Durham University

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Decarbonising heat to achieve net-zero

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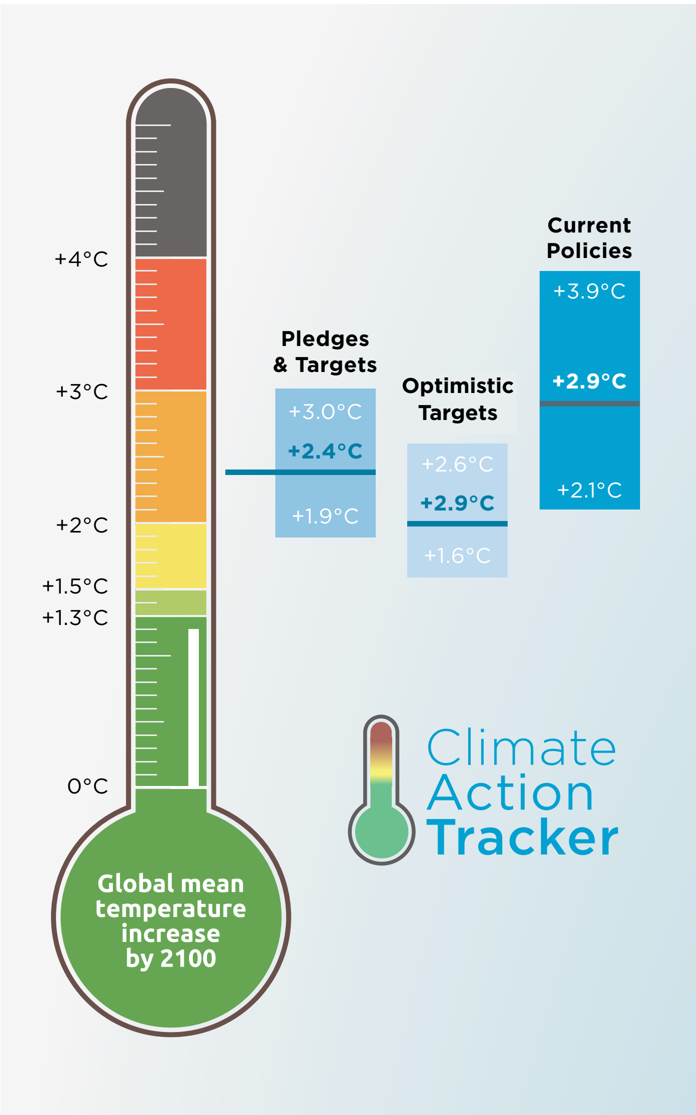
Context

The UK relies upon burning fossil fuels (mostly natural gas) for 77% of the heat it requires for domestic and industrial properties which generates more than 30% of the nation's greenhouse gas emissions. In contrast to the substantial progress the UK has made in decarbonising electricity generation almost nothing has been done to decarbonise heat. Here we show how to decarbonise heat on a local, regional and national scale and thereby help the UK meet its net-zero (carbon) commitments.

The Climate Action Tracker, an independent scientific organisation, estimates that current global policies will likely result in about 2.9°C of warming above the pre-industrial average temperature (Baxter, Arslan & Beer, 2021).



This temperature increase will:

- Cause a significant rise in sea level
- Turn parts of the planet into deserts
- Cause increased disruptive weather events including floods, droughts and heat-waves

Limiting global warming to the Paris Agreement target of 1.5°C above the pre-industrial level means that the emissions of greenhouse gases (GHGs) need to be reduced drastically in the coming years and decades, and brought to zero around mid-century (Baxter, Arslan & Beer, 2021)

Net-zero refers to our ambition to eliminate the effects of emissions of CO_2 and other GHG from human activity. There are different approaches to achieve this. For example, by removing the CO_2 directly from the atmosphere or preventing CO_2 from going into the atmosphere in the first place, so that the emissions balance is zero (Energy saving trust, 2021).

The UK government has legally committed to achieving net-zero by 2050.

Decarbonising heat - essential for achieving net-zero

The UK has made significant progress towards reducing its emissions. 2020 was the greenest year on record for national electricity production, with over 200 days of coal-free generation and all-time-highs for wind and solar energy (**Durham Energy Institute, 2020**). However, the UK still heavily relies on natural gas to fuel the gas-fired power plants that replaced coal-fired stations and to provide heating.

In the UK, over a third of all GHG emissions are associated with the heating and cooling of homes and workplaces. Thus, decarbonising the heating sector would significantly advance the efforts to achieve net-zero emissions.

However, the technologies that will help to decarbonise the more than 21 million gas boilers installed in our homes and similar larger systems of our workplaces are still under development. Furthermore, new technologies find it hard to compete with gas systems which currently enjoy tax exemptions by a system that does not fully recognise the long term costs of CO_2 emissions.

Three ways towards decarbonising heat

Since emissions associated with heating are scattered and unevenly distributed, we need to take a different approach than the one used for decarbonising the electricity sector.

This briefing presents three research-based options for shifting heating from natural gas:

1 **Changing heat generation**

2 **Reducing heat loss**

3 **Reducing and shifting heat demand**

1 Changing heat generation

Using electric heating systems, hydrogen as fuel and geothermal heat

Using electric heating systems

The use of electricity for heating and cooling can reduce or even eliminate CO_2 emissions as long as it is generated from wind, solar energy other zero carbon sources. Thus replacing gas boilers with electric heating is a key Government policy focus. In fact, the heating sector is expecting the Government to announce a gas boiler ban in new homes, starting from as early as 2025, in an attempt to achieve net-zero by 2050.

The main challenge of transitioning from natural gas to electric heating systems is that this will increase electricity demand, putting the UK electricity system under increased stress. It is likely the demand will outstrip the renewable electricity supply. This could result in burning more gas for electricity generation, which given the low efficiency of gas-fired power stations, could double GHG emissions.

Additionally, replacing existing gas boilers with electric water heaters, radiators or heat pumps comes at a cost, and we must consider who is going to pay for the equipment. Further, electricity is more costly than gas, increasing the running costs. On the positive side, replacing gas boilers represents an opportunity to introduce innovations. Examples are the introduction of "AI" or "smart" radiators, water heaters or heat pumps that manage the increased electricity demand, and the use of solar water heating.

Using hydrogen as fuel

Substituting natural gas (mainly methane, CH_4) with hydrogen (H_2) as the fuel would reduce CO_2 emissions. The combustion of H_2 produces water vapour, not CO_2. Currently CH_4 / H_2 and H_2 boilers are being developed to reduce or eliminate CO_2 emissions.

Challenges of using H_2 as fuel:

1. **Combustion of H2 with air can produce nitrogen oxide (NOx) gases, which have harmful health and environmental impacts. Design and operation considerations should avoid this.**

2. **Research is needed to fit existing gas distribution networks to transport H_2 in a safe manner.** **See case study 1 on the following page.**

Case study 1: HyNTS Future grid project

The Durham Energy Institute (DEI) is working with the UK National Grid on the HyNTS FutureGrid project to investigate how H_2 might be delivered to homes and businesses using existing pipelines. This would mean that an entirely new heating system would not be required.

The research facilities will be separate from the main National Transmission System and will be built at DNV GL's site at Spadeadam, Cumbria, UK. The project will use decommissioned assets from the UK's gas transmission system to test up to 100% H_2 blends in a controlled environment, without affecting the existing gas transmission network.

The project focuses on H_2 storage and compression, understanding consumer demand and the development of new standards and regulations.

To know more:

Durham University (2020)
"Durham research supports £12.7m National Grid hydrogen research facility".
Accessed 29th June 2021.

3. The H_2 source must be considered if it is going to be used on a large scale. Three of the main options exist at the moment:

Blue hydrogen

- **Obtaining H_2 from fossil fuels coupled to a carbon capture and storage (CCS) process to avoid CO_2 emissions**

Gold hydrogen

- **Extracting the H_2 in the subsurface as a naturally occurring gas**
- **This would eliminate manufacture costs**

DEI is working on this approach in collaboration with Oxford University

Green hydrogen

- **Producing H_2 from water via electrolysis**
- **Electricity for electrolysis comes from renewable sources**
- **No CO_2 emissions**
- **Expensive large scale production**
- **Price is expected to drop quickly if the plans for using it in heating, industry and transportation result in high demand**

DEI led Network H_2 is working towards the production of green hydrogen at large scale and is developing a facility to demonstrate H_2-fuelled heating, storage and power generation with potential commercial applications.

Using geothermal heat

Low-grade geothermal heat can provide a stable source of heat with minimal energy loss as no conversion from electricity to heat is required (**Gluyas et al, 2018**). Geothermal energy has the benefits of being a local form of energy, it is present everywhere on Earth and it is not shaped by external political or economic fluctuations. In fact, low-grade geothermal energy use has been implemented by many European countries that use localised and collective heating, in both domestic and industrial settings.

Unfortunately, UK housing policies have largely focused on heating demand from individual households instead of shared community assets. From the 1980s onwards, heat networks became popularly associated with tower blocks that had poorly-maintained heating systems and fell out of favour. Consequently, the UK has not reaped the benefits of heating networks which are very well suited for densely populated areas and new-build dwellings.

Case study 2: Geothermal heating from abandoned mines

Water in mines is usually warmed geothermally. Mine water heat is abundant and widely distributed, often located in areas of high heat demand. It can provide more consistent heating throughout the year than other heat pump-based systems, which draw heat from the air or ground. Taking advantage of the heat in mine water can also benefit some of the most deprived communities which suffered the abandonment of deep mining in the UK, by reducing costs for consumers, attracting inward investment and hence redevelopment. Additionally, mine energy schemes could provide largescale underground thermal-energy storage for the UK. This would help to meet heating demand throughout the year without stressing the electricity grid.

For over 10 years DEI has been researching the potential of geothermal heating in the UK. DEI has been working closely with industry, research and policy partners, helping to reduce waste heat and to meet heat demand across the seasons. As a result, the Coal Authority has 42 projects in the UK pipeline, and both County Durham and South Tyneside will have schemes for housing and municipal buildings (4-5MW) operational by 2025.

To know more:

- **Gluyas, J.G., Adams, C.A. & Wilson, I.A.G. (2020) "The theoretical potential for large-scale underground thermal energy storage (UTES) within the UK" Energy Reports 6(7): 229-237.**
- **North East Local Enterprise Partnership (2021) "The Case for Mine Energy – unlocking deployment at scale in the UK: A mine energy white paper".**

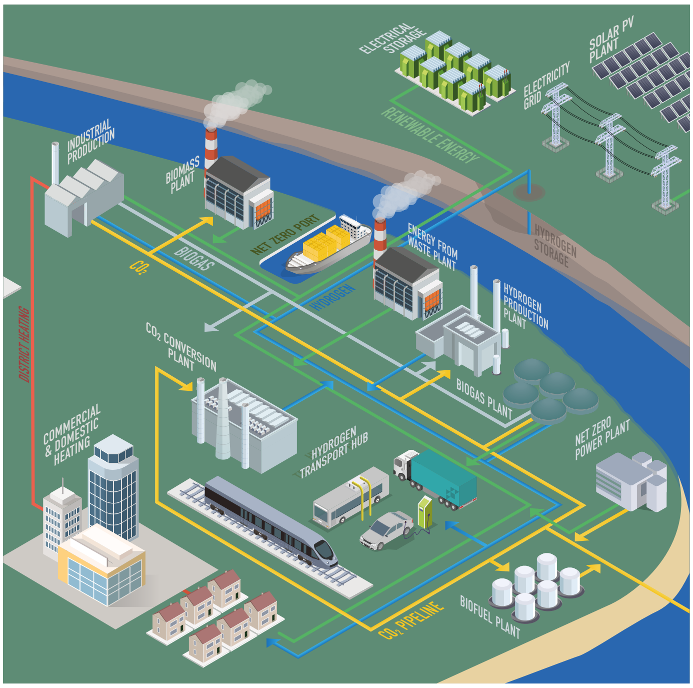
2 Reducing heat loss

Once the heat has been generated, the way it is utilised also impacts the amount of CO_2 emissions associated with it. The efficiency of the energy systems can be maximised in several ways, such as capturing waste heat and combining it with other energy sources, using it for industrial processes or even to heat buildings.

Case study 3: Industrial heat decarbonisation system in action

DEI, in collaboration with the Teesside Industrial cluster, is working on capturing and reusing heat and waste heat in more effective ways to use it within industrial processes. Furthermore the research and development looks at exporting heat to meet the domestic demand in the neighbouring area.

Durham is developing energy network systems that use a liquid desiccant solution to transport energy. The waste heat will be harvested at multiple locations at different temperatures by regenerating the desiccant solution. The thermal energy will be stored in the form of the absorption potential of the substance, which has the advantage of having a minimum energy loss, even when distributed over long distances. The energy can then be released where it is needed for use in dehumidification and cooling. The implementation of this network will allow significant reductions in GHG emissions in industrial production and potentially provide an additional revenue source.



DEI have also developed the Trigeneration Recovery Efficient Energy Storage (TREES) technology which is a flexible zero-loss energy storage and zero carbon energy conversion system. It uses a novel thermochemical sorption system driven by low-grade heat, from either geothermal, solar thermal or industrial waste heat sources, and renewable electricity, The system provides the unique opportunity to combine thermal and electrical energy storage and delivers heating, cooling and/or electrical power in one integrated system.

To know more:

Geyer, Delwati, Buchholz, Giampieri, Smallbone, Roskilly, Buchholz and Provost (2018) "Use cases with economics and simulation for thermo-chemical district networks" Sustainability 10(3)

Bao, Huashan, Ma, Zhiwei & Roskilly, Anthony Paul (2016). "Integrated chemisorption cycles for ultra-low grade heat recovery and thermo-electric energy storage and exploitation." Applied Energy 164: 228-236.

3 Reducing and shifting heat demand

Changing behaviour, increasing energy efficiency of buildings, interconnecting systems

Changing behaviour

An approach to reduce the demand for heating and cooling involves changing cultural expectations and behaviours, and challenge the increased demand for energy to create higher levels of comfort at work and at home.

Case study 4:

The customer-led network revolution

The **customer-led network revolution** (CLNR) investigated how to support greater uptake by customers of new sources of generation, low carbon technologies like electric vehicles and heat pumps, and smart appliances. It also monitored energy use behaviours, trialled direct control methods using smart technology to assess customer habits and encourage better electricity and heat usage.

The researchers found that the use of electric vehicles or heat pumps can effectively double the domestic electricity demand, a scenario that would present significant challenges to electricity systems. Additionally, the findings identify ways in which such technologies are introduced and interwoven into household practices. How installation and instruction are undertaken is critical in shaping the initial reception and the ongoing effectiveness of new technologies.

Increasing energy efficiency of buildings

Another way to reduce CO_2 emissions is to increase the energy efficiency of buildings and processes so that they maintain good thermal performance.

Case study 5: Solid Wall Insulation Innovation

A well insulated home typically uses 25% less energy than a similar property that is uninsulated, and thus pays 25% less in bills. In the North East, many properties built before 1920 are made of solid stone or brick walls which lack cavities for insulation fillings. The **Solid Wall Insulation Innovation (SWII) project** assesses the impact of domestic smart energy controls and an innovative advice system on energy usage and fuel poverty. The project also looks into how to further reduce CO_2 emissions of the properties. So far, the project has found that introducing solar panels on their own could only achieve a 20% emissions reduction while appliance scheduling alone could achieve 17%. However, when combined, they could get up to a 70% reduction. The next step for this project will be to explore the benefits of integrating heat and power with scheduling and household energy trading.

To know more:

Stacpoole, Kitty and Sun, Hongjian and Jiang, Jing (2019) "Smart scheduling of household appliances to decarbonise domestic energy consumption." IEEE/CIC International Conference on Communications in China Workshops 2019 proceedings, pp. 216-221.

Interconnected systems

The benefits of changing behaviour and increasing the energy efficiency of buildings do not have to be isolated. Interconnected systems can further reduce emissions.

Case study 6: Ubiquitous Storage Empowering Response (USER) project

Instead of generating more energy to satisfy demand during short and infrequent periods, it makes sense to find smarter ways to use the already existing one. The **Ubiquitous Storage Empowering Response (USER) project** demonstrates how Artificial Intelligence (AI) energy-led hot water tanks can help households heat their homes more economically and at the same time trade their heat with other households.

Integrating AI to heat pumps can reduce CO_2 emissions by 20%, and a reduction of 55% is possible when the AI is integrated with solar panels. Moreover, it was found that the level of running costs of the system are close to the cost of gas-fired systems during the summer and very close in spring and autumn.
More research is needed to reduce the cost during winter and make USER competitive.

To know more:

Stanley J. Lowres, Hongjian Sun, Jing Jiang (2021) "Heat Pump Day-Ahead Scheduling for the Decarbonisation of Domestic Heating". Durham University

A just transition

Although the need for heating affects us all in the UK, the required level of heating and cost is not the same for everyone. The heating demand and the amount of energy needed to heat different spaces in similar locations depend on the context. For example:

- People living in poorly insulated houses tend to spend more on heating and are less likely to be able to afford improvements.
- Those in private rented accommodation may be subject to excess heating costs with little ability to change their living conditions.

Progress towards the decarbonisation of heat in the UK should be based on a set of principles that can ensure a "just transition". These principles should be implemented through programmes of action, building on participatory governance and energy vulnerability studies.

At Durham University, we implement the following six principles in our research.

- **Fairness** - It is essential to consider who will pay for infrastructure changes. Not everyone has access to the same opportunities because of context.
- **Knowledge** - Trustworthiness, reliability and accessibility of the information. Even policymakers or local authorities can find it difficult to choose which is the best solution to implement. Reliable and accessible information on what is available, their true impacts and costs needs to be available.
- **Inclusion** - The proposed solutions must work with existing homes and with norms and expectations around comfort. Rather than starting with a technological idea and asking users to adapt to it, a people-centred design approach starts with the product or service and designs the technology to work in practice.
- **Equity** - Progressive heat decarbonisation should benefit the neediest first and avoid regressive outcomes. Rather than promoting particular disruptive technologies (such as heat pumps), decarbonisation should seek to adopt least-disruptive decarbonisation mechanisms, using a range of technological options. Recent research on the repurposing of gas boilers to work with H_2 is an example of low-cost, low-disruption decarbonisation.
- **Democracy** - The decarbonisation process must respond to diverse concerns and be open to different voices.
- **Low-emissions** - An accessible process with fair outcomes will help to make decarbonisation socially and environmentally sustainable.

Case study 7:

Developing an energy vulnerability strategy for Haringey Borough Council

Haringey is the borough with the greatest level of inequality in London and the 13th most deprived borough in England.
To tackle this, researchers from DEI worked with Haringey Borough Council's Carbon Management team to develop the borough's Affordable Energy Strategy (2020-2024). The design of the strategy and its underpinning research focused on understanding the complexity of energy vulnerability in the area. An approach developed through the EPSRC funded the Interdisciplinary Cluster on Energy Systems, Equity and Vulnerability (InCluESEV). The research showed that access to retrofitting opportunities is generally limited for energy vulnerable households, such as those in private rented properties on low incomes. On the other hand, there is a widespread lack of understanding of energy technologies.
Help when the technologies are introduced and afterwards is often missing, limiting its effective and efficient use.

Many users feel disempowered with respect to addressing their own energy vulnerability. Although local projects existed to address unaffordable domestic energy costs, we found the projects were working separately which resulted in fragmented community initiatives. The new strategy overcomes these problems by adopting a whole systems approach to create integrated and socially inclusive policies and practices.

To know more:

London Borough of Haringey (2021) "Haringey Borough's Affordable Warmth strategy"

Adams, C., Bell S., Taylor, P., Alimsis V., Hutchinson, G., Kumar, A. and Turner, B. R. (2013) "Equity across borders: A whole systems approach" in Bickerstaff, K., Walker, G. and Bulkekley, H. (eds.) Energy justice in a changing climate: Social equity and low-carbon energy, London: Zed Books, pp. 91-115. ISBN 978178032567.

Find out more about the InCluESEV project and our work with Haringey

Recommendations

There is a wide range of options to decarbonise heat, such as changing the heat generation, reducing the demand and shifting behaviour. Combining these solutions with smart technology and energy storage can reduce demand, balance different sources and enable heat trading. Some alternatives, such as the use of H_2, need more momentum in order to reduce their cost and become more competitive with natural gas systems. However, it is very important to ensure that **user engagement and understanding are at the centre of these changes** so that vulnerable groups are not further marginalised by the introduction of new technologies.

- **Design fair policies and solutions for decarbonising heating and cooling that address energy poverty.**
- **Consider the current context and avoid idealized assumptions. Some proposed solutions have failed not because of the idea, but because of the implementation.**
- **Examine the consequences of the interaction between policies at different levels to ensure that they work in unison rather than oppose each other in the short, medium and long term.**
- **Propose solutions that offer benefits within the electoral-cycle, but also garner longer-term cross-party support.**