efficiency and heat recovery technologies which have low or medium investment costs could be implemented cost effectively in many plants although there were concerns around the availability of finance. Finally, the clustering of industrial sites in order to share low-carbon energy or share carbon capture infrastructure was seen as an option to reduce emissions further.

3.2.7. Glass – Based on *Parsons Brinckerhoff and DNV GL (2015d)*

After pulp and paper, the next largest CO_2 emitting industrial sector is the glass industry emitting 2.2 million tonnes of CO_2 in 2012. In 2012, the sector produced over three million tonnes of products comprising 65% container glass, 30% flat glass and 5% fibre/speciality glass.

Glass is energy intensive and energy is one of its largest operational costs. While there are different methods to manufacture different types of glass, all glass products have a common origin, glass feedstocks first need to be melted. The feedstocks for glass, sand, minerals and recycled glass are melted together in a furnace at around 1,500°C before being removed from the furnace and shaped into the required product with further possible processing depending on the final product.

The glass decarbonisation roadmap showed that there is the potential for significant reductions in carbon emissions from the glass sector. There are a number of key options suggested to be of most use.

Firstly, glass is often recycled, but the recyclate is used as aggregate, often in roads. Using closed loop recycling processes, where glass is recycled back into glass would give greater CO_2 savings than using it as aggregate. Secondly, the greater use of electricity for melting alongside the decarbonisation of grid electricity was seen as a key approach to reduce emissions. Thirdly, it was suggested that biogas could be used as a fuel for glass melting however as with the other sectors, the report recognised that the total resource for bio-energy was limited and it was uncertain where the optimal use of bio-energy would be.

The glass decarbonisation roadmap also suggests that CCS has large emissions reduction potential however it also has many barriers and glass companies involved in the roadmap had a preference to avoid CCS technologies. It was also recognised that if carbon capture was to be used, because of the scale of glass manufacturing sites, industrial clusters would need to be developed to reduce costs and share infrastructure.

3.2.8. Ceramic Sector – Based on *Parsons Brinckerhoff and DNV GL (2015b)*

The ceramics sector is the smallest sector (based on emissions) for which a decarbonisation roadmap has been produced. It emitted 1.2 million tonnes of CO_2 in 2012. The vast majority of products (89%) comprise heavy clay construction products and the remaining 11% includes refractory materials, white wares and technical ceramics such as armour plating and artificial joints.

There are two main parts of ceramic production. Firstly, mechanical and chemical processes (which use energy) are used to convert raw materials into a powder, malleable solid, or slurry. These products are then shaped and the resultant blanks are dried and fired in kilns or ovens which is a very energy intensive process. Further firing steps or finishing processes will be used depending on the final product. Fuel costs represent 35% of total manufacturing costs.

The pathway analysis carried out as part of the roadmap showed that the maximum technically possible carbon reduction pathway would result in emissions reductions of 60% from the sector but that even a business as usual pathway would deliver a 27% reduction in emissions using best available technology. In order to achieve the 60% emissions reduction, fossil fuels which currently provide most of the heat for ceramic industries would need to be replaced by electric heating as the grid electricity mix decarbonises. However, significant technological development would be required as there are currently no large scale electric continuous kiln designs suitable for firing heavy clay products. It was also shown in the roadmap that replacing some fossil fuels with bio-energy could reduce emissions although competition with other sectors for biomass resource would limit availability.

Energy efficiency and heat recovery technologies were seen to be able to provide the most significant early emission reductions in the sector alongside technologies which can recover lost heat from exhausts for example. Like in the other sectors, CCS was seen to have some potential but only if sites could collaborate in order to share infrastructure.

3.2.9. Industrial heat scenarios overview

The sections above considered the largest CO_2 emitting industrial sectors in the UK but did not cover all industries. Figure 10 from Skea et al. (2013) showed that other sectors including vehicle manufacture, electronic engineering and mineral and non-ferrous metal production also used significant amounts of energy and so will have significant attributed CO_2 emissions. However smaller sectors are not broken down in significant detail and they have not been the subject of any major research around their future in a low-carbon world.

The roadmaps described previously considered the biggest industrial emission sectors and also a wide selection of technologies and processes used to produce heat. Because there is so little known about the smaller sectors and industries, we base our scenario of a low-carbon industrial future on the roadmaps and consider the key technologies for decarbonising industrial heat.

Overall, the roadmaps agree with the Committee on Climate Change's analysis that the key technologies to reduce emissions from industrial energy and heat use are through using bio-energy in its various forms, deploying tougher energy efficiency across the sectors, using greater levels of electricity rather than fossil fuels for processes which will over time be decarbonised and also using CCS technologies where these may be suitable.

However, the most suitable path to decarbonisation for industry depends very much on the temperature (value) of the heat required. Processes which require high value heat such as glass manufacturing or steel production may need to use combustion processes with or without CCS for example. Processes which use lower heat temperatures such as food and drink may be more suited to low-carbon heat provided by electrical technologies.

3.3. Chapter overview

In this chapter, we have considered the various pathways and scenarios for transforming the UK's current heat system into a much lower-carbon heat system. This has been split into space and hot water heating and industrial heating.

With space and hot water heating, we have shown that there are a number of competing visons for how the sector can be transformed. These vary from full electrification, to hybridisation, to conversion to hydrogen. However, for the rest of this working paper, we take forward two scenarios which it is suggested can fully transform the UK's heat sector towards full decarbonisation. While other pathways exist such as hybridisation or full conversion to bio-energy, these are limited in their decarbonisation potential and may be niche options rather than fully transformative.

Firstly we take forward Pathway 1 which focuses on reducing demand and then providing much of the space and hot water heat load from electricity either by onsite heat production through electricity using appliances such as heat pumps or by distributing low-carbon heat using heat networks. There are complicated tradeoffs in determining the optimum levels of the combination of demand reduction, heat networks and standalone heating systems and so we do not provide a specific target. However, the Committee on Climate Change has suggested that up to 20% of total building heat demand could be provided by heat networks in 2050 (Committee on Climate Change, 2016b) and so we use this as a rough figure meaning that around 80% of heat would need to be provided by onsite electrically powered heat systems. It should be noted that there are various assumptions for the optimal penetration of heat networks versus onsite generation under this low demand and more electric scenario (Carbon Connect, 2014).

Secondly, we take forward Pathway 2 which suggests UK space and hot water heating can be decarbonised by converting the UK's gas network to transport low-carbon hydrogen produced from methane using CCS. This is in our view an unlikely pathway with various issues but is considered for the rest of the working paper due to the presence of hydrogen conversion in the current heat discourse. Under this scenario, those houses and buildings not currently connected to the gas grid would, by 2050 use primarily on-site electric heating technologies.

Finally in this chapter, we considered the limited scenarios for the decarbonisation of industrial heating. Industrial 'road-maps' produced for the UK Government showed that while there are some key methods to decarbonise, including energy efficiency, bioenergy, electrification of heat using low-carbon electricity and CCS, there were major differences in technological suitability between sectors. An added complexity for the industrial heat sector is the potential for carbon leakage if high energy costs mean that industries relocate abroad making a clear pathway for the decarbonisation of industrial heat not obvious.

4. Developing a map of the UK's heat sector businesses

In order to understand what a transformation to low-carbon heating would mean for UK heat sector businesses, as well as understanding what a low carbon transformation may entail (the topic of the previous chapter) we needed to understand the structure of the UK's existing heat sector. In order to do this, a visual map was developed which both acted as a database in which the information about companies could be collated and organised but also as a tool to visualise the industry which may be of use to the wider energy community. This chapter describes the methodology used to develop the map.

The mapping process has identified the key sectors and sub-sectors present in the UK's heat market and the risk and opportunity analysis in chapter 5 has been produced based on the outputs from the mapping process. To assess the prevalence and success of similar examples of business mapping, previous examples were investigated. From the few results on the subject of business mapping, two categories emerged from our research. Strategic and investment planning; focusing mainly on business efficiency and profitability, and geographic cluster mapping; predominantly looking into novel methods of evaluating regional business diversity and success. Overall, there were no other studies found in our research that even vaguely mirrored our requirements and expected outputs. Because of the limited examples of network maps being developed in this way to represent business sectors, the development of the map was an iterative and explorative process.

After a review of potential mapping options, we eventually settled on the 'Kumu' online stakeholder mapping software which is accessible through web browsers. Further information on our choice of this particular mapping software is contained in annex 1.

4.1. Locating businesses and other actors present in the UK heat sector

The next stage of research following choosing the mapping tool was to identify the companies currently active in the UK's heat sector. This task was particularly problematic as it is impossible to be sure that all companies in the sector are included as part of the process; it is in fact likely that some companies have been missed.

Initially, industries were identified from the researchers' prior knowledge of the sector by thinking through the various sectors along the heat supply chain from primary energy source to final end use appliances and parts thereof. This included the producers of the primary fuels, the network operators and their main equipment suppliers, energy suppliers, appliance manufacturers and plumbing and heating equipment manufacturers to name but a few. Each identified level in the supply chain was then expanded on in order to show which companies were active and then to highlight other sectors.

Following on from this, publicly available data sets were then used for each sector in order to identify actors.

- For the upstream gas sector, DECC oil and gas production data was used which names all associated and dry gas production sites alongside their ownership thus identifying the companies producing gas in the UK (DECC, 2016b).
- For electricity and gas supply, the 'big 6', as by far the largest were added to the map. Because there are now a large number of domestic electricity and gas supply licenses operating, not all suppliers were included unless further searches showed a specific interest in the heat sector. The larger non-domestic suppliers were also included in the map.
- For industrial heat demand sectors, the 15 largest heat using sectors from DECC's 2013 estimates of heat use were used (DECC, 2013a, these 15 sectors repreented over 90% of total industrial heat use). Sectors as a whole were included on the map rather than companies within each sector.
- Membership lists from what were identified as the key trade associations representing heat companies from our previous experience and wider research were then added to the map once the non-heat specific companies had been removed[7]. The trade associations from which membership data was extracted were:
    - The Energy and Utilities Alliance which represents much of the heating industry although is particularly focused on appliances
    - Major industrial energy users trade body, The Energy Intensive Users Group
    - ICOM (Industrial and Commercial Energy Association) which represents non-domestic energy users
    - UK LPG representing the liquid petroleum gas industry
    - The Energy Networks Association representing energy networks

[7] For the trade associations memberships used, annex 2 includes information explaining which companies have not been included (as they were deemed from their websites not to be involved in heating).

- Energy UK, a cross sector trade body
- UK District Energy Association

Finally, some companies interested in heat but who were not members of the previously mentioned trade associations were found via trade shows. Specifically, companies who had a stand at the Plumbing and Heating Exhibition at Alexandra Palace in London in 2017 who were not already included, were added to the list of businesses.

It was decided that membership data from the Renewable Energy Association and the Federation of Environmental Trade Associations was not included on the map. The membership of both associations includes primarily new entrants rather than large incumbent actors and also includes a number of very small companies including heating system installers and engineers.

While we believe it very likely that some companies will have been missed by this mapping process, we have taken a great level of care to research the companies which have been included and believe, in light of previous limited examples of sectoral mapping exercises, our mapping approach has highlighted the vast majority of incumbent companies in the heat market. More importantly for the sake of the rest of the working paper, our mapping has highlighted the key sectors in the UK heat market and it is this data which forms the basis of the sectoral risk analysis which is the subject of section 5.

4.2. Determining company size and company interests

Once the list of companies had been assembled, the next step was to determine the size of the companies as we view this as important for both the potential power of the company to affect the heat regime but also because size may be a good indicator of the relative market position of different companies and sectors in the heat regime.

Determining the size of a company is no easy task and there is not a universally used indicator; often used metrics are number of employees, turnover and market value yet each of these have their own problems (Lowes *et al.*, 2017). As such, we attempted to gather information on each of these aspects of company size using online resources which host company information.

Company size data of turnover, market value and number of employees were collected from Companies House (2017) and Endole (2017) who collate Companies House data into a reader friendly format. This data related to UK business activities only. Further information on the collation of company size data is included in annex 3.

Based on some basic statistical analysis considered in annex 3, market value was identified as the most valuable indicator of company size. Therefore, the companies were then ranked by market value and once ranked, for the companies with market value data, split into four size groups for the purposes of map formatting. The size groups were simply chosen by dividing the total number of data points by four and then allocating the sizes to the ranked company depending on where they sat in the ranking list. i.e. the smallest quarter was ‘small’, the next quarter was ‘medium’ and so on. Based on this ranking and split, the size bands were as follows:

- ‘Small’ = market value is from £144 million to £532,200, for mapping purposes allocated as size group 1
- ‘Medium’ = market value is from £547,000 to £3,337,100, for mapping purposes allocated as group 2
- ‘Large’ = market value is from £3,820,000 to £45,440,000, for mapping purposes allocated as group 3
- ‘Very large’ = market value is from £47,760,000 to £110,330,000,000, for mapping purposes allocated as group 4

Data regarding the geographical scale of companies was also gathered from company websites. The geographical reach of companies, based on their delivery or service ranges, was assessed from information on their corresponding websites. The categories decided upon for geographical reach were ‘regional’; UK based but not delivering nationwide, ‘national’; UK based and delivering nationwide, or international; companies delivering to more than one continent. It is hoped that this information will enrich the company size information.

Data on the companies’ business interests was also gathered from company websites and while subjective and based on limited data, companies were ranked based on whether their primary business interest in low-carbon heating was ‘full’, ‘some’ or ‘none’. We believe this to be the most limited aspect of the map but hope it may shine some general light on the interests of different sectors.

4.3. Formatting the map in Kumu

In order to make the data suitable for import into Kumu, each company was associated with a particular sector based on information from each of the companies’ websites. The sectors emerged as this allocation process was carried out. Where companies had major interests in more than one sector, companies were generally allocated to the sector which most closely matched their business interests. However, many companies have some interests across sectors but as we discovered, including all sector membership would be very onerous and the map would have been extremely complicated and messy.

The business data was then imported into Kumu as an excel spreadsheet and the allocation of sectors and the links between sectors created the overall shape of and connections within the map. The map was then modified in order to highlight particular features, primarily to link the size of nodes to the size of the company (based on their market value ranking) and to change the colour of the nodes based on the company's interest in low-carbon business.

The formatting steps are described in more detail in annex 4.

The map can be accessed here:
https://embed.kumu.io/122bd7e33980257722a649af7a8ec58f?settings=0

4.4. Results from the mapping

As a result of the mapping, a number of sectors and sub-sectors emerged through the mapping process. These are shown below in Table 2[8]. Each of these sectors and the risks and opportunities associated with a transformation to low-carbon heating are considered in more detail in the following section.

Table 2. Heat business sectors and sub-sectors identified through the business mapping process

Sector	Sub-sector
Consultancy	N/A
Fuel producers	Biomass producers
	Coal producers
	Electricity generators
	Oil producers
	Upstream gas and gas storage
Heating appliances and technology	Biomass boilers
	Cookers/kitchen appliances
	Controls
	Cylinders
	Data and communications
	Demand reduction
	Electric heaters
	Fire places and stoves

[8] As explained in more detail in the following section, LPG is not broken down into sub-sectors due to its relatively small market size

	Gas boilers
	Heat pumps
	Metering
	Micro-CHP
	Non-domestic heating products
	Oil boilers
	Plumbing and heating supplies
	Radiators
	Solar thermal
	Water heaters
Installation and maintenance	Low-carbon heat installers
	Plumbers and engineers
LPG	N/A
Suppliers	Domestic supply including Big 6
	Non-domestic supply
	Oil supply
Transportation	District heating and district heat generation
	Electricity networks
	Electricity network products
	Engineering and construction
	Gas networks
	Pipeline products

As described previously, where company size data was available (market value), this was also collected and input onto the map. The map data was analysed to give a rough overall size (market value) for the sectors described above and the results of this analysis are shown below in Figure 15. Attributing the market value of a particular firm to a particular sector is complex. This is because firms operate across sectors and subsectors and some companies operate under various names and operations. In situations where firms operate across sectors, we have used our best judgement based on company knowledge to place firms within the most appropriate sector[9].

It may also be the case that while we have identified some businesses which operate in the heat sector and included their market value (company size) data in our analysis, only a portion of that company may be involved with heating. This is likely to be problematic and could identify businesses or business sectors as having larger value in the heat sector than they actually do. Further more detailed

[9] One example is the placing of Viessmann and Worcester Bosch within the gas boiler sector despite the fact that these companies also manufacture other appliances such as oil boilers, solar thermal and electric heating systems. However, the biggest segment of these companies' UK activity is within the gas boiler market.

investigation of within company financial information could reduce the impact of this issue but, this is currently beyond the scope of this research and we expect that this information would not be freely available as it is not required to be publicly available. Overall, while this issue may have some impact on sectoral and company value, we believe its actual impact on the overall mapping and identification of sectors is very limited.

In the following sub-sections, we consider the sectors identified by the map in more detail. For each sub-sector identified, we have included a screen grab from the Kumu map. Annex 4 gives more information about the design of the map but the key visual features of the map are shown below in Table 3:

Table 3. Description of key visual features of interactive map

Map component	**Description of appearance**	**Example**
Sectors or sub-sectors	Black circles	
Trade associations	Purple circles	
Businesses with limited interested in low-carbon heat	Red circles	
Businesses with some interest in low-carbon heat	Amber circles	
Businesses primarily interested in low-carbon heat	Green circles	
Business size based on company value	Reflected in size of relevant circle	

Figure 14 below shows a screen grab which covers the whole of the map and allows the following sections considering specific sectors to be seen in context. Because of the size of the map, it is not possible to find information regarding specific companies from the map and readers are encouraged to view the interactive version of the map:
https://embed.kumu.io/122bd7e33980257722a649af7a8ec58f?settings=0

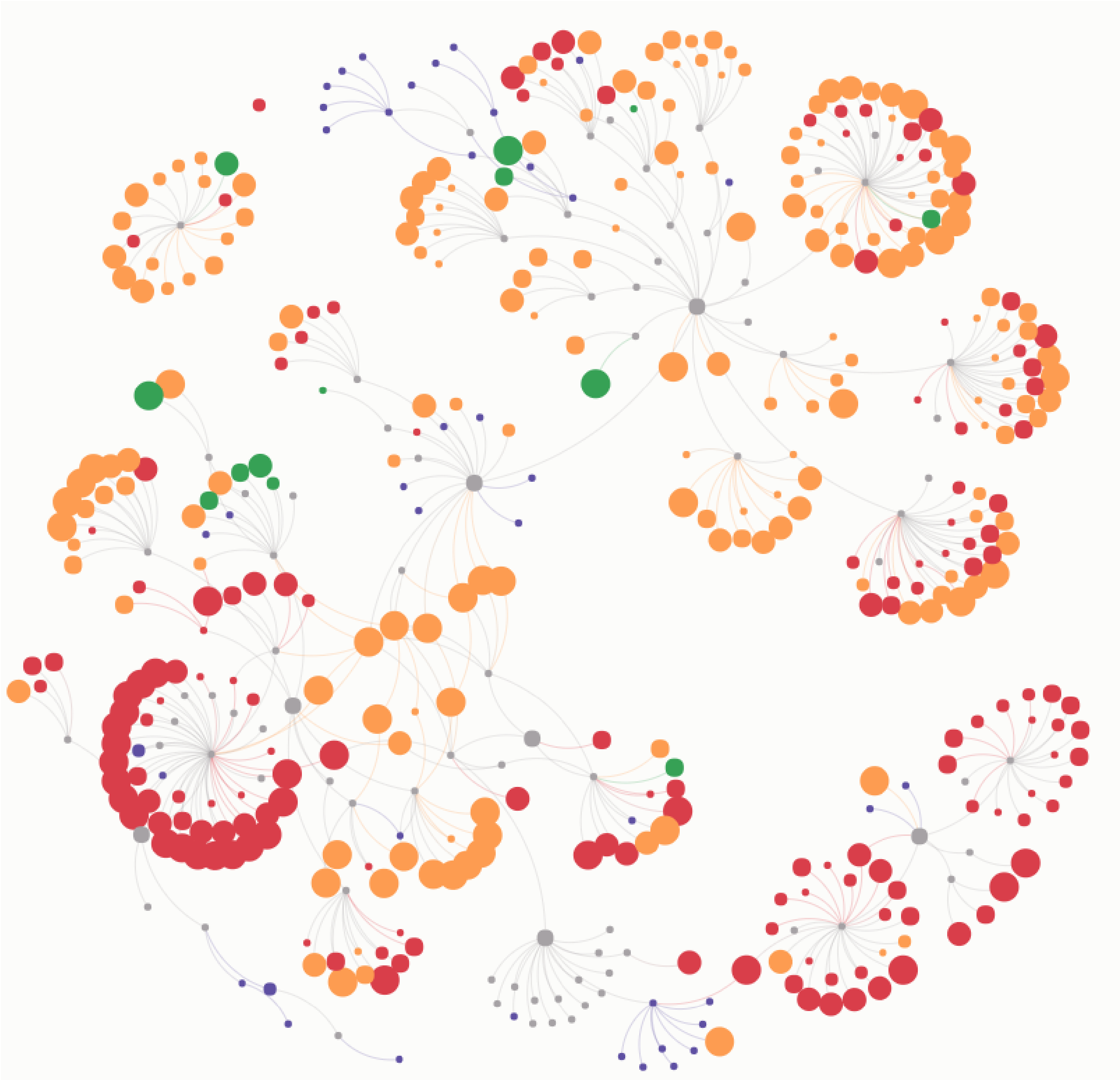


Figure 14. A screen grab showing the entirety of the UK heat sector business map

Figure 15 below shows the sizes (based on total value) of each sector identified from the mapping, displaying the large scale of the upstream sector relative to other sectors. In order to expand on Figure 15, we have also broken the data down into the sub-sections shown in Table 2 to highlight the approximate size of specific sub sectors in Figure 16. In order to remove the dominance of the upstream gas sector on this graph, we have removed the 'fuel producers' sector from the graph shown in Figure 16.

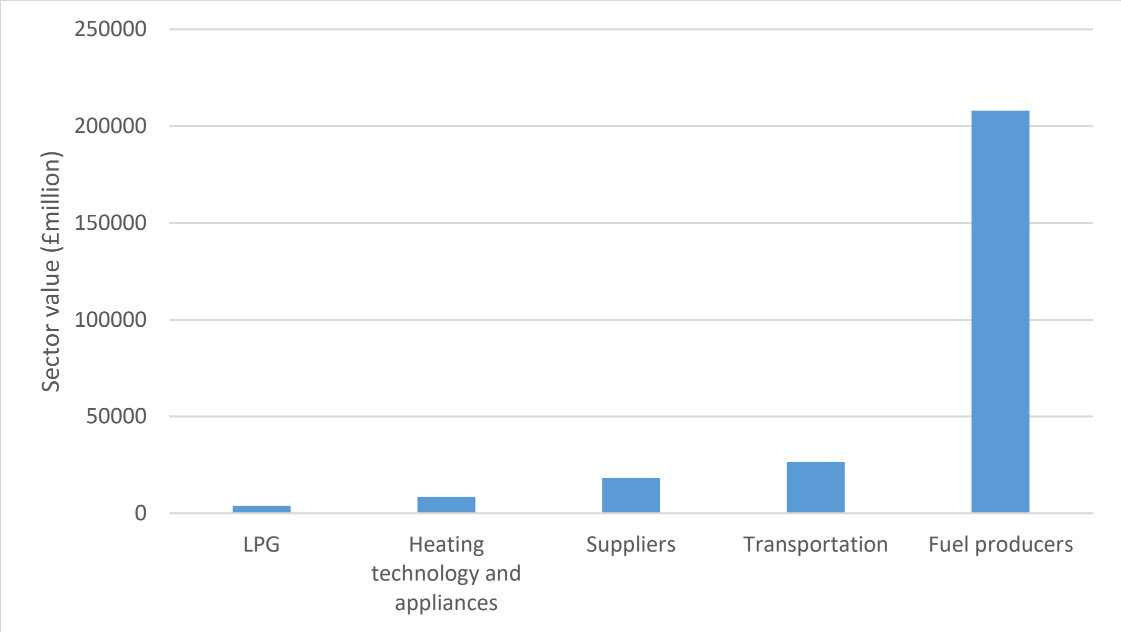


Figure 15. The value of businesses active in the UK heat market split by sector. Based on financial data for year 2015/2016. Some data points are missing. Data displayed in the graph does not include consultancies active in the sector or any information regarding industrial heat users. For this analysis, while recognised as being important, the heating engineer/installer industry has not been considered as data on this sector is limited as the sector is formed of a large number of small businesses. Fuel producers includes UK companies who produce coal or gas and electricity and other fuels are not included.

Figure 16 shows that after the upstream gas producers (not included on the graph), the largest sub-sector is the energy suppliers involved in supplying heat, primarily in the form of gas and electricity. Following from this, the next two largest sectors are the electricity and then the gas networks which transport much of the energy used for heat. Following this, the next largest sector is the 'plumbing and heating supplies' sector which sells and produces much of the equipment used in heating systems. The liquid petroleum gas (LPG) sector is also of a notable size and this may be linked to the fact that for LPG sector, the supply, transportation and appliances are all considered together and often operated by the same companies. Engineering and construction firms also emerge as a large sector linked to energy transportation although many of these firms may be carrying out large volumes of their business not associated with the heat sector.

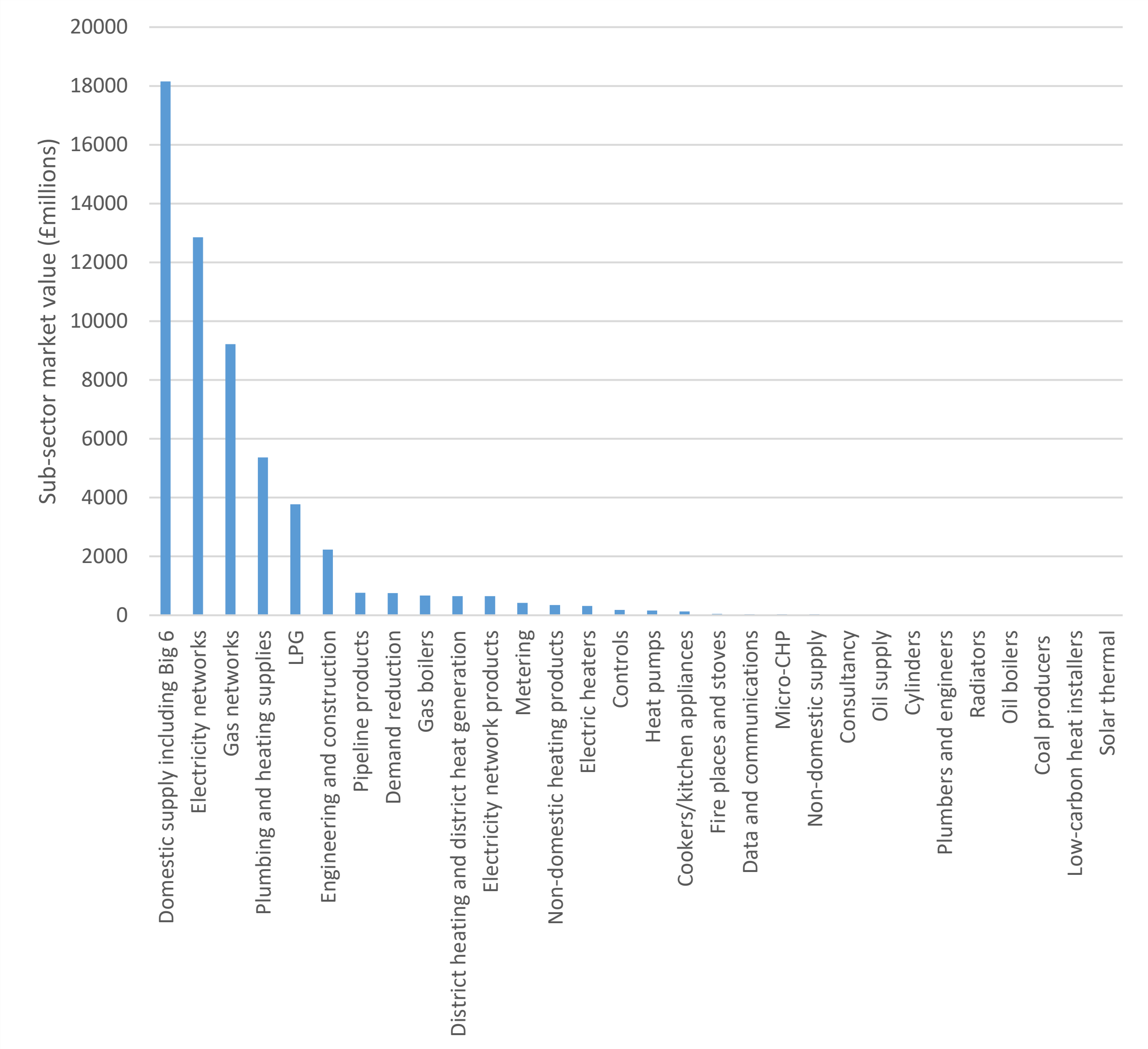


Figure 16. The value of businesses active in the UK heat market split by sub-sector. Based on financial data for year 2015/2016. Some data points are missing and the attribution of certain companies to certain sub-sectors is known to have methodological limitations. Data displayed in the graph does not include any information regarding industrial heat users.

4.4.1. Fuel producers

The analysis in Figure 15 shows that the 'fuel producers' sector is by far the largest sector within UK heat businesses, around eight times bigger than the next largest sector. This sector primarily represents gas production and the upstream gas sector (although it also includes a very small element of market value from gas storage and coal). A screen grab of the upstream gas sector from the map is shown below in Figure 17. The image shows that the upstream gas sector is formed of a high number of very large companies and some smaller companies but that this sector mostly operates distinctly from the rest of the heat sector. In this sector, upstream oil and gas firms Shell, BP and BG (Shell) are the three largest companies by market size operating in the UK heat market.

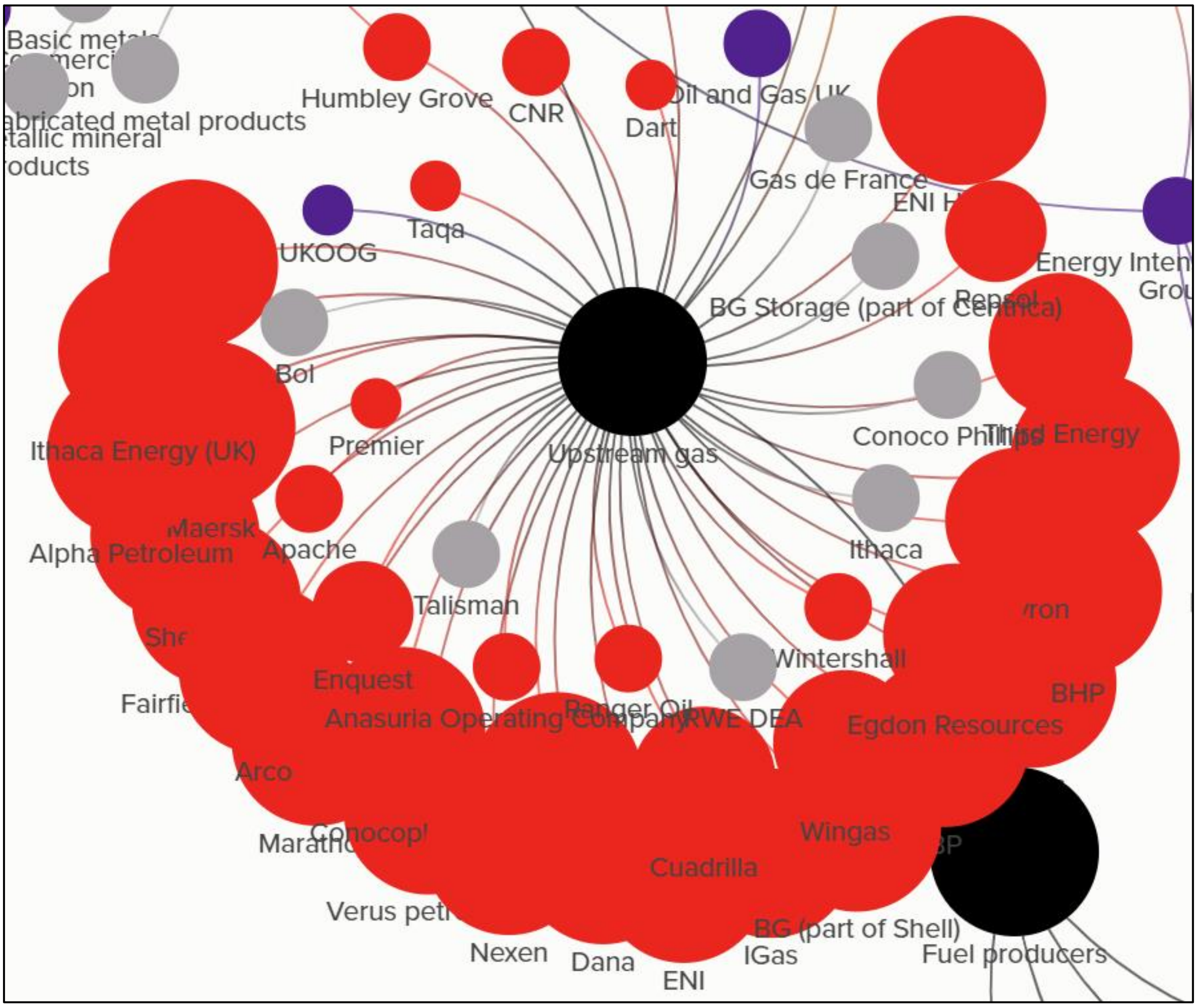


Figure 17. Screen grab from the heat business map of the upstream gas sector

While most firms identified in this sector are only involved in gas production, this sector also has some connection to the gas storage sector. Centrica also stands out as a large firm in the upstream sector but with much wider interests across the heat market, including energy supply and installation and maintenance. This highlights Centrica as a particularly important actor operating across the UK heat market. The companies in this sector are primarily red indicating that from our analysis they only have an interest in unsustainable (high carbon) activities, in this case the production of fossil gas.

4.4.2. Transportation

The next largest sector is the heat/energy transportation sector and this is shown in the screen-grab in Figure 18. There are a number of sub-sectors within this sector however, the electricity and gas networks which transport the vast majority of the UK's heat are the most significant by market value. As shown in Figure 16, electricity and gas networks are the third and fourth largest sectors after gas production and energy suppliers together worth around £22 billion according to our analysis.

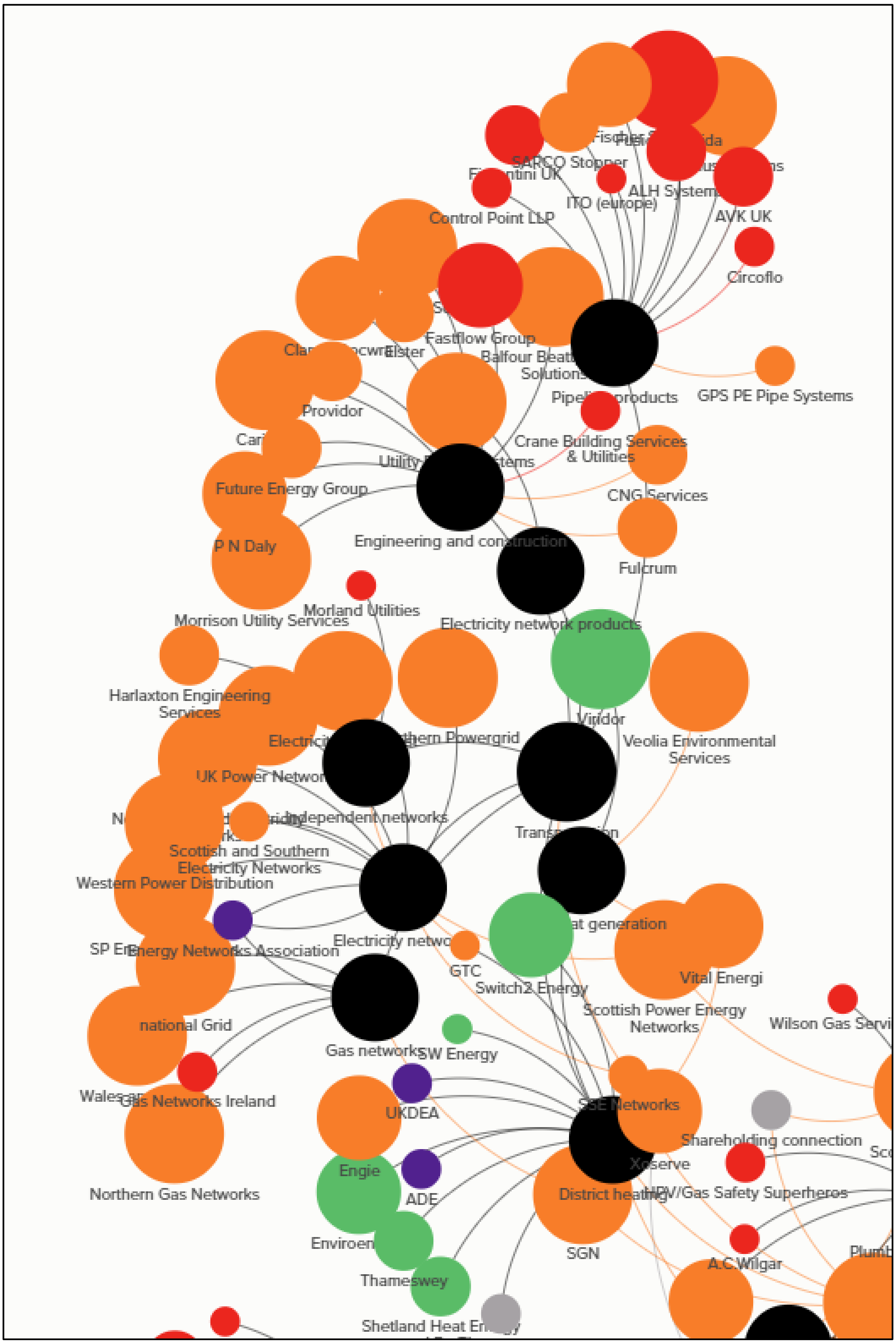


Figure 18. Screen grab from the heat business map of the transportation sector

The transportation sector also includes the district heating sector which includes those who own and operate some of the UK's district heat networks and those who are involved in heat generation for the networks. The transportation sector also includes independent network operators which may operate a number of different transportation technologies. Finally, this sector also includes sub-sectors which support the networks such as the companies that produce the gas and electricity equipment as well as the construction and engineering companies which are sometimes involved in the building of these networks on behalf of the network operators.

As shown in Figure 18 and on the map, many of the companies in the transportation sector are shaded orange indicating some interest in low-carbon heating based on analysis of company websites. There are also some companies which apparently have no interest in low-carbon heat and some companies with a high level of interest in low-carbon heat. This is very different to the fuel production sector where companies involved in gas production were seen to have a very limited interest in low-carbon heating.

4.4.3. Suppliers

The third largest major sector was suppliers of energy. The largest part of this sector was the 'big 6' energy companies and those who supply energy to domestic customers who together have a market value of approximately £18 billion. It is worth bearing in mind that some of the big 6 companies are also involved in non-domestic energy supply and but that there are also companies who focus specifically on domestic or industrial consumers. This sector also includes oil suppliers.

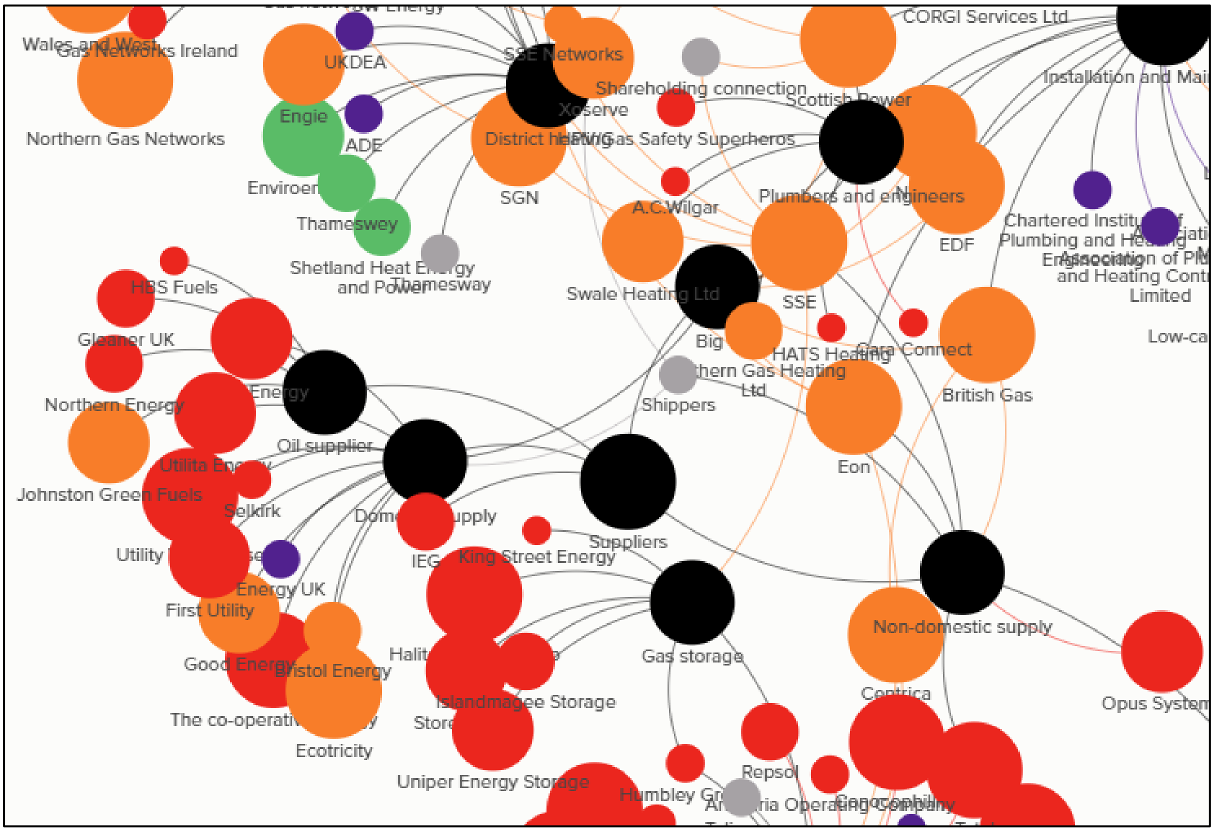


Figure 19. A screen-grab from the map showing the energy supply sector

A screen-grab of the supply sector is shown below in Figure 19 and this sectors is quite central in the map. This centrality is primarily associated with the Big 6 companies and the (vertically) integrated nature of them, some of which have an interest in energy network ownership, district heating and the installations and maintenance sector or a combination of these other sectors. Interestingly, the smaller non-big 6 domestic suppliers are primarily focused on the supply of heat as electricity or gas and from our mapping have no major interest in the networks or installations and maintenance sectors. The non-big 6 non-domestic suppliers also appear to have no major interest in installation and maintenance or heat networks indicating that the big 6, as well as being larger companies, have a much more integrated position in the heat sector than non-big 6 companies.

This sector contains a combination of levels of interest in low-carbon heating. The big 6 companies, perhaps due to their wide interests have some interest in low carbon heating whereas companies that provide energy to non-domestic users and oil providers have limited interest in low-carbon heating. Most small suppliers are generally involved with the supply of high carbon heat however, some have some interest in low-carbon heating. The district heating sector contains a high number of companies interested in primarily low-carbon heating.

4.4.4. Heating appliances and technology

Heating appliances and technology is the next smallest sector identified from the company mapping. As can be seen in Figure 20, the sector has a large number of sub-sectors within it and the sector overall contains the largest number of companies. Sub sectors include the various different heating appliances (domestic and non-domestic), cookers, data and communications, controls, metering, cylinders and plumbing and heating supplies. However, despite the high numbers of sectors and businesses within them, the market value of the sector from our analysis is less than a third of the transportation sector at approximately £8 billion.

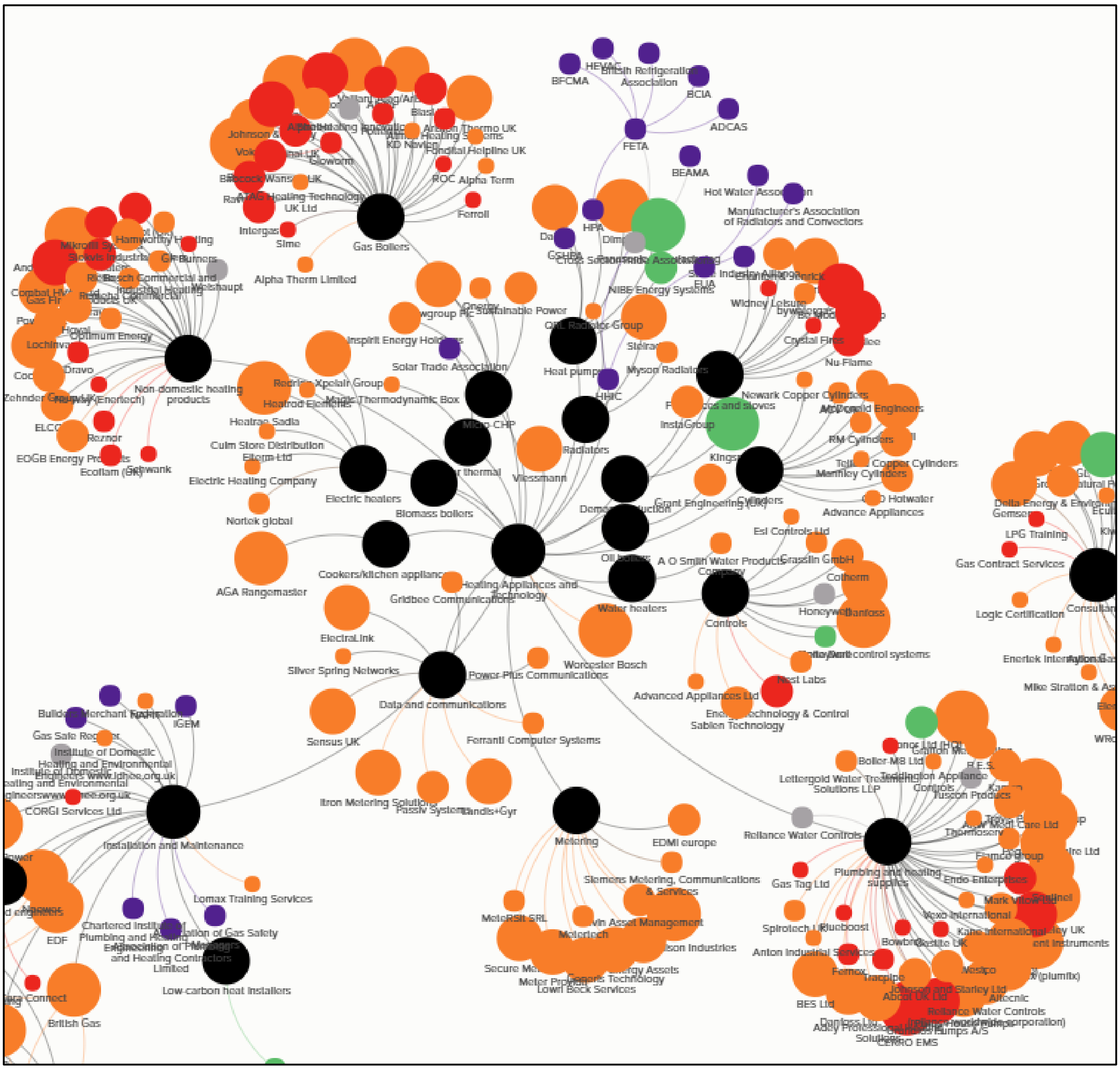


Figure 20. A screen-grab from the map showing the heating appliances and technology sector

From our mapping, it appears that the sector is not particularly integrated with other sectors although there are some larger appliance companies which are involved with a number of different types of heating appliances. We are also aware from the mapping that some of the larger appliance companies are involved with the installation and maintenance sector, particularly around training engineers to fit appliances. Generally however, most companies seem to stick to one particular appliance or technology.

Many of the companies in the sector produce both lower carbon and higher carbon technologies or technologies which are expected to be of value whether in both high-carbon or low-carbon heat systems. For example, many of the appliance companies are involved with both fossil fuel and renewable heat appliances. Further still, many companies make products, such as hot water cylinders, controls or plumbing supplies which will have value in both a high or low-carbon heat system. As a result, the majority of companies in this sector are shaded orange to show that they have some interest in low-carbon heat (even though that may not have been an active decision). The companies shaded red are primarily companies that produce fossil fuel appliances or components which work with solely with fossil fuel appliances while the green shaded companies are interested solely in low-carbon or renewable heat.

4.4.5. Liquified Petroleum Gas (LPG)

LPG was the final major sector which emerged from the mapping exercise. The market value of the sector as mapped was around £3.7 billion making it the smallest of the sectors. The LPG sector is seen as a discrete sector because of the high level of vertical integration where companies often offer combinations of energy supply, storage (in the form of local tanks) and sometimes boilers. LPG is also unique in its transportability and variety of uses.

LPG is used to heat around 190,000 homes, by businesses for cooking and heating (sometimes in mobile situations), for leisure (camping and barbecuing) and also for some transport (UK LPG, 2017b). As shown in the screen-grab in Figure 21, the LPG sector is formed of subsectors including LPG suppliers, LPG transportation and LPG equipment. It is important to note that some of the largest companies in the LPG sector such as Calor and Flogas operate across subsectors but have in the map been assigned as suppliers. There are also other very large companies such as Phillips 66 (a multinational refining firm who produce LPG) and BOC (a very large gas (of various types) supplier) who have from the mapping been assigned to the LPG section because of trade association membership data. However, the presence of these companies who are only partly interested in LPG highlights the issue with the mapping process in general and in particular the issues with understanding the value of a particular company in a particular sector. Further still, it is also the case that some of the companies in the appliance sector produce appliances for LPG combustion meaning that the involvement aspects of the appliance sector in the LPG sector is not included on the map or in the sector value calculation.

On the map it can be seen that most companies in the LPG sector are shaded red. This is because these companies have been seen to be primarily involved in fossil LPG which could not be part of a low carbon heat system. Of the companies shaded orange, two also distribute biomass fuels and Calor is also currently involved in the development of a bioenergy LPG replacement.

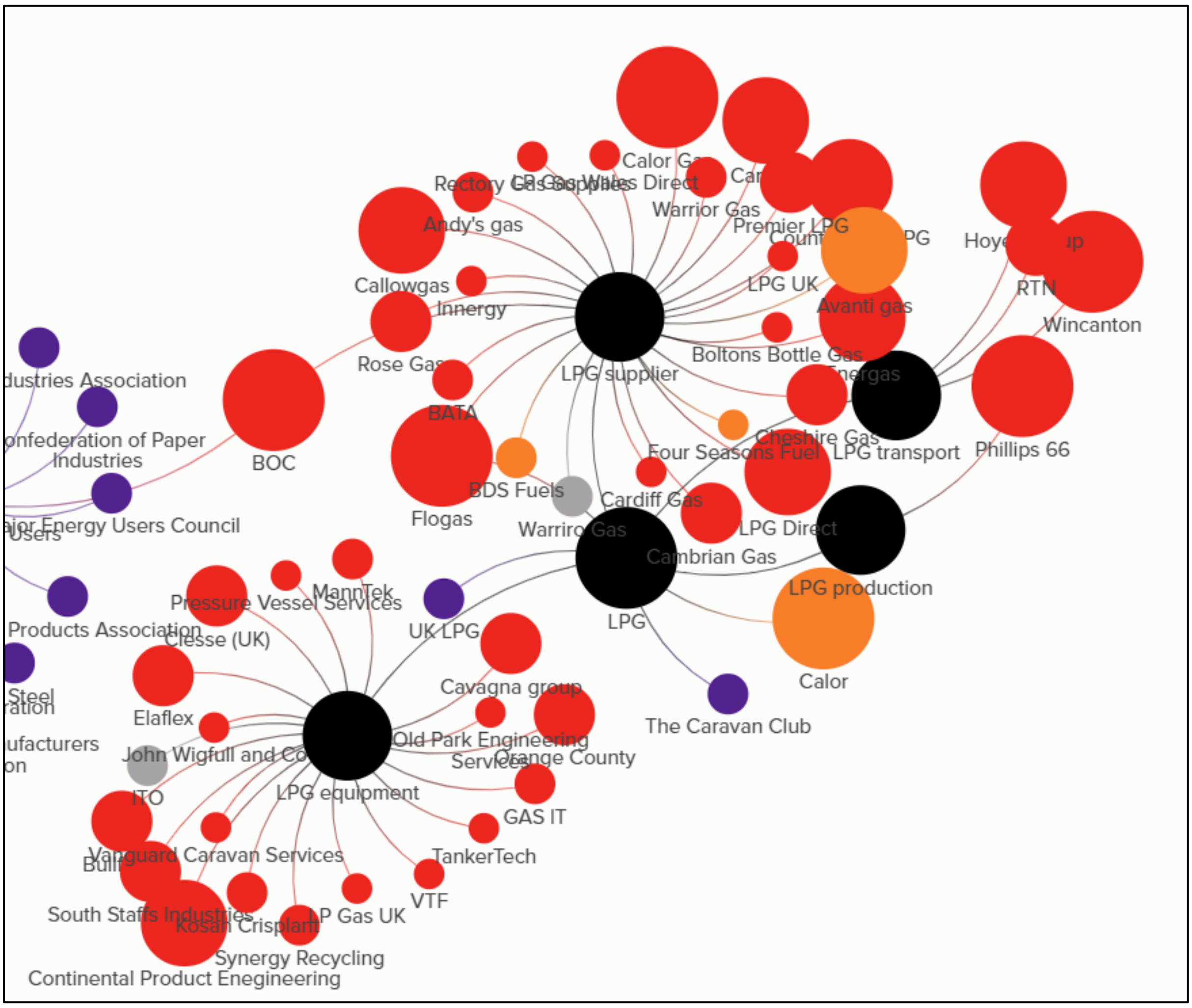


Figure 21. A screen-grab from the map showing the LPG sector

4.5. Mapping chapter summary

This chapter has described the process used to map the UK's heat sector businesses and the results of that mapping exercise. It first considered the choice of software used to display and design the map and then described the process for discovering which companies are active in the UK's heat sector and which should therefore go on the map. The chapter then went on to describe how company size would be measured for the purposes of the mapping and finally discussed how the map would be formatted to display the company data.

In the mapping process we encountered a number of issues with the business mapping procedure.

Firstly, there are a number of options of mapping software to use and map options have their own benefits and issues. Whilst we are overall satisfied with the resulting mapping, we were 'locked-in' to this particular mapping software once we had invested time into it.

Secondly, it is not possible to determine all companies operating in a particular market. Not only is information about some companies not available, markets change rapidly and so new companies will emerge and old companies will disappear. While we have done our best to include all relevant companies, it is very likely that a number have been missed.

Thirdly, there are known issues with measuring company size. We chose to use market value as the metric because data on this metric was most widely available but we are aware of the limits of using this metric. Because the companies identified in the mapping operate across sectors both within and outside the heat sector, it is also the case that because we have had to assign companies to specific sectors and sub-sectors, which is itself problematic, this also means that the value of companies and sectors will not be completely reliable.

Nonetheless we have created the map which has both shone a light on the companies active in the UK heat sector which we believe will have value to both academia, Government and industry. The map can be accessed by following this link: https://embed.kumu.io/122bd7e33980257722a649af7a8ec58f?settings=0

As well as opening up the heat sector, the map has also split the heat sector into further sectors and sub-sectors. In this chapter we have provided detail on the size, contents and activity of these sectors. Importantly for this working paper and the Heat, Incumbency and Transformations project overall, the mapping process has led to the emergence of the key heat market sectors and given a good indication of their overall and relative sizes. It is these sectors on which the risk and opportunity analysis which is the subject of the following chapter is based. The emergence of these sectors and their relative size has also allowed us to develop some hypotheses for the next and final stages of the project considered in chapter 6.

5. Risks and opportunities of heat decarbonisation to UK heat sector businesses

This section builds on the research discussed in the previous chapters of this paper considering future space and hot water heating pathways discussed in section 3 alongside the map of businesses operating in the UK's heat sector. It synthesises the outputs from these previous chapters to consider what the transformation to low-carbon heating may mean for each of the sectors identified under pathway 1 and pathway 2.

As a reminder, the two pathways are:

- Pathway 1 – **Decentralised heat** – this scenario focuses on primarily reducing heat demand with the remainder of heat requirements met through either onsite heat generation from heat pumps, electric heaters and solar thermal or with heat being provided via district heat networks themselves using low-carbon heat
- Pathway 2 – **Hydrogen conversion –** this scenario maintains the centralised heat model with hydrogen being produced from natural gas at centralised hubs where carbon is also being captured and stored from the process. Hydrogen is transported using the existing gas network then burnt in suitable boilers in each dwelling for space and hot water heating

Pathways and scenarios towards low-carbon heating are contested and using the two very different pathways identified we believe we have covered the key options for UK heat system decarbonisation. However we appreciate that even within each of the pathways identified, elements are likely to be contested such as the expected level of heat demand and the growth of certain technologies and infrastructures. We are also aware that the mapping exercise, while thorough, has limits in that not all companies in the heat sector may be covered and some companies identified may be associated with more than one sector or sub-sectors.

In light of these analytical complexities, we focus our analysis of opportunities and risks for businesses on sub-sectors rather than on specific companies which may be operating in or producing products across more than one sector. We have also made our approach to assessing risks and opportunities for each subsector discursive rather than using numerical risk assessment. We have however, from our discussion of each sub-sector under each pathway, employed a traffic light approach to considering risk where:

- Red: Sector at major risk from heat decarbonisation

- Amber: Sector faces some risk from heat decarbonisation
- Green: Sector at low-risk from heat decarbonisation with clear opportunities for growth

The following sub-sections consider the risks and opportunities for each of the heat business sectors identified in detail with each sector in table format broken down into sub-sectors and considered under each pathway (apart from the industrial heat demand sector considered in the following section). Sectors and sub-sectors within them are considered alphabetically. We have not allocated a particular timescale to this analysis because of the additional complexity this would introduce but appreciate that the risk and opportunities described will not all emerge at the same time. However, in light of the need for the rapid decarbonisation of the heat sector, these are all risks and opportunities that are expected to emerge well in advance of 2050.

Within the risk and opportunity analysis, we have not focused on industrial heat demand. While we recognise that decarbonisation is likely to be a challenge for industrial heat, there are much wider issues around carbon leakage, industrial strategy and technology development which make analysing risks and opportunities for this sector extremely complex.

5.1. Consultancy

The first major sector from the mapping is the consultancy sector, this includes companies that provide advice and analysis for various other heat sector actors such as NGO, charities, businesses and government. This sector was not broken down into sub-sectors as the mapping analysis highlighted only a relatively small number of companies within the sector. Table 4 considers the consultancy sector in detail.

Table 4. Risks and opportunities of a move towards low-carbon heating for the consultancies active in the heat sector

Sub-sector	Description of sector's interest in heat	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
N/A	The consultancy sector appeared as an important sector in our mapping work. This sector provides advice and	In either pathway there is likely to be an ongoing need for consultancy guidance and advice around moving to low-carbon	In either pathway there is likely to be an ongoing need for consultancy guidance and advice around moving to low-carbon

	analysis for companies, organisations and HM Government regarding heat.	heat. In light of the potential changes to the system, the workload for consultants could increase. Therefore the risk for this sector from heat decarbonisation is low.	heat. In light of the potential changes to the system, the workload for consultants could increase. Therefore the risk for this sector from heat decarbonisation is low.

5.2. Fuel producers

Fuel producers was another major sector to emerge from the mapping analysis. This sector produces the primary energy (and electricity) that is used for heating purposes. The risks for this sector are extremely sub-sector specific and are considered in more detail in Table 5.

Table 5. Risks and opportunities of a move towards low-carbon heating for fuel producers active in the heat sector

Sub-sector	Description of sector's interest in heat	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
Biomass producers	This sector produces the biomass resource for combustion in order to produce heat.	Both pathways would likely see an increasing role for bio-energy used to decarbonise heat however this would need to be focused almost fully on the industrial sector. This implies growth in the sector albeit it with different end users.	Both pathways would likely see an increasing role for bio-energy used to decarbonise heat however this would need to be focused almost fully on the industrial sector. This implies growth in the sector albeit it with different end users.
Coal	This sector produces the coal used for space and hot water heating.	This pathway would not expect to use any coal for heat due to its high carbon content and the requirement to fully decarbonise heating at a distributed level. This sector is therefore at high risk from decarbonisation. There	This pathway would not use any unabated coal for heat but it is possible coal could continue to be used to produce hydrogen with CCS. There are number of options for fuels which can be used to produce hydrogen and

		appear to be no opportunities.	so the likelihood of using coal for hydrogen production is very uncertain. This sector is therefore at high risk from this pathway with some specific and limited opportunities.
Electricity generators	This sector generates the electricity used by some households to produce heat in electrically powered heating appliances.	Under this pathway, much greater levels of electricity capacity and greater levels of generation are expected in order to support the high levels of heat electrification. The risk to this sector under this pathway is low and the opportunity is high.	If more homes are connected to the gas grid then this could reduce electricity demand for heat however this is seen as unlikely. There may be room for some significant growth in electricity demand as those homes currently using oil for heating will be required to move to a lower form of heating which would likely be electric forms of heating for those off the gas grid. This sector therefore faces some risk but primarily opportunities under this pathway.
Oil producers	This sector produces oil for space and hot water heating purposes.	Removing oil for space and hot water heating is seen as a necessity in both low carbon heat pathways due to the high carbon content of heating oil. Any pathway towards low carbon heat sees no role for oil to be used in heating and so this sector is at risk from the move towards low carbon heat.	Removing oil for space and hot water heating is seen as a necessity in both low carbon heat pathways due to the high carbon content of heating oil. Any pathway towards low carbon heat sees no role for oil to be used in heating and so this sector is at risk from the move towards low carbon heat.

Upstream gas and gas storage	This sector produces and stores natural gas, some of which is used for space and how water heating purposes.	In this pathway, the role for unabated gas heating is eliminated and as such the demand for natural gas and gas storage for heat is also eliminated, placing this sector at high risk. There seem to be limited opportunities for growth in this sector under this scenario.	While this pathway envisages the elimination of direct natural gas use for heating, if hydrogen is to be produced at scale, some scenarios suggest hydrogen could be produced from natural gas using CCS. This could in fact increase the required level of natural gas as there are conversion losses in the hydrogen production process. This pathway would therefore mean that the risks to this sector from the move towards low-carbon heating are low.

5.3. Heating appliances and technology

This sector emerged as a major sector formed of many sub-sectors. This sector is comprised of sub-sectors which manufacture products used in homes and buildings to convert primary energy and electricity into heat, to control these appliances and to distribute this heat around buildings. It also includes components and parts for the appliances as well as the sub-sectors which sells and distributes appliances and associated technology.

As with the previous sector, the risks and opportunities across this sector vary significantly by sub-sector. These sub-sectoral risks and opportunities are considered in more detail below in Table 6.

Table 6. Risks and opportunities of a move towards low-carbon heating for appliance and technology companies active in the heat sector

Sub-sector	**Description of sector's interest in heat**	**Risks and opportunities under pathway 1 – decentralised low-carbon heat**	**Risks and opportunities under pathway 2 – centralised hydrogen production**

Biomass boilers	This sub-sector produces the appliances used to combust biomass to produce heat.	In both pathways, the role of biomass for space and hot water heating is seen to be very limited as the most beneficial place to use biomass resource is seen to be industry. As such, the potential for a biomass boiler market in a low-carbon heat is limited and this sector would be at risk from a move towards low-carbon heat. There may be some limited opportunities for biomass boilers in the industrial sector.	In both pathways, the role of biomass for space and hot water heating is seen to be very limited as the most beneficial place to use biomass resource is seen to be industry. As such, the potential for a biomass boiler market in a low-carbon heat is limited and this sector would be at risk from a move towards low-carbon heat. There may be some limited opportunities for biomass boilers in the industrial sector.
Cookers/kitchen appliances	This sector produces the appliances used to provide heat for cooking.	Under this pathway, change in this sector would be very likely. While the greenhouse gas emissions from cooking are very small, it seems unlikely that the gas grid would be maintained only for cooking and much cooking would likely be electrified and gas cookers and hobs replaced with electric appliances. The sub-sector would still be required but would need to change implying some risk for the sub-sector. New opportunities would emerge as the electric cooking market grows.	If the hydrogen pathway is taken, cooking appliances using gas would need to be replaced to make them suitable for hydrogen or would need to be replaced with electrically powered cooking appliances. The sub-sector would still be required but would need to change implying some risk for the sub-sector. New opportunities would emerge as the electric and hydrogen cooking market grows.
Controls	This sector produces controls	In this scenario, with the development of	It is unclear how the control market would

	and associated systems that control heating appliances such as smart controls and more basic controls such as thermostats and thermostatic radiator valves.	decentralised systems, the role of controls and smart controls is likely to be very important in order to optimise the system. As such the control market would be likely to increase meaning this sector faces low risk from heat decarbonisation and would see expanding opportunities.	develop in this scenario and the sector is seen to have medium risk.
Cylinders	This sub-sector manufactures cylinders used for the storage of hot water.	In this pathway, with the installation of many heat pumps, the cylinder market would be expected to grow as heat pump systems require hot water storage in order to ensure the systems run at maximum efficiency and that hot water is always available. There is therefore potential for the growth of this sector under this pathway and the risk is low.	If the gas grid is converted to hydrogen, there is no reason to expect that the current trend to remove hot water storage tanks from homes when combination boilers are installed would change. However, off the gas grid, where houses are likely to move to heat pumps, the market for cylinders may increase. Because of the potential for growth in some areas and the potential of reductions in others, this sector is seen to be a medium risk from a move towards low carbon heat under this scenario with some opportunity for growth in the off gas grid market.
Data and communications	This sector includes companies involved with using, measuring and transferring	It is unclear how heat decarbonisation could specifically affect this sub-sector under this pathway, particularly in	It is unclear how heat decarbonisation could specifically affect this sub-sector under this pathway, particularly in

	data associated with metering and heating systems.	the context of current technological developments and the roll out of smart meters. However, we would expect growth in the role of smart appliances and storage in this pathway in order to optimise the performance of heat pump systems and decentralised energy generation. We therefore see this sector as facing low-risk from heat decarbonisation under this pathway with the potential for growth.	the context of current technological developments and the roll out of smart meters. Off the gas grid where increased electrification of heat is likely, there is room for growth of data and communications however on the grid it's not possible to see how this sector could change. However as there is likelihood of some growth, this sector is seen as low-risk.
Demand reduction	This sub-sector manufactures and installs technologies which can reduce the demand for energy.	Reducing the demand for heat is central to this pathway in order allow the optimisation of the system. Therefore, companies in this sub-sector are at low risk from heat decarbonisation and there is significant room for growth.	The role for demand reduction in this pathway is not clear although it's likely that in any scenario there will be a market for demand reduction technologies particularly if efforts are made to protect the fuel poor from cost increases associated with the move towards hydrogen. Because of this, this subsector is seen to face low-risks as a result of heat decarbonisation and is expected to see some growth.
Electric heaters	This sector manufactures appliances which convert electricity directly into heat.	While this pathway sees a much greater role for electric heating, this is expected to be	This pathway would see an only limited role for direct electric heating in low-demand properties not on the

		provided through heat pumps rather than direct electric appliances. However, the capital costs of heat pumps mean that it may be more effective to use direct electric heating in properties with very low heat demand. The role for electric heating is fairly uncertain in this scenario and reflected in a medium level of risk.	gas grid. As such, this heat decarbonisation pathway suggests only a limited role for electric heaters for space heating and sees this sector as high risk. There may be some opportunities in niche applications and possibly in properties not on the gas grid.
Fire places and stoves	This sector manufactures fire places and stoves.	Under this pathway, in a world of low demand and electrified heating the role for gas fires and wood bruning stoves would be very low, particularly if biomass resource is being used by industry and is not available for stoves. In this scenario the risk for this sub-sector from heat decarbonisation is seen to be high.	In any low-carbon scenario, if biomass is being used by industry, its use for space heating may be limited and so the use of biomass stoves would also be limited. For companies manufacturing gas fires, if the grid was converted to hydrogen, these fires would need to be made suitable to burn hydrogen. Because of these complexities, this sector is seen to be at medium risk from heat decarbonisation under this scenario.
Gas boilers	This sub-sector manufacturers gas boilers.	Under this pathway, no unabated gas is expected to be used for heat in 2050 and there would therefore be no requirement for gas boilers. This pathway therefore represents a major risk	If the UK were to move towards hydrogen, gas boilers would still likely be needed however, these would need to be replaced in order to be able to burn hydrogen. It may also be that more efficient systems

		to boiler manufacturers. However, there would be significant growth in other heat technologies offering some potential growth opportunities within this sector if companies diversify. One important area of growth would be for heat exchanges used for buildings connected to the districh heat networks.	such as CHP systems are used in order to optimise the use of hydrogen. Because of this change, this pathway offers some risk for this sector but also offers some opportunities.
Heat pumps	This sub-sector manufacturers heat pumps.	Under this pathway, the number of heat pumps is expected to increase significantly at a household level and the use of heat pumps connected to district heating schemes is also likely to increase. This pathway is therefore very low risk for the heat pump industry.	The role for heat pumps on homes connected to the gas grid is limited in this scenario as these homes will use hydrogen. However, for those off the gas grid, there may be significant growth opportunities for heat pumps in order to decarbonise this sector.
Metering	This sector includes companies who manufacture, install and operate metering equipment.	In either pathway, there will still be a role for metering however the volume and type of meters may change. In this pathway, the role of gas meters would disappear as consumers no longer use gas and either use electricity for heating or are connected to district heat networks. Because of this uncertainty, we believe	This pathway implies little change for metering from current practices. Therefore the risk to this sector is low.

		this sector has some risk.	
Micro-CHP	This sector manufactures appliances which, at a small often building scale, produce heat and electricity simultaneously in order to increase efficiency.	Micro-CHP units tend to rely on solid or gaseous fuels and so in this pathway where heating is to be decarbonised using heat pumps or district heat networks, the role of CHP is very limited. This heat decarbonisation pathway would not therefore see any role for micro-CHP and is therefore high risk for the sub-sector.	Under this scenario it's generally expected that the main appliances using hydrogen will be boilers however, it may make sense to use CHP systems to maximise system benefits. There is some potential role for micro-CHP in this scenario but it is very uncertain and so the risk for this sub-sector from heat decarbonisation is high. While there may be some opportunities, these appear unknown.
Non-domestic heating products	This sector produces appliances and equipment for the non-domestic heat sectors such as large boilers, burners and industrial heaters.	The shape of this sector under either pathway is complex. For space and hot water heating, this sub-sector is likely to mirror the domestic sector where gas and fossil fuel using products are eliminated in this scenario. For industrial heat uses, the role of non-domestic heating product manufacturers depends very much on to what extent and how industrial heat is decarbonised. Because of this complexity and uncertainty, we ascribe a medium level of risk to this sector from heat decarbonisation under this pathway.	The shape of this sector under either pathway is complex. Under this pathway, for space and hot water heating, the use of hydrogen for space and hot water heating in the non-domestic sector implies changes to the type of appliances used to provide heat so that they are suitable for using hydrogen. For industrial heat uses, the role of non-domestic heating product manufacturers depends very much on to what extent and how industrial heat is decarbonised. Because of this complexity and uncertainty, we ascribe a medium level of risk

		There are potential risks and opportunities.	to this sector from heat decarbonisation under this pathway. There are potential risks and opportunities.
Oil boilers	This sector manufactures boilers which combust oil to produce heat.	Neither pathway envisages a role for oil boilers due to the carbon intensity of oil. Therefore, this sector is at high risk from either decarbonisation pathway.	Neither pathway envisages a role for oil boilers due to the carbon intensity of oil. Therefore, this sector is at high risk from either decarbonisation pathway.
Plumbing and heating supplies	This sector manufactures and sells equipment associated with heating systems such as pipework, filters and flues.	In either scenario there will still be a market for plumbing and heating supplies manufactured and sold by this sector. However, under this pathway there will be a more limited role for gas related equipment and so the risks across this sub-sector are not homogenous. Therefore we believe this pathway offers some risk to the plumbing and heating supply sector.	In either scenario, there will still be a market for plumbing and heating supplies manufactured and sold by the sector. For the on gas grid sector, hydrogen conversion would likely mean little change for the sector however for the off gas grid, the move to greater levels of heat pumps would suggest a greater role for heat pump related products and fewer oil related products. Therefore we believe this pathway offers some risk to the plumbing and heating supply sector but also has significant opportunities.
Radiators	This sector manufactures wet radiators used to distribute heat.	In either scenario, radiators are still expected to be required and so this pathway offers little risk to radiator manufacturers.	In either scenario, radiators are still expected to be required and so this pathway offers little risk to radiator manufacturers.

Solar thermal	This sector manufactures equipment which produces heat from solar irradiation.	The role of solar thermal systems is uncertain in either pathway however is likely to play a role in pathway one as it can be combined with heat pump systems to provide distributed and very low-carbon heat. The uncertainty however means that this decarbonisation pathway implies a medium level of risk for this sub-sector.	The role of solar thermal systems is uncertain in either pathway however in this more centralised heat pathway its role is particularly uncertain. This uncertainty means that this decarbonisation pathway implies a medium level of risk for this sub-sector.
Water heaters	This sub-sector produces appliances which use electricity to directly heat water.	The majority of hot water in this pathway is expected to be produced using heat pumps or via district heating systems. However, in buildings with very low heat demand, water heaters could be used where no heat pump or district heat connection is present. This decarbonisation pathway therefore offers some risk and opportunities for growth to the water heater industry.	The majority of hot water in this pathway is expected to be produced using hydrogen or heat pumps in off-gas grid areas. However, in buildings with very low heat demand, water heaters could be used where no heat pump or gas connection is available. This decarbonisation pathway therefore offers some risk and opportunities for growth to the water heater industry.

5.4. Installation and maintenance

This sector is involved with the installation and maintenance of heating appliances and heating systems. For the sake of our research, it has been split into two sub-sectors, low-carbon heat installers and plumbers and engineers who install and maintain higher carbon heating systems. Within this sector there are many hundreds of companies and many of these operate at a very small scale. We have not investigated this sector in detail as part of the mapping because it is such a large and diverse sector although we appreciate the importance of this sector for the move towards low-carbon heating. Table 7 considers the sub-sectors in more detail.

Table 7. Risks and opportunities of a move towards low-carbon heating for the heat system installation and maintenance sector

Sub-sector	Description of sector's interest in heat	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
Low-carbon heat installers	The sector installs and maintains low-carbon heating appliances such as heat pumps, biomass boilers and solar thermal systems.	Under this pathway, major growth in the use of decentralised low-carbon heating systems is expected and so the installation sector would be expected to grow with it. This pathway therefore offers low-risk for the sector.	Under this scenario, while the gas grid would see conversion to hydrogen, in order to decarbonise off-grid areas, the growth in low-carbon installations off the gas grid are still likely to be required and so the low-carbon heat installers would see some growth. This pathway therefore offers growth potential and medium risk for the sector.
Plumbers and engineers	This sub-sector is formed of the companies which install and maintain wet central heating systems which are primarily gas based.	Under this scenario because of major changes in heating systems, existing plumbers and engineers would need to re-skill in order to fit low-carbon heating systems. This would represent a major change and offer high risks for this sector.	If gas networks were converted to hydrogen and hydrogen boilers used in people's homes then it seems likely that the current role of plumbers and gas engineers would be maintained but they would be servicing and installing hydrogen boilers. This pathway is therefore low risk for the plumbing and heating engineer sub-sector.

5.5. LPG (Liquified Petroleum Gas)

Despite being a relatively small sector providing heat for only around 190,000 homes and some businesses not on the gas grid (UK LPG, 2017a), the LPG sector emerged as a major sector in the mapping exercise, possibly due to the sector having its own trade association. From the mapping exercise, 4 sub-sectors for the sector emerged, however, due to the small scale of the sector, we consider the risks and opportunities for the sector overall and these are shown in Table 8.

Table 8. Risks and opportunities of a move towards low-carbon heating for the LPG sector

Sub-sector	Description of sector's interest in heat	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
N/A	This sector produces, transports and retails liquefied petroleum gas and also manufactures, installs and maintains the equipment used to combust LPG to produce heat.	In either pathway, because of the high carbon content of LPG, it is not seen to have a role in a low-carbon heat system. While there is the potential to use bio-LPG fuel, there is great uncertainty over availability and optimum use. This sector faces a very high risk from heat decarbonisation.	In either pathway, because of the high carbon content of LPG, it is not seen to have a role in a low-carbon heat system. While there is the potential to use bio-LPG fuels, there is great uncertainty over availability and optimum use. This sector faces a very high risk from heat decarbonisation.

5.6. Suppliers

The supply sector currently retails electricity to nearly all homes and buildings and gas to around 83% of homes in GB (Consumer Focus, 2013). Table 9 shows the risks and opportunities for the sub-sectors of supply under the two identified heat decarbonisation pathways.

Table 9. Risks and opportunities of a move towards low-carbon heating for the supply sector

Sub-sector	Description of sector's interest in heat	Risks and opportunities under pathway 1 – decentralised low-carbon heat	Risks and opportunities under pathway 2 – centralised hydrogen production
Domestic supply	This sub-sector currently sells gas	Because of the major reduction in gas use	Under this pathway, for on gas grid areas which

including Big 6	and electricity to all homes connected to the electricity and gas grid.	proposed under this pathway associated with the move towards decentralised heat supply, sales of gas for heat would be expected to reduce to near zero levels. However, in this scenario, volumes of electricity sold would be expected to increase significantly in order to power heat pump systems. The major changes associated with pathways means that it represents a high risk to domestic energy suppliers. It is however recognised that there may be significant opportunities for growth and diversification.	would switch to hydrogen, it is very unclear who the suppliers would be and how they may operate and this represents a high level of risk. For off-gas grid areas moving towards heat pumps, it's likely that the required level of electricity would rise, increasing volumes of electricity sold. The major changes associated with pathways means that it represents a high risk to domestic energy suppliers. It is however recognised that there may be significant opportunities for growth and diversification.
Non-domestic supply	This sector sells gas and electricity to commercial and industrial energy users.	For space and hot water heating, this scenario is very similar as that for domestic consumers, sales of gas would be expected to reduce and sales of electricity to increase. For industrial users of heat, the pathway is unclear and so the uncertainty associated with the major changes for space and hot water heating mean that this pathway represents a high risk for non-domestic energy suppliers.	For space and hot water heating, this scenario is very similar as that for domestic consumers. There are likely to be increased volumes of electricity sales to power heat pumps for those off the gas grid but the situation regarding who produces and sells hydrogen is very unclear. For industrial users of heat, the pathway is also unclear and so the uncertainty associated with the major changes for space and hot water heating mean that this pathway represents a high risk

			for non-domestic energy suppliers.
Oil supply	This sector supplies oil used for space and hot water heating.	In either scenario, this sub-sector is at high risk from heat decarbonisation due to the high carbon emissions associated with burning oil for heat. While liquid biofuels could replace some fossil oil, the availability and optimum use of bio-resources is very uncertain. This pathway represents a high risk for the oil supply sub-sector.	In either scenario, this sub-sector is at high risk from heat decarbonisation due to the high carbon emissions associated with burning oil for heat. While liquid biofuels could replace some fossil oil, the availability and optimum use of bio-resources is very uncertain. This pathway represents a high risk for the oil supply sub-sector.

5.7. Transportation

Through the mapping exercise this sector emerged as a major sector and is responsible of the transportation of energy used for heating in the UK heat system. Whether each sub-sector faces a risk or opportunity as a result of decarbonisation varies significantly between sector and by pathway and each sub-sector is considered in further detail in Table 10.

Table 10. Risks and opportunities of a move towards low-carbon heating for the transportation sector

Sub-sector	**Description of sector's interest in heat**	**Risks and opportunities under pathway 1 – decentralised low-carbon heat**	**Risks and opportunities under pathway 2 – centralised hydrogen production**
District heating and district heat generation	This sub-sector is involved in the development, ownership or operation of district heating systems and the associate heat generation facilities. It is currently relatively small and is	In this pathway, there is a major role for district heating specifically in urban areas and therefore this pathway suggests growth for the sector and is therefore low risk and high opportunity.	In this pathway, if the gas grid is converted to hydrogen, the role for district heating would be limited as urban areas would be covered by gas networks supplied by hydrogen. This pathway is high risk for the district heating sector.

	therefore not broken down into greater levels of detail.		
Electricity networks	These networks transport electricity to homes and businesses, some of which is used for heat.	Under this pathway, with the major expansion of the use of heat pumps, the electricity networks would be expected to grow significantly and so this pathway is low-risk for the electricity networks in the sense that it would require major growth in electricity infrastructure.	Under this pathway, although the on-gas sector would be converted to hydrogen, it is likely that there would still be significant growth in the electricity networks as areas off the gas grid move towards low carbon heat provided by heat pumps requiring electricity to run. This pathway is therefore low-risk for the electricity networks from a heat perspective.
Electricity network products	This sub-sector provides the equipment for the construction and maintenance of electricity networks.	As the scale of the electricity networks increases under this scenario, the requirement for products and equipment for the networks also increases. This pathway is therefore low-risk for this sub-sector.	As the scale of the electricity networks increases under this scenario, the requirement for products and equipment for the networks also increases. This pathway is therefore low-risk for this sub-sector.
Engineering and construction	This sub-sector supports the development and construction of various different networks.	Under this scenario, the growth of district heating and electricity network capacity would require a significant role for the engineering and construction sub-sector. This pathway is low-risk for the sector and has significant opportunities for growth.	Under this scenario the development of new networks is limited although there may be some growth in electricity networks in off gas grid areas. The uncertainty of this scenario offers some risk for the engineering and construction sector.
Gas networks	This sub-sector owns and operates	Under this pathway, there would be a very	Under this scenario the gas networks are

	the gas networks which transport natural gas to homes and buildings for heat.	limited role for the gas networks in providing heat in a decarbonised heat system. This pathway represents a major risk to the gas networks. It is possible that the gas networks could diversify and use their expertise into networks for the development of district heating.	maintained and used for hydrogen transportation. However, the operation of the gas networks would need to change significantly to accommodate hydrogen and this could have major impacts on market structure. This pathway therefore offers some risk for the gas networks.
Pipeline products	This sector provides pipeline products for the transportation of gas in the case of gas networks or for the transportation of hot water and steam in the case of district heating networks.	In this scenario, the requirement for gas network products would be reduced but the need for district heating network products would be increased. The transformation low-carbon heat under this scenario would have heterogeneous impacts for different aspects of this sub-sector therefore creating some risks and some opportunities.	In this scenario, the requirement for district heat products would be reduced, but as gas networks would be maintained there would still be a need for gas network products. The transformation low-carbon heat under this scenario would have heterogeneous impacts for different aspects of this sub-sector therefore creating some risk.

5.8. Chapter conclusions

In this chapter we have used a risk analysis approach to combine our insights from the heat sector mapping exercise in section 4 alongside our understandings of scenarios and pathways for low-carbon heat in the UK. Businesses in the heat system were considered by sector and sub-sector alongside two scenarios for low carbon heat, one which envisages a primarily electric, decentralised and low-heat demand future and another which considers a centralised scenario where the gas network is converted to low-carbon hydrogen.

We have considered each business sector and the sub-sector within it alongside the two pathways, considering what each pathway means for each of the sub-sectors.

For each section, we have summarised our thoughts on the risks and opportunities and allocated a level of risk for each sub-sector under the pathways.

For all sectors, there is some risk associated with the move towards low-carbon heating because of the significant level of change required and this is the similar under both pathways. However, where the risk lies varies significantly between scenarios and sectors. It is not possible to summarise the complexity of where the risks sit however it is possible to draw out some very basic observations on the differences between the scenarios.

Quite simply, as would be expected, pathway 1 which represents a major change away from using gas as an energy vector offers a much higher risk to the large incumbent companies including gas networks and gas boiler manufacturers. It offers much lower risk and much greater opportunities to those sectors involved in the electric heat sector such as electricity networks and electric heating appliance manufacturers. Because of the significant risk posed to incumbent gas interested companies by pathway 1, we hypothesize that those companies and sectors put at risk by pathway 1 are likely to be unsupportive or potentially opposed to this pathway. This includes coal, oil and gas producers, gas and oil appliance manufacturers, the LPG industry, energy suppliers and gas networks. This is a hypothesis we explore in further detail in our upcoming working paper which considers the behaviour of incumbents.

However pathway 2, which maintains the gas system but sees it converted to hydrogen, offers a reduced risk to the some incumbent companies and their associated sectors. Specifically, gas boiler and appliance manufacturers and gas networks see much lower levels of risk under this pathway and therefore we hypothesize that these sectors may be supportive of this pathway rather than pathway 1. It is however recognised that the level of change required to convert the gas grid to low-carbon gas also creates significant risk for the incumbent gas companies.

Finally it is worth noting that certain sectors are at risk as a result of both pathways and other sectors may see significant opportunities in both pathways. The highest carbon heat technologies, coal, oil and LPG are at major risk from either decarbonisation pathway and as a result of the significant change in both pathways, energy suppliers are seen to be at risk from either pathway. We therefore hypothesize that these sectors are likely to be opposed to both pathways. Conversely, there are sectors which do not appear to face any significant risks from pathways including electricity networks, radiator manufacturers, heat pump manufacturers (who will still benefit from changes off the gas grid), data and communication firms and biomass producers. We therefore expect these sectors to have only limited interest or engagement around heat decarbonisation issues.

Based on our mapping exercise, we also hypothesize that the largest companies and sectors put at risk by decarbonisation may be the most involved in lobbying, innovation and investment associated with heat decarbonisation. These actors including gas producers, gas and oil boiler manufacturers, gas networks, energy suppliers and the LPG sector have both the most to lose and the greatest capacity to affect system change.

We believe this risk analysis has significant value for policy makers and the development of low carbon heat policy and Governance. It indicates the potential impacts of the two decarbonisation pathways on particular sectors and in doing so identifies those companies most at risk from each decarbonisation pathway. The value for policy makers is in the identification of where potential growth opportunities are and where major sectors are at risk as this could link to UK industrial strategy. Specifically for policy makers working on heat decarbonisation the risk analysis also indicates the vested interests of each sector identifying which sectors may attempt to influence the development of heat policy and regulation in order to protect their interests.

6. Working paper conclusions

For the development of this working paper we have carried out three main tasks which we hope will inform the debate around the UK's move towards low-carbon heating. The final task was dependent on the outputs of the previous tasks.

We have firstly considered the reasons for why change in the UK heat sector is needed and shown that there are two key pathways currently seen to be important for delivering a low-carbon heat system in the UK, one based around a decentralised, low-demand, primarily electrically powered heat system (pathway 1) and another currently novel idea for a pathway based around decarbonising the gas grid using low-carbon hydrogen while using electric forms of heat off the gas grid (pathway 2). We have also considered the potential changes required for industrial energy and heat demand in the UK. The development of the two pathways for heat system decarbonisation has been vital for the risk analysis aspect of the paper. It has identified what are seen to be two key options to decarbonise the UK heat sector and then based on these pathways has allowed analysis which considers how heat business sectors may be affected by decarbonisation under each potential pathway.

Secondly, we have developed a sectoral map of the businesses active in the UK's heat sector. This map shines light on a very important but often neglected aspect of the energy system in the UK, giving an idea not just of the shape of the sector and the companies present but also an idea of the size and value of the sector. This map should be of value to those working in the sector, particularly those involved in the regulatory, policy and economic aspects of decarbonisation policy. For this paper the map has been particularly important for determining the sectors on which the risk and opportunity analysis has been based.

Finally, based on the development of the company and sectoral map and the development of the two decarbonisation scenarios we have carried out a risk analysis of each of the sub-sectors under the two identified decarbonisation pathways to consider the risks and opportunities for business sectors operating in the UK heat sector. This analysis has shown that there are major differences in the levels of risk posed by the two potential decarbonisation pathways for each sub-sector. For companies heavily invested in gas such as gas networks and appliance manufacturers, pathway 1 represents a high risk pathway whereas pathway 2 is a lower risk pathway for the gas interested incumbents. There are also companies which would see increased risk as a result of both pathways such as energy suppliers and those involved in oil, coal and LPG heating. Finally, some sectors identified from the mapping are not seen to be at risk by either pathway.

We believe that the risk and opportunity analysis will have significant value for policy makers interested in heat decarbonisation and in the energy aspects of UK industrial strategy. In highlighting the threats and opportunities posed to businesses by decarbonisation it shows where opportunities for growth lie and also indicates the vested interests of actors in promoting particular pathways for heat decarbonisation.

Based on the risk and opportunity analysis, we have developed a number of hypotheses.

H1: Incumbents put at risk by pathway 1 are expected to be opposed to this pathway

H2: Incumbents who see reduced risk as a result of pathway 2 are expected to be supportive of this pathway

H3: Incumbents put at risk by both pathways are expected to be opposed to both pathways

H4: The largest sectors put at risk by decarbonisation are expected to be the most active in their engagement around heat decarbonisation policy, innovation and investment

Building on this analysis and the associated conclusions and hypotheses, the next and final stage of the project will consider the behaviour of the incumbent interests in the sectors identified in the mapping exercise in light of the risks posed to them by decarbonisation. We expect the final working paper of the project to be released in May 2018.

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Annex 1 – Further information regarding the choice of mapping software

6.1. Choosing appropriate mapping software

The first task was to choose a suitable mapping tool or software to present our map of UK heat sector businesses. We were looking for a tool that provided a balance of aesthetics and potential for manual modification that would be easy to access and share.

The first required task was to search for and choose appropriate software to use for the actual mapping. In the project team we had experience of VUE (Visual Understanding Experience) as well as knowledge of Microsoft Visio. However we knew from our experience that VUE was relatively simple and required the manual placing of map nodes and that Microsoft Visio was primarily for flow diagrams and organisational charts.

We therefore undertook an online review of potential mapping software in order to discover other options for mapping software which may be suitable for the project. There is a very wide number of options for online mapping tools. The most potentially useful mapping tools are shown in Table 11 which gives the name of the software, its source and also considers the positives and negatives of each option. This careful approach was used as it became clear that once an option had been chosen and time was invested into that mapping tool, time was invested into both learning how to use the tool but also in shaping the data which once collated, may not be in a useful format for use in other models. We would effectively be locked in to a particular mapping tool.

Table 11. Potential mapping software options discovered through online searches shown with the positives and negatives of each option

Mapping tool	Available from	Positives	Negatives
VUE (Visual Understanding Environment)	http://vue.tufts.edu/	• Prior knowledge and experience • Free • Simple • Easily modifiable	• Not aesthetically pleasing • Limited in that it's just nodes which cannot be manipulated depending on variables • Not interactive • Not possible to host online
Kumu	https://kumu.io	• Aesthetically good	• More complicated • Unknown

		• Can be used to produce presentations • Interactive • Can highlight different sectors and attributes • Can drag data straight from excel	• Some costs • Will require some time to practice • More network based, possibility of software obsolescence
Microsoft Visio	www.microsoft.com/UK/visio	• Free • Relatively simple • Some interactivity i.e. you can expand nodes and find more information • Can be shared online subject to some limits	• More focused on flow charts and diagrams
Gephi	https://gephi.org/features/	• Very visual • Multi layers	• Very complex • More for quantitative visualisation
Compendium by OU	http://www.compendiumng.org/	• Free • UK based (Open University) • Quite simple	• Not aesthetically good • Similar to VUE • More for connections and information rather than a map • Primarily for flow diagrams • Not fully interactive
Y ed	http://www.yworks.com/products/yed/gallery	• Free • Relatively straightforward	• Not aesthetically good • More diagrammatic rather than map based
Coggle	https://coggle.it/	• Free • Aesthetically OK	• Simplistic • Similar to Vue
3D Topiscape	http://www.topicscape.com/	• Aesthetically good	• Paid for • Only useful for relatively simplistic inputs • Looks dated

After considering the options, we eventually chose Kumu as our mapping software. Kumu was founded and is still located on Oahu Island, Hawaii and makes a profit from subscriptions to the software. In our case, because we are using the software to produce a map which will be publically accessible, Kumu is free of charge to use although there is a small charge for exporting PDFs of maps from the site.

Kumu is hosted online and fully cloud based. All editing is done by opening the Kumu website on a web browser and the maps can be accessed via the website either as a standalone page, or embedded into other webpages. This means that the map can be easily shared and is widely accessible. Kumu is also aesthetically pleasing and auto-sorts the shape of maps based on the connections between different nodes. The Kumu tool also allows map nodes to be sized and coloured based on different variables, an ability we wanted in order to size the different nodes which represent each company, in a way which was linked to the size of the company. It also allows nodes to be coloured depending on certain characteristics and for extra information to be ascribed to nodes, i.e. you can click on a company and information about the company can be displayed.

We felt that Kumu offered the correct balance between complexity and aesthetics and was able to offer all of the functions we needed for our mapping exercise. The software also allowed the map data (minus aesthetic editing) to be downloaded in the form of a Microsoft Excel 'xlsx' file. It also allowed maps to be produced by uploading an 'xlsx' file to the website. This gave a great level of flexibility, allowing data to be collated in Excel and then uploaded to the mapping tool. Our key concern was that during the course of the project the company may fold or the software may become obsolete and so we used the Excel export function frequently in order to back up the underlying map data.

Annex 2 – Additional information regarding companies included/excluded from mapping

- From Energy and Utilities Alliance members downloaded in October 2016, **removed** companies are:
  - Amec Foster Wheeler, not a heat focus
  - BFM, no record
  - BSI group, not relevant
  - Burdens, contractors, not relevant
  - BUSS metering, no info on website
  - ByBox, nothing relevant
  - Centrica Storage, not heat
  - Co op energy, may be on supplier list
  - D I UK. No record
  - Deep water blue, not related
  - Develop training – not related
  - Elgin, roadworks
  - Encore personell – recruitment
  - Fabdec – not related
  - G4S
  - Gateway storage company – storage in Ireland
  - Harvey water softeners
  - I.E chp, due to be liquidated
  - IVECO: trucks
  - Lightsout computer services – IT
  - Monarch water – water softening
  - PQMS training – training
  - UTL – Asset management
- From ICOM membership, very similar to EUA but missing somewhich have been **added** to map:
  - Andrews water heaters
  - Deep water blue limited (not added as water treatment)
  - Dravo
  - Potterton commercial
- From UKLPG, these have **not** been included:
  - Not included 'Assured Solutions' as cleaning products
  - Not Autogas Ltd – transport
  - Ballymar Gas Ltd – No website so presumably small

- Beta gas, no online info
- Canal and River Trust bat safety scheme
- Cardonal college trading as Glasgow clyde college
- Coleman, Camping people
- Express Pipework Systems – no heat interest
- FG Gas Engineering – no website
- Finch consulting – couldn't find a firm of that name with a heat interest
- Gas Con – Small consultancy, not specifically heat
- Gas Safe Consultants – not specifically heat
- Gaulds Gas, no web information
- GSE Systems, not heating related
- JD Lindley – no website
- LPG Energy Ltd – no website
- LPG Engineering Ltd – no website
- LPG Inspection Services – no website
- Meridian Electrical Eastern LtD – Transport focus
- MJV Gas and Heating – small heating engineer
- MNLPG – no website
- National Grid Metering – Part of National Grid
- ND Brown – road transport
- North West Refurb – no website
- Park Home Insulations – Not heat generation
- Pen Underwriting Ltd – Insurance
- Petrotec Services – tank cleaning and maintenance
- Portable Gas Supplies – no website
- PGS Training – gas safety training, not heating
- Proteus Equipment, road-works related
- Recovercyl – no website
- Samia Haddad Independent LPG Consultancy – no website
- Seeco – no related website
- SJI LPG Engineering – no website
- South West Peninsular Training – training and not heat specific
- SSE metering, already part of SSE included already
- Trimetals – metal storage units
- Warwickshire College – not heat related
- Westfield LPG – transport focused
- William Kellett and Sons – no website

- ENA Membership
    - Included Ireland Gas Networks which covers North and South Ireland
    - ESB Networks not inlcuded as only Republic of Ireland according to ENA map
    - Have not included associates which are Channel Islands, rail and airports
- UKDEA
    - Just including full members, not associates
    - Not including local authorities as project is business focused
    - Included GTC already as independent networks
    - EON already included as a supplier
- REA membership – too big to include, 500 plus members and mostly small and sustainable
- Energy UK members not included
    - Not AES, power gen only
    - Allen and Overy, Lawyers
    - Alstom, Trains
    - APX Spot Exchange – electricity
    - British Gas – Already include
    - British Hydropower Association, electricity only
    - Burglass Energy Advisory – electricity focus
    - Calon Energy – Electricity generation
    - Carron Energy – Electricity generation
    - Centrica – Included
    - CGI – No heat interest
    - Chibu Electric Power electricity generation
    - CLP Power – Electricity Generation
    - Corby Power – Electricity generation
    - CRF Hydropower – electricity generation
    - Deloitte– Accountants
    - DNV GL – Already included
    - Dong 0 Electricity Generation
    - Doosan power –electricity generation
    - Drax – electricity generation
    - Eon – Already Included
    - EAGA – Charity
    - EDF – Already Included
    - ESB – Only electricity in UK

- Electroroute – power
- Elexon – electricity
- Energy Helpline – not heat
- Energylinx – switching
- Enernoc – data
- Engie – already included
- EP Invest – power only
- ESCP – research body
- EY – Accountants
- Fichtner – electricity engineering consultancy
- Flow Energy – Smart products
- Garbhaig Hydro Power Company – Electricity generation
- GE – Electricity focus
- Gentrack – software
- Green Frog Power – Electricity generation
- Guernsey Electricity – Electricity generation
- Haven Power – Electricity Generation
- Horizon Power – electricity Generation
- IBM – IT
- Intergen – major projects
- Interim partners – management consultants
- Jersey Electricity Company – Electricity
- Latcham Direct – Customer Communications
- Local Waste Solutions – Waste
- Lynemouth Power – Power generation
- Manx Utilities – Not gas or heat
- Marsh – Insurance and risk
- Met Office – Weather
- Mott Macdonald – consultancy but not heat
- National Grid – Already Included
- Nord Pool – Power market
- North Connect – Interconnector
- Nuclear Decomissioning Authority – Nuclear
- NuScale Power – Nuclear
- Osaka Gas UK – Oil development
- Partnerships for Renewables – Onshore wind
- Poyry – Management consultants
- PwC – Accountants

- RES – Electricity only
- RSK – Consultancy
- Ruddle Merz – Consultancy
- RWE npower – already included
- Scottish Power – already included
- Sener engineering – not heat
- SGN – Already included
- Smartest Energy – Electricity focus
- SQS Group – IT Consultancy
- SSE – already included
- Stag Energy – Electricity
- Statoil – already included
- TGC Renewables – Electricity
- Tidal Lagoon Power – Electricity
- Tokyo Electric Power – Electricity
- Trilliant – electricity focus
- UK Power reserve – primarily electricity
- Utilitywise – supply consultancy
- Vitol – upstream energy markets
- Vivid economics – economics consultancy
- Vuepoint Solutions – utility softward
- Wood Mackensie – Energy consultancy and analysis

Annex 3 – Further information on company size

This annex provides some more detail on the collation and use of company size data as part of the business mapping process.

1. To ensure accuracy, random company size data from Endole (who gather company size data) was cross referenced with Companies House records to check for errors in the collating process; no discrepancies were found. Although gathered in 2017, the data used was from financial year 15/16 due to the data collection being carried out in the months running up the end of financial year 16/17.
2. Some gaps in the data are present as UK law does not require that small companies (either >£10.2 million turnover, >£1.5million balance sheet total or >50 employees) have to report all information (HM Government, 2006). There was also limited information regarding companies headquartered abroad.
3. The company size data were analysed to consider whether there were statistically significant relationships between the metrics considered. Regression analysis showed a statistically significant (>95% confidence) relationship between market value and number of employees and a statistically significant relationship between market value and company turnover. This relationship gives us both confidence in the data and allows us to use market value as the key ranking criteria for further development. The research also delivered the greatest number of data points for market value. Of the 421 companies researched, market value data was available for 311, turnover data for 198 and number of employees for 185. Because of the relationship between market value and number of staff and market value and turnover, for further analysis of company size this correlation also suggests that market value data alone could be collected as this on its own is representative of other aspects of company size and this would reduce the time taken to collate data.

Annex 4- Steps used to format map

1. Kumu was used in ‘Stakeholder map’ mode
2. A map description and basic instructions were added
3. Company nodes were sized based on their size ranking using the allocated ranking group with smallest companies being the smallest and largest companies being the largest
4. Major sectors and sub-sectors were made larger and coloured black to make them stand out
5. Trade associations and trade bodies were coloured purple
6. Companies were coloured based on their interest in low-carbon heat with no interest as red, some interest as amber and full interest as green.