National Infrastructure Commission

Second National Infrastructure Assessment: Baseline Report

UK Energy Research Centre response

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Introduction

UKERC has particular expertise in the energy system changes needed to deliver decarbonisation. In our submission we address questions 1, 2, 4, 8, 9, 10, 11, 12. In each instance we provide a summary of some of the main issues where we have expertise and insights relevant to the question. In many cases the issues are complex and wide ranging, with interactions between different challenges and across questions. UKERC has the capacity to organise workshops, roundtables and briefings and we would be happy to discuss any of the issues presented in our submission in more detail and to convene activities in support of the Commission's analysis.

1: Do the nine challenges identified by the Commission cover the most pressing issues that economic infrastructure will face over the next 30 years? If not, what other challenges should the Commission consider?

UKERC research focuses on energy related issues, in our answer to this question we consider energy production and use. Since provision of energy for all uses is the principal contributor to CO_2 emissions, we also focus on achieving net zero at least cost to consumers (note also our response to question 4 on wider environmental issues). In this regard, the principal omission from the challenges as defined is a specific challenge on decarbonisation of transport, which accounts for some 27% of GHG emissions.[1] We understand of course that mobility is included in the levelling up challenges, with links to decarbonisation. We also appreciate that decarbonised power provides one route to decarbonise transport and that new networks for hydrogen provides another. Many of the priorities for improving interurban mobility and reducing congestion can also reduce emissions of CO2, as well as local pollution. However, there may be trade-offs if improved overall mobility leads to more trips using fossil fuel modes. It is also somewhat surprising that heat is explicitly included in the decarbonisation challenge framing, whilst emissions from transport are not. We note the considerable potential for interaction between end use sectors, for example in placing competing demands on distribution networks that can be partly ameliorated through coordinating time of use of heat pumps and charging of vehicles.

The Committee's previous recommendations on charging infrastructure are welcome and the Baseline Report notes the target to end sales of non-plugin vehicles. However, these are only two aspects of a much wider challenge. It is also important to ensure that policies promote the adoption of electric vehicles prior to the start of the sales ban, work to reduce the purchase of the most polluting vehicles and help to reduce total travel by car.

[1] Department of Transport. 2021. Decarbonising Transport – A Better, Greener Britain. Access here.

Given recent and unprecedented increases in natural gas and electricity prices we also wonder whether the framing of the decarbonisation of power and heat challenges need to incorporate explicit recognition of price security and affordability. Whilst it might be unwieldy to try to reword the challenges to bring in additional objectives, we suggest that this changed context is reflected in the priorities that the Commission considers. It is important to consider carefully how to manage the transition away from gas in many sectors. We describe this as gas by design.[2,3]

2: What changes to funding policy help address the Commission's nine challenges and what evidence is there to support this? Your response can cover any number of the Commission's challenges.

In our answer to this question we assume that funding policy refers to any intervention that seeks to direct investment towards lower carbon infrastructure and systems, as well as direct flows of public funds to lower carbon alternatives. Our answer encompasses electricity market design and incentives, the wider impact of cost on consumers and importance of complementary policies, and investment in network infrastructures.

Until recently a focus of decarbonisation policy has been to provide subsidy to low carbon technologies - including renewable energy - that were more expensive than fossil fuel options, such as gas-fired power stations. The cost of doing so has generally been borne by electricity consumers, not general taxation. The mechanisms have varied but include the Renewables Obligation and Contracts for Difference (CfDs). Additional important policies include other obligations on energy companies such as energy efficiency commitments, and the carbon price floor. Policy also affects the level of investment in electricity infrastructure, which has increased in order to accommodate lower carbon options. Energy infrastructure is not paid for from public funds, but regulation of networks includes provision for investment and upgrading, ultimately this cost is also borne by consumers.

Beyond subsidy - the importance of electricity market design

In the last few years an important change has occurred that affects funding priorities for low carbon power. New renewable energy projects no longer require subsidies in the traditional sense of paying a high price per unit of energy generated. This is because new renewable energy projects are able to deliver electricity at or below the generation costs of fossil fuelled equivalents. However, this does not remove the need for a funding policy per se, since it appears that investment has been strongly encouraged by government backed long run contracts (the CfDs). UKERC analysis indicates that the presence or absence of such a contract could affect the cost of capital of a hypothetical future offshore wind project by as much as five percentage

[2] Bradshaw.2018. Future UK Gas Security: A Position Paper. Access here.
[3] Bradshaw.2021. UK consumers pay for the cost of 'Gas by Default.' Access here.

points. In the mid-2030s this could be equivalent to a £5bn per year difference in the cost of electricity generation.[4]

Thus, whilst the need for direct subsidies is now limited, a funding policy need still exists, since the CfD represents a transfer of risk. Wholesale market price risks are removed from investors in low carbon generation, but a risk that CfD prices are higher than necessary is placed upon consumers. Setting CfD prices by auction reduces the potential for generators to be over-rewarded and with gas prices at record highs, this risk may appear small at present. However, any policy that intervenes in the market to provide a 15 or even 35-year contract to particular generation options represents a major intervention that deserves careful scrutiny.

Long run fixed price contracts also insulate renewable generators from market price signals that could help to optimise overall operational efficiency. As the share of renewable generation has increased a range of challenges have emerged. The correlation of renewable outputs leads to wholesale market price cannibalisation with prices very low or negative at some times of the day and year. The impact of network constraints has become more significant. The volume of trading (and bid prices) in the Balancing Mechanism has increased, and the System Operator has contracted for new ancillary service requirements to keep the system secure as the share of variable renewables has increased. The impact on overall costs to consumers is complex, since if renewables reduce overall generation costs, then any increases in balancing or ancillary service costs maybe offset. Minimising overall system costs is the key challenge. The overall impact on consumer bills is complex given the scale of the transformation of power generation that a move to net zero necessitates. As a result, there are a range of views over the most appropriate set of interventions and future structure for the wholesale electricity market. We discuss the various issues in our response to the call for evidence issued by BEIS last year.[5]

As the share of renewables rises further there will be a need to increase the availability of a variety of sources of low carbon flexibility, from demand response, interconnection, low carbon flexible generation and storage (see also our answer to question 8). Recent record gas price rises also underline the potential value of moving away from a system where gas-fired plants set system price much of the time.

If the net zero target is to be met there is continued need to incentivise investment in low carbon generation. For this reason, the UK Government has committed to further rounds of CfD auctions. In the longer term, it is possible to envisage reforms to the underlying structure of the wholesale market and to network charging. These may help to address issues such as price cannibalisation, create greater incentives for low-carbon flexibility and reduce network constraints. Investment in flexibility (such as storage or demand response) may itself require subsidy and/or changes to incentives that impact on consumer bills.

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[4] UKERC. 2021. Risk and investment in zero-carbon electricity markets. Access here.
[5] UKERC. 2021. Response to BEIS call for evidence: Enabling a high renewable, net zero electricity system. Access here.

A broad definition of funding policies therefore needs to include electricity market design issues. What might the market of the future look like? How can we evaluate different prospective market arrangements? When could prospective changes happen? Detailed consideration of electricity market design may be beyond the scope of the National Infrastructure Assessment. However, electricity market design will be hugely important to delivering decarbonisation cost effectively.

The wider impact of policies on consumers

If we look more broadly at the changes that will be needed to decarbonise heat and transport it becomes apparent that funding policies also play an important role, but that taxes and subsidies need to be set in a wider context of complementary policies.

Government has signalled an intent to move policy costs away from electricity consumers and onto the use of gas. This is likely to be politically challenging until gas prices fall, but as a point of principle it has considerable merit. In the past electricity generation was more polluting than using gas directly, so levying the cost of subsidies for greener electricity on electricity users was consistent with the polluter pays principle. It also helped to drive innovation, since market growth in renewable energy was an important source of learning effects and cost reduction. If policy now seeks to encourage consumers to move to electric heating using heat pumps it no longer makes sense to levy all the carbon/innovation costs on electricity use alone. Doing so could be counter-productive and as the power sector decarbonises the polluter pays rationale diminishes. Previous UKERC research has highlighted how experience in other countries shows that the presence of a downstream carbon tax can help shift households away from more polluting heating fuels (such as fuel-oil), towards electricity.[6] It is important to note that this research also emphasises the importance of capital subsidies for heat pumps, installer training and certification, and regulation in shifting domestic heating away from fossil fuels.

Making progress with energy efficiency, heat pumps and roll out of electric vehicles (EVs) requires a mix of policies. There is good evidence to suggest that subsidies that target purchase price help to kick start the markets for technologies such as heat pumps and EVs. Since any subsidy represents a transfer payment, ultimately borne by householders through taxes or bills, it is important to consider how such subsidies are paid for and undertake careful analysis of the balance of costs and benefits. In sectors where capital costs represent an impediment to consumer uptake then capital subsidies may be a more effective way to promote uptake of low carbon technologies than taxes on fossil fuels. Uptake of energy efficiency and low carbon technologies can be subject to non-price market failures, and it is important for taxes and subsidies to be viewed in the context of a suite of interventions. Regulation can play an important role, since the least efficient or most polluting options can be removed from the market. Labelling and information provision are also key to market transformation and there will be a need to ensure that skills and supply chains keep up with new developments. The recent failure of the Green Homes Grant, in part due

[6] UKERC. 2016. Best practice in heat decarbonisation policy. Access here.

to a lack of installers, provides a clear example of how a funding policy deployed in isolation is unlikely to be successful (see also our answer to question 10).

Infrastructural transformation

Decarbonisation will require the upgrade of network infrastructure, particularly electricity networks, and the provision of entirely new infrastructure such as carbon capture and storage systems or heat distribution networks. Gas infrastructure will need to be repurposed for hydrogen and/or will serve a reduced role, at least in overall energy terms (peak capacity may need to be retained for some time to come). New infrastructure needs to be paid for and delivered as cost effectively as possible. As with power generation, policy can affect risks and the returns required by investors, hence total costs including interest payments. Government is likely to face a coordination challenge, because it is important to avoid an ongoing chicken and egg scenario where lower carbon technologies such as EVs or heat pumps are constrained by a lack of network capacity. At the same time, if network investment proceeds ahead of demand we may end up with excess capacity.

A general characteristic of much of the investment needed to deliver net zero is that the energy system will move from the less capital-intensive structure that delivers fuels to a more capital-intensive system that harnesses flows of renewable energy. Doing so efficiently and cost effectively also requires investment to improve energy efficiency, particularly in buildings. Whilst in the long-term this shift may offer the prospect of cheaper overall energy there is a transitional cost – new infrastructure needs to be built and paid for. One way to conceptualise this is to consider it as a shift from the cost of fuel to the cost of finance. This suggests that there may be cost savings if policies are focused on delivering investment at a low cost of capital. This may require government agencies coordinating infrastructure developments and ensuring that network regulation is attractive to low-cost sources of finance. The Commission may wish to evaluate the relative merits of approaches that focus on technology neutral options such as a low carbon obligation, against more directive approaches that determine energy technology and infrastructure needs. Both approaches can use market mechanisms such as auctions to determine the prices paid for new infrastructure. However, there are likely to be important choices about the extent and nature of government decision making. All of this needs to be set in the context of the urgency of the carbon challenge.

4: What interactions exist between addressing the Commission’s nine challenges for the next Assessment and the government’s target to halt biodiversity loss by 2030 and implement biodiversity net gain? Your response can cover any number of the Commission’s challenges.

There are positive and negative interactions between all nine challenges and the Government’s biodiversity targets. In all cases a key to success will be to embed environmental considerations within the challenges, as opposed to having them as external drivers. This will require interdisciplinary working, bringing specialists with environmental expertise into close working relations with others at the start of the planning. Explicit time and resource should be dedicated to ensuring regular and effective communications between disciplines.

The Commission's second Baseline Report makes an excellent step towards this integrative approach in including environmental impact as one of its analysis topics and as a strategic theme for the second assessment, however undertaking this in practice will be a significant challenge. Whilst the assessment is correct in that infrastructure policy can reduce environmental impacts, and whilst Net Biodiversity Gain is an explicit policy aspiration, on the ground we have only a nascent record of success in achieving this.

Here we take Challenge 2, decarbonising electricity, as a focus for our response, but much of this response will also be transferable to the other challenges. The decarbonisation of electricity will be driven largely by investment in renewable energy, with a current emphasis on bioenergy, solar and wind.[7] This development will necessitate expansive land and marine use change. Given land and sea use change is one of the greatest drivers of environmental degradation[8] there is a real risk that solving the carbon problem will be at the expense of creating a host of other environmental problems, including biodiversity loss.[9,10] Any decarbonisation pathway is also likely to result in significant competition for land and marine space, as space needed for energy production can directly compete with other land and marine use requirements such as greenhouse gas removal, including afforestation, and needs for food production.

There are several steps which can be taken to reduce this environmental risk and address the implications of competition, and instead enable a neutral or positive (net gain) environmental impact.[11]

A key initiative is to use spatially resolved land and marine systems approaches enabling a holistic, whole systems perspective and to ensure optimal solutions that maximise wider environmental co-benefits. For example, current decarbonisation plans have considered which energy types can be implemented, but there has been very little focus on where installations and crops will be sited and what their environmental implications will be.[12,13] Ongoing research within the UKERC Energy,

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[7] Climate Change Committee. 2020. The Sixth Carbon Budget. The UK's path to Net Zero. Access here.
[8] IPBES. 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Access here.
[9] Holland et al. In Press. The influence of the global electric power system on terrestrial biodiversity. Proceedings of the National Academy of Sciences.
[10] Shepherd et al. 2021. Scotland's onshore wind energy generation, impact on natural capital & satisfying no-nuclear energy policy. Access here.
[11] Hooper et al. 2018. Capturing benefits. In Offshore Energy and Marine Spatial Planning. Access here.
[12] Holland et al. 2018. Incorporating ecosystem services into the design of future energy systems. Access here.
[13] Hooper et al. 2018. Do energy scenarios pay sufficient attention to the environment? Lessons from the UK to support improved policy outcomes. Access here.

Environment and Landscape theme has developed spatial models[14,15] to map the infrastructure development needs to decarbonise electricity (including solar, wind and bioenergy) onto existing the existing environment, including the built infrastructure. These models allow varying spatial distributions of infrastructure to be considered and provide the associated implications from a plausibility and cost perspective, but also includes natural capital implications. In line with the second assessment these models will be continue to be developed and applied in the coming years. The recent ECOWIND call is also likely to shed light on the potential of offshore wind to deliver net gain.[16]

A second initiative to be recommended is the development and implementation of green investment, including for example, payments for ecosystem services and environment credits. These green investments can act as mechanisms to drive infrastructure developments to internalise environmental impacts, reducing negative effects and inciting developments which result in net gain.

It is also advised that environmental policy drivers are fully considered alongside infrastructure policy drivers. These include the 25-year Environment Plan, the Environment Bill, and agricultural policy reform. Constraints enforced by these policies should ideally be embedded within the nine challenges from the outset. Strengthening partnerships between BEIS, Defra and other governmental departments including MHCLG, and the bringing together of academics, industry, user groups and stakeholders from different disciplines is also recommended.

Low carbon technologies have a range of residual emissions and/or embedded CO2 (emissions created through manufacture and installation), including release of stored environmental carbon, and on balance may not achieve decarbonisation at the scale initially expected. As a result, a holistic view of the extent of decarbonisation will be critical if decisions around infrastructure are to be successful in minimising the whole life carbon footprint of low carbon technologies.

8: What are the greatest risks to security of supply in a decarbonised power system that meets government ambition for 2035 and what solutions exist to mitigate these risks?

One of the biggest risks to a decarbonised power system arises from the challenges of balancing supply and demand - stable operation of the power system depends on matching generation and demand second-by-second. This has been achieved in Britain to date predominantly through the use of stores of fossil fuel,[17] used to

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[14] Delafield. 2021. Spatial Optimisation of Renewable Energy Deployment in Great Britain: A Natural Capital Analysis. Doctoral Thesis. University of Exeter.
[15] Watson et al. 2022. The Global Impact of Offshore Wind: Implications for Ecosystem Services & Environmental Net Gain. In development.
[16] NERC/UKRI. 2021. Ecological Consequences of Offshore Wind (ECOWind) Access here. 2
[17] This includes the inherent storage of natural gas in pipelines, reservoirs and tankers, since the last large scale gas storage installation closed in 2017.

generate electricity as demand varies through a day and across the year. Stores of fossil fuels also enable the meeting of demand for heat in industrial processes and the very large seasonal variation in demand for heat in buildings.

If we are to achieve net zero, future use of fossil fuel stores will be dependent on the capture and storage (CCS) of CO_2 emissions associated either with their combustion to produce heat for the generation of electricity or their conversion into 'blue' hydrogen or similar fuels. At present, none of Britain's electricity generation capacity is connected to a CCS system.

The extent of the potential gap in the supply of low carbon electricity can be understood in terms of the residual demand for power. Residual demand is that which remains to be met at any one moment after the use of whatever power is available at that time from variable renewables (wind, solar and hydro) and must therefore be met by other sources such conventional power plants, storage or imports.

Much has been made of the need for a 'flexible' system to manage variations in residual power demand. This will be useful, but it must be better understood to ensure the provision of the right mix of facilities at an appropriate scale. These must be able to adjust the production or consumption of energy quickly enough to balance ramps in residual demand, and at short notice in response to unexpected changes. They must also be 'schedulable', i.e. capable of having their performance planned, with confidence, at a few days' notice. Finally, there must be some degree of 'persistence' with performance available beyond a few hours. As can be seen in **Table *1***, few of the facilities currently envisaged for the future power system provide all three of these features in full.

Table 1: Power system resources and aspect of 'flexibility' (source author's own)

	Flexible?	Schedulable?	Persistent?
Wind	If it's windy, yes	No	Sometimes
Nuclear	No, not really	Yes, for the most part	Yes
CCGT burning blue or green H_2	Yes	Yes, for the most part	Yes, if fuel is available
CCGT burning CH_4, with CCS	Perhaps, but at a cost	Yes, for the most part	Yes, if fuel is available
Batteries	Yes	Yes, for the most part	To an extent, if power is rationed
Pumped hydro	Yes	Yes, for the most part	Only if power is rationed
Flexible demand	Yes	Depends what it is	Not beyond a few hours?
Interconnectors	Yes	Depends on availability within the system from which the imports originate	Depends on availability within the system from which the imports originate

The extent to which heat and transport demand are electrified will be the biggest influence on the scale of need in the power system. Arguably, the seasonal variation in demand for heat is the biggest challenge. However, if buildings are well-insulated and stores of heat such as hot water cylinders are sufficient, supplies of power to electric heating in buildings might be interruptible for a few hours without detriment to occupants' comfort. Similarly, the total energy storage capacity of batteries in electric vehicles and the potential for them to be charged at times that closely match the availability of wind and solar power, or even for these batteries to be discharged into buildings or 'the grid', could offer significant flexibility. However, while helping to reduce the scale of challenge, such flexibility is insufficient on its own to meet residual electricity demand during a 'wind drought' of between one and three weeks for which persistence of a service is required.[18]

[18] Although it occurred in late June/July – so not the most challenging time from the perspective of electricity demand – there was a 33 day period in 2018 across which the average capacity factor of Britain's wind fleet was only 8.4% compared with the year-round capacity factor for that year of 28.1%. More recently, there was a 6.5 day period in December 2021 within which the half-hourly wind fleet capacity factor never exceeded 20%.

A recent report[19] suggests that the future need for 'long-duration storage' to be added to the existing 30 GWh of pumped hydro storage[20] on the GB power system is between 30 and 90 GWh, complemented by between 0.9 and 1 TWh of hydrogen storage. Another study has noted that Britain's natural gas system currently provides 3-4 TWh of flexibility to balance daily variations in energy demand and around 100 TWh towards seasonal balancing.[21] Before it closed in 2017, the Rough gas storage facility had a capacity of around 35 TWh.

Our own initial assessment of the volume of energy required to meet residual electricity demand during a one week 'wind drought' in 2030 is around 10 TWh. Because of the variation of the wind resource, whatever mix of resources used to balance variations in residual demand will have a low annual capacity factor but must be capable of a peak rate of production of between 30 and 40 GW.[22] By 2050 when Britain's annual demand for electricity may have doubled, these required energy and power ratings may also have roughly doubled.[23]

We believe there is now an urgent need for more work to assess more precisely the volume of need for different flexible, schedulable and persistent resources alongside an evaluation of what sort of risk we would accept being exposed to in a one, two or three week 'wind drought'. Work is also needed on the sorts of commercial or regulatory instruments to best incentivise the development and optimal utilisation of different resources. A key question is whether 'scarcity pricing' in wholesale markets and the currently quite narrowly framed capacity market (which addresses only a few hours of need around the time of peak electricity demand) will suffice.

[19] See Danny et al., 2021. Whole-System Value of Long-Duration Energy Storage in a Net-Zero Emission Energy System for Great Britain. Access here.

[20] Scottish Government. 2017. Scottish Energy Strategy: The future of energy in Scotland. Access here.

[21] MacLean et al. 2021. Net Zero – Keeping The Energy System Balanced. Access here.
The same study estimates that, based on recent actual/proposed installation costs of large 'grid-scale' projects in Australia and the UK, 3-4 TWh of battery energy storage would cost over £1 trillion.

[22] The peak demand for electricity can be reduced by flexible demand, e.g. for electric vehicle charging, or heating or cooling in buildings being switched off at the time of peak residual demand, thus reducing the size of that peak. In addition, in our initial modelling – not yet published – we assumed that 5.7 GW of nuclear generation capacity would be operational and able to help meet demand.

[23] In contrast, with the very large total wind generation capacity envisaged for Britain, there will be periods when, relative to demand, there will be a surplus of power from variable renewables and quite inflexible nuclear production. By 2030, this surplus could be as big as 30 GW. The combination of large surpluses and deficits of residual demand with continued use of nuclear power points to a role for storage capacity capable of conversion both to and from electricity.

9: What evidence do you have on the barriers to converting the existing gas grid to hydrogen, installing heat pumps in different types of properties, or rolling out low carbon heat networks? What are the potential solutions to these barriers?

Hydrogen

The barriers to converting the natural gas network to hydrogen can be grouped in a number of categories, as detailed below, alongside potential solutions.

Technical barriers mainly include accurate real time metering of hydrogen, operation of compressors and integrity of seals.[24] Technical issues remain with regards to storage, where salt caverns are not well geographically distributed, and in hydrogen production, where green hydrogen and blue hydrogen face issue of scale and CO_2 capture efficiency.[25] Solutions to these issues could be met via the national development of hydrogen transmission infrastructure,[26] and by gathering more evidence on the capture and production efficiency of blue hydrogen production, and the demonstration of large-scale electrolysis.[27]

The safety case is being proved now but there is still some work to be done. Findings from recent safety studies at the domestic scale suggest that with correct installation hydrogen has the potential to be at least as safe as current domestic natural gas systems. However, more supply chain data will be needed before regulators permit the commercial development of hydrogen networks.[28]

Public perceptions of hydrogen could also be a barrier particularly around perceptions of safety, but also issues around equity and consumer choice. People may not like being removed from the gas network to a less familiar fuel source such as hydrogen. People may also object if the hydrogen network is paid for across all bills as a tariff, which is one proposal currently.[29]

The efficiency of methane reforming plant and the ultimate CO_{2e} intensity of hydrogen delivered to consumers may prove a barrier to conversion including the efficiency of hydrogen production, the efficiency of CO_2 capture at natural gas plants, the fugitive emissions in the upstream supply chain and from the hydrogen pipeline network.[30] The leakage rate from future hydrogen gas networks is particularly uncertain, and with a GWP of 4, hydrogen leakage could become a not-insignificant contributor to the life cycle emissions of hydrogen supplied to consumers.[31]

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[24] National Physics Laboratory. 2022. Measurement needs within the hydrogen industry. Access here.
[25] Sustainable Gas Institute. 2017. White Paper 3: A greener gas grid: What are the options? Access here.
[26] National Grid. 2021. Making plans for a hydrogen ‘backbone’ across Britain. Access here.
[27] Gigastack. Access here.
[28] Hy4Heat. Access here.
[29] Cox, E. 2022. Public perceptions of low-carbon hydrogen. Access here.
[30] BEIS. 2018. Hydrogen supply chain evidence base. Access here.
[31] BEIS. 2018. Hydrogen for Heating: Atmospheric Impacts. Access here.

Cost may also be a barrier to the development of the network. While the network itself might be cheap to repurpose relative to the costs of new pipeline infrastructure, the estimated cost of hydrogen to the consumer when all the other necessary capital and operating expenditures are accounted for, may prove too costly for investors, government, and consumers.[32,29]

Due to the different steps required to scale up hydrogen from production, transmission, through to end-use, the complexity of hydrogen supply and value chains makes gradual deployment more difficult, creating a risk of a 'chicken and egg' situation.[33] Policy interventions are needed to scale up hydrogen value chains across production, transmission and distribution, storage and end-use to reach the minimum economies of scale for market penetration.[34] Or else there are risks that the converted natural gas network won't be fully utilised.

Heat pumps

There are a variety of barriers to the installation of heat pumps in UK buildings, and these are summarised below together with recommended policy solutions:

The installation and up-front purchase costs of heat pumps are currently a key barrier to uptake. For example, installing an air-to-water heat pump system typically costs several times that of replacing a gas boiler,[35] with costs varying according to the size of the property and the amount of retrofitting required.[36] Possible means of overcoming this affordability barrier include longer-term up-front grant incentives than the proposed three-year Boiler Upgrade Scheme, green financing schemes and market products, and supporting industry initiatives to achieve cost reduction through technological learning and experience.[35] Heat pumps require competent specification, installation and maintenance to maximise their performance and efficiency; the current lack of qualified installers is a priority area for action. It has been estimated that the UK heat pump industry supports only around 2,000 full-time jobs in installing and maintaining heat pumps.[37] Analysis by the Heat Pump Association suggests that approximately 50,000 qualified installers would be needed to deploy 1 million heat pumps by 2030.[38] This would require rapid scaling up of training, both for new installers and to upskill the current workforce. According to Eunomia for CITB (2021), it would be feasible to train between 7,500 and 15,000 installers per year over the next ten years.[39]

Heat pumps are typically comprised of separate physical units and therefore have greater space requirements than gas combi boilers, which is a constraint to uptake in

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32 BEIS. 2021. Hydrogen Production Costs 2021. Access here.
33 IEA. 2019. The future of hydrogen, Access here.
34 IRENA. 2020. Green hydrogen: A guide to policy making. Access here.
35 Trask, et al. 2022. The Future of Home Heating: the Roles of Heat Pumps and Hydrogen. Access here.
36 Myers, M. et al., 2018. The Cost of Installing Heating Measures in Domestic Properties. Access here.
37 House of Commons Business, Energy and Industrial Strategy Committee. 2022. Decarbonising heat in homes. Access here.
38 HPA. 2020. Building the installer base for net zero heating. Access here.
39 Eunomia for CITB. 2021. Building skills for net zero. Access here.

certain residential apartment types. Low-temperature heat pump systems need to be fitted in conjunction with adequate home insulation and may also require oversized or thicker radiators and underfloor heating. High-temperature heat pumps have been developed which currently represent only a small share of the UK market. These may be more appropriate than lower temperature heat pumps for retrofitting in existing properties, since they can supply heating at an output temperature of at least 65°C. This means that they could be more easily integrated with standard smaller or thinner radiators typically used in conventional central heating systems.[40]

If a large share of homes are fitted with heat pumps, this will have a significant impact on total and peak electricity demand. While heat demand from heat pumps is more distributed across different parts of the day compared to gas boilers, there would still be a need for grid reinforcement of local distribution networks. Smart heating controls for heat pumps can also assist by smoothing out demand over longer periods of time, especially if linked to a smart meter to obtain real-time tariff signals.[41]

While the Government-funded Electrification of Heat (EoH) project has reportedly demonstrated that "*there is no property type or architectural era that is unsuitable for a heat pump* (HP)",[42] the trial is still at an early stage and there are concerns that important cases in the British housing stock are underrepresented.[43] Ongoing evidence gathering by the EPSRC-funded NEUPA[44] project indicates that the adequacy of last-mile electricity networks to facilitate greater power flows because of HPs is wide-ranging throughout Britain. Much of the last-mile electricity networks could be more than 50 years old, and because of cost-saving measures implemented over the course of its development, immediate – and potentially disruptive – electricity network-based and/or within household interventions will be required to support HP uptake in many households. The most disruptive and immediate network interventions will be required for around 20% of British households that are supplied by looped services.[45]

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[40] BEIS. 2016. Evidence Gathering – Low Carbon Heating Technologies: Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report. Access here.
[41] Carmichael, R. et al., 2020. Smart and flexible electric heat. Access here.
[42] Energy Systems Catapult. 2021. All housing types are suitable for heat pumps, finds Electrification of Heat project. Access here.
[43] Maxine Frerk. 2021. Heat pump propaganda. Access here.
[44] Network Headroom, Engineering Upgrades and Public Acceptance (NEUPA): *Connecting Engineering for Heat System Change to Consumers and Citizens*. Access here.
[45] Electricity North West Limited. 2021. Engineering Justification Paper – Service Unlooping Programme. Access here.

Heat networks

Heat networks are recognised as efficient and cost-effective options for meeting heat demand in areas with high heat demand density.[46] While they have been widely adopted in some Scandinavian countries since the 1970s in response to the oil crisis (Sweden and Denmark supply more than 60% of their heat via heat networks), the roll out of heat networks in the UK has been very limited - currently, around 2% of UK heat demand is met via heat networks. This lack of progress is mainly due to the abundant and cheap North Sea natural gas which has been made available across the country via extensive network of pipelines.[47] However, to achieve net zero by 2050, the shift away from natural gas heating is inevitable. The Climate Change Committee recommends that 20% of UK heat will need to come from low carbon heat networks by 2050 if the UK is to meet its carbon targets cost effectively.[48]

Key barriers to rolling out low carbon heat networks can be classified under three main headings, governance, technical and economic competitiveness.

A diverse range of stakeholders (investors, developers, operators and users) are required to be involved in the lifecycle of a heat network, from development to operation. Satisfying their varying objectives and requirements is a key challenge, which requires careful design of regulation and market for heat.[49] In a recent announcement, the Government appointed Ofgem as Great Britain heat networks regulator.[50] Owing to its experience in regulating gas and electricity markets, Ofgem can play a crucial role in protecting consumers by ensuring fair pricing and quality of service. By increasing investors' confidence in the market, Ofgem is expected to facilitate the growth of the heat network market. In addition, local authorities could play a unique role in coordinating stakeholders and identifying suitable heat networks locations. Lessons can be learnt here from the large scale deployment of heat networks in Sweden in which the municipal governments played a crucial role.[51]

In response to concerns and uncertainties around the impacts of biomass heating on air quality in urban areas,[52] and to maximise the use of renewable low grade waste heat and natural heat sources in net zero compliant heat networks, moving towards lower temperature heat networks is necessary. However, unlike high temperature heat networks, fourth and fifth generation heat networks (4GHN and 5GHN, respectively) that operate at supply temperature of below 50°C, are not mature yet. There are technical challenges that needs to be addressed such as assessing heat sources, seasonal storage of heat and uncertain real-world performance.[53]

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[46] BEIS. UK Heat Networks Market Development. Access here.
[47] UKERC. 2016. Best practice in heat decarbonisation policy. Access here.
[48] Climate Change Committee. 2016. The future of heating in buildings. Access here.
[49] ETI. 2018. District Heat Networks in the UK: Potential, Barriers and Opportunities. Access here.
[50] BEIS, Ofgem and Lord Callanan. 2021. UK government announces major expansion of heat networks in latest step to power homes with green energy. Access here.
[51] Gross et.al., 2019. Path dependency in provision of domestic heating. Access here.
[52] Air Quality Expert Group. 2017. The Potential Air Quality Impacts from Biomass Combustion. Access here.
[53] Verhoeven et al., 2014. Minewater 2.0 project in Heerlen the Netherlands: Transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling. Access here.

Supporting trial projects on 4GHN and 5GHN will steepen the learning curve and help improving their performance.

Heat network projects are capital intensive and when running on electricity (i.e. 4GHN and 5GHN) the levelised cost of heat could be greater that provided by gas boilers. The reduction of capital costs[49] and lower price of electricity relative to natural gas are vital for making heat networks economically competitive compared to natural gas boilers. Furthermore, high heat demand density is critical to justify investment. Requiring certain large non-domestic buildings to connect to heat networks (as suggested in the BEIS' consultation on Heat Network Zoning[54]) could create the minimum level of heat demand needed.

Overall, there are currently several initiatives that are designed to facilitate the development of low carbon heat networks (e.g. Heat Network Transformation Programme,[55] Heat network zoning, etc) which are important steps in the right direction. Performance of these initiatives need to be continuously monitored and if needed they should be adjusted to ensure they address the key barriers identified.

10: What evidence do you have of the barriers and potential solutions to deploying energy efficiency in the English building stock?

While there is no single technically correct answer to the question about energy efficiency deployment, key principles and good practice are well established. Effectiveness requires sustained commitment from government, industry and property owners. Better information alone has resulted in minimal change unless matched with supporting regulation and incentives. This entails government setting an overarching energy savings target, translated into policy to promote rapid deployment of lower-cost measures, and to promote innovation and deployment of more complex solutions for whole-building retrofits combining fabric and heating upgrades.[56]

The main barriers to progress during the last decade stem from UK Government dismantling policy measures and incentives which had supported improvements, alongside the poorly planned introduction and rapid withdrawal of new policies[57] (see table 2 below).

[54] BEIS. 2021. Proposals for heat network zoning. Access here.
[55] BEIS. 2021. Heat and Buildings Strategy. Access here.
[56] Rosenow, et al. 2018. The remaining potential for energy savings in UK households. Access here.
[57] Wade et al. 2021. Local heat and energy efficiency policy: Ambiguity and ambivalence in England and Scotland. Access here.

Table 2: History of UK energy efficiency policy deployment and withdrawal

Year	Introduction / withdrawal	Policy Introduction or Withdrawal
1992	Introduction	Energy Savings Trust created for domestic sector services
1994	Introduction	Privatised electricity suppliers obliged to provide domestic energy saving advice
2000	Introduction	Privatised gas suppliers obliged to provide domestic energy saving advice
2000	Introduction	English Warm Front funding scheme for vulnerable households
2001	Introduction	Carbon Trust created for private & public sector services
2005	Introduction	Building regulations require installation of condensing boilers
2011	Withdrawal	English Warm Front funding ended
2012	Withdrawal	Energy Savings Trust & Carbon Trust core grant funding ended
2013	Introduction	Residential sector Green Deal introduced
2013	Withdrawal	End to subsidies under the energy supplier obligation CERT programme
2015	Withdrawal	Withdrawal of planned 2016 zero carbon homes standard
2016	Withdrawal	End of residential sector Green Deal policy
2018	Part withdrawn	Annual Energy Supplier Obligation (ECO) budget halved for 2018-2022 period
2019	Withdrawal	CRC non-domestic energy efficiency scheme abolished
2020	Introduction / withdrawal	English Green Homes Grant introduced (withdrawn March 2021, leaving only the Local Authority Delivery arm for low-income households).

In 2019, the installation rate of domestic loft and wall insulation was 95% lower than 2012.[58] Some decline can be attributed to low-cost measures having been achieved, with the remaining interventions being more expensive. But scope for socially cost-effective work remains considerable. For housing alone, investing in efficient heating, insulation, controls, lighting and appliances could deliver a net benefit of £7.5 billion to the UK economy.[59] The full economic benefits of reducing energy demand by a

[58] Climate Change Committee. 2019. UK Housing – Fit for the Future? Access here.
[59] Rosenow et al. 2017. Unlocking Britain's First Fuel: The potential for energy savings in UK housing. Access here.

quarter could be up to £47 billion through improved health, economic stimulus and energy system capacity saved.

UK Government Solutions

UK Government needs to establish policy instruments to meet the targets in the Heat and Buildings Strategy. Significant change depends on three linked approaches:

- High quality, ambitious policy.
- Institutions and arrangements for governance and implementation.
- Expanding the ambition and reach of policy over time.

To ensure effectiveness consultation and collaboration will be essential, including consideration of regulation and coordination agencies to implement policy. Experimentation and learning will be key. Cross sector support will be essential to ensure instruments are fit for purpose, and to secure industry and property owner backing. Policy must be expanded beyond short-term pay back to establish societal necessity and longer-term benefits; establishing standards, guarantees and an enforcement system. The approach was exemplified in the Bonfield Review[60] relating to consumer advice, protection, standards and enforcement, but has not been rigorously followed through.

Alongside this:

- The long-standing gap in policy and support for the non-domestic sector needs to be resolved, with a timeline for introducing regulation.
- Energy retail markets could be reformed to create an energy services market, incentivising energy efficiency and rewarding retailers for avoiding waste of energy, and not the sale of KWh.[61]
- The UK has no energy agency to manage the complexity of central and local policy. It could create one, or alternatively adopt “hybrid” energy efficiency programmes that fuse industry-led, voluntary programmes with selective government intervention.

Local authority solutions

More systematic, comprehensive and faster improvements could be achieved through clearer government frameworks for local authority action.[62,63,64] UK Government needs to work with regional and local governments to agree the programme and division of powers and resources for coordinated planning, costing, and financing. The most effective solutions are likely to differ regionally, requiring local knowledge to develop area-based and prioritised plans for property upgrades. Central government however needs to avoid externalising hard problems to lower

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60 Bonfield. 2016. Each Home Counts: Review of Consumer Advice, Protection, Standards and Enforcement for Energy Efficiency and Renewable Energy. Access here.
61 Energy Systems Catapult. SSH2: Introduction to Heat as a Service. Access here.
62 Webb et al., 2017. What We Know about Local Authority Engagement in UK Energy Systems. Access here.
63 Tingey and Webb. 2020. Net Zero Localities: Ambition & Value in UK Local Authority Investment. Access here.
64 Tingey et al. Housing retrofit: Six types of local authority energy service models. Access here.

levels of government, without proper devolution of resources and powers to match responsibilities.

Scottish Government's Heat in Buildings Strategy is an example of a structure for national/local coordination.[65] It proposes a new statutory power for Local Heat and Energy Efficiency Strategies (LHEES) and delivery plans, establishment of a Public Energy Agency to work with LAs and citizens, and a timeline for future regulation.

Our evaluations of Energy Efficient Scotland and LHEES Pilots have revealed the practical challenges of managing such programmes,[66,67,68] including:

- High rates of private ownership; engaging with owners and resolving finance questions takes time; particular issues arise for multi-owner buildings.
- Owners need clarity about the finance available to support upgrades.
- Decisions are needed on the share of costs to be socialised under what tax provisions; ultimately we have a societal need to decarbonise heat.
- Supply chains, skills, materials innovation all need explicit strategy; this has benefits for local economies, including through explicit provision for local businesses to participate as qualified, trusted traders.
- Programme managers need the skills to engage different audiences in identifying local economic and welfare benefits. Information on energy and carbon reductions does not motivate significant change. It is essential to explain co-benefits of area-based action, relating to local jobs, comfort, health and aesthetics.
- Central data repository on buildings and energy networks is needed to support rapid, reliable planning and prioritisation, using socio-economic metrics, on an area basis.
- Reliance on property owners making decisions on energy efficiency upgrades to their property is too slow to meet emission targets. An area-based plan and 'offer' to building owners can increase the rate of improvements and reduce costs through economies of scale. This needs to be backed by consumer protections; a timeline for future regulation, and a (trustworthy) narrative of building 'makeover', economic renewal and climate protection.

[65] Webb and van der Horst. 2021. Understanding policy divergence after United Kingdom devolution: Strategic action fields in Scottish energy efficiency policy. Access here.
[66] Wade et al. 2020. Emerging linked ecologies for a national scale retrofitting programme: The role of local authorities and delivery partners. Access here.
[67] Wade & Webb. 2020. Energy Efficient Scotland Phase 2 Pilots: Final Social Evaluation Report. Access here.
[68] Wade F, & Webb, J. 2020 Local Heat and Energy Efficiency Strategies (LHEES): phase 2 pilots evaluation. Access here.

11: What barriers exist to the long term growth of the hydrogen sector beyond 2030 and how can they be overcome? Are any parts of the value chain (production, storage, transportation) more challenging than others and if so why?

Two key challenges to long-term growth are associated with hydrogen production and hydrogen storage.

A range of low-carbon hydrogen production technologies exist that are at different stages of technical development. Currently, the cheapest route is via methane reformation with CCS (so called "blue" hydrogen) and this production method is expected by the Government to dominate in the short to medium term.[69] However, blue hydrogen production still emits CO_2 emissions, which are estimated by 2050 to be in the range 30 – 160 g/kWh depending on various technical assumptions.[70,71] The Government's estimates for hydrogen production in 2050 are 250 – 460 TWh,[72] this would result in CO_2 emissions of between 7.5 and 72 Mt if all hydrogen was produced via this method. Post 2030, for the UK to be on a pathway to net zero there needs to be a move away from producing blue hydrogen to lower carbon production methods. Alongside carbon emissions, there are also the risks associated with relying on natural gas as a feedstock, which exposes the UK to rises in gas prices as have been seen recently. Alternative "green" hydrogen production methods include electrolysis using renewable energy (which has the potential for close to zero emissions of CO_2) and biomass gasification with CCS (which has the potential for net negative emissions). Delivering hydrogen production via these technologies at the necessary scale and at costs that are similar to, or below, those of blue hydrogen, present major challenges that will need to be addressed. For instance, it is unclear how much renewable electricity and sustainable supplies of biomass will be available for hydrogen production in 2050. Furthermore, the cost of hydrogen production from renewable electricity would need to decrease by 40% from current levels to be competitive with blue hydrogen production in 2050.[73]

A recent survey by UKERC has shown support for using green hydrogen as an energy source.[74] Survey responses were disaggregated by income and gender and coded from -3 (strongly oppose) to +3 (strongly support). The average score was 0.81, showing some support. However, within this, there was a lot of variability. All combinations of income and gender were somewhat supportive of green hydrogen, with no mean scores falling below 0; however, men and high-income groups were generally much more supportive.

[69] HM Government. 2021. Impact Assessment for the sixth carbon budget, Table 6. Access here.
[70] CCC. 2018. Hydrogen in a low carbon economy. Access here.
[71] BEIS. 2021. Consultation on a UK Low Carbon Hydrogen Standard. Access here.
[72] HM Government. 2021. UK Hydrogen Strategy. p38. Access here.
[73] HM Government. 2021. UK Hydrogen Strategy, Table 2.2. Access here.
[74] UKERC. 2022. Public perceptions of low-carbon hydrogen. Access here.

As hydrogen production grows, so significant storage also will be required, particularly in the years after 2030. National Grid estimates a required storage level of 12-50 TWh by 2050,[75] while a study for the Climate Change Committee (CCC) calculated a figure of 20 TWh by the same date.[76] The CCC note that the optimal mix of hydrogen storage solutions will depend on the volume and seasonality of hydrogen demand, availability, costs and the role that imported hydrogen could play in meeting seasonal swings in demand. Centrica are reportedly looking to repurpose the natural gas storage at Rough (closed in 2017) for hydrogen, providing a capacity of 9 TWh.[77] However, that leaves a further requirement for 10 – 40 TWh of storage in the longer term. UKERC researchers have for a number of years been calling for the Government to adopt a more proactive "gas by design" approach to the future of gaseous fuels in the UK.[78] We therefore strongly support the Government's plans to undertake a review of hydrogen storage requirements and to explore regulatory and business models that could support the development of sufficient hydrogen storage as production increases.

12: What are the main barriers to delivering the carbon capture and storage networks required to support the transition to a net zero economy? What are the solutions to overcoming these barriers?

The current focus of onshore CO_2 transport and storage networks is on developing high pressure pipelines centred around a number of industrial clusters. The first two clusters for CCUS deployment were announced in October 2021, following the 2020 commitment of £1bn funding to support projects at four sites.[79]

However, the Government's Industrial Decarbonisation Strategy highlights that CCUS will also be an important decarbonisation option for a significant number of so-called "dispersed sites", which collectively are responsible for half of industrial emissions. The importance of CCUS was also confirmed by recent UKERC modelling,[80] which showed that if the option is not widely available (outside the current clusters) then the model fails to decarbonise industry in line with the 2050 Net Zero commitment. A recent Element Energy report for BEIS[81] identified key dispersed sites that would be suitable for CCUS in the UK as well as the unique challenges and barriers to deployment. Amongst the challenges identified was the need to consider a range of alternative transport options for CO_2, including shipping, road and rail transport. It is therefore very important that future government support,

[75] National Grid. 2021. Future Energy Scenarios. Access here.
[76] Imperial College. 2018. Analysis of Alternative UK Heat Decarbonisation Pathways. Access here.
[77] EDIE. 2021. Hydrogen: Shell opens Europe's largest electrolyser as Centrica eyes storage at Rough. Access here.
[78] UKERC. 2021. Blog: Still waiting on 'Gas by Design'. Access here.
[79] HM Government. 2020. The ten point plan for a green industrial revolution. Access here.
[80] UKERC. 2021. Sensitivity analysis of net zero pathways for UK industry. Access here.
[81] BEIS. 2020. Carbon capture, usage and storage (CCUS) deployment at dispersed sites, BEIS research paper 2020/030. Access here.

including funding and business model development, includes a strategy for dispersed sites, ensuring viable technology and infrastructure solutions can be made available to them.

A second associated challenge is that of public perceptions of CCUS. At present, public knowledge of CCUS is relatively limited. In March 2021, 35% of the UK public had never heard of CCUS and only 30% said they know at least a little about it. Among this 30%, 65% said they supported it, 7% were opposed and 25% were neutral.[82] A recent public dialogue on behalf of BEIS highlighted that public support was predicated on it being an effective strategy to reduce emissions and that it must be safe.[83] Furthermore it showed that people living close to the current industrial clusters saw local benefits, such as providing jobs and revitalising the local economy, to be important. However, in the Midlands, where there are no current CCUS proposals, participants did not see the technology in terms of specific local benefits. If CCUS technology is to be deployed more widely across the country beyond the current industrial clusters then more work is needed to engage the communities involved. Gough et al. (2018)[84] have previously highlighted that gaining a social licence to operate CCUS is significantly dependent on fostering stakeholder networks to build trust and confidence, which then influences perceptions around the trade-off between economic benefits and physical risks.

[82] BEIS. 2021. BEIS Public Attitudes Tracker (March 2021, Wave 37). Access here.
[83] BEIS. 202. Carbon Capture Usage and Storage. Public Dialogue. Access here.
[84] Gough et al. 2018. Understanding key elements in establishing a social license for CCS: an empirical approach. Access here.