Heat Networks

A Critical evaluation of customer experience, the market and technology, as background to the BEIS consultation, "Heat Networks: Building a Market Framework"

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Executive Summary

Heat networks distribute thermal energy in the form of steam, hot water or chilled liquids from a central source of production through a network of pipes to multiple properties for the use of heating, cooling or hot water. A "District heat network" is defined by legislation as the distribution of heat to multiple buildings or sites and a "Communal heat network" is defined as the distribution of heat to multiple dwellings in a single building.

In 2015 the Committee on Climate Change (CCC) estimated that around 18% of UK heat will need to come from heat networks, which would be almost 6 million households. In the UK there are currently approximately 480,000 customers spread across around 12,000 communal heat networks (serving only one building) and 2,000 district heat networks (serving multiple buildings).

To promote heat networks, the government's Heat Network Delivery Unit (HNDU) provides practical support to local authorities and project developers in the early phases of scheme development. In 2015, the UK Government announced £320m of funding through the Heat Network Investment Project (HNIP), with a view to delivering up to £2 billion in new investment, and support is also being given by the Scottish government. BEIS supports using local planning powers to force compulsory connection, through zoning, concession arrangements, and mandated connections.

Research by the Competition and Markets Authority (CMA), by the consumer advocacy organisation, Which?, and by Citizens' Advice all reveal that the current experience of heat networks is poor. A significant minority of customers face higher heating bills compared to domestic gas consumers; there are more interruptions of supply; and inferior customer service. Heat network customers are significantly more likely to be retired, classified as vulnerable, and identifying themselves as financially precarious than the general population. 88% of networks do not allow customers to disconnect.

The push from BEIS to encourage a decarbonisation of heat networks will lower the average efficiency of the sector; because currently most heat networks are supplied by gas, with 64% of larger systems using Combined Heat and Power cogeneration (CHP). When heat networks employ other technology then costs to customers can be expected to rise.

CMA identifies a very crowded stakeholder landscape; and the conflicting interests between property developers, energy supply companies (ESCOs), local authorities and tenants; as acting to the disadvantage of customers. Currently the market is unregulated, except that since 2014 there are some mandatory requirements around metering and billing for new systems

Heat networks have high market penetration in some countries, for example, Denmark and the Netherlands. In the Netherlands, customer prices are capped at the reference price of domestic gas heating.

BEIS is proposing a regulatory regime that is inferior to the licencing arrangements for the gas and electricity markets. Although the fractured stakeholder landscape is identified as a key contributor to poor outcomes, they are proposing a regulation model that preserves that dysfunctionality.

They are also proposing to use significant government subsidies, and local authority planning compulsion to mandate people to connect to heat networks. A high proportion of those who face such compulsion will be social housing tenants, so the pattern of heat network customers being disproportionately more likely to be vulnerable or in difficult circumstances will be perpetuated.

When properly designed, correctly dimensioned, implemented to professional standards and efficiently run, heat networks can provide good, and cost-effective outcomes. 64% of UK district networks use gas fired CHP (also known as cogeneration), and technically, CHP, especially from gas, is extraordinarily efficient. This report will use the terms CHP and cogeneration interchangeably, as that follows the literature.

However, in addition to seeking to grow the heat network sector, the government's objective is to simultaneously decarbonise the heat networks themselves. The efficacy of such decarbonisation is assumed by BEIS, but not clearly substantiated, There seem to be unchallenged assumptions about the renewable electricity capacity, and fundamentally, the operating principles of heat pumps do not seem to be clearly understood by many in the sector. BEIS is proposing that ambient ground loops, a form of shared but small district heat network, relying upon ground source heat pumps, should be excluded from regulation. This is the part of the heat network sector most likely to directly compete with domestic gas for new build private sector property, and there seems to be no reasoned case for its exclusion from regulation and technical standards.

There are two separate, relevant issues under consultation: regulation and standards. In principle the regulatory regime should not offer weaker protection for customers of heat networks than enjoyed by customers of domestic gas.

With regard to technical standards, the sector is more diverse than the domestic gas heating industry. Some useful work has already been done by trade bodies, but the government should promote a path to a formal British Standard. Some smaller manufacturers seem to be concerned about bearing the costs of standardisation.

Requiring all heat networks to be authorised on the basis of standards compliance provides the opportunity for authorisation to also be based upon substantiation of their decarbonisation credentials. There is some useful technical guidance from the EU's standards body, CENELEC, on how this can be done for cogenerations systems. Professor Marc Rosen, an academic expert on district heating, and former president of the Engineering Institute of Canada, has proposed a mechanism of thermodynamic analysis for heat networks.

Part One: Understanding heat networks

Background

In the UK there are approximately 480,000 customers spread across around 12,000 communal heat networks (serving only one building) and 2,000 district heat networks (serving multiple buildings). Legislation [1] defines a "District heat network" as the distribution of heat from a central source of production through a network to multiple buildings or sites and a "Communal heat network" as the distribution of heat from a central source to multiple dwellings in a single building.[2]

In 2015 the Committee on Climate Change (CCC) estimated that around 18% of UK heat will need to come from heat networks by 2050 if the UK is to meet its carbon targets cost-effectively. Up to £16 billion of capital investment in heat networks is likely to be needed to deliver such growth. [3] In 2018, there were 27.6 million households, an increase of 350,000 on the previous year, [4] assuming linear growth to 2050 would give a projected number of 33.2 million households by the middle of the century. 18% of that projected total would be almost 6 million households.

District Heat Networks have a long history; with the first recorded systems in Ancient Rome, where hot water distribution systems supplied heat to baths and greenhouses.[5] The first commercial district heating scheme was introduced in Lockport, New York, in 1877.[6] For the purpose of both economic viability, and minimisation of environmental impact, district heating is typically linked with cogeneration, sometimes called combined heat and power (CHP), which improves the efficiency of energy produced, as it produces more useable energy (electricity and heat) from less fuel.[7] As the BEIS consultation document states, most heat networks currently in the UK are fuelled by natural gas (Methane) CHPs.[8] The BEIS survey of 2013[9] indicates that this is true of larger district networks, 64% of which are cogeneration systems.[10]

The advantage of cogeneration is summarised by Flin [11]:

> *Typically, large, conventional fossil fuel power plants operate at efficiencies of 35–40 per cent. This means that most of the energy of the fuel is wasted. By contrast, cogeneration plants have typical operating efficiencies between 70 and 90 per cent. Cogeneration plants*

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[1] The Heat Network (Metering and Billing) Regulations, 2014.

[2] "*Heat Networks Building a Market Framework*", Consultation Document: Heat Networks: Consultation on Market Framework, Department of Business, Energy and Industrial Strategy, February 2020, https://www.gov.uk/government/consultations/heat-networks-building-a-market-framework

[3] Ibid, p 10.

[4] "*Families and households in the UK: 2018",* Office of National Statistics, https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2018

[5] "*Cogeneration and District Energy Systems*", p97, Marc A. Rosen and Seama Koohi-Fayegh. The Institute of Engineering and Technology, 2016

[6] Rosen and Koohi-Fayegh, ibid.

[7] "*Cogeneration, a Users' Guide*", David Flin. The Institute of Engineering and Technology, 2010

[8] "*Heat Networks Building a Market Framework*", ibid.

[9] "*Summary Evidence on District Heating Networks in the UK*", Department of Energy and Climate Change, 2013, https://www.gov.uk/government/publications/summary-evidence-on-district-heating-networks-in-the-uk

[10] "*Summary Evidence on District Heating Networks in the UK*", Ibid. However, where small communal networks are also taken into account, as they were in the BEIS report in 2013, it showed the average number of dwellings connected to UK heat networks was only 35, mainly in older installations, and only 3% of systems are CHP systems.

[11] Flin, p3, ibid.

> *produce more output for the same level of emissions, by using the heat generated by conventional fossil fuel plants, which is normally wasted, reducing energy demand elsewhere.*

Cogeneration is achieved either by top cycling, where waste heat from electricity generation is captured and used for either an industrial process requiring heat, such as drying, or for domestic heating in a district network. Bottom cycling reuses waste heat generated from an industrial process, such as a glass manufacturing, to power electricity generation. Of course, waste heat from industrial processes can be directly fed into a district network for domestic heating.[12] In 2010, 90% of bottom cycling cogeneration plants in the UK were in energy-intensive industries, such as oil refineries and food processing facilities.[13] The use of waste heat to generate electricity, for example from hospitals, is noted by commentators otherwise sceptical about the prospects for renewables. [14]

The scale of adoption of cogeneration has varied greatly between countries, having historically been favoured by states with centrally planned economies: by 1975, 42% of the former USSR's urban heating was by district heating and cogeneration.[15] This includes one system still in operation that generates 250 MW of thermal power and 385 MW of electrical power, with an overall efficiency of 87 % [16] District Networks using cogeneration also flourished in European, social democratic states: Denmark, Finland and the Netherlands generate over 33% of their electricity needs from cogeneration.[17] Penetration of district heating has been less pronounced in countries with a liberalised energy market, such that domestic heating is seen as a commodity that is purchased by a consumer who exercises choice, rather than a service that is provided to a citizen. This is seen as an historical factor inhibiting the development of cogeneration in the UK, by COGEN Europe, [18].[19]

Case Studies

It is useful to consider some examples of successful District Heating Systems, before further unpacking the concepts.

> **Lutherstadt, Wittenberg** [20]
> The municipal authority replaced a coal fired electricity generation plant with a natural gas fuelled cogeneration plant in 1995: This outputs 6224 kW in electricity which is then sold to the local utility provider, and 7948 kW of heat, which is supplied by a district heating network to 20000 households. In addition to the reduction of 22 000 tons of CO_2, the plant reduced carbon monoxide emissions by 70% and SO_2 emissions by over 95%. Ash emissions are also reduced to an insignificant level. The gains in reduction of greenhouse gases and pollutants are jointly attributable to switching from coal to natural gas, and from the use of cogeneration.

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[12] Flin, p10, ibid.
[13] Flin, p 35, ibid.
[14] "*Forget Wind Turbines, here's how we can meet net zero, without derailing the economy*", Paterson O., Daily Telegraph, 4th March 2020, https://www.telegraph.co.uk/news/2020/03/04/forget-wind-turbines-can-meet-net-zero-without-derailing-economy/?WT.mc_id=tmg_share_em
[15] "*Burning Up, A Global History of Fossil Fuel Consumption*", pp 29-30, Simon Pirani, Pluto Press, 2018.
[16] Rosen and Koohi-Fayegh, p73, op cit.
[17] Flin, p2, op cit.
[18] *"Country Profile, UK"*, COGEN EUROPE, https://www.cogeneurope.eu/knowledge-centre/country-profiles/united-kingdom, 2012.
[19] *"CODE 2 Cogeneration Observatory and Dissemination Europe"* COGEN EUROPE, http://www.code2-project.eu/wp-content/uploads/CODE-2-European-Cogeneration-Roadmap.pdf, 2015
[20] Flin, p54, op cit.

Southampton City Council [21]
In collaboration with ENGIE UK, this trigeneration scheme (electricity, heat and cooling) is suppled by a geothermal bore hole, and by CHP. It has an output capacity of 26MW heat; 9MW of cooling; 7MW of electricity, and connects 45 energy users through a 14 km pipe network, that includes 1000 residential homes. There is an estimated carbon saving of 12000 tonnes per year.

Marstal, Denmark [22]
This is an example of a Solar/Biomass fuelled system, serving 1550 dwellings. It is served by 87000 m^2 of photovoltaic collectors, a 4MW cogeneration unit running on biomass (using 81 TJ of willow woodchips per year), a Thermal Energy Storage (TES) unit, and a heat pump with a nominal COP of 3.2 that consumes 0.962 MW of electricity annually and produces a capacity 1.5 MW of heat. The system works with a complicated cycle so that solar power is preferred, which is augmented by the cogeneration unit when electricity prices are high, and the heat pump when prices are low. During the winter months the heat pump is employed even where its electricity requirements are high cost. Surplus thermal energy generated from the photovoltaic sub-system during the summer months is stored in the TES, and this is used as the ground source for the heat pump. The heat pump draws electricity from the grid, which may therefore be using non-renewable sources. Based upon reasonable assumptions of coppicing potential [23], the biomass fuel would require say 6 km^2 of managed willow. System profitability is predicated upon two factors: nearly all nearby dwellings are connected; and the reference comparator is the relatively expensive alternative of heating oil.

The Whitehall District Heating Scheme (WDHS), London [24]
A district heating system was first installed in 1966, through which 33 government buildings including Downing Street, are supplied heat by a 24 km pipe network. The heat only boilers were replaced by a cogeneration system in 1995, fuelled by natural gas (with an oil back up). Heat is supplied at 160◦C, and use is metered at each building so that users are billed by consumption. Electricity is supplied to the Ministry of Defence by private wire, and any surplus is sold to the grid. Experience has shown that the cogeneration system saves £344k per year, but maintenance costs are considerable, averaging £130k per year for the cogeneration plant, with an additional £530k for the heating distribution system.

Aberdeen City Council [25]
Aberdeen Council owns four multi-story blocks in Stokeshill, comprising 288 flats, 98% of which were tenanted and 2% privately owned. These were heated by inefficient electric storage heating that was approaching end of life in 2000, Aberdeen Heat and Power (AH&P) was formed as a not for profit company to handle financing for a district heating network, and 40% of capital costs were recovered from the Community Energy Programme. An energy centre was built close to one of the four multi-storey blocks. This houses a 210 kW gas engine cogeneration unit and two 700 kW gas-fired boilers for peak load and back-up. Aberdeen CC concluded that project success for a scheme of this scale, even though it was relatively straightforward, required a strategic plan and a whole life costing to establish

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[21] Heat Networks Investment Project: Case study brochure, BEIS, 2018
[22] Rosen and Koohi-Fayegh, pp 130-131, op cit.
[23] "*Energy and Civilisation*", Vaclav Smil, p765 & 214, The MIT Press, 2018.
[24] Flin, p116, op cit.
[25] Flin pp112-113, op cit.

profitability, that external expertise is essential, that a dedicated project manager is necessary and that financing requires an arms-length management company.

Customer Experience

Less is known about the currently installed heating networks in the UK than might be expected. There is no publicly available, central database of district heating networks across the Great Britain.[26],[27]

Therefore, to gain data, Citizens Advice issued an information request in 2015[28] to all Local Authorities in England, Wales and Scotland to help build a clearer evidence base, identify the biggest potential issues and note any areas of best practice that should be replicated across the sector. Local Authorities were chosen as the contact point for this information as the most likely body to have information, but they are under no obligation to either collate or hold such data.

Customer surveys and a review of the sector have also been conducted by the consumer group Which? in 2015 [29], and the Competition and Markets Authority (CMA) in 2018 [30].

While the case studies commonly quoted are of big, and relatively prestigious schemes [31], the reality is that in the UK most heat networks are small scale, in older buildings, predominantly in the social housing sector.

CMA found that dwellings served by heat networks are predominantly flats (94%) and have two or fewer bedrooms (86%), and that around 75% were more than 15 years old; 79% are communal schemes (accounting for 56% of dwellings); 21% district heating schemes (44% of dwellings); Only 13% of networks and 27% of dwellings are metered (where individual heat charges directly relate to individual heat consumption), and there is a median of 31 dwellings per network, with three quarters of schemes supplying fewer than 45 dwellings. [32] This is significantly different from many other European heat network markets, where a much larger proportion of heat demand is delivered by relatively fewer, larger schemes. [33]

Customers supplied by heat networks are likely to be older people and there is a higher proportion of vulnerable or financially precarious people then in the general population; they are significantly more likely to be in social housing.

A survey for BEIS found that around two thirds of surveyed customers supplied by a heat network were renting their property from a housing association or a local authority. Only 20% of all heat network customers lived in private accommodation which they owned, compared to 65% nationally. The remaining 11% of heat network customers were renting privately-owned accommodation. Over

[26] Although under regulation 3 of the Heat Network (Metering and Billing) Regulations 2014, heat suppliers must notify the UK Office for Product Safety and Standards (OPSS). of their networks, this is only relating to billing, and the register is not published.

[27] Although heat networks do seem to be recorded by the Northern Ireland Authority for Utility Regulation,

[28] "*District heating networks – analysis of information request*". Citizens Advice, January 2016. https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/District%20Heating%20Information%20Request%20-%20January%202016.pdf

[29] "*Turning up the heat: The experience of district heating consumers*", Which?, 2015

[30] "*Heat Networks Market Study*", https://www.gov.uk/cma-cases/heat-networks-market-study , p8, CMA, 2018

[31] Heat Networks Investment Project: Case study brochure, BEIS, 2018

[32] "*Heat Networks Market Study*", CMA, p,34, op cit.

[33] "*Heat Networks Building a Market Framework*",p28, op cit.

four in ten (44%) heat network customers were retired; the equivalent figure for the wider population was only 14%. The survey also identified that among the heat network population, 40% were classified as vulnerable consumers and roughly a quarter (27%) identified themselves as financially struggling. [34]

Consumers are typically locked into their contract with the network, with 88% of networks not supporting the option of disconnecting because customers pay the standing charges whether or not they use the heat (i.e. they are effectively unable to disconnect and terminate their contract); and for many heat network customers, the only practical substitute to being supplied by a heat network is the use of electric heating, which is an expensive alternative. [35]

Long supply contracts are common for companies that build and operate networks, to help de-risk the high upfront investment. For example, Cofely East London Energy has a 40 year contract for running the Olympic Park scheme and E.ON has an 80 year agreement for the Cranbrook scheme. [36] Customers are also obliged to sign up to long-term contracts (these can be as long as 20 years) [37] Citizens Advice point out that unlike the gas and electricity sectors, the delivery of heat to homes is unregulated. People heating their homes in this way are not subject to the same protections as those heating their homes using individual gas boilers or electricity.

While most customers are generally satisfied, Which?'s survey indicated that opinions are polarised, and many customers are very unhappy. [38] Customers complain, for example, that they have too little control of the temperature; that energy is wasted in heating communal areas; that the temperature is uncomfortably warm, requiring them to keep the windows open; and that there is an insufficient supply of hot water.

Excessive temperature can be explained by the high outflow temperatures used in communal networks, especially where the schemes are unmetered so that the high temperatures are carried through the pipes in the dwellings, rather than being terminated at an Heat Interface Unit (HIU). These problems are, however, also reported by Which? as occurring in some newer, metered schemes. Running out of hot water would indicate an incorrectly dimensioned system, and where no supplementary heating is employed for peak demand periods. Some users have complained of being only intermittently supplied with hot water for up to 18 months.

Citizens Advice report that a small number of networks have no mechanism at all for customers to control the temperature in their own homes. Replies to the Citizens Advice survey were reporting on operators rather than customers, and 70% of respondents reported that thermostatic radiator valves were present in more than half of the homes on their networks, and over 60% indicated that room thermostats were present in more than half of their homes. Hot water tank thermostats were present in almost half of respondents' networks. [39]

Service is too often poor, with 6% of operators reporting to Citizens Advice that there was no routine inspection and maintenance programme in place. As Citizens Advice note, "*given that the costs of the system rely heavily on the level of efficiency and prevention of breakdowns it would be*

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[34] "*BEIS Heat Networks Consumer Survey, BEIS research paper Number 27*", pp 17-18. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/665447/HNCS_Results_Report_-_FINAL.pdf

[35] "*Heat Networks Market Study*", pp 51-52, CMA, op cit.

[36] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.

[37] "*District heating networks – analysis of information request*". Citizens Advice, op cit.

[38] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.

[39] "*District heating networks – analysis of information request*". Citizens Advice, op cit.

expected that all heat suppliers should have some form of inspection and maintenance programme in place". [40] 43% of respondents stated that they had no set minimum standard of efficiency.

Common frustration is reported by Which? at the level of customer service, with many schemes having no single point of contact for complaints, and many having an off-hand attitude. [41]

A greater proportion of heat network customers had experienced a loss of heating in the last 12 months (37% compared to 24% of consumers not served by a heat network), and 32% of all networks had experienced an interruption to the supply of heating and/or hot water in 2016. [42]

Distribution networks that deliver gas and electricity to homes and businesses are subject to licence conditions that obligate them to respond within 24 hours to any such interruption in supply. Heat suppliers are not subject to such obligations, and worryingly, given the high proportion of vulnerable customers, only 32% of operators offer a priority reconnection for vulnerable customers in the case that supply is interrupted. [43] Citizens Advice Scotland has recommended to the Scottish Government to introduce price controls and a statutory licence for heat network suppliers covering consumer protection and efficiency standards; [44] and that the Scottish government is considering a requirement for developers to obtain a district heating consent, which would have conditions including the requirement to have a licence and meet licensing conditions. [45]

Many heat network customers enjoy heating bills below the comparator price of an individual gas boiler. However, CMA report that '*there is evidence of great variation in pricing in the heat network sector, with pockets of heat network consumers paying high annual prices, including consumers paying more than £1,000, or even £2,000, per year*.' [46] They note that heat network providers face little competitive pressure to offer reasonable prices, reliable supply and high quality of service.

Comparing prices in the networks they surveyed, CMA found that compared to average prices to run a comparator independent gas boiler, 8% of heat networks charged more; 6% charged over 10% more, and 3% charged over 25% more. When compared not to average gas prices, but the best gas prices available, then 17% of heat networks charged more, and 13% charged over 10% more.[47] The CMA noted that the costs calculator, produced by the Heat Trust (which is a voluntary trade association) to compare heat network consumer prices with individual gas customer prices, corresponds to their own calculations of average gas prices, rather the best gas prices in the market. [48], [49]

Higher unit prices and total charges were more often associated with private networks and with metered networks, and CMA argues that there is a risk that the factors which drive excessive prices could become embedded as the sector grows. [50] CMA note these factors as being: the conflicting

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[40] "*District heating networks – analysis of information request*". Citizens Advice, op cit.
[41] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
[42] "*Heat Networks Market Study*", p42, CMA, op cit.
[43] "*District heating networks – analysis of information request*". Citizens Advice, op cit.
[44] "*Different rules for different fuels – exploring consumer protection in the district heating market". Citizens Advice Scotland*, May 2017. https://www.cas.org.uk/publications/different-rules-different-fuels-exploring-consumer-protection-district-heating-market
[45] "*Scotland's Energy Efficiency Programme: Second Consultation on Local Heat & Energy Efficiency Strategies, and Regulation of District and Communal Heating*", Scottish Government, 14 November 2017.
[46] "*Heat Networks Market Study*", p33, CMA, op cit.
[47] "*Heat Networks Market Study*", p38, CMA, op cit.
[48] Heat Trust Calculator: https://heattrust.org/heat-cost-comparator
[49] "*Heat Networks Market Study*", p53, CMA, op cit.
[50] "*Heat Networks Market Study*", pp 6-7, CMA, op cit.

interests of property developers, heat network operators and customers; that monopoly supply gives consumers no commercial leverage; and the low transparency behind billing and pricing. [51]

Comparing end user prices is more complex than might be expected, due to the UK's heterogenous housing stock, differing energy efficiencies of households, different usage patterns, and the fact that heat networks can rely on diverse technologies; [52]

The consumer organisation, Which?, has pointed out that users of individual gas boilers need to include the cost of servicing and maintaining their heating systems, and that this needs to be factored into any comparison, as for heat network customers these costs are often bundled into service charges. [53] However, it should also be considered that for both private sector and social housing tenants, the costs of maintenance and periodic replacement of an individual gas boiler would fall on the landlord, not the consumer. It also needs to be borne in mind that heat networks are often employed in high-rise buildings that do not benefit from a gas supply to individual dwellings, due to both safety and installation cost considerations, so their cost comparator may be relatively expensive electric heating. [54] The report from Which? also observes that the term 'electric heating' can include a number of different technologies, such as electric combi boilers, immersion heaters, storage heaters or heat pumps, which further complicates comparisons.

Which?'s example compares average costs (based upon the period 2010 to 2016) from gas heating, and a heating network. Entire life costs for gas average at between 9.55 and 11.60 p/kWh; compared to between 5.51 and 14.94 p/kWh for district heating, covering a wide range. However, it needs to be remembered that currently most heat networks in the UK are fuelled by natural gas CHPs.[55] The BEIS survey of 2013[56] indicates that this is true of larger district networks, 64% of which are cogeneration systems.[57] It is therefore not surprising that the CMA found that average prices on the large majority of heat networks within their sample were close to or lower than the price of the comparator of individual gas boilers, [58] as gas fired CHP is known to be thermally and energy efficient. However, CMA also observed, than when factoring in whole life costs (WLC), then the WLC of district heat networks are mostly higher than the cost of a gas boiler and ongoing costs of gas. [59]

However, the push from BEIS to encourage a decarbonisation of heat networks will lower the average efficiency of the sector; because when heat networks employ other technology then costs to customers can be expected to rise. Citizens Advice also found that a third of the systems reported on in their survey, did not have a minimum level of efficiency, which not only has the potential to

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[51] "*Heat Networks Market Study*", p 5, CMA, op cit.
[52] "*United Kingdom housing energy fact file*", Palmer J and Cooper I, Department of Energy and Climate Change, 2013
[53] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
[54] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
[55] "*Heat Networks Building a Market Framework*", ibid.
[56] "*Summary Evidence on District Heating Networks in the UK*", Department of Energy and Climate Change, 2013, https://www.gov.uk/government/publications/summary-evidence-on-district-heating-networks-in-the-uk
[57] "*Summary Evidence on District Heating Networks in the UK*", Ibid. However, where small communal networks are also taken into account, as they were in the BEIS report in 2013, it showed the average number of dwellings connected to UK heat networks was only 35, mainly in older installations, and only 3% of systems are CHP systems.
[58] "*Heat Networks Market Study*", p 38, CMA, op cit.
[59] "*Heat Networks Market Study*", p 56, CMA, op cit.

adversely affect customers' bills, but also to impact their efficiency from the perspective of carbon emissions. [60]

The Heat Network (Metering and Billing) Regulations 2014 implement the requirements in the Energy Efficiency Directive with respect to the supply of distributed heat, cooling and hot water. Under this legislation. billing requirements, and meters are now required for new systems, however legacy systems are not covered by this requirement.

The CMA notes that a significant number of customers are dissatisfied because regular bills are not provided. Where bills are provided, customers feel that that these bills were inaccurate. [61] This is borne out by the Heat Trust, which is a voluntary trade association that allows customers of its members a route to complain to the Energy Ombudsman. They report that most billing complaints received by the Energy Ombudsman were to dispute the level of standing charge and the lack of clarity on what costs are recovered from standing charges. Billing complaints account for over two thirds of complaints sent to the Energy Ombudsman. [62]

Which?'s survey revealed customer dissatisfaction over high standing charges, lack of explanation of what the charges are for, and unsatisfactory customer service when bills are queried. [63]

Given that customers of heat networks are locked into long term contractual commitments, it is surprising how little choice those customers have whether or not to enter into the contract. Social housing tenants often have little choice on which accommodation to accept, and private owner occupiers are not always advised that the dwelling they are considering is on a heat network. According to CMA, key information for customers lacks transparency both before and after moving into a property. [64] Matters such as contract duration, exclusivity and relative pricing of heat networks compared to other energy options are often not considered by customers until after they have decided to move into a property.[65] There is currently no requirement for the performance of heat networks to be included in Energy Performance Certificates through the regulations which govern property sales disclosure.

Which?'s report details dissatisfaction over misleading claims about prices made before customers joined heat networks [66], and the CMA reports that for private properties often only vague information is given about the heating being "green" or "eco-friendly" with no mention of it being a heat network; prospective social housing tenants often receive little information, with information about heating costs being bundled into utility service costs. Most customers only appreciate that a heat network is a different model of heating once they move in, and even then, the information is often inadequate. Many owner occupiers only learn they are on a heat network after they have completed the purchase. [67]

To address these acknowledged areas of dissatisfaction, BEIS has worked with industry and consumer groups to support the development of the UK-wide Heat Trust scheme, an independent and voluntary consumer protection scheme designed specifically for heat network operators. It puts

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60 "*District heating Networks Analysis of information request, January 2016*", P14, Citizens Advice, op cit.
61 "*Heat Networks Market Study*", p 44, CMA, op cit.
62 "*Heat Trust Annual Report Findings from year one*"
http://heattrust.org/images/docs/Heat_Trust_Annual_Report_Final_-_Web.pdf
63 "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
64 "*Heat Networks Market Study*", p 5, CMA, op cit.
65 "*Heat Networks Market Study*", p 9, CMA, op cit.
66 "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
67 "*Heat Networks Market Study*", pp 65 -66, CMA, op cit.

in place a common standard for the quality and level of customer service that is provided to domestic and micro-business consumers by their heat energy supplier. It also provides an independent dispute resolution service through an agreement with the Energy Ombudsman. The Heat Trust does not cover pricing and as a voluntary scheme is limited in the sanctions it can impose. [68]

In some cases, poor customer experience and poor system performance is attributable to an incorrectly designed, dimensioned, and implemented system. BEIS say that some network operators "*struggle to make the case for interventions that could improve consumer outcomes".*[69] This sounds very much like a euphemism for recognising that some companies don't care about poor customer experience, and either cannot afford or don't have the will to remedy failings. Even were heat network operators to be replaced, via a "step in" by an operator of last resort in a future regulatory environment, it would not remove the need to carry out expensive remedial works in poorly designed and executed networks.

BEIS considers that the "*relatively low reputation of the sector … can deter investment*" [70]

Structural shortcomings of the district heating sector

The district heating sector is unregulated, and a supplier does not need to be licensed to operate. Which?'s report observes that unlike for mains gas and electric heating customers, the Energy Ombudsman is not required by Ofgem to provide an independent complaints mediation service to district heating customers. Depending on who owns the network, some consumers can seek redress through specific ombudsman schemes, such as the Local Government Ombudsman. However, many consumers do not have access to any independent adjudication. [71]

Given that the carbon reduction drivers behind the government's support for district networks, there is a surprising policy and market failure that the electricity and heat markets do not consistently reward CHP for efficiency savings at the energy system level.[72] Indeed, heat networks are promoted, often through planning requirements, without necessarily requiring that they actually achieve carbon emissions abatement; although heat network schemes approved by the Greater London Authority or funded by the Department for Business, Energy & Industrial Strategy (BEIS) do have to meet certain requirements including quality and pricing which is competitive relative to alternative fuels.

The CMA has raised the potential concern that a property developer could have the incentive to design and build a network which has cheaper up-front costs at the expense of higher long-run operation and maintenance costs (based on the premise that if construction costs are reduced and the sale value of the property remains the same, this would increase developers' profit margins as ongoing costs will be borne by customers instead). For example, developers may choose not to install key components, in order to reduce capital expenditure, without regard to how the network as a whole will operate in the longer term. This can reduce the operational efficiency of the network and therefore the quality of the service. [73] They argue that the lack of measurable and enforceable standards for the design, build, commissioning and operation of heat networks means that customers are afforded little guaranteed protection and means that there is a significant risk to

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[68] "*Heat Networks Building a Market Framework*", p15, op cit.
[69] "*Heat Networks Building a Market Framework*", p15, op cit.
[70] "*Heat Networks Building a Market Framework*", p17, op cit.
[71] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
[72] *"CODE 2 Cogeneration Observatory and Dissemination Europe"* COGEN EUROPE, op cit.
[73] "*Heat Networks Market Study*", p 49, CMA, op cit.

customers from misaligned incentives between property developers, heat network operators and customers. [74]

CMA also reports that the lack of standards and expertise in this market can lead to property developers demanding inappropriate requirements when specifying the network. These requirements can increase the upfront and ongoing costs of operating networks. Design engineers may not challenge this due to concerns regarding their professional indemnity insurance. Which?'s report expresses their concern that while some standards are in place to promote the good design of heating networks, these standards are not mandated, leading to added complexity and higher costs than necessary. For example, many schemes in the UK have been over-sized and are therefore less efficient.

Although it is generally assumed that heat networks will lead to lower costs for customers, the research commissioned by BEIS on international heat networks frameworks found evidence that introducing a price cap based on the cost of natural gas has affected the ability of some schemes to recover costs. [75] This is because the tariff calculation system does not reflect the actual costs of the heat supply, which are very different from the costs incurred when using gas boilers. Schemes being unable to recover their costs when charging prices capped at the comparator price of natural gas boilers is incompatible with the claim that these schemes will offer lower prices for consumers.

Government support for heat networks

Perhaps surprisingly, by 2012 the UK already had the 6th highest installed CHP capacity in EU for both electricity, and heat. [76] Through the Climate Change Act (2008) the UK has committed to decarbonising energy delivered to homes and businesses, and it is proposed by the Committee on Climate Change that 18% of UK heat will need to come from heat networks by 2050 if the UK is to meet its carbon targets cost effectively, and therefore both BEIS and the Scottish Government [77] are seeking to expand the number of heat networks significantly over the next decade.

However, any significant expansion of heat networks into private housing to displace domestic gas is likely to prove very unpopular, as Which? concludes [78]: "*Given the popularity of gas heating, the inability of district heating customers to switch, and the disruption which will result from the installation of new networks, there is likely to be significant consumer resistance to extending district heating to existing private housing*."

Practical and regulatory support [79]
The government's Heat Network Delivery Unit (HNDU) provides practical support to local authorities and project developers in the early phases of scheme development.

To support the development of the heat network sector, the government is committed to disseminating data, tools and good practice lessons learned by Heat Network Investment Project

[74] "*Heat Networks Market Study*", p 50, CMA, op cit.
[75] "*International Heat Networks*", https://www.gov.uk/government/publications/international-heat-networks-market-frameworks-review , BEIS, CAG Consultants (March, 2019), International Heat Networks
[76] European Commission, 2014. Eurostat CHP data for 2012 which quotes data from UK Department of Energy and Climate, 2014, Combined heat and power: chapter 7, Digest of United Kingdom energy statistics (DUKES)

[77] While energy policy is reserved to the UK government, heat is a devolved matter in Scotland, this is because heat is not referred to in Schedule 5 of the Scotland Act 1998, in which section 'Head D – Energy' reserves energy powers to the UK, or elsewhere in the Act. As such, heat policy is not reserved to the UK.
[78] "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.
[79] "*Heat Networks Building a Market Framework*", p8, op cit.

(HNIP) and HNDU. BEIS has commissioned Triple Point to produce standardised documentation to remove hurdles for investors, and to produce a set of Sales, Operations and Maintenance Set ('SOMS') contract documentation for heat network developers and operators.

Triple Point also supports and promotes investment by maintaining a list of potential investors, holding conferences, and publicising the pipeline of investment opportunities. [80]

The Government is also seeking through its Future Homes Standard to provide a regulatory framework that will accelerate the deployment of heat networks.

Subsidies

In 2015, the UK Government announced £320m of funding through the Heat Network Investment Project (HNIP), with a view to delivering up to £2 billion in new investment and the Scottish Government's District Heating Loan Fund, established in 2011, and the Low Carbon Infrastructure Transition Programme have supported heat network investment in Scotland. [81],[82]. In addition, the non-domestic Renewable Heat Incentive (RHI) and Energy Company Obligation (ECO), subsidise the cost of building or running district networks.

BEIS has worked with industry to establish minimum standards for the design, installation, and operation of heat networks across the UK through the development of the Code of Practice from Association of Decentralised Energy (ADE) and CIBSE. These voluntary requirements are comparable to the quality and performance standards for regulated utilities such as gas and electricity and draw on legislation and industry best-practice. All networks receiving HNIP funding must meet the Heat Trust standards or equivalent and comply with the Code of Practice's technical standards. [83]

Compulsion through the planning process

The planning regime can be a key driver of the development of new heat networks in some parts of the UK where the local/development plan sets requirements over and above Building Regulations. According to the CMA [84]: "*Whilst this affects only a subset of the new heat networks being built, it can result in a failure to take heat network customer interests into account when a developer chooses a heating and hot water solution*"

The approach to planning in the UK is devolved and governed by different primary legislation in each country. In England, the National Planning Policy Framework is supplemented by local plans; for example, the London Plan [85] includes an explicit requirement to consider heat networks for major developments, at competitive price, but when transposing this into local plans, London boroughs only need to 'generally conform' with the competitive price requirements. The system in Wales is similar to England, with the framework provided by Planning Policy Wales, and further defined by local plans.

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80 "*Heat Networks Building a Market Framework*", p12, op cit.

81 "*Shared warmth: a heat network market that benefits customers, investors and the environment*" https://www.theade.co.uk/assets/docs/nws/Task_force_report_v7_pipes.pdf , ADE industry heat network task force report, 31 January 2018.

82 In contrast to Scotland, the Wales Act 2017 reserves heat and cooling policy including the regulation of the heat supply industry and the Renewable Heat Incentive, it devolves to the Welsh Assembly the power to incentivise local heat networks and renewable heat schemes.

83 "*Heat Networks Building a Market Framework*",p15, op cit.

84 "*Heat Networks Market Study*", p48, CMA, op cit.

85 "*Decentralised energy in development proposals, London Plan*", Policy 5.6. https://www.london.gov.uk/what-we-do/planning/london-plan/current-london-plan/london-plan-chapter-five-londons-response/pol-22

In Scotland, the framework is provided by Scottish Planning Policy, such that local development plans should support the development of heat networks in as many locations as possible.

BEIS supports using local planning powers to force compulsory connection, through zoning, concession arrangements, and mandated connections.

1. Zoning is where a municipal authority uses local planning to identify a defined locality for a strategic heat network development. They then use planning powers to require new buildings in the zone to connect to the network; they voluntarily connect public buildings under their control in the zone, and they offer discounts to other buildings to encourage connection.

2. Concession arrangements are an extension of zoning, where the anchor load guaranteed by the local authority provides a foundation for a commercial relationship with a third party, usually from the private sector, who would, for example, provide upfront capital.

3. Mandating connections to a heat network within locally designated zones, either centrally or locally, would clearly be a mechanism for reducing connection risk. However, a centrally imposed approach would be a significant intervention into local planning and development decisions. BEIS is considering the alternative of granting local authorities the powers to take such decisions on mandating. [86]

The CMA is concerned that there are insufficient safeguards currently in place to protect customer interests at the planning stage.[87] In particular that "*planning requirements which drive the construction-of or connection-to a heat network, can lead to heat network customers facing higher prices than if alterative heat and hot water solutions were installed*." [88]

Commercial challenges to cogeneration and district heating

District heating schemes are large scale and complex engineering projects, and therefore their commercial viability depends upon return on investment, and risk evaluation and appetite.

Where cogeneration is included, which almost always improves the commercial viability, then either the electricity is consumed or sold directly by the operators of the system, for example the UK's Whitehall network supplies electricity by private wire to the Ministry of Defence; or the electricity will be sold to an electricity utility, in the UK case, to the National Grid.

A supply side impediment in the UK has been the spark spread, as explained by COGEN EUROPE:

> *The economics of any particular CHP plant depend heavily on the difference between the fuel price the operator pays for the primary fuel and the electricity price which the operator can get (or avoid) for the electricity the plant generates: the so-called 'spark spread'. As a rough guide, if the ratio (electricity price/fuel price) is around 3, then the plant will be economic. If the ratio is less than 2, it will not be. The economics of CHPs are therefore sensitive to changes in both the electricity price and the primary fuel price*. [89]

The price at which electricity can be sold is susceptible to market forces, but the economic viability of district networks can also be subject to unintended consequences where the market is

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86 "*Heat Networks Building a Market Framework*",p26, op cit.
87 "*Heat Networks Market Study*", p48, CMA, op cit.
88 "*Heat Networks Market Study*", p50, CMA, op cit.
89 *"CODE 2 Cogeneration Observatory and Dissemination Europe"* COGEN EUROPE, op cit.

constrained by political considerations. In West Denmark, where electricity produced by government supported wind farms has achieved 25%, this has undermined the viable market for the electricity from district networks, who have therefore been removing CHP and replacing with heat only boilers. [90] So instead of there being two complementary mechanisms for decarbonisation, a politically preferred one has crowded out the other.

It is also necessary to consider the equilibrium model of the energy market, as explained by Rosen and Koohi-Fayegh [91]

> *An energy equilibrium model of a competitive energy market closely examines the interaction between energy supplies and demands, and determines the optimal levels of production (supply) and consumption (demand) that satisfy the equilibrium property that the prices consumers pay for each commodity should equal the marginal costs of production.*

This places a demand side constraint on heating networks where consumers will only choose to connect to the network if the prices are competitive, and if the marginal costs of the heat production exceeds the market norms they will not choose to do so, therefore the heating network will not be commercially viable.

The Association of Decentralised Energy (ADE) launched a task force in 2017 [92], which observed that heat networks do not have the regulatory assurance of the electricity, gas and water industries, which guarantees those industries customer demand, and that in contrast the main barrier raised by potential investors in the heat network market is demand risk. However, the existing utilities enjoying demand assurance have much greater customer bases, allowing risk to be spread. ADE therefore suggest further work "*to determine if wider socialisation of liabilities would be needed*" [93], it is hard to interpret this in any way other than a call for a public underwriting of their risk liability. They also moot the idea of compulsory connection through local authorities requiring social housing to be heated via a district network.

BEIS has considered two mechanisms for addressing demand risk. [94]

1. The Regulated Asset Base (RAB) model is used in the UK for monopoly infrastructure assets such as water, gas and electricity networks. The company receives a licence from an economic regulator, which grants it the right to charge a regulated price to users in exchange for provision of the infrastructure in question. To prevent monopolistic disadvantages, the charge is set by an independent regulator who holds the company to account to ensure any expenditure is in the interest of users. Demand risk is overcome by passing any overrun costs to customers, and due to the very large customer base each individual customer carries only a small risk, in exchange for which they benefit from regulated prices. The RAB model is not considered appropriate by BEIS for heat networks due to both the small customer base, and the fragmentation of the sector into several relatively small networks. The good networks, and their customers, should not subsidise the bad.

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[90] Blarke MB. Applied Energy, 2012; op cit.
[91] Rosen and Koohi-Fayegh, p238, op cit.
[92] "*Shared warmth: a heat network market that benefits customers, investors and the environment*" https://www.theade.co.uk/assets/docs/nws/Task_force_report_v7_pipes.pdf , ADE industry heat network task force report, 31 January 2018.
[93] "*Shared warmth: a heat network market that benefits customers, investors and the environment*" , ibid.
[94] "*Heat Networks Building a Market Framework*",pp 20 - 22, op cit.

2. Under the Demand Assurance model, proposed by ADE, a heat network developer would seek approval of a strategic plan (from a regulator or local agent) which sets out estimated heat demand arising from consumer connections as the heat network is built out. If approved, the heat demand, would be assured to cover any future demand shortfall or some element of it. It is assumed that this risk would need to be underwritten by government and funded by either taxpayers or through consumer bills (potentially heat network consumers or wider energy consumers). This is considered inappropriate by BEIS because such a demand assurance scheme would create uncertain and potentially costly liabilities for the body responsible for underwriting the risk, and could also create perverse incentives for developers to over-expand networks, as they would be rewarded for failing to meet their planned connection potential.

Another commercial constraint is that the potential owners or investors will often not have the specialist engineering knowledge to design, implement, operate and manage a district network. The solution is outsourcing the contract energy management (CEM) to an energy service company (ESCO).

As the Competition and Markets Authority (CMA) reports:[95]

> *The ESCO enters into a long-term agreement under which it has the right to access and operate the network and to charge customers for heat, normally under specified terms and conditions, such as by reference to a gas benchmark price. These agreements can vary in duration, but will tend to last a minimum of 20 years, and pass responsibility for the replacement of assets to the ESCO, which bills customers and collects revenues directly from them.*

Up to 60 % of cogeneration plants in the UK have some recourse to CEM from an ESCO [96] As the CMA observes, an ESCO will have its own institutional and commercial interests, that may affect the design considerations, so that property developers and heat network operators may not take the interests of end customers into account when taking decisions on the design and build of networks. [97] and ESCOs typically set consumer price based on the cost of an alternative reference model and therefore any potential benefits or savings won't necessarily be passed on to customers. [98]

The consumer organisation, Which?, [99] points out that in some cases the ESCO who adopts the district heating scheme (and so has an interest in the long-term performance of the network) is not involved in the early planning and design stages. This effect is compounded by the fact that the district heating sector is fragmented and multiple organisations can be involved in the design, construction, operation and maintenance of a single network.

The CMA argues that two factors can lead to inappropriate design considerations: [100]

[95] "*Heat Networks Market Study*", https://www.gov.uk/cma-cases/heat-networks-market-study , p8, CMA, 2018
[96] Flin, p46, op cit.
[97] "*Heat Networks Market Study*", p7, CMA, ibid.
[98] "*Heat Networks Market Study*", p50, CMA, ibid.
[99] "*Turning up the heat: The experience of district heating consumers*", Which?, 2015.

[100] "*Heat Networks Market Study*", p8, CMA, ibid.

1. *Where the heat network does not provide heating and hot water solutions at the lowest cost to customers, but is the most cost-effective way for the developer to meet planning requirements.*

2. *Where property developers fail to consider the whole life costs and try to minimise the upfront costs of designing and installing a heat network, and this results in higher ongoing costs for the operation and maintenance of the network, which fall on customers.*

Research by the Citizens Advice Bureau suggests that while efficiency varies between heating networks, newer systems are not always the most efficient, suggesting that energy efficiency is not always the driving design consideration. [101]

[101] "*Heating networks – analysis of information request*". Citizens Advice, January 2016. https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/District%20Heating%20Information%20Request%20-%20January%202016.pdf

Part Two: Technical considerations

Cogeneration and other heat sources

Most district heat networks use waste heat from thermal electricity generation systems. As described by Rosen and Koohi-Fayegh: [102]

> *In thermal electrical generating stations, the energy content of a resource (normally a fossil fuel) is converted to heat (in the form of steam or hot gases) which is then converted to mechanical energy (in the form of a rotating shaft), which in turn is converted to electricity. A portion (normally 20–45 per cent) of the heat is converted to electricity, and the remainder is rejected to the environment as waste.*
>
> *Cogeneration systems are similar to thermal electricity generation systems, except that a percentage of the generated heat is delivered as a product, normally as steam or hot water, and the quantities of electricity and waste heat produced are reduced. Overall, cogeneration efficiencies based on both the electrical and thermal energy products of over 80 per cent are achievable. Most thermal systems for large-scale electricity generation are based on steam and/or gas turbine cycles, and can be modified relatively straightforwardly for cogeneration.*

As any system for generating electricity which also produces heat as a waste product can be used for cogeneration, then practically any potential fuel can be used. Most significantly, methane can be used in gas turbines, in combined cycle (CCGT) turbines, and for reciprocating generators, such as either internal combustion of Sterling engines; diesel can be used in reciprocating engines; and solid fuels, including biomass and burnable waste, can be used in boilers to power steam turbines. In addition, hydrogen and natural gas can be used in fuel cells. [103] Although there is an assumption in a UK context that heat networks will always be used to further the aim of decarbonisation, it is optimistic to assume that all states have the same objective. For example, Dr Andrei Ter-Gazarian, senior research associate for Moscow Power Engineering, has recently advocated using electric powered heating in heat networks as a mechanism for replacing natural gas by cheaper coal, which would actually increase carbon emissions by conscious design. [104]

In March 2018, BEIS published experimental statistics on heat networks, which indicated 90% of heat networks in the UK use at least some natural gas as their fuel source. The next most widely used fuel source was electricity (5% of networks) followed by bioenergy and waste (2% of networks). [105]

The future is likely to see a wider range of heating sources incorporated into UK heat networks, from industrial waste heat, to water and ground source heat pumps, geothermal sources, etc. However, the base line comparator for all of these sources should be cogeneration, which has a proven and well understood heritage in heat networks.

Cogeneration performance

Rosen and Koohi-Fayegh argue that to properly evaluate the performance characteristics of any system it is insufficient to carry out an analysis based only on energy inputs and outputs, rather it is necessary to carry out a thermodynamic (or exergy) analysis [106] which takes into account the

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[102] Rosen and Koohi-Fayegh, p54, op cit.
[103] Flin, p29, op cit.
[104] "*Energy Storage for Power Systems, 3rd Edition*", Ter-Gazarian A., p250, The Institution of Engineering and Technology, 2020.
[105] "*Heat Networks Market Study*", https://www.gov.uk/cma-cases/heat-networks-market-study , p21, CMA, 2018
[106] Rosen and Koohi-Fayegh, *ch2, Thermodynamic analysis: fundamentals, energy and exergy*, pp 9-48, op cit.

temperature at which the heat output is produced. [107] For district heating, it is the usefulness or quality of an energy quantity, rather than simply the energy quantity itself, that is of value. For example, the heat rejected from the condensers of an electrical generating station, although great in quantity, is of little usefulness since its temperature is only a few degrees above that of the surrounding water or air (i.e., the thermal energy is of low quality). [108]

In non-technical terms, how well a cogeneration plant performs depends upon how much useful heat is produced, at what cost in lost electricity production, compared to an equivalent generator not also being used for heating. More technically: modelling a cogeneration system produces a coefficient of performance, COP_{CHP} , as a function of the heat product output and the degree to which the electricity output is curtailed. [109] COP_{CHP} can be compared to COP of a heat pump, in the special case where electricity production is curtailed 100%, because a heat pump does not generate electricity. This is useful as it allows direct comparison between the thermodynamic performance of a heat pump and of a cogeneration system.

> *This measure of performance treats the cogeneration plant as a heat pump in that a cogeneration plant in general foregoes electrical output to produce useful heat, while a heat pump uses electricity to produce useful heat.* [110]

It is worth noting that, for gas turbine and diesel engines, very little electrical output is curtailed in order to produce useful product heat, so in layperson's terms: for a gas turbine cogeneration plant, you get the useful heat for more or less nothing. This is because the less the potential electrical product is curtailed for a given output of useful heat, the better the COP_{CHP}. This could be described technically such that: where the curtailing of the electrical output tends to zero, then COP_{CHP} increases and asymptotically approaches infinity. [111]

Although outside of the scope of the current consultation, it is notable that the thermal efficiency, COP_{CHP}, of a domestic micro-cogeneration unit therefore tends to be superior to the efficiency of a heat pump, COP. Micro cogeneration replaces a domestic gas heating boiler with a sterling engine generator that also uses natural gas as fuel, but which produces electricity as well as heat. The UK's 2006 budget made an extra £50 million available to micro-cogeneration under the Low Carbon Building Programme, [112] and it was anticipated that replacing domestic gas boilers with micro cogeneration CHP, as each boiler reached end of life, could cut the typical household energy bill by £150 a year and reduce $CO2$ emissions from the household by up to 1.5 tonnes per year. This approach would conserve the domestic gas supply infrastructure, and the gas service industry. The Micro cogeneration unit commercially available from Helec operates, according to its specification, [113] with up to 95% system efficiency.

Heat pumps in district networks

The distinction made by Professor Rosen is an acute one. Cogeneration **produces** electricity and heat from given fuel inputs, and the efficiency is a product of the curtailing of the potential electrical output in order to create the heat output. In contrast, a heat pump **consumes** electricity that is generated in a separate process.

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[107] Rosen and Koohi-Fayegh, p109, op cit.
[108] Rosen and Koohi-Fayegh, p37, op cit.
[109] Rosen and Koohi-Fayegh, p89, op cit.
[110] Rosen and Koohi-Fayegh, p90, op cit.
[111] Rosen and Koohi-Fayegh, p92, op cit.
[112] Flin, pp50-51, op cit.
[113] Webpage, Sterling Engine CHP, Helec, https://helec.co.uk/products/stirling-engine-chp/, retrieved May 2020.

The electricity consumption of the heat pumps must therefore also factor in the efficiency of its generation and transmission, especially where the electricity used by a heat pump is not from renewable sources, It is reasonable to compare the overall efficiency of the electricity generation and transmission as well as the heat pump itself; compared to the efficiency of a comparator domestic gas boiler, and its supply network. Modern domestic gas boilers for space heating and hot water are rated at around 97% efficient, whereas an efficient combined cycle gas turbine(CCGT) generating electricity would achieve a combined efficiency of the gas and steam cycles of just over 60% [114]; while transport losses (using natural gas to power compressor stations on pipelines) are typically just 2 to 3% for gas, compared to energy loss on high voltage electricity transmission lines of 6 to 7%. [115]

It is reasonable to assume that the heat pumps will often be powered by electricity from non-renewable sources, therefore, as the study by Buro Happold for the Mayor of London observes "*the carbon intensity and cost of secondary heat sources are linked to those of the electricity grid*". [116] One study based on Danish experience shows that heat pumps are an effective mechanism for addressing intermittency issues created by incorporating renewables sources into a district network.[117] Where heat pumps are used to address gaps in renewably sourced electricity, then inevitably they will be using electricity generated by non-renewable sources.

The example of the Marstal system, described earlier, shows that heat pumps can also play a useful role in transferring stored thermal energy from a TES into a heat network, using the TES as their source, and stepping the temperature up to that required for the network. It is also worth noting that the outflow temperature of a district network or communal network is typically designed to be sufficiently high to supply domestic hot water, which is not the case for the majority of heat pumps installed in domestic buildings, and is not the case for ambient loop networks. [118]

Industrial waste heat in district networks:

COGEN EUROPE observes that: [119]

> *[The] United Kingdom [has] a large share of industry where steam is an important energy carrier, such as oil refineries, chemicals, pulp and paper, and food and beverages. Within those sectors, where steam is dominant, there is a large potential for CHP.*

While their argument is that the steam could be used for bottom cycled electricity generation, directly using the steam to drive a turbine, where the waste heat is generated sufficiently proximate to buildings that need heating, then the heat could instead be fed into a district network. The Buro Happold report for the Mayor of London also emphasises the degree to which heat pumps can be used to utilise waste heat, for example from industrial processes, data centres or warmer ambient air proximate to electricity transformer stations. [120]

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[114] "*Natural Gas, Fuel for the 21st Century",* Vaclav Smil, p85, Wiley, 2015.
[115] Smil, ibid, p58.
[116] "*Secondary Heat Study- London's Zero Carbon Energy Resource*", BuroHappold, (2013),: https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/031250%20GLA%20Secondary%20Heat%20-%20Summary%20Report_0.pdf
[117] "*Towards an intermittency-friendly energy system: comparing electric boilers and heat pumps in distributed cogeneration*". Blarke MB. Applied Energy, 2012; 91(1):349–65.
[118] "*Hybrid heat pumps study*", Element Energy, for Department for Business, Energy & Industrial Strategy https://www.gov.uk/government/publications/hybrid-heat-pumps-study (April 2018)
[119] *"CODE 2 Cogeneration Observatory and Dissemination Europe"* COGEN EUROPE, op cit.
[120] BuroHappold, ibid.

Cogeneration and heat pumps

The way that heat pumps are described is often confusing. For example, the consultation framework states that heat networks are "*uniquely able to unlock otherwise inaccessible larger scale renewable and recovered heat sources such as waste heat and heat from rivers and mines."* [121]

It is a category error to conflate heat from rivers as being "recovered" in a manner analogous with waste heat from industrial sources being actually recovered. Mines of course are a different case as they do store geothermal energy, and abandoned UK mine-workings are estimated to contain 2bn m^3 of water at temperatures which are constantly around 12-16°C, and in some instances higher still, so there is heat that can be recovered, and stepped up to useable levels with a heat pump. [122] Bristol City Council is contemplating a heat network drawing heat from abandoned mineshafts. [123]

Where an industrial or commercial process has used fuel energy to achieve a useful purpose, then heat may be produced as waste. There are, for example, data centres and electricity transformer stations in Brent Park, where the useful waste heat could be captured in a TES and then the energy transferred into a heat network, and the temperature stepped up to a useful level, via heat pumps. [124] It is therefore accurate to describe the process of preventing that work done in producing the excess heat from being wasted, and thereby using it for the secondary useful purpose of heating, as being recovery. [125] The already existing Islington scheme incorporates such waste heat from the London Underground, alongside gas fuelled CHP and a thermal store. [126]

Yet the consultation document specifically describes the operation of heat pumps as recovering either renewable energy or waste heat, even when transferring heat from sources that have not experienced anthropogenic or geothermal warming, such as rivers: [127] "*Heat networks are uniquely able to unlock otherwise inaccessible sources of larger scale renewable and recovered heat such as waste heat and heat from rivers and mines. In 2013 BuroHappold estimated that 38% of London's heat demand could be met from this kind of waste-heat recovery*", (emphasis added).

Heat pumps drawing thermal energy from water, ground or air sources that have not absorbed waste heat from anthropogenic activity, operate by transferring heat against the natural direction of energy flow, from a lower temperature source to a higher temperature destination. A heat pump is conceptually similar to a refrigerator,[128] where a refrigerant gas is passed through an evaporator on its way to the heat source, where it expands to become a vapour accompanied by its temperature falling to below the temperature of the heat source, such that it draws heat in from the environment; the now warmer and lower-pressure, working fluid is then pumped in gaseous form

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[121] "*Heat Networks Building a Market Framework*", op cit.
[122] "*Disused coal mines could help decarbonise our heating. Here's how"*, Adams C and Gluyas J, New Statesman, 2018, https://www.citymetric.com/horizons/disused-coal-mines-could-help-decarbonise-our-heating-here-s-how-3519
[123] Bristol City Council, Cabinet Report Pack, March 2020, p 354 https://democracy.bristol.gov.uk/documents/g3693/Public%20reports%20pack%2003rd-Mar-2020%2016.00%20Cabinet.pdf?T=10
[124] BuroHappold, ibid.
[125] BuroHappold, op cit.
[126] Heat Networks Investment Project: Case study brochure, BEIS, 2018.
[127] "*Heat Networks Building a Market Framework*", op cit.
[128] "*Transition to heat pumps for domestic heating, a critical evaluation*", anewman consulting, unpublished report for GMB trade union, 2020.

through a compressor, where its pressure is boosted transitioning it back to a liquid, simultaneously causing its temperature to rise, and this raised heat is then used for space heating. [129]

Heat pumps can indeed be employed to recover waste heat from a thermal store, or from an environment where the ambient temperature has been raised by anthropogenic activity, or from a geothermal source like a deep mineshaft. However, outside of that particular use, they are properly thought of as a relatively efficient form of electrically powered heating technology, where the function of the ground, water or air source is to provide a lower temperature environment than the area to be heated, thus allowing the cycle of expansion and compression of the working liquid to transfer thermal energy against the temperature gradient via a circulating working liquid and heat exchangers.

The description by BEIS of the water sourced heat pump employed by the Kingston Heights district network is therefore misleading when it says: "*This system recovers solar energy naturally stored in river water*." [130],[131] The category error can be observed if we note that this is equivalent to saying that water at the bottom of a hill is naturally storing gravitational energy, which can be recovered by an electrical pump moving the water to the top of the hill.

This category error may be significant as presenting heat pumps not just as a relatively efficient form of electric heating, but as recovering energy that would otherwise be wasted, i.e. as a form of renewable energy. This introduces a potential bias that heat pump technology is assumed to be inherently environmentally beneficial, without a critical evaluation of each individual case. For example, a gas fuelled CHP may offer superior greenhouse gas abatement than a heat pump supplied by the electricity grid.

Ambient networks

Ambient loop networks employ distributed heat pump systems, which draw heat from a shared low temperature loop.[132] A series of ground arrays, typically boreholes, are linked together to form a shared ground loop array acting as a heat energy source to multiple properties (District Heating) or multiple occupancy buildings (Communal Heating). Note that the existing definitions in the Heat Network (Metering and Billing) Regulations 2014 for district heat networks and communal heating systems do not cover such ambient loop networks. [133]

The shared ground loop system transfers ambient temperature low grade heat energy from the ground (-5°C to 20°C) to individual ground source heat pumps located inside each individual dwelling. Each heat pump then upgrades the ground's heat energy to provide independently controllable heat and hot water to the property. [134]

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[129] Rosen and Koohi-Fayegh, p90, op cit.

[130] Heat Networks Investment Project: Case study brochure, BEIS, 2018.

[131] Although this would be true if the trivial case is made that, with the exception of nuclear energy, all fuel sources store solar energy, e.g. coal and natural gas store solar energy in fossilised organic matter that derives from photosynthesis.

[132] "*Ambient Loops Employing Distributed Heat Pumps*", P Spurway, CIBSE ENERGY PERFORMANCE GROUP, 2019

[133] "*Heat Networks Building a Market Framework*", p30, op cit.

[134] https://www.kensaheatpumps.com/the-technology/heat-sources-collectors/shared-ground-loop-arrays/ , Kensa heat pumps, retrieved May 2020.

Up to January 2020, a total of £141.9 million in subsidies has been paid under the Domestic Renewable Heat Initiative (RHI) scheme towards to 5812 ground source heat pumps. [135] An average subsidy of £24,415 per installation. Given the huge public subsidy, it is necessary to evaluate whether heat pumps, including ambient loop systems, achieve a cost-effective outcome.

Even assuming a 30% reduction of installation costs for heat pump systems due to increased volume, then gas heating systems offer considerably cheaper installations and lifetime costs.

It is overoptimistic to assume that the electricity used to power heat pump systems would come primarily from renewables, and heating 20% of the UK housing stock in this way would require an additional 14 GW of peak electricity capacity. [136]

UK domestic central heating systems with gas boilers and radiators are designed for flow temperatures of 80ºC outward flow and 60ºC return flow ('80/60'). However, the typical output temperature from domestic heat pumps and hybrids is 55ºC. This means that either larger radiators (T Low emitters) must be fitted, or under-floor heating must be used. This means that ambient loop systems would require the existing radiators to be replaced when retrofitting to an existing property, further increasing cost.

It must be considered whether Ambient loop networks are designed to replace the domestic gas supply altogether, or to operate as a hybrid heat pump which uses an auxiliary gas boiler for Domestic Water Heating (DWH), and for supplementing peak load. DWH comprises between 10% and 20% of heating costs for a typical residential property, though this may be up to 30% in a very well insulated building. DWH achieves 40ºC, which is higher than can be achieved by stand-alone heat pump, and therefore additional electric resistive heating, or supplementary gas heating, is required.

The Department for Business, Energy & Industrial Strategy (BEIS) commissioned Element Energy [137] to produce a detailed report on Heat Pumps. This report models different assumptions for system installation costs in three scenarios:

1. where installation costs fall by 30% by 2030 due to increased volume,
2. where installation costs fall by 30% by 2050 due to less increased volume,
3. where installation remain static due to very modest increased volume.

They then compared the lifetime costs of a conventional gas heating system, a heat pump system and a Hybrid heat pump system (which uses an auxiliary gas supply for peak demand and DWH), based on installation today, installation in 2030, and installation in 2050.

Their report concludes that in all 9 of these scenarios, "*gas heating remains lower in cost than electrical heating using the HP over the whole time period 2017-2050 and in all scenarios considered*"

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[135] *"Public reports and data: Domestic RHI",* https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/public-reports-and-data-domestic-rhi , Ofgem, retrieved May 2020.

[136] "*Transition to heat pumps for domestic heating, a critical evaluation*", anewman consulting, unpublished report for GMB trade union, 2020.

[137] "*Hybrid heat pumps study*", Element Energy, for Department for Business, Energy & Industrial Strategy https://www.gov.uk/government/publications/hybrid-heat-pumps-study (April 2018)

Energy Saving Trust [138] produced a report based upon a comprehensive heat pump field trial that tested 83 heat installations in the UK: 29 air source and 54 ground source, for 12 months from 2008 until 2010. This field trial found that COP for operational systems varied between 1.3 to 3.6 for ground source heat pumps and from 1.2 to 3.3 for air source, in most cases lower that manufacturer claims. A subsequent phase 2 field trial programme tested 44 installations, and following system design improvements, the average COP was 2.82 for ground source, and 2.45 for air sourced installations. In most cases the COP was lower in a real-life deployment than in the ideal conditions that the manufacturers assume.

One reason was poor installation, through both errors in system commissioning, but also through incorrect rating specifications. If a heat pump is too big, then it will always be operating inefficiently, but if it is too small, then the heat pump component will not be adequate, and the electric resistive heater, or gas boiler will be required to contribute more frequently than anticipated.

System commissioning errors, for Ground Source Heat Pump systems in particular, can dramatically increase operational costs, where, for example, there is insufficient ground array of pipes, or the pipes are too close together. This would be an area of concern for ambient loop networks.

A second phase of field tests were conducted by Energy Savings Trust to retest 44 sites out of the original 83 test sites. This was to remedy design failures found in the phase one testing, and retest to judge the efficiency of the improvements. Of these remedial works, 12 were major interventions requiring the input of heat pump experts and manufacturers, where, for example, the original systems had been wrongly sized and needed to be replaced. Nine systems required medium scale interventions by a qualified plumber, but these were still non-trivial, for example, installing buffer tanks, or high efficiency circulation pumps. The requirement for remedial works is attributed to greater understanding of field pumps being developed, and the first phase of installations had been undertaken before the introduction of the Microgeneration Certification Scheme (MCS), which established standards for installers. What this does show is that the skill level and capability of installers is a significant factor in system performance. It should be noted however that there has not been a comparable survey since the MCS was introduced, and the scheme's impact on upskilling the industry has not been assessed. Industry practitioner experts observe that it is essential that the hydronic systems are accurately designed, and will not work efficiently without very careful planning of both primary and circuitry pipework and emitters. Heat Pump installations are much less forgiving than domestic gas heating systems, and require a higher skill level for design. [139] Even after the introduction of the MSC qualification, there are examples of poorly designed systems, with consequently high running costs; furthermore building controls may have become more lax, and buildings are not always performance tested to ensure compliance with regulations. [140] There is a clear need for the standard and quality of heat pump installations, including ambient loop networks, to be regulated, and the current building controls are not an appropriate mechanism.

Another reason found for unsatisfactory performance was unsuitable usage, especially where a heat pump is employed without underfloor heating, and without legacy radiators being replaced by larger units suitable for lower temperature operation. Usage for DWH also reduces COP. Heat Pump systems installed into poorly insulated and draughty properties require a higher flow temperature.

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[138] "*The heat is on, heat pump field trials, phase 2*" Energy Savings Trust, August 2013, https://energysavingtrust.org.uk/policy-research/heat-heat-pump-field-trials-phase-2
[139] "*Has Gas had its day*", Berridge R. Installer Online, May 2020. https://www.installeronline.co.uk/gas-day-rob-berridge-takes-look/?fbclid=IwAR2Po_FO8WOmO4A0Ygo5XVX-sxUpv9SaUNqL9rkn6VGKS8-QOAESG32Wl9o#
[140] Berridge, ibid.

Customer behaviour also contributed to poor performance, for example, using inefficient heating cycles. Element Energy observed that 73% of UK households use a scheduled heating cycle, for example bringing the heating on twice a day. The report concludes that this is the worst heating cycle for a heat pump, while the optimal performance is continuous heating. Given the concerns expressed about poor information given to customers of heat networks, both before moving in and during residency, it is not surprising that customers with heat pumps do not appreciate that they work better with a different pattern of usage.

The quoted advantages of wholesale transition from domestic gas heating to heat pumps involve a methodological error. For each individual transition from gas to HP any advantage would have marginal impact on the overall energy endowment. However, any wholesale transition would require additional electricity generating capacity, and would involve a wasteful capital write-off of gas industry infrastructure.

Comparing end user prices for an ambient loop network compared to individual gas boilers is more complex than might be expected, due to the UK's heterogenous housing stock, differing energy efficiencies of households, different usage patterns, and the fact that heat networks can rely on diverse technologies; [141] and even heat pump solutions differ in their use of heat source, and whether or not they contribute to DWH. [142]

The consumer organisation, Which, has pointed out that users of individual gas boilers need to include the cost of servicing and maintaining their heating systems, and that this needs to be factored into any comparison. [143] It would also be true though that an ambient loop network is shared by typically only a few dwellings, and although routine maintenance and servicing costs may be lower than for a gas boiler, factoring in the replacement costs over the longer term will be a non-trivial consideration. Which?'s report also points out that in modern, well-insulated properties, the proportion of energy used for DWH, compared to that used for space heating, increases.

In the case of a heat pump, the thermal advantage of its Coefficient of Performance is sufficient to give heat capable of satisfying space heating, providing T_{low} emiters, such as larger radiators or underfloor heating are installed. However, heat pumps do not provide hot water at sufficient temperature for domestic use. [144] One option is to have a hybrid system that uses gas to either step up the temperature from the level provided by the heat pump, sometimes using a water tank, or to use only gas for DWH; another option is to use electric resistive heating to heat the water. [145]

Consider a two-storey house of 200m^2 floor area built to 2010 Building Regulations standards, with a known space heating demand of 55 kWh/m^2/yr, then for 200m^2 11,000 kWh per year is required. In addition, assuming four people are living in the house, a further 4,000 kWh is required for DWH. [146] Based upon current utility prices, then in this example the COP of a hybrid heat pump (where a gas boiler contributes to the water heating) would need to achieve COP of 4.5 to break even on fuel costs compared to an individual domestic gas boiler; the same house using a heat pump with a COP

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141 "*United Kingdom housing energy fact file*", Palmer J and Cooper I, Department of Energy and Climate Change, 2013

142 "*Hybrid heat pumps study*", Element Energy, for Department for Business, Energy & Industrial Strategy https://www.gov.uk/government/publications/hybrid-heat-pumps-study (April 2018)

143 "*Turning up the heat: The experience of district heating consumers*", Which?, op cit.

144 "*Hybrid heat pumps study*", Element Energy, op cit.

145 "*Hybrid heat pumps study*", Element Energy, op cit.

146 This example from "*Heat Pumps: The Real Cost*", Pullen T, Homebuilding and Renovating, May 2012, https://www.homebuilding.co.uk/heat-pumps-the-real-cost/

of 4.5 and electric resistive heating for DWH, would have 98% higher fuel costs compared to an individual gas boiler, with a more realistic COP of 3, then fuel costs would be 136% higher than domestic gas.

Energy Saving Trust [147] found in their first round of field tests that COP for operational systems varied between 1.3 to 3.6 for ground source heat pumps and from 1.2 to 3.3 for air source; the subsequent phase 2 field trial programme tested 44 installations, and following system design improvements, the average COP was 2.82 for ground source, and 2.45 for air sourced installations.

Therefore, it is reasonable to assume that ambient loop networks will tend to have higher energy prices throughout their lifetime, in addition to having considerably higher installation costs.

Decarbonisation through Stabilisation triangles

Back in 2004, two climate scientists from Princeton, Stephen Pacala and Robert Socolow, published a paper in the journal, *Science*, [148] which recognised that to prevent anthropogenic climate change it is necessary to reduce emissions and keep them low: the divergence between the projected growth of emissions achieved by "business as usual", and the flat path achieved by mitigation, they described as the "stabilization triangle". Given the immense scale of the task, they proposed that the stabilisation triangle should be conceptualised as several complementary smaller wedges, each of which would reduce carbon emissions by one billion tonnes of carbon, and each of which represents a different contribution to decarbonisation, for example the installation of one million 2 MW windfarms to replace an equivalent capacity of coal fuelled electricity generation would comprise a "wedge", and the tripling of the world's nuclear fission capacity would comprise another "wedge".

It is not necessary to agree with the precise quantification of the goal, or with the balance of the different mitigation strategies, and Princeton University's Carbon Mitigation Initiative explores different options. [149] However, the strength of the technique is that not all eggs are in the same basket. Three of the conceptually distinct wedges comprise: increasing the contribution from renewable electricity and fuels; improving energy efficiency and conservation; and switching to lower carbon fuels. All of these strategies can be employed through the implementation of district networks.

Flin argues that the following strategies can be employed to reduce the carbon impact of power generation: [150]

- *using renewable energies that generate electricity with a minimum of emissions;*
- *switching from high to lower CO2-emitting fuels (such as replacing coal with gas);*
- *using carbon sequestration, which collects and stores CO2 to prevent it from entering the atmosphere;*
- *using energy conservation, which reduces the energy required to produce the effect; customers buy energy for what it can do rather than for the energy itself;*
- *using cogeneration, sometimes called combined heat and power (CHP), which improves the efficiency of energy produced. As a result, the use of cogeneration means that less fuel is*

[147] "*The heat is on, heat pump field trials, phase 2*" Energy Savings Trust, August 2013, https://energysavingtrust.org.uk/policy-research/heat-heat-pump-field-trials-phase-2
[148] https://cmi.princeton.edu/wp-content/uploads/2020/01/Stabilization_Wedges_-Solving_the_Climate_Problem_for_the_Next_50_Years_with_Current_Technologies_Science.pdf , Pacala and Socolow, Science vol 305, pp 968-972, 2004.
[149] https://cmi.princeton.edu/about/ Princeton University's Carbon Mitigation Initiative, retrieved May 2020.
[150] Flin, p11, op cit.

> *used, and therefore fewer emissions produced, in generating the same amount of energy. Cogeneration produces more energy from less fuel.*

It is therefore concerning that the BEIS consultation document for heat networks does not explicitly acknowledge the contribution from cogeneration, nor recognise that natural gas employed with cogeneration is a particularly efficient mechanism for producing usable heat. This contrasts with the European framework, where legislation has included specific measures to encourage the wider use of high-efficiency CHP in the EU since 2004, when the CHP Directive 2004/08/EC was introduced as a measure for improving security of supply and energy efficiency. [151]

The BEIS consultation document tilts towards an excessive and overly optimistic emphasis on renewables, without recognition of the huge challenges in seeking to both fully decarbonise electricity generation, while simultaneously shifting both domestic heating and motor transport towards electricity. Indeed, they argue instead, rather illogically, that the carbon savings made by gas CHP plants are being reduced as the carbon emissions of grid electricity falls. This would only be the case if the electricity grid was approaching 100% renewables.

According to BEIS: "*As we move towards 2050, we know that meeting our climate targets will require a transition from gas-fired networks to lower carbon alternatives such as large heat-pumps, hydrogen or waste-heat recovery*". [152] There are a lot of assumptions in this statement that are open to challenge, and the impact on consumer heating costs may be substantial. Based upon reasonable engineering assumptions, it is estimated that shifting 20% of domestic heating from individual natural gas boilers to electric powered heat pumps would also require additional electricity generating capacity, estimated at £28 billion. [153] Both the new electricity capacity, and the write off of gas industry capital have to be factored as energy inputs into the overall Energy Return on Energy Investment (EROEI) for heating networks.

There is also no recognition that natural gas employed in the current network for domestic supply, used in space heating, hot water and cooking, is itself efficient, using a clean, cheap and convenient fuel, and that natural gas is the lowest carbon fossil fuel. Given that district networks will not be universally fuelled by renewables, then it cannot be reliably assumed that they will be result in a lower carbon outcome than would be achieved by maintaining the current domestic gas endowment, especially if combined with measures to reduce fuel use by modifying customer behaviour, and future expansion of the proportion of biomethane and possibly hydrogen.

Assessing decarbonisation

Given that government support for the expansion of heat networks is to achieve a public policy objective of reducing carbon emissions, and that to achieve this end the government is committed to significant financial support, and also local authority compulsion of consumers to connect to networks, then it is necessary to evaluate whether the public policy objective is actually achieved, it is proportionate to expect that the proposed gain in decarbonisation should be scrutinised for large district networks that are underwritten by not only public money, but also zoning and other planning compulsion.

District heat systems, like any complex system, generate waste, including solid, liquid and gaseous emissions. The majority of significant district heating schemes include cogeneration, and multiple

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[151] *"CODE 2 Cogeneration Observatory and Dissemination Europe"* COGEN EUROPE, op cit.
[152] "*Heat Networks Building a Market Framework*", p75, op cit.
[153] "*Transition to heat pumps for domestic heating, a critical evaluation*", anewman consulting, unpublished report for GMB trade union, 2020.

sources of heat energy. Considerable work has been done by companies, government agencies and researchers to evaluate the waste (including CO_2) of such systems that have multiple inputs and products, but there is no consensus; different methods produce different results, and they are often too complex to convince decision and policy makers of their benefits. [154] It is therefore necessary for the UK to standardise upon a shared analytical approach.

The European Parliament issued a directive in February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market. [155] Also, the European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC) put forth in 2004 a workshop agreement manual [156] for determination of CHP. These documents are widely accepted for analysing the primary energy savings due to cogeneration.

However, while useful, these European standards and guidance manual are limited to cogeneration systems, rather than heat networks, a broader analytical approach is therefore required.

Professor Marc Rosen from the University of Ontario Institute of Technology, and a former President of the Engineering Institute of Canada, has proposed that incorporating thermodynamic analysis as inputs to these European regulations would strengthen them markedly, and also thermodynamic analysis is suitable for other multigeneration systems, such as heat networks.[157]

In addition to thermodynamic analysis, district energy systems can be modelled and optimised using energy equilibrium models. [158] There are several algorithms for their solution, including the well-known Project Independence Evaluation System (PIES) algorithm of Ahn and Hogan. [159] The energy equilibrium model can be set up, formulated, and solved within software called the Waterloo Energy Modelling System (WATEMS). [160]

Many methods can also be used to analyse the economic impacts of implementing Heat networks, for example, analysis of the present worth of partial social welfare change or analysis of payback-period: CO2 emission levels, can be introduced into these model systems. [161]

[154] Rosen and Koohi-Fayegh, pp 185 – 187, op cit.

[155] European Parliament. Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market and Amending Directive 92/42/EEC. Off J Eur Union 2004;L52(47):50–60.

[156] CEN/CENELEC Workshop Agreement Manual for Determination of Combined Heat and Power (CHP). CWA 45547, European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC), Brussels; 2004.

[157] Rosen and Koohi-Fayegh, p213, op cit.

[158] Rosen and Koohi-Fayegh, pp 213 - 237, op cit.

[159] "*On convergence of the PIES algorithm for computing equilibria*", Ahn BH, Hogan WW. Oper Res, 1982;30(2):281–300.

[160] Rosen and Koohi-Fayegh, p 238, op cit.

[161] Rosen and Koohi-Fayegh, pp 237-246, op cit.

Part Three: What good regulation would look like

Currently, the regulatory environment for heat networks is the Wild West.

Due to laudable ambition to place the UK as a trailblazer of decarbonisation, significant financial subsidy is being provided for what are regarded as lower carbon heating initiatives, and compulsion is being contemplated through local authority planning regulations to force customers to connect to heating networks.

However, customers of heating networks have significantly fewer consumer rights than customers of the regulated utilities: gas, electricity and water. The majority of heat network customers also have no ability to disconnect from a heat network to move to an alternative supplier, and this monopoly supply position leads to a minority of customers having a very poor quality of service and high prices. Heat network customers are more likely to be older, poorer and more vulnerable than the general population, yet are unprotected.

Structural problems of the heat network market also lock in a number of undesirable features that contribute to underperformance, and there is no mandatory requirement to follow technical standards.

In addition, the evidence base to support the contention that any particular technology, or heat network design actually achieves carbon emission reduction is often under-analysed. This is particularly the case if cost effectiveness is taken into account.

The objectives of regulation should therefore be guided by the following principles

1. Consumer protection, including pricing, should be no weaker than for customers of the gas network.
2. The structural problems of the dysfunctional market need to be addressed, to remove systemic factors that contribute to poor performance.
3. Decarbonisation outcomes should be analysed and substantiated before compulsion is used to force people to connect to networks.
4. Where networks receive public support, not only should they adhere to mandatory technical standards, but their decarbonisation targets should be analysed and substantiated.

BEIS are proposing a weaker regulatory model for heat networks than the current licencing model for gas, electricity and water. [162] BEIS argues that a licencing model is unsuitable for the following reasons:

- The 'one size fits all' supply licence already used for the gas and electricity markets, is starting to hold back progress by preventing consumers from benefitting from innovation, and is slowing down decarbonisation [163]

- The essentially monopolistic nature of the service to end consumers.

- The complex and diverse stakeholder landscape with many different models and structures for the ownership and operation of schemes.

[162] "*Heat Networks Building a Market Framework*", pp 36-39, op cit.
[163] "*Flexible and responsive energy retail markets consultation*", BEIS and Ofgem (2019), https://www.gov.uk/government/consultations/flexible-and-responsive-energy-retail-market s

- Disproportionate cost

This is unconvincing.

Firstly, Ofgem, has already taken steps in moving from prescriptive rules to outcomes-based principles, and further reforms are being considered. These reforms are not inconsistent with the licencing regime.

Secondly, the monopolistic service to end customers leads to situations where, according to the CMA, heat network providers face little competitive pressure to offer reasonable prices, reliable supply and high quality of service. [164]

Thirdly, the complex landscape of stakeholders is itself a structural factor contributing to the low reputation of the heat network market, and its poor reputation with customers. The aim of regulation should be to remedy these failings.

Finally, BEIS expresses concern over the balance between potential costs of funding the regulator's activities – which may affect consumer bills – against the level of oversight and anticipated compliance activity required for this market. They wish to ensure regulation is proportionate and that any resulting costs to consumers remains appropriate to benefits delivered. [165] This seems to accept that the regulatory framework for heat networks will inevitably place customers at a disadvantage compared to customers in the existing domestic gas market: heat network customers will be faced with either weaker regulation, or higher prices.

[164] "*Heat Networks Market Study*", p33, CMA, op cit.
[165] "*Heat Networks Building a Market Framework*",p32, BEIS, January 2020.