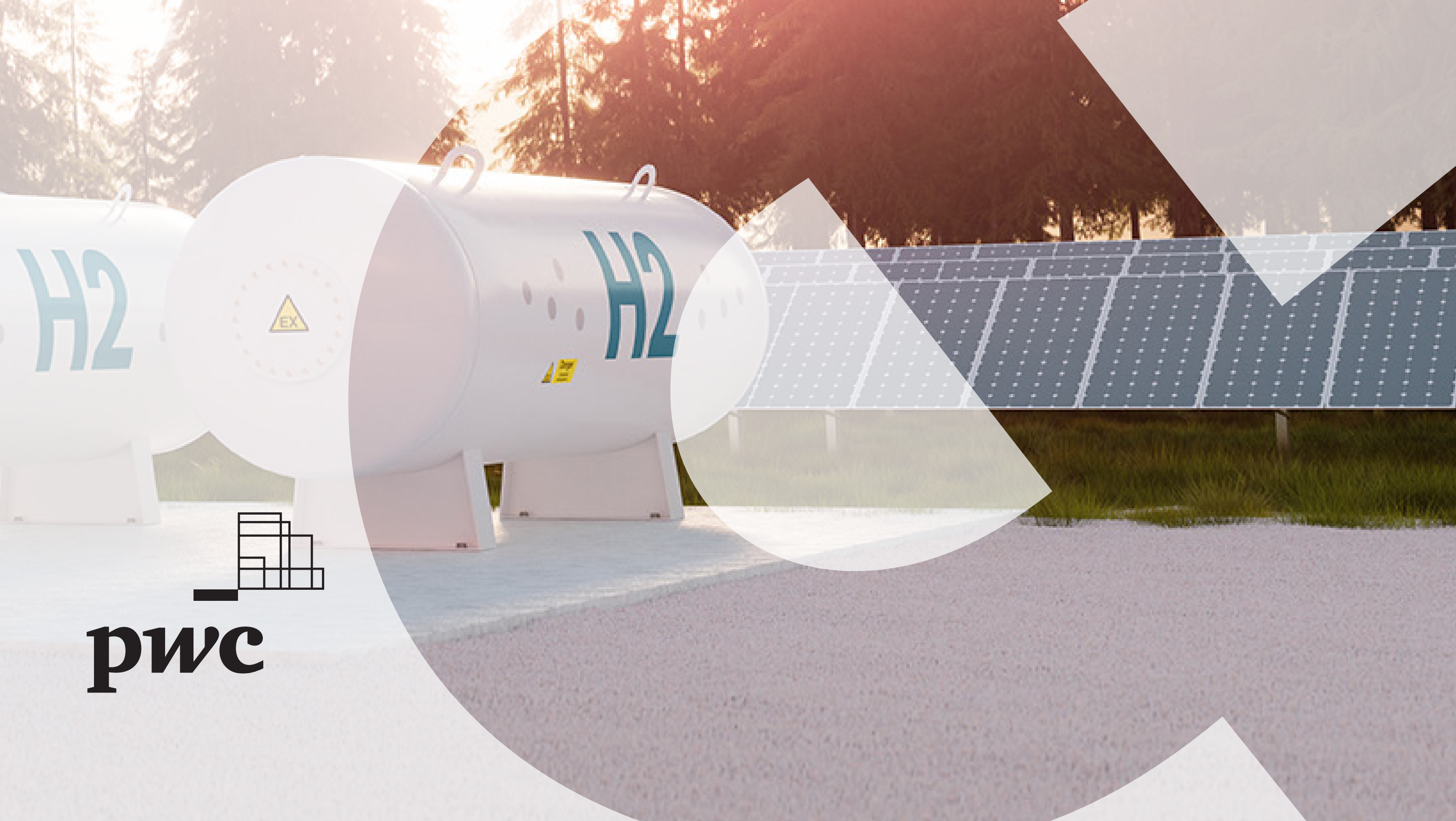
strategy&

The Economic Value of Hydrogen for Domestic Heat in the UK

For Cadent Gas Limited

October 2023



pwc

Contents

Overview

Decarbonising domestic heat is critical for achieving the UK government's Net Zero targets. According to recent reports, around 20% of UK territorial emissions come from combustion of fuels for domestic heating. A Department for Business Energy and Industrial Strategy ('BEIS') committee report stated that in 2019, 17% of heating emissions from buildings came from homes, which was comparable to the combined contribution of all petrol and diesel cars.

There are a number of options to achieving zero emission domestic heating, ranging from district heating, electrification of heating (such as heat pumps), and installation of hydrogen appliances which can use hydrogen gas instead of natural gas.

A decarbonised future is likely to require a balanced transition involving all of these options, not least because the varied nature of the UK housing stock means that a 'one size fits all' solution may not be viable. Recent events in the UK energy market have also highlighted the need for the UK to have a portfolio of energy sources that will deliver an affordable, resilient and secure supply. The establishment of the Department of Energy Security and Net Zero (DESNZ) has demonstrated that the UK government recognises that the needs of a low-carbon future and a resilient and secure energy supply are inextricably linked.

As one of a suite of options which may be required to support the delivery of decarbonised heating, we have been commissioned by Cadent Gas to provide an independent analysis of the potential value of hydrogen use in domestic heat for the UK economy.

This report presents the findings from our analysis, research into existing studies and expert interviews on the role hydrogen can play in decarbonising homes and the economic opportunity for the UK.

Our analysis of the potential economic impact of hydrogen for domestic heat is based upon five decarbonisation pathways produced by the Climate Change Committee ('CCC'). Each of these illustrate credible scenarios for deployment of combinations of heat decarbonisation technologies to achieve zero emission heating in homes.

In our analysis the size of the economic impact is driven directly by the demand for hydrogen for domestic heat in a given scenario.

Using the CCC's 'Headwinds' scenario, in which 71% of homes are heated, fully or in-part using hydrogen powered boilers, we estimate that the cumulative economic contribution in terms of Gross Value Added (GVA) of Hydrogen for Domestic Heat amounts to £47.9bn and supports 612k jobs cumulatively by 2050. Using the CCC's 'Balanced Pathways' scenario, in which 11% of homes are heated, fully or in-part using hydrogen powered boilers, we estimate a cumulative GVA impact of £4.5bn and an associated 57k jobs cumulatively by 2050.

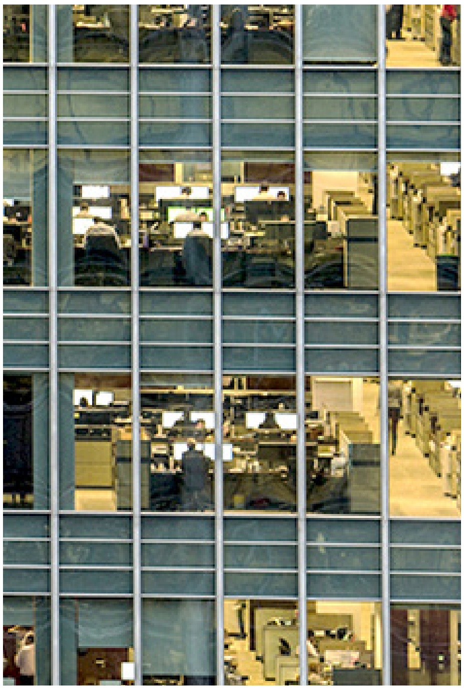
In the Balanced Pathways scenario, according to the CCC's Sixth Carbon Budget, installations of heatpumps should average 15.3 per 1,000 households per year up to 2030 yet in 2021, the rate of installations in the UK was 1.48 per 1,000 households per year. Current deployment falls below the trajectory for Balanced Pathways, though it is too early to determine which transition pathway we are following.

In our research, we find that independent published analysis and reports support the case for hydrogen in helping to transition 'hard to decarbonise' homes, with a report produced for the CCC stating 18%-37% of UK homes could be considered to be 'hard to decarbonise'.

Internationally, our research finds that countries across the world are developing strategies and investing to capture what is expected to be a significant market opportunity in hydrogen and there are actions that both the public and private sector can take to realise these opportunities. Evidence found suggests that the UK ranks as the third most attractive market in Europe for hydrogen investment.

We recognise that securing a decarbonised domestic heating future will require multiple solutions. We suggest that the findings in our report demonstrate that there is economic value in the role hydrogen could potentially provide in this future, especially given 85% of the nation's residential buildings are connected to UK's gas grid system. Our report also identifies the questions which need to be answered in relation to using hydrogen as part of the UK's gas distribution mix.

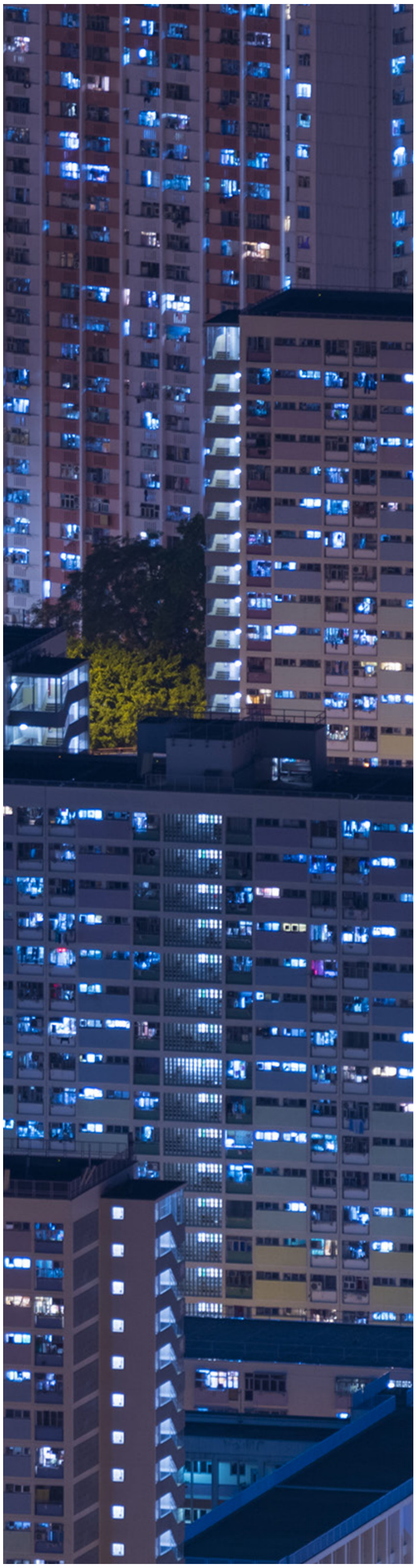
We are delighted to present our report as a contribution to the vital discussion around developing the portfolio of options required to support a balanced transition to Net Zero.



Introduction

> “Low carbon or carbon neutral heating solutions already exist, however a top-down ‘blanket’ solution such as all-electric or all-hydrogen is projected to cost twice or three-and-a-half times as much respectively compared to a bottom-up approach that chooses the best low carbon heating solutions on a place by place basis.”
>
> **Energy Systems Catapult, 2022**

PwC UK was commissioned by Cadent Gas Limited to estimate the economic potential from decarbonising domestic heat using hydrogen, as well as to summarise evidence on the role hydrogen can play in the transition to zero carbon homes, and the international context for developing the hydrogen economy in the UK.



The purpose of this report

Domestic heating in the UK is a significant contributor to greenhouse gas emissions. A Department for Business, Energy and Industrial Strategy ('BEIS') select committee report in 2022 noted that the heating sector in the UK accounts for almost one third of the UK's annual carbon footprint and 17% of heating emissions from buildings comes from homes[1]. The CCC has also emphasised that decarbonising homes are a key component required to progress towards Net Zero[2].

However, the challenge of decarbonising domestic heating is considerable. A recent published review of the government's approach to Net Zero ("Mission Net Zero: Independent Review of Net Zero") from Chris Skidmore noted that while progress has been made in reducing indirect greenhouse gas emissions from the home (e.g. using appliances, lighting, etc.) as the power sector has decarbonised, direct emissions from heating have not changed significantly since 2015[3].

The pace of decarbonisation therefore, has to increase significantly compared to previous years. The BEIS report estimates that in order to reduce emissions from residential building to zero by 2050, the annual rate of domestic decarbonisation of homes needs to increase to 3.4%. This is up to six times higher than annual average rates of decarbonisation in the period 1990 to 2020 (around 0.56% p.a.)[4].

The UK government is facilitating change through setting an ambition to end the sale of new and replacement natural gas boilers from 2035[5], and legislating to ban installation of natural gas boilers in new build homes from 2025 under the 'Future Homes Standard'. However, the BEIS committee noted that the suitability of different heating options will be dependent on multiple factors including regional geography, house type, what heating systems are currently in use, and whether existing homes are connected to the gas grid. This means that a one-size-its-all solution will not be viable for achieving decarbonisation and consumer choice will be critical[6].

A range of options will also be important for addressing affordability concerns. Current estimates suggest 'the total cost of heat decarbonisation in each home will be, on average, under £10,000' including the cost of eficiency measures, however there is likely to be a challenge in convincing consumers to spend this amount upgrading existing functional heating systems[7]. Options like hybrid heating systems (which combine a heat pump with a gas boiler for peak usage) might act as a transition approach on the path to a fully low-carbon solution[8]. For example, retrofit hybrids allow heat pumps to be installed alongside existing gas boilers with the ability for the user to switch between them.

[1] House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22, page 5.
[2] Climate Change Committee: Sixth Carbon Budget (2020) - The UK's path to Net Zero report.
[3] Rt Hon Chris Skidmore MP (2023) – Mission Zero: Independent Review of Net Zero, page 238.
[4] House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22, page 7.
[5] Department for Business, Energy and Industrial Strategy (2022) – Open consultation: Improving boiler standards and efficiency, page 8-9.
[6] House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22, page 3.
[7] Climate Change Committee: Sixth Carbon Budget (2020) - The UK's path to Net Zero report.
[8] Department for Business, Energy and Industrial Strategy (2022) – Open consultation: Improving boiler standards and efficiency, page 57.

> The CCC estimates that an investment of about £250 billion will be needed to fully decarbonise homes by 2050, the equivalent of about £9 billion each year from the late 2020s to 2050."
>
> **CCC, Sixth Carbon Budget, 2020 (Balanced Pathways Scenario)**

A portfolio of options to decarbonise heat will both facilitate consumer choice as well as provide a balanced path to achieve Net Zero, that helps maintain the security and resilience of the energy supply. Public and industry bodies like the CCC and the Energy Systems Catapult have stated that a key part of achieving decarbonisation of heating is having a range of options including district heating, electriication of heating (e.g. heat pumps), and converting to using blue or green hydrogen gas[9,10].

The role of hydrogen in supporting the decarbonisation of domestic heating is currently at an early phase of exploration by industry. DESNZ's "Powering Up Britain" report underscores the government's commitment to the widespread use of heat pumps and makes reference to Hydrogen as 'a potential energy solution for harder to electrify areas like parts of industry, heavier transport such as aviation and shipping, and potentially heating buildings'[11].

The technical feasibility of replacing methane in homes was established by the hy4heat programme through the development of a hydrogen heated home[12]. The viability of further deployment of hydrogen for domestic heat continues to be explored.

A hydrogen conversion project, covering up to 2,000 homes, will progress by 2025 to aid the heat policy decision in 2026[13].

There is clear support for continued exploration of hydrogen as an option for decarbonised heating. The Skidmore review has recommended that the government deliver a comprehensive programme of trials and projects across different end use technologies and sectors to expand the evidence base for determining most suitable end uses of hydrogen, including for domestic heating[14].

To contribute to this discussion, PwC Strategy& has been commissioned by Cadent Gas Limited to estimate the potential economic impact from a supply chain developed to support different levels of domestic heat decarbonisation using hydrogen. We also summarise evidence gathered on both the role hydrogen can perform in decarbonising homes and the international context for the hydrogen economy.

[9] Climate Change Committee: Sixth Carbon Budget (2020) – The UK's path to Net Zero report.

[10] Energy Systems Catapult (2023) – A Guide to Decarbonisation of Heat.

[11] Department for Energy Security & Net Zero (2023) - Powering Up Britain.

[12] Hy4Heat programme website (2021) - Safety Assessment.

[13] Department for Energy Security & Net Zero (DESNZ) website (2023) - "More about the hydrogen village trial.

[14] Rt Hon Chris Skidmore MP (2023) – Mission Zero: Independent Review of Net Zero, page 113.

Our approach

We have conducted quantitative analysis and qualitative research to establish an evidence base on the potential economic value of hydrogen for domestic heat in the UK, along with its possible role in supporting the transition to decarbonised heating and the international context for developing the hydrogen economy in the UK.

Qualitative evidence review: There are a number of published reports and studies which assess evidence of hydrogen as an option for decarbonising of domestic heating. Our review focused on two key areas, frstly the ways in which using hydrogen for domestic heating provides economic value, and secondly to understand and gather evidence on the international context for developing hydrogen supply chains in the UK. The aim of this review is to set out useful insights from the evidence about actions that might help the UK realise opportunities from hydrogen for domestic heat.

Our approach consisted in conducting desk research to review evidence on using hydrogen for domestic heat from reports, studies, and strategy papers on the topics of:

- The hydrogen economy and hydrogen supply chains.
- Government strategy and policy.
- Technical studies into the feasibility of hydrogen for domestic heat.
- Jobs and skills transition.

We reviewed over 40 sources, drawing where possible from independent organisations such as the CCC, Energy Systems Catapult and other organisations who had conducted relevant studies.

Our review of the evidence was supported by interviews with stakeholders involved in the energy sector, as well as representatives of workers and housing associations. We spoke to interviewees about the beneits and costs of hydrogen for domestic heat which were drawn from our evidence review. Highlights from our evidence review are presented in this report.

Quantitative Analysis: To estimate the potential economic and jobs contribution of hydrogen for domestic heat to the UK economy, we focus on calculating the GVA from hydrogen activities across the supply chain. Figure 1 provides a summary of the overall approach used to estimate economic and jobs contributions.

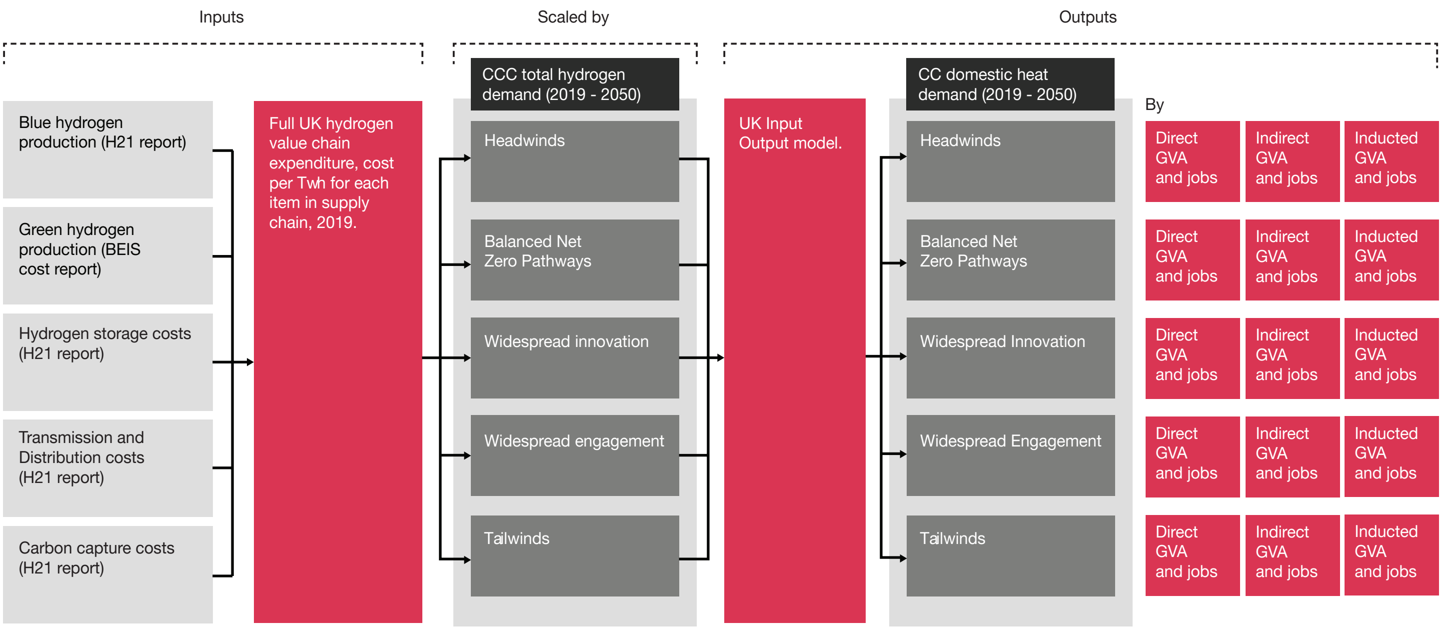
This required us to develop an estimate of the supply chain expenditure (distinguishing capital investment and operational costs) required to meet different levels of hydrogen use for residential heating demand out to 2050. We used publicly available data supply chain costs, which were adjusted to account for differences in production costs between green and blue hydrogen[15].

These cost estimates were applied to the latest UK Office for National Statistics ('ONS') Supply-Use Tables to determine the total GVA and jobs contribution figures resulting from expenditure across the entire hydrogen supply chain.

To determine the contribution from supply chain elements related specifically to domestic heat we use scenarios from the CCC. The CCC produces five different scenarios for decarbonising the UK economy. These are: 'Headwinds'; 'Tailwinds'; 'Widespread Innovation'; 'Widespread Engagement' and 'Balanced Net Zero Pathway' as referenced in Figure 1. We extract the percentage contribution of hydrogen for domestic heat relative to total hydrogen demand in each CCC scenario published in the Sixth Carbon Budget. This approach gives us a full range of estimates for potential economic contribution of hydrogen for domestic heat using different scenarios of hydrogen usage.

Our approach generates estimates of GVA resulting from direct expenditure in the hydrogen for domestic heat industry (Direct GVA), from additional expenditure in supporting sectors (Indirect GVA) and from economic impact which is driven by employees across the supply chain spending their wages on goods and services (Induced GVA).

Figure 1: Approach for quantitative analysis



[15] For blue hydrogen production costs, we took figures from the H21 North of England report 2018, retrieved October 2022. For green hydrogen production costs, we took figures from BEIS Hydrogen Production Costs 2021, retrieved November 2022.

Our analysis is based on CCC scenarios with varying degrees of domestic heat decarbonisation using hydrogen. In the highest of the CCC scenarios for hydrogen deployment for domestic heating ('Headwinds scenario'), 71% of homes are heated using hydrogen. We use this scenario to illustrate the economic impact of hydrogen for domestic heat when deployed at scale.

Other CCC scenarios are analysed such as the 'Balanced-Pathways' scenario, where 11% of homes are heated or partially heated through hydrogen, and the 'Widespread Engagement' scenario where no homes are decarbonised through hydrogen[16].

There are several important limitations to note in this approach, which are explained further in our 'GVA and Jobs Contribution Methodology' annex. Most importantly, estimates of economic contribution out to 2050 will necessarily carry high levels of uncertainty, most significantly around costs, levels of technology deployment and technology evolution. Our approach effectively provides an indicative estimate of the potential scale of impacts across varying technology deployment scenarios, though we note that further technical analysis could incorporate more primary cost research and modelling to capture dynamic effects – for example through computable general equilibrium ('CGE') modelling.

The scope of our analysis is limited to estimating the potential economic contribution of developing a hydrogen supply chain for domestic heat using the scenarios outlined above. Our analysis does not consider how this would compare to the development of supply chains for alternative potential domestic heating options such as heat pumps, nor does it consider wider impacts outside of jobs and GVA.

Furthermore our analysis does not constitute a full cost beneit analysis of domestic heat decarbonisation.

[16] Element Energy (2021) - Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget: A study for the Committee on Climate Change.

Evidence on the potential role of hydrogen in decarbonising domestic heat

Key Takeaways from this chapter

- Evidence reviewed suggests hydrogen could play a role in heating homes in the UK, in particular those homes considered ‘hard to decarbonise’, which make up 18-37% of the housing stock and where in some circumstances it may be the most cost-effective energy transition solution.
- Hydrogen in storage, as well as for domestic heat has the potential to mitigate the cost of meeting future peak demand through providing flexibility at both the building and the system level.
- The gas industry employs high levels of technically skilled labour, including over 140,000 boiler engineers across the UK. According to reports reviewed, the relative cost of reskilling these workers for hydrogen gas may present an opportunity for low cost skill transition, but more action is needed to increase rates of Net Zero skills uptake.

Based upon several reports, the UK faces a unique challenge in reaching zero carbon domestic heat. Its housing stock is one of the oldest in Europe, and most existing homes are expected to still be in place in 2050[17]. This means that decarbonising the heat source for most UK homes will require retrofit of new technology into an existing, old and thermally ineficient housing stock.

Several commentators in a recent report to the House of Commons stated the opinion that ‘there is no silver bullet’[18] to decarbonise domestic heat.

Reports reviewed broadly support a portfolio approach to decarbonising domestic heat. Among the factors impacting the suitability of options for specific houses are: regional geography; house type; the heating systems currently in use; and whether existing homes are connected to the gas grid. These factors are significant for understanding the cost of decarbonising homes with different technologies for groups or regions[19].

Additionally, the transition to zero carbon domestic heat has consequences for the energy system and for the workforce. We have therefore reviewed evidence to understand where hydrogen may play a role in transitioning to zero carbon domestic heat. From our review we highlight three areas where there is support for hydrogen playing a beneficial role in heat decarbonisation.

Evidence on ‘hard to decarbonise’ homes

The Energy and Utilities Alliance (‘EUA’) estimate that 37%-54%[20] of homes in the UK are ‘hard to decarbonise’[21], due to space constraints and other factors. This is partially supported by an independent report commissioned by the CCC and produced by Element Energy in 2019 which estimated that 18%-37% of UK homes could be considered ‘hard to decarbonise’ due to space constraints, heritage status and other factors. This study demonstrated that in some circumstances abatement costs are lowest in a ‘Hydrogen-Led Scenario’[22]. It should also be noted that the Energy Systems Catapult has concluded that the retrofit of heatpumps is technically feasible for all property types, though their assessment does did not consider cost effectiveness[23].

The evidence that we have reviewed suggests that the costs of retrofitting heat decarbonising technologies are critical for organisations such as housing associations. There are currently 4.4m social housing units[24] in the UK, and the cost of decarbonising these homes will be ‘at least £39bn’ by 2050 according to the National Housing Federation and Savills[25].

---

[17] Climate Change Committee: Sixth Carbon Budget (2020) – The UK’s path to Net Zero report.

[18] Kwasi Kwarteng, quoted in the House of Commons – Business, Energy and Industrial Strategy Committee (2022) - Decarbonising Heat in Homes: Seventh Report of Session 2021-22.

[19] House of Commons – Business, Energy and Industrial Strategy Committee (2022) - Decarbonising Heat in Homes: Seventh Report of Session 2021-22.

[20] Energy and Utilities Alliance (2021) - Decarbonising heat in homes: Putting Consumers First.

[21] This is a technical term for homes in which measures to reach Net Zero are uneconomic, logistically or technically troublesome or impose unacceptable impacts on tenants or others.

[22] Element Energy (2019) -Analysis on abating direct emission from hard to decarbonise homes: A study for the Committee on Climate Change note: “This is in a scenario which is hydrogen led i.e. the majority of homes are decarbonised through hydrogen by 2050 and 96% CO2 emissions abatement is achieved”. Element Energy estimated that the total cost of abatement was lower than than in a ‘no-hydrogen’ scenario; but noted also that costs may be underestimated, as costs of hydrogen storage are not included.

[23] Energy Systems catapult (2021) – Article: “All housing types are suitable for heat pumps, finds Electrification of Heat Project”.

[24] Regulator of Social Housing (2022) – Registered provider social housing stock and rents in England 2021 to 2022.

[25] Savills UK (2021) – Decarbonising The Housing Association Sector: Costs and funding options.

> Almost all of the UK's 29 million homes will require upgrading by 2050, that is about 1 million homes per year, and is equivalent to more than 19,000 homes per week. Current retrofit rates are inadequate for achieving even a significant portion of the required level of decarbonisation to meet the 2050 targets.
>
> **UK Energy Research Centre**

Through interviews conducted for this report, housing providers and several experts suggested that hydrogen ready boilers could have an important role for future domestic heating due to low up front cost of installation and installation convenience (e.g. fitting into existing space).

This is supported by a number of sources, for example, in a review on hydrogen for heat in buildings, Climate Exchange found that 'the total cost for converting a home to 100% hydrogen is £3,000-£4,000' - with the cost of the boiler itself ranging between £700-£2,500 without installation[25]. This presents an opportunity for UK businesses too, given approximately 1.7m boilers were sold by UK boiler manufacturers in 2019[26].

A social housing provider interviewed for this study indicated that the additional cost of decarbonising through hydrogen ready boilers would be effectively zero as they could be installed at no additional cost within 'existing replacement cycles'.

In contrast, replacement of methane gas boilers with alternative technologies to hydrogen boilers could be challenging without financial support. Several reports reviewed supported this statement. For example, an analysis produced by the Local Government Association found that without "funding support, social landlords may have to consider disposing of some hard to decarbonise homes to meet their energy performance targets"[27]. In addition an evidence review commissioned by the Scottish Government on the use of hydrogen for heating in buildings showed that the cost difference between a methane-ready and hydrogen-ready boiler is relatively small[28].

Given the complexities around installation and the potential upfront cost, a consistent message from stakeholders was that there was a lack of communication and information from government available on how to promote decarbonisation. This message was also reflected in evidence presented to the House of Commons BE committee in its report 'Decarbonising Heat in Homes'[29].

> Homes become hard to decarbonise when the measures to reach Net Zero are uneconomic, logistically or technically troublesome, or impose unacceptable impacts on tenants or others."
>
> **Local Government Association, 2021**

[25] Delta EE/Climate Xchange (Robert Castek and Stephen Harkin) (2021) – Evidence review for hydrogen for heat in buildings.

[26] As quoted by Energy Utilities Association's Chief Executive Officer, Mike Foster, in 2019.

[27] Local Government Association (2022) – Hard to Decarbonise Homes.

[28] Delta EE/Climate Xchange (Robert Castek and Stephen Harkin) (2021) – Evidence review for hydrogen for heat in buildings.

[29] Business, Energy and Industrial Strategy Committee (2022) – 'Decarbonising Heat In Homes', page 42.

> (It is) much more complicated than simply switching from boilers to heat pumps, not least due to the unsuitability of some homes for heat pumps, but also because it appears that delivering peak heat to homes in winter may be an insurmountable challenge for all electrically delivered heat.
>
> Thus, alternative, and complementary approaches are needed, to align with practical constraints of people's homes and deliver huge swings in demand and service peak heat.
>
> **BEIS Committee Report to the House of Commons, 2022**

Evidence on the role of hydrogen in mitigating cost of high future peak demand

Studies we have reviewed for this report suggest that an important reason for using hydrogen to decarbonise domestic heat is to support in meeting future peak demand. For example this can be through enabling flexibility via hybrid heat pumps and hydrogen storage solutions, or through diversifying energy demand away from pure electrification and reducing the burden placed upon the electricity network.

The House of Commons Science and Technology committee report into 'The role of hydrogen in achieving Net Zero' presented evidence gathered from industry and across society. In it a number of witnesses suggested that hydrogen had a role to play in meeting future peak demand in what is likely to be a highly electrified energy system.

For example, EDF were quoted in the report as stating that, "national peak heat demand is high", and that complete electrification of heating would be "challenging in terms of the scale of network and generating capacity which would be required". In the report EDF are further quoted as recommending a mixed strategy which utilises both low carbon hydrogen and electrification[30].

In the same report, National Grid were quoted, stating that hydrogen had a potentially important role in meeting demand as it could help "to manage peak (demand) for decarbonised heating"[31].

Most CCC scenarios suggest that hydrogen in domestic heat can offer support to the electricity system by offsetting peak electricity demand in a largely electrified energy system. For example, the Sixth Carbon Budget, 'Balanced Pathways' scenario, assumes that 5% of homes are decarbonised through hydrogen boilers by 2050 with another 6% reliant on hybrid hydrogen heat pumps.

The Sixth Carbon Budget also recognised that alternative options for decarbonising heat in residential buildings maybe more efficient than hydrogen. Nevertheless, it suggests that hydrogen is particularly valuable where it can provide flexibility at the system level and at the building level, 'and could play a role in decarbonising areas where there is a clear technical case'[32].

Several stakeholders we interviewed supported the view that hydrogen could play an important role in mitigating the cost of meeting peak demand in various ways. For example, one stakeholder from an energy company explained that hydrogen could play an important role in meeting peak demand through storage, through distribution to hybrid hydrogen heat pumps, as well as through homes where heat is entirely decarbonised through hydrogen.

[30] House of Commons – Science and Technology Committee (2022) – The role of hydrogen in achieving Net Zero: Fourth Report of Session 2022–23.

[31] House of Commons – Science and Technology Committee (2022) – The role of hydrogen in achieving Net Zero: Fourth Report of Session 2022–23.

[32] For example, where there is co-location with hydrogen clusters, Climate Change Committee: Sixth Carbon Budget (2020) – The UK's path to Net Zero report.

> There is a cohort of 120,000 qualified gas engineers in the UK, and those with Gas Safe qualifications may only need one extra day's training."
>
> "Building Skills for Net Zero", Construction Industry Training Board (CITB), 2021

Evidence found on jobs and skills

The BEIS committee report on decarbonising heat in homes concluded from its assessment of issues around low carbon skills that, "It is vital that the heating and energy eficiency workforce has the capacity and skills required for the job at hand". It went on to suggest that, "the government must urgently develop a low carbon heating training programme, in partnership with industry and trade unions"[33]. This demonstrates the importance of considering the cost of reskilling both in terms of time and willingness of current workers to reskill.

Sources suggest that there are 120,000-140,000 registered gas engineers spread across the country[34], and based upon our analysis of Nomis data, there are approximately 51,000 employees in the upstream gas industry sectors supporting domestic heat, working in manufacture, electricity generation from gas, and transmission and distribution of natural gas[35].

When asked, stakeholders interviewed for this report suggested that it would be easier to upskill gas engineers to work on hydrogen than to upskill them to work on other heating technologies. The Heat in Buildings Strategy published by BEIS states that 'Hydrogen boiler engineers and home retroitters will likely require similar expertise and training as natural gas boiler engineers'.

However, existing natural gas boiler engineers may still require some additional training to familiarise themselves with the differences between using and installing products that use hydrogen as a fuel source, in contrast to natural gas. In 'Building Skills for Net Zero', Eunomia demonstrated that additional training for gas boiler engineers was expected to take one day[36].

In the same report it was found that 50% of gas engineers would be willing to retrain to support heat pump roll out, provided there is suficient demand[37]. This demonstrates that sufficiently skilled engineers are not constrained to heat pump roll out but in the context of jobs and skills in this aspect of transition, hydrogen will be easier to deploy to decarbonise homes.

The Heat In Buildings Strategy further estimated that by 2050, a hydrogen economy would require an additional 19,800 more boiler installers, and that within 10 years from today all boiler engineers could be upskilled to support the mass roll out of hydrogen boilers.

The evidence suggests there could be a relative saving on training costs, as well as time costs, from gas workers retraining to work on hydrogen for heating as compared to heat electriication. The BEIS committee report on decarbonising homes pointed towards an absence of clarity and clear policy for retraining existing domestic heat workers; the same report recommends that this should be addressed[38].

33 House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22.

34 Gas Safe Register (2019) – News 2019: Ten years of keeping people gas safe.

35 Nomis (2022) – Business Register and Employment Survey : open access, employees, 2021 latest data.

36 Eunomia Research and Consulting Ltd (2021) – Industry insights and analysis: Building Skills for Net Zero – Report prepared by Eunomia for CITB. This Eunomia report was commissioned by the UK government and presented in the Heat in Buildings Strategy.

37 Department for Business, Energy and Industrial Strategy (2021) – Heat and Buildings Strategy.

38 House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22.

Understanding the economic potential of hydrogen for domestic heat to the UK economy

Key Takeaways

- We estimate cumulative Jobs and GVA contribution for hydrogen for domestic heat using five CCC scenarios.
- Using the CCC's 'Headwinds' scenario, we estimate £48bn in GVA and 612,000 in jobs cumulatively to the UK economy in the period to 2050. Using the CCC's 'Balanced Pathways' scenario we estimate £5bn in GVA and 57,000 in jobs cumulatively to the UK economy in the period to 2050.
- Our analysis indicates that the North-West of England could benefit the most from hydrogen for domestic heat activities out of all the UK regions, growing by £13bn in GVA in the period to 2050. This is based upon our methodology which accounts for the current number of gas related jobs and the total number of hydrogen projects that have been announced within the region.
- We also estimate the wider hydrogen supply chain could contribute £124bn and 1.6m jobs to the UK, in the period to 2050.

The UK has set itself a target of decarbonising the electricity grid by 2035 and has also set the ambition of reaching its Net Zero target across all sectors by 2050. Hydrogen is one of several low carbon solutions that is available to the UK to help it meet its environmental ambitions.

The construction of a hydrogen supply chain that converts natural resources into hydrogen and transports it for heating homes represents a potentially significant economic opportunity. However, the current hydrogen supply chain is not yet fully established, which means there will be a need for continued investments to meet the future demand for low carbon hydrogen. These investments will require expenditure on goods and services from both domestic and international companies, thereby creating economic activity and contributing to economic growth.

Published analysis already shows that direct investment across the supply chain for hydrogen could result in up to **cumulative £87bn** in GVA to the Economy by 2050 and annual long term employment of up to 27,500 per year[39] – though these estimates exclude expenditure on boilers.

In this section, we present our results on the potential economic growth opportunity for hydrogen focused specifically on its role in domestic heat.

[39] Wood/Optimat (2022)- Supply Chains to Support a Hydrogen Economy. GVA figure is based on an average annual estimate produced in this report and does not include expenditure on domestic heat.

The economic value of hydrogen for domestic heat to the UK

As set out in our methodology section, we use a range of Net Zero transition scenarios from the CCC to estimate Cumulative Jobs and GVA from development of a supply chain to support the deployment of hydrogen for domestic heat. In this segment we focus on the CCC's 'Headwinds' scenario which contains the highest deployment of hydrogen for domestic heat of all the CCC scenarios, as it illustrates the impact of deploying hydrogen for domestic heat at scale. We present results for the rest of the CCC scenarios in the next segment.

Our analysis suggests that the expenditure to create the supply chain for converting hydrogen into domestic heat could contribute up to £48bn in GVA and 612,000 jobs (in Full-Time Equivalent (FTE) terms) cumulatively in the period to 2050 within the UK[40] using the CCC 'Headwinds' scenario. This is inclusive of jobs that are created during transition, but not required into the long-term (e.g. workers who support the construction of a hydrogen power plant but move onto other projects once construction is finished).

Separating each type of economic contribution enables us to understand what type of economic effects are created as a result of purchases of goods and services for the hydrogen economy.

Table 1 illustrates the economic contribution from each 'tier' of economic contribution - direct, supplier and employee expenditure, and by each sector[41] in the economy. These economic contributions are also often referred to as direct, indirect and induced effects. The manufacturing, construction and business services sectors collectively constitute 69% (£33bn) of the total economic contribution arising from hydrogen for domestic heat activities in the period to 2050. This includes economic activity from the purchases of goods and services from suppliers such as providers of parts for a hydrogen production plant, construction activities and consultants who help oversee the overall development of the hydrogen supply chain.

Figures can also be understood in average annual contribution terms. In average annual terms (over the period to 2050), this is equivalent to £1.6bn in GVA. These contributions are more likely to vary however, depending on the year up to which the impacts are being assessed. This is explored in **Table 3** later in this report.

Table 1: Total estimated economic and jobs contributions by sector and by type of economic contribution, for hydrogen for domestic heat, using the CCC 'Headwinds' scenario, in the period to 2050

	Direct expenditure		Supplier expenditure		Employee expenditure		Total	
Sector	**GVA (£m)**	**Jobs (FTEs)**	**GVA (£m)**	**Jobs (FTEs)**	**GVA (£m)**	**Jobs (FTEs)**	**GVA (£m)**	**Jobs (FTEs)**
Agriculture, forestry and fishing	-	-	100	1,100	100	1,500	200	2,600
Mining	700	400	300	1,700	<100	100	1,000	2,200
Manufacturing	8,200	93,000	2,900	37,500	800	9,200	11,900	139,700
Utilities	400	1,900	800	4,700	400	1,900	1,700	8,600
Construction	6,800	100,000	3,400	50,400	200	3,600	10,500	154,000
Retail, distribution and catering	500	6,500	2,100	32,800	2,300	44,800	4,800	84,000
Transport and communication	100	900	1,800	27,700	1,000	12,700	3,000	41,300
Business services	2,400	48,800	3,400	40,000	4,900	16,100	10,700	104,900
Public admin and other services	400	5,600	1,800	35,300	1,900	33,700	4,100	74,600
Total	**19,400**	**257,000**	**16,700**	**231,200**	**11,800**	**123,700**	**47,900**	**611,900**

Source: PwC Analysis (2022)

[40] These figures are based upon the low carbon hydrogen demand estimates from the CCC 'Headwinds'. Please refer to our sensitivity analysis to understand how these figures vary in other scenarios.

[41] For the purposes of analysis, PwC UK has defined its own set of aggregated sectors. Each aggregated sector constitutes a set of underlying ONS-defined sectors.

Contextualising the economic contribution from hydrogen for domestic heat

To contextualise the £48bn economic contribution from hydrogen for domestic heat in the period to 2050 (or £1.6bn in average annual contributions) we provide below a select number of industries for comparative purposes:

- £51bn – the total size of England's 'Accommodation and food service activities' industry in 2019[42,43].
- £1.7bn – the total size of South West England's 'Arts, entertainment and recreation' industry in 2019[42,43].
- £1.5bn – annual estimated contribution of smart grids to the midlands by 2050[44].

(Source: ONS – Regional gross value added (balanced) by industry: all ITL regions).

Economic contribution by scenario

In the segment above we use the CCC's 'Headwinds' scenario[45] to estimate potential future economic contribution. The demand profile in the CCC 'Headwinds' scenario matches the demand profiles of the 'System Transformation' scenario in National Grid ESO's Future Energy Scenarios (FES)[46,47]. So, we would expect the economic and jobs contributions to be similar across these scenarios from these two sources. However, other scenarios are possible and these would result in different economic contributions from hydrogen for domestic heating.

Table 2 illustrates the economic contribution from other CCC scenarios, based upon different CCC projections for hydrogen demand for domestic heating. We present below the overall economic contribution, as well as for the direct, indirect and induced levels.

Table 2: Total estimated economic and jobs contributions, by scenario and by contribution for domestic heat only, in the period to 2050, figures rounded to the nearest 100

Level of economic contribution		Climate Change Committee Scenario				
		Headwinds	Tailwinds	Balanced Net Zero Pathway	Widespread Innovation	Widespread Engagement
% of low carbon hydrogen demand for domestic heating		38.6%	14.9%	6.1%	5.4%	0.0%
Direct expenditure	GVA (£m)	19,400	4,800	1,800	1,200	-
	Jobs (FTEs)	257,000	63,000	23,400	15,300	-
Supplier expenditure	GVA (£m)	16,700	4,100	1,600	1,000	-
	Jobs (FTEs)	231,200	56,600	21,600	13,800	-
Employee expenditure	GVA (£m)	11,800	2,900	1,100	700	-
	Jobs (FTEs)	123,700	30,500	11,400	7,500	-
Total	GVA (£m)	47,900	11,700	4,500	2,900	-
	Jobs (FTEs)	611,900	150,100	56,500	36,500	-

Source: PwC Analysis (2022), Climate Change Committee – Sixth Carbon Budget (2020).

[42] Office for National Statistics (2019), Although more recent data for 2020 is available, we have used 2019 estimates as this year is more likely to reflect how the economy will operate in future years.

[43] Office for National Statistics (2023) – Regional gross value added (balanced) by industry: all ITL regions. Table 1c: ITL 1 & UK current price estimates [note 1,2].

[44] Midlands Engine, Simens & University of Birmingham (2021), "Smart Energy, An Energy System for the 21st Century.

[45] Climate Change Committee: Sixth Carbon Budget (2020) – Charts and data in the report.

[46] National Grid ESO (2022) – Future Energy Scenarios 2022 Data Workbook.

[47] The CCC 'Headwinds' scenario suggests an estimate of 145TWH of low carbon hydrogen demand for domestic heating in 2050. The FES 'System Transformation' scenario also suggests an estimate of 145TWH demanded in 2050 by residential end users. Therefore, we are treating the potential economic contribution from these scenarios as synonymous.

Of the scenarios used for our analysis, the ‘Headwinds’ scenario results in the highest estimated economic contribution as this scenario contains both the highest estimated demand for low carbon hydrogen (376TWh in 2050) and the highest estimated contribution specifically for domestic heat (145TWh of low carbon hydrogen for domestic use).

Economic value of hydrogen for domestic heat over time

Scaling our analysis to different time periods demonstrates how economic and jobs contributions from hydrogen for domestic heat can vary over time.

As the demand for low carbon hydrogen changes over time, so does the cumulative economic and employment contribution from developing the hydrogen for domestic heat supply chain. For example, as demand for low carbon hydrogen is lower in the period from 2022-2035 than in the period from 2035-2050, cumulative economic contribution is likely to be lower over this earlier time period.

Table 3 highlights how we expect GVA and employment contributions to evolve over time in the CCC ‘Headwinds’ scenario[48]. This includes the period to 2035 but also out to 2050. We have outlined the cumulative contributions at 5-year intervals, partly due to these intervals best demonstrating the overall changes that we can expect over time and due to our methodology.

Table 3: Total estimated cumulative GVA and jobs contributions, in the CCC’s ‘Headwinds’ scenario, for period up to 2030, 2035, 2040, 2045 and 2050 for domestic heat supply chain, figures rounded to the nearest 100

Supply chain type	Economic contribution (cumulative)	2030	2035	2040	2045	2050
Domestic heat	GVA (£m)	3,300	14,600	28,500	42,800	47,900
	Jobs (FTE)	42,900	189,000	369,100	549,600	611,900

Source: Strategy& analysis

The distribution of growth in jobs and economic value

Regional economic contribution

Over the last century, much of the UK’s overall economic development has been driven by regional economic growth in London and the South-East of England, leaving other parts of the UK behind in terms of economic development. The UK has subsequently identified the need for a strategy to course-correct the imbalanced economic growth and more effectively support regions outside of London and the South-East of England. The Levelling Up White Paper[49] published by the UK government in February 2022 outlines the high-level strategy and objectives the UK has set out to balance future economic activities by 2030 and provide a more regional focus to the UK’s economic growth.

We analyse the potential impact of hydrogen for domestic heat (and the wider supply chain) on regional UK economic development. **Table 4** outlines our estimates of regional economic growth and jobs contributions across the UK, from the activities in relation to domestic heat only.

Table 4: Total estimated cumulative GVA and jobs contributions, in the Headwinds scenario, by UK region, for domestic heat supply chain, for period up to 2050, figures rounded to the nearest 100.

Region	GVA by Region (£m)	Gross Jobs by Region (FTE)
North West England	13,000	74,400
South East England	7,000	79,700
Scotland	5,000	50,600
Yorkshire and The Humber	4,500	63,500
East Midlands England	4,000	42,100
West Midlands England	4,000	51,600
Wales	3,000	27,400
South West England	2,200	49,000
North East England	2,000	33,400
London	1,500	69,600
East of England	1,200	54,200
Northern Ireland	400	16,400
Total	£47,900	611,900

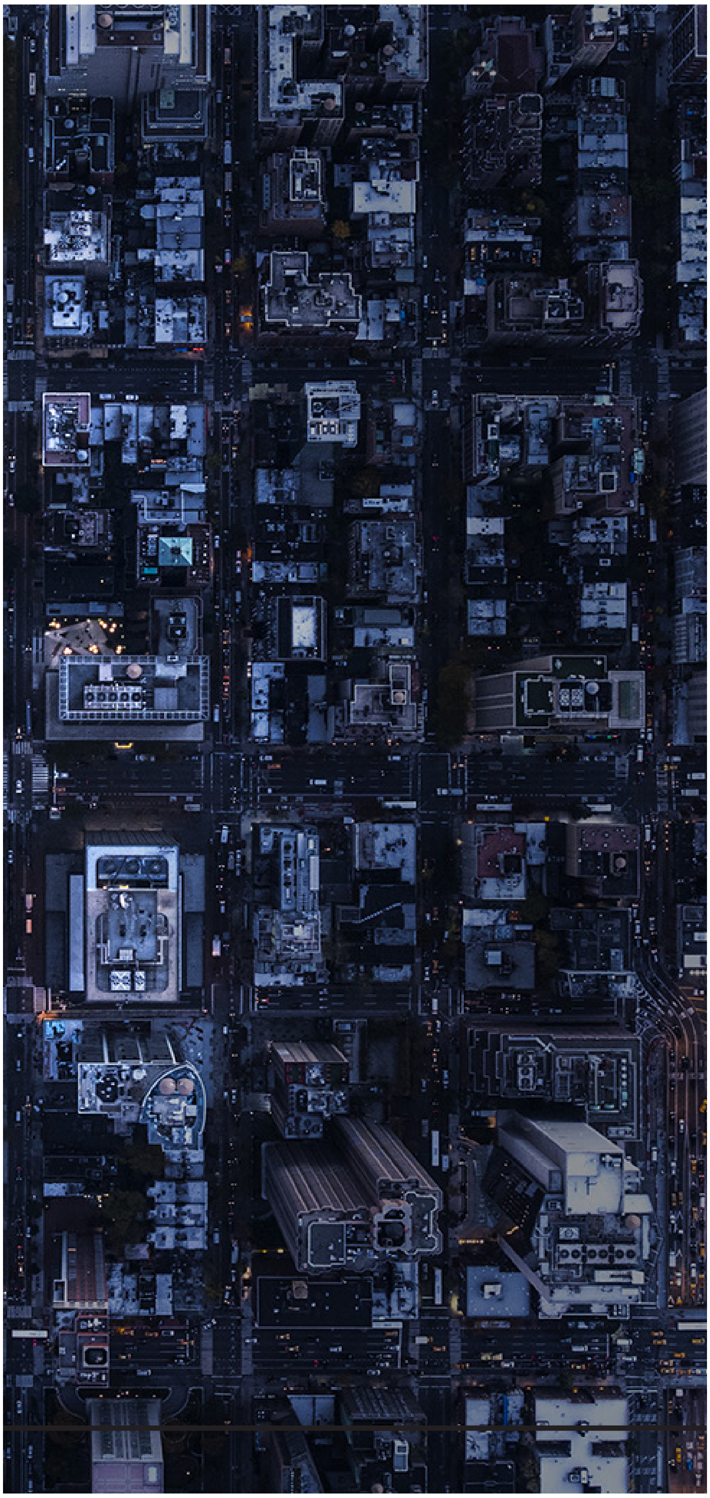
Source: Strategy& analysis

[48] Our analysis begins from the year 2019 as this is when we begin to observe demand for low carbon hydrogen, albeit beginning with very small values.

[49] Department for Levelling Up, Housing and Communities (2022) – Levelling Up the United Kingdom: executive summary.

Our analysis suggests that of the £48bn contribution to UK GVA, (in the CCC's 'Headwinds' scenario), £13bn (27%) of this figure can be attributed to economic activity in the North-West of England. This is followed by South-East England, Yorkshire and The Humber and Scotland which all individually benefit from activities relating to hydrogen for domestic heat by nearly £5bn and more.

This demonstrates that the hydrogen economy provides a significant opportunity for the UK to support its levelling-up agenda and help regional economies across the UK. With most hydrogen projects being deployed in areas outside of London, there is a significant opportunity to support UK government's wider policy objectives, including Levelling-up, skills and Net Zero agendas.



Economic contribution across the wider hydrogen supply chain

Comparison by supply chain type

Understanding how our economic contribution figures break down across the hydrogen supply chain enables us to illustrate which components of the supply chain provide the highest economic value, and which areas we consider are more limited in their contributions.

We first set out the economic contribution across the full UK hydrogen supply chain including contributions from other end-uses of hydrogen such as transport, industrials and commercials and power generation. This is because most of the hydrogen supply chain will be shared with multiple downstream uses (e.g. domestic heat, transport), and upstream activities (e.g. production, compression, transmission and storage). Therefore, when assessing economic contribution figures at each stage of the hydrogen supply chain, it is more comprehensive to consider the economic contribution for all downstream uses in aggregate.

Table 5 highlights how our economic contribution figures for domestic heat compares to the full hydrogen supply chain. We estimate **£124bn in cumulative GVA** and **1.6m** jobs will be contributed to the UK economy in total from the full hydrogen supply chain.

Table 5: Total estimated economic and jobs contributions, for whole hydrogen supply chain and domestic heat only using the CCC 'Headwinds' scenario, in the period to 2050, figures rounded to the nearest 100

Supply chain type economic contribution (cumulative)		Whole hydrogen supply chain[50]	Domestic heat
Domestic heat	GVA (£m)	50,300	19,400
	Jobs (FTEs)	665,500	257,000
Supplier expenditure	GVA (£m)	43,300	16,700
	Jobs (FTEs)	598,600	231,200
Employee expenditure	GVA (£m)	30,400	11,800
	Jobs (FTEs)	320,200	123,700
Total	GVA (£m)	124,000	47,900
	Jobs (FTEs)	1,584,300	611,900

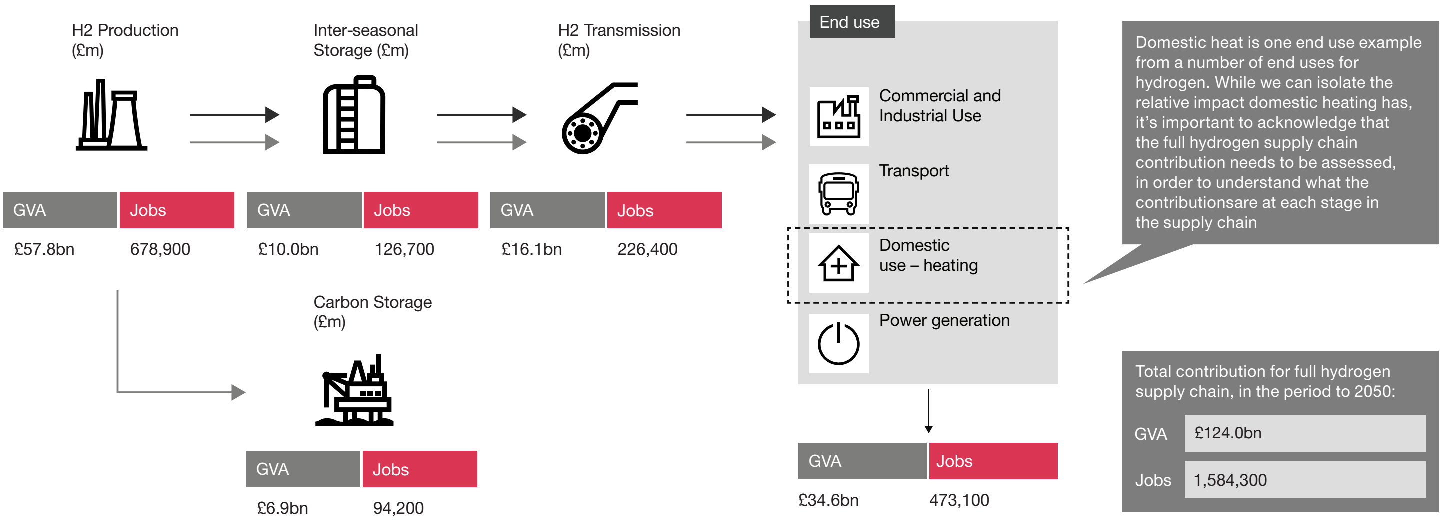
Source: Strategy& analysis

[50] Figures for the whole hydrogen supply chain include figures for domestic heat. These figures include contributions from other end uses that are noted in the CCC scenarios.

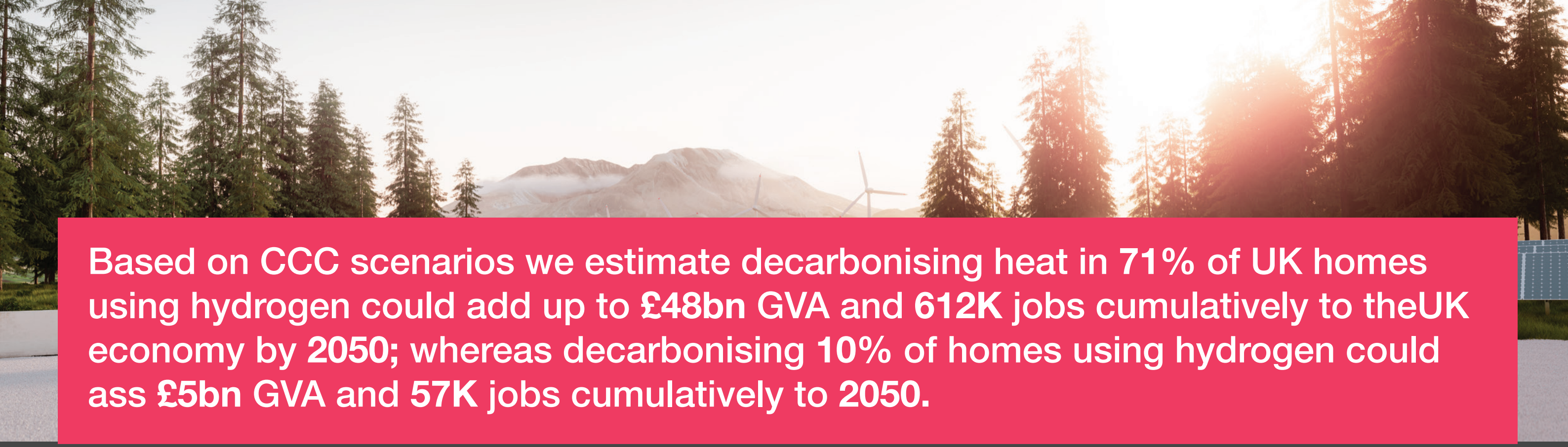
Economic contribution by supply chain stage

Figure 2 illustrates the breakdown in economic contribution of each stage of the hydrogen supply chain. This shows most of the GVA and jobs contributions are driven by the economic activities in the initial hydrogen production stage – £58bn (out of £124bn), equivalent to ~47% of the total economic contribution.

Figure 2: GVA and Jobs contribution at each stage of the full hydrogen supply chain, in the period to 2050, figures rounded to the nearest 100



Source: Strategy& analysis



Based on CCC scenarios we estimate decarbonising heat in 71% of UK homes using hydrogen could add up to £48bn GVA and 612K jobs cumulatively to theUK economy by 2050; whereas decarbonising 10% of homes using hydrogen could ass £5bn GVA and 57K jobs cumulatively to 2050.

We estimate potential cumulative GVA and jobs under 5 CCC scenarios for deployment of hydrogen for domestic heat:

Headwinds:
GVA - £48bn
Jobs - 612k

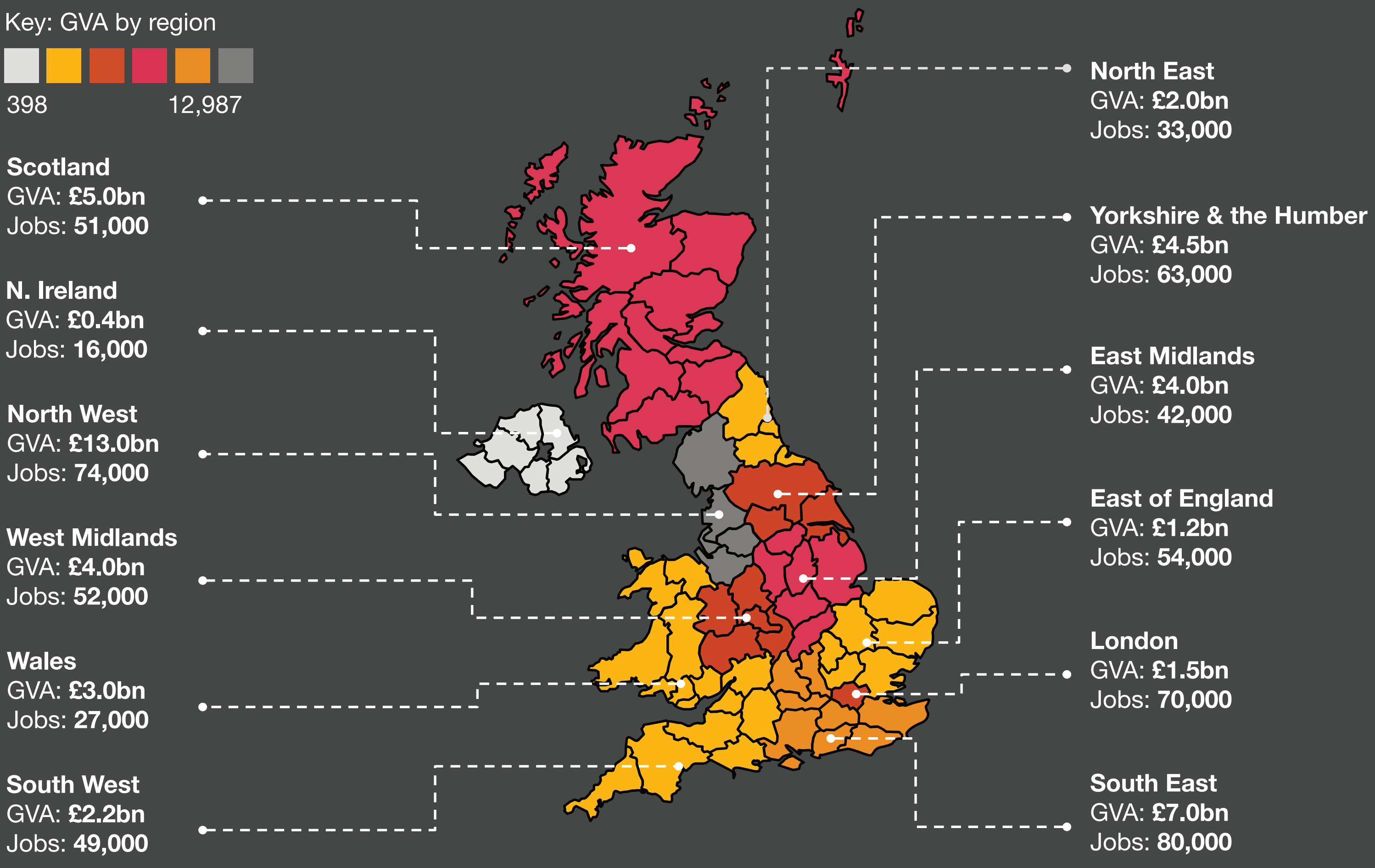
Tailwinds:
GVA - £12bn
Jobs - 150k

Balanced Pathways:
GVA - £5bn
Jobs - 57k

Widespread Innovation
GVA - £3bn
Jobs - 37k

Widespread Engagement
GVA - £0bn
Jobs - 0

This could impact all regions in the UK particularly in NW England



These impacts will affect key sectors

Creating growth opportunities in

Manufacturing:
GVA - **£11.9bn**
Jobs - **140,000**

Construction:
GVA - **£10.5bn**
Jobs - **154,000**

Business services:
GVA - **£10.7bn**
Jobs - **105,000**

Hydrogen presents important opportunities in the Net Zero Transition

'Hard to Decarbonise Homes'
Up to 37% of homes are space constrained and could be cheaper to decarbonise with hydrogen boilers.

Supporting skills transition
~140,000 boiler engineers employed across the country. The time taken to retrain **to use hydrogen boilers is one day.**

Supporting Export Growth
International Hydrogen Economy is worth an estimated US $11.7tn in 2050. The UK has advantages in hydrogen production and research.

These findings are based upon the existing literature and evidence review which PwC Strategy& conducted around hydrogen for domestic heat.

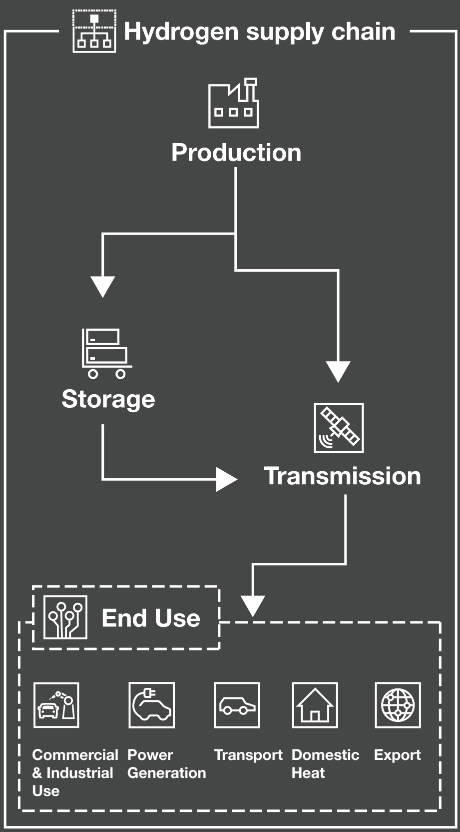
Projects are underway across the country to realise the potential value across the supply chain

Icons for each case study represents which part of the supply chain the case study specialises in:

Cluster of hydrogen projects in the North West of England
- Cluster with potential to deliver £17bn GVA gains and 6k annual jobs for the North West England region.

Green Hydrogen in Manchester
- Project aims to produce 200MW green hydrogen for industry, transport, and heating
- Project's first phase (20MW) could create c.200 construction jobs, and 10 operational jobs.

Cluster of hydrogen projects on the East Coast of England
- A large consortium of stakeholders have organised a 15-year programme to decarbonise the industrial processes and domestic heating in the East Coast region of England.
- 4.4m domestic properties are expected to switch to a low carbon heating solution.



Hydrogen Hub in Aberdeen
- Aberdeen City Council and BP have committed £3mn to design a green hydrogen hub with intention to supply hydrogen for heat in future phases.

Hydrogen manufacturing site in Yorkshire and the Humber
- A private company has announced a £16m investment to expand its current Hull manufacturing site, trebling its capacity to produce heat pumps and hydrogen boilers.

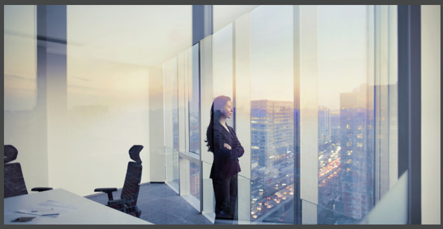
Hydrogen Hub in Solent
- Hydrogen hub with est. £22bn GDP contribution to deliver low carbon fuel for transportation, heat for homes, etc.

Cluster of hydrogen projects in South West of England
- Partnership of 9 organisations to bring Hydrogen to the South West, delivering sustainable growth and job opportunities.

Low regret actions could be considered now which may help to capitalise on this opportunity

Effective communication campaign: A clear communications campaign is needed to raise public awareness around the challenge of decarbonising homes, the value of trials and the trade offs between options.

Increased spend on R&D and skills: R&D spend represents a low / no regrets option for public & private sector organisations to improve the opportunities for the UK in terms of export of technology and improved skills.



Develop a place-by-place heat decarbonisation framework: to determine which technologies could be most cost effective for decarbonising domestic heat to support local authority strategies.

Evidence reviewed on the opportunity for the UK in the international hydrogen market

Key Takeaways

- The international market for hydrogen and its supply chain is forecast to grow significantly, the potential market opportunity is driving countries to pursue strategies for investment in this area.
- Reports reviewed state that exporters and investors require suficient revenue predictability to recoup upfront capital investment. Greater certainty over future support for hydrogen would improve investor confidence.
- A low/no regrets option to achieving international advantage in the hydrogen economy is to expand investment in relation to Research and Development ('R&D'), this is supported by stakeholders interviewed for this report.

The UK has an opportunity to develop a high value sector by creating the technology and skills which could position the UK as an exporter of hydrogen, components of the hydrogen supply chain and skilled people. While the sector is still in its early stages of development with technology and consumer uncertainties, the value of the sector internationally has been forecast to reach $11.7tn by 2050, with annual hydrogen sales projected to reach $600bn by that time[51].

The scale of the opportunity has prompted a number of countries to develop their hydrogen supply chains. The European Union ('EU') strategy, for example, has an objective to install at least 6 Gigawatt ('GW') of renewable-sourced hydrogen by 2024 and 40 GW by 2030 across the EU. Along with this target for hydrogen production, the EU also announced a target for 10m tonnes of green hydrogen import by 2030, thus creating an opportunity for green hydrogen export for the UK[52]. The Hydrogen Council estimated that global investment into the hydrogen economy would reach $500bn by 2030[53].

In the UK, a recent published analysis by Wood/Optimat[54], produced on behalf of BEIS, it was estimated that the UK could capture between 7% and 11% of the blue and green hydrogen[55] production and export and engineering trade. Illustratively capturing 7% of hydrogen sales in 2050 could yield £50bn[56] in annual revenue to UK based companies in 2050.

Several stakeholders interviewed for this report described the UK as having advantages in the development of safety standards for hydrogen which could be exported in the form of expertise[57]. According to a recent report from the Energy Networks Association, there is an intention across industry to invest in the hydrogen economy, with gas networks 'ready to invest £6.8bn in hydrogen focused projects by 2031/32'[58].

The recent 'Hydrogen Sector Development Plan' published by BEIS[54] set out the strategic aim of the UK government to 'position the UK as a future exporter of low carbon hydrogen'. According to our review, in order to achieve the investment required, improved certainty around future demand may be needed.

Reports reviewed state that UK leadership is key to encouraging the investment to support the UK capturing more of the international market. The report from BEIS stated that that whilst the UK has shown leadership through enshrining Net Zero commitments in law, generation of the Ten Point Plan, as well as the development of industrial clusters, confidence in investment is still developing and that '(confidence) is often fragile and can be undermined very quickly'[59].

According to a frequently cited report by International Renewable Energy Agency (IRENA) on the Geopolitics of Hydrogen, the potential for low-carbon hydrogen production is significant but may be undermined if there is not a supportive framework for hydrogen demand. Stakeholders interviewed for this project supported this, stating that hydrogen demand in domestic heating could drive investment due to confidence in future revenues given the relative stability and predictability of heat demand[60].

[51] Department for Business, Energy and Industrial Strategy (2022) – Hydrogen sector development action plan.

[52] European Commission – EU Hydrogen Strategy (2022): Framework to support the uptake of renewable and low-carbon hydrogen.

[53] The Hydrogen Council (2021) – Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness.

[54] Wood/Optimat (2022) – Supply Chains to Support a Hydrogen Economy.

[55] Blue hydrogen is hydrogen produced from natural gas and supported by carbon capture and storage. Green hydrogen is hydrogen produced from low/zero carbon energy.

[56] PwC UK analysis from synthesis of reports capturing size of global market and potential market share captured by UK firms.

[57] Based upon feedback from stakeholders interviewed for this report.

[58] Energy Networks Association (2023) - A hydrogen vision for the UK.

[59] Department for Business, Energy and Industrial Strategy (2022) – Hydrogen Sector Development Action Plan.

[60] International Renewable Energy Agency (2022) – Geopolitics of the Energy Transformation: The Hydrogen Factor.

“

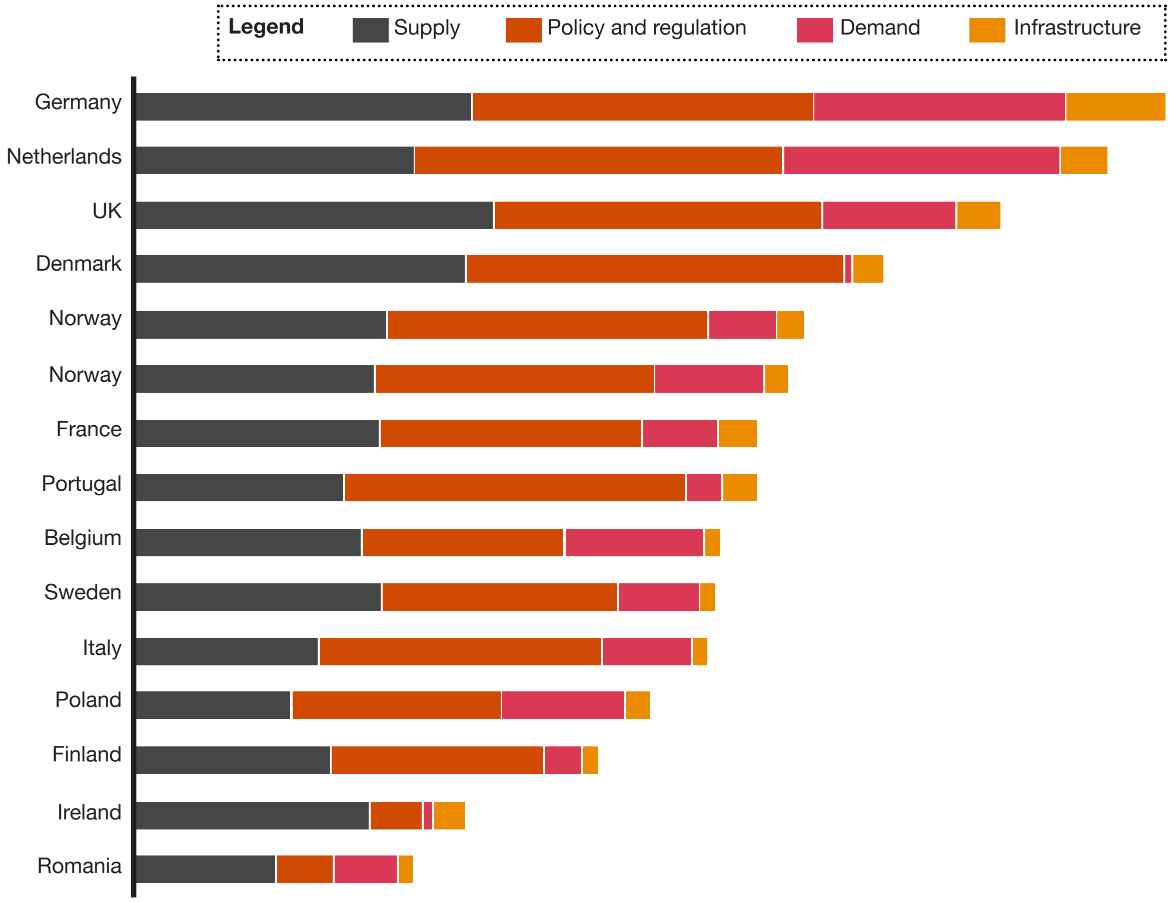
From the perspective of an exporter, revenue security is crucial. Without an assured stream of revenues, it is not possible to recoup the upfront capital expenses incurred to build hydrogen projects.

Geopolitics of the Energy Transformation: The Hydrogen Factor, IRENA, 2022

Aurora Energy Research has analysed how attractive each European country is in terms of hydrogen investment, through the Hydrogen Market Attractiveness Rating (HyMAR). In the latest rating, the UK scored highly amongst European countries in its attractiveness for low carbon hydrogen investment, falling behind two countries – the Netherlands and Germany, in their rankings due to hydrogen demand and infrastructure[61].

A broader list of rankings is provided in **Figure 3** below. The stakeholders we interviewed pointed out that hydrogen demand from domestic heat would be 'stable and predictable' and commitments to using hydrogen in domestic heat could make investment in the hydrogen supply chain more attractive for this reason, which is supported by studies reviewed for this report.

Figure 3: Aurora's Hydrogen Market Attractiveness Rating[62] (HyMAR) by country, Aurora Energy Research, Aurora Hydrogen Conference, November 2022



Source: Aurora Energy Research, presented at the Aurora Hydrogen Conference (November 2022)

The need for innovation

Stakeholders interviewed reported that there was a need for the further investment in R&D activities to keep pace with international progress in the development of hydrogen technology. This finding from stakeholders is supported by recent published analysis by the IEA[63] which sets out the pace of innovation in hydrogen technology across the world. In it, the UK has a relatively low ranking, having produced only 3% of patents registered in the hydrogen supply chain between 2011-2020, as compared to the EU which ranked highest, capturing 28% of all patents registered for technology supporting the hydrogen supply chain.

Stakeholders interviewed for this report supported the idea both private and public sector bodies should take further steps, such as increasing support for research in academic institutions and to encourage further investment in R&D in hydrogen across the supply chain. This would support efforts to capture a larger portion of the international market for hydrogen technology and would capitalise on the UK's advantage as a centre for research and academia.

[61] Aurora Energy Research (2022) – Hydrogen Conference London.

[62] The Hydrogen Market Attractiveness Rating (HyMAR) outlines how attractive the major European economies are for low-carbon hydrogen investment. The basis of the score for each country is based upon a set of four categories that helps determine how attractive hydrogen investment is for each country: Supply, Policy and Regulation, Demand and Infrastructure. These four categories are determined by 22 underlying metrics, which determines the overall score for each country. This rating is frequently updated.

[63] International Energy Agency (2023) - "Hydrogen patents for a clean energy future"

Conclusions

We find that there is evidence for hydrogen having a role to play in transitioning 'hard to decarbonise' homes, supporting the energy system during peak demand and also providing jobs for gas industry workers throughout the country. Many would face a lower cost of training for installing and maintaining hydrogen boilers as compared to alternative heating options.

We estimate that using a CCC scenario where 71% of current gas-supplied homes are decarbonised through hydrogen, there is a potential £48bn cumulative GVA to the economy by 2050, with £5bn achievable in a scenario where 11% of homes are decarbonised using hydrogen for domestic heat. Our estimate includes direct expenditure in the hydrogen value chain, expenditure in the wider supply chain and through employee spend on goods and services.

The government has committed to a decision on the use of hydrogen for domestic heat in 2026. Ahead of this decision, this section sets out several low or no regrets actions which could help to realise opportunities from hydrogen for domestic heat.

1. Develop a clear framework to understand which technologies can provide a cost effective mix for decarbonising domestic heat

There is a clear argument for ongoing support to test and trial hydrogen as a complementary option for domestic heating alongside alternative heating solutions. On the basis of our findings we encourage an ongoing assessment of the: :

i. Cost benefit analysis at both the household and system level to inform ability-to-afford assessments.

ii. Technical suitability of options by location.

iii. Skills and investment required, as well as the impact on the current ‘gas workforce and opportunities to retrain.

iv. Timeframe to transition to new technologies (including levels of consumer adoption).

v. Impact on energy system resilience, including peak demand planning.

While our report has contributed to this evidence base, our research suggests that there is still more to be done. In particular, our findings suggest that many domestic heat decarbonisation decisions can be made at the local level, but there is currently insufficient evidence around the most suitable options to consider by location. There is a lack of understanding about the trade-offs between heating options and how costs and suitability of options may vary across housing types and geographically. Both private and public sector bodies thus have an important role to play in developing the evidence base around local technology constraints in order to inform decision making at the local level.

2. Develop a clear communications strategy to address gaps in public and organisational awareness on options for decarbonising homes

Stakeholders interviewed as well as published studies and articles reviewed suggest there is limited public awareness around the options for domestic heat decarbonisation as well as the trade-offs between options. This also reportedly creates uncertainty with organisations who will need to make firm decisions on how to decarbonise homes in order to meet decarbonisation objectives. Interviewees also suggested that the lack of public awareness could have implications for the uptake of new technologies when they become available, and could impact the deployment of capital for investing in the supply chain. For example, according to the House of Commons BEIS committee on decarbonising domestic heat, the government should establish a national consumer awareness campaign to inform the public about alternatives to methane gas heating. This should enable more informed choices to be made around investment at the organisational level, as well as behaviour change at the individual level[64].

3. Invest in R&D to develop the UK’s strategic advantages across the supply chain and innovate and improve products to reduce costs for consumers

According to stakeholders and evidence we reviewed, investing in R&D to support innovation in the hydrogen sector is a low or no regrets option for advancing the UK’s position in the international hydrogen economy. The UK has a number of funds set up to support innovation targeting Net Zero and within the hydrogen economy, but can go further to identify enabling technologies for commercialisation. This will help meet aims set out in the sector development plan (to position the UK as a global exporter of low carbon hydrogen). Our interviewees also suggested that the development of academic centres of excellence will concentrate research and innovation activities in the UK and support the export of education and training.

The solutions required to achieve decarbonised domestic heating will require innovation and advancements in heating technologies including hydrogen. Developing improved product capabilities and scaling up supply will be vital for decarbonisation, as the BEIS committee notes that, “at present the costs of innovations in decarbonising home heating currently lie too heavily on households for us to be confident that consumers will not baulk at the impact on their family budgets”[65]. Therefore, there are compelling reasons to encourage innovation from both an international trade and domestic consumer adoption perspective.

[64] House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021–22.

[65] House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021-22

Annex

GVA and jobs contributions methodology

Overview

Economic contribution of the hydrogen supply chain is defined in terms of its contribution to Gross Domestic Product ('GDP') and employment support.

Contribution to GDP is measured in terms of GVA. GVA is a monetary measure of the value an entity adds during its production process. Hence, it is the difference between the price of its products (outputs) and the price of the inputs it uses in producing these (or intermediate consumption). GVA is an alternative term for GDP at factor cost, which is GDP without taxes and subsidies on products. As such, GVA is the company – and industry – level equivalent of GDP.

All analysis is done in gross terms and has not assessed the net contribution of the total investment into the hydrogen supply chain to the economy (i.e. this has not considered what would have happened in the economy if the analysed hydrogen-based activities did not happen).

Contribution to GDP and employment are estimated at the direct, indirect and induced levels. Direct contribution results from the company's/entity's own operations: it includes the people employed directly by a company/entity in the supply chain and the economic value the company/entity creates. Indirect contribution is generated in a company's/entity's supply chain through the procurement of inputs. Induced contribution is generated through employees spending their wages, both a company's/entity's own employees and those in its supply chain. In the report these tiers of contribution are termed direct, supplier expenditure and employee expenditure.

Whilst contributions are usually measured at the per company/entity level, for the purposes of this analysis we have assumed economic impact are presented as a single hydrogen supply chain. Therefore, the company/entity instead will refer to the single owner of the hydrogen supply chain, and its effects are described as the effects this single hydrogen supply chain has on the economy.

Approach to estimating direct economic contribution

The hydrogen supply chain's direct contribution to GDP is measured using an approach developed by Scottish and Southern Energy[66] ('SSE'). The following equation is used to estimate direct GVA:

Direct GVA = GVA per Output by industry X Expenditure from supply chain by industry

Direct employment is estimated by the following equation:

Direct employment = Employment per £m of output in FY22 X Expenditure from supply chain by industry

This approach to estimating direct GVA was selected because our typical methodology of estimating direct GVA, which requires retrieving data around proitability and employee expenditure, was not possible on this occasion. As the sole owner of the hydrogen supply chain is yet to have been selected and agreed, and even if there are multiple owners of the hydrogen supply chain, there is significant challenge in trying to calculate a full estimate of future profit before taxes, future employee expenditure expenditure and future depreciation and amortisation costs of assets with time. Due to these data input difficulties, this alternative approach was adopted for this analysis.

Approach to estimating indirect and induced economic contribution

Indirect and induced economic contributions are estimated using an Input-Output (I-O) model for the UK constructed partially by the Office for National Statistics. The I-O tables are derived from the UK Supply and Use Tables (SUTs) which provide a picture of the flows of products and services in the economy for a single year. This is typically used to enable the UK to estimate the overall GDP for the year.

The tables typically provide figures around the quantity of inputs that are required from each of the other industries in order to produce one unit of final output in that industry. This shows how industries relate to one another, outlining the quantitative input requirements from other industries. On this basis, it is possible to estimate how activity by one entity stimulates economic activity elsewhere in the economy.

The indirect contribution is estimated using PwC's supply chain expenditure model used for construction of the hydrogen supply chain. This was based upon publicly available data, including from the H21 North of England report[67], BEIS production cost estimates and various hydrogen demand forecasts (e.g. CCC). Equally, we modelled the supplier's input requirements from other sectors to produce its own unit of output. In this way we can trace back the input requirements through the entire supply chain and calculate the total value of production stimulated. This process of one entity stimulating economic activity in other entities is referred to as the 'multiplier effect'.

[66] SSE – Calculating the economic contribution of 10 years of onshore wind at SSE – 2008 to 2018.
[67] H21 North of England Report/2018.

In addition to the indirect and induced effects, an I-O table provides data on the share of revenue that constitutes profit and wages for each sector. This ratio can be applied to the total production value stimulated, and hence the total GVA in the supply chain can be estimated by sector associated with this.

Approach to estimating regional economic contribution

In lieu of regional UK I-O tables being publicly available at the time of analysis, we developed three potential approaches which could be used to calculate the potential UK regional economic and jobs contributions figures. We proceeded on one methodology which has been outlined below.

Regional economic contribution figures are estimated based upon:

1. Regional allocation of SIC 352: (Manufacture of gas, distribution of gaseous fuels through mains) Employees obtained through the Business Register and Employment Survey, and
2. Number of announced projects related to hydrogen within each UK region obtained via desktop research during analysis (September 2022 – December 2022).

For every announced future hydrogen project within each UK region, we then scaled the estimated number of employees in each UK region by the number of announced hydrogen projects. This provided us with an adjusted estimate on the number of 'hydrogen' employees working within each region.

Regional economic contribution figures were then scaled from the total UK economic and jobs contribution figures, to obtain an adjusted number of hydrogen-related employees and GVA in each UK region.

Limitations in our approach

We recognise that our approach is one way in which economic contributions from hydrogen for domestic heat can be calculated. We understand that there are limitations in how we have derived these calculations. This includes:

We have used 2018 UK ONS Supply-Use Tables – industry by industry to estimate the GVA and employment contributions. This means that our estimates assume that the required inputs per unit of final use from each industry is the same until 2050. To more accurately measure the economic contribution in the period to 2050, we would require year-by-year Supply-Use tables for each year, from 2018 to 2050 to account for the changes in each year. Since this is not available, our analysis assumes that the 2018 figures apply to each year until 2050, which we recognise will not reflect each future year's figures. At the time of analysis, the 2018 Supply-Use Tables were the latest tables available to us.

No predictions of inflation/deflation have been included within the analysis. We have not forecasted how future year macroeconomic outlooks could impact our analysis and therefore, the potential changes in costs in future years.

Similarly, we have not estimated the potential impacts of other factors in production which could influence the cost of production with time. For example, new technologies could be introduced which reduces the cost of production for materials/services in future years.

We have assumed the cost items included in the H21 Leeds City Gate report are in itself accurate.

Data sources

Data sources used to perform the economic contribution analysis are outlined below:

Data table	2050
UK Input-Output tables	ONS – UK input-output analytical tables - industry by industry (released date 01 April 2022, retrieved November 2022).
OpEx and CapEx cost estimates for hydrogen supply chain (and for domestic heat)	PwC UK in-house analysis. Cost estimates based upon the following sources: • H21 Leeds City Gate (retrieved October 2022). • H21 North of England report 2018 (retrieved October 2022). • Climate Change Committee – sixth carbon budget – Charts and data in the report (published 9 December 2020, retrieved November 2022).Department for Business, Energy and Industrial Strategy – Hydrogen Production Costs 2021 annex: Key assumptions and outputs for production technologies (published 17 August 2021, retrieved December 2022).
Industry employment by region	Business register and employment survey : open access, employees, 2021 latest data (retrieved November 2022).

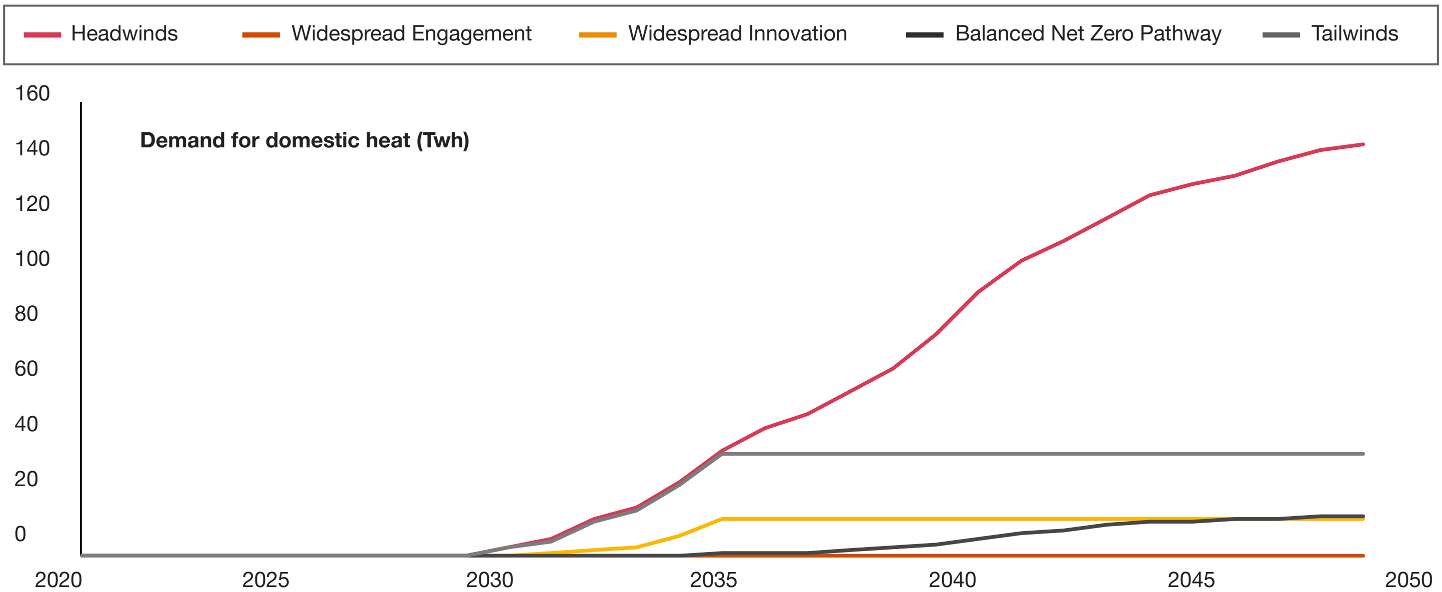
Climate Change Committee – Scenario details

The CCC have outlined five future hydrogen scenarios for the UK which includes the expected demand for low carbon hydrogen in each year between 2020-2050. We have used these demand estimates to outline the potential economic contribution from hydrogen for domestic heat activities, by using 'residential buildings' as a proxy for the demand that we would expect from 'domestic heat'.

To provide more context on how these demand proiles have been pulled together, we refer to the Scottish Renewables summary definitions on each CCC scenario below[68]. These descriptions establish the characteristics the CCC expects to see under each scenario (and therefore, the estimate of economic contribution we provide under each scenario). Please refer to the full report from the CCC Sixth Carbon Budget (link here) for a more detailed and comprehensive description around each CCC scenario.

Scenario name	Description
Headwinds	This scenario is based on behaviour change and new technology development, but we do not see widespread behavioural shifts or innovations that significantly reduce the cost of green technologies ahead of the CCC's current projections. This scenario is more reliant on the use of large hydrogen and carbon capture and storage (CCS) infrastructure to achieve net-zero.
Widespread Engagement	In this scenario the CCC assumes higher levels of societal and behavioural changes. People and businesses are willing to make more changes to their behaviour which reduces demand for the most high-carbon activities and increases the uptake of some climate mitigation measures. Assumptions on cost reductions are similar to Headwinds.
Widespread Innovation	The CCC assumes greater success in reducing costs of low-carbon technologies. This allows more widespread electrification, a more resource and energy-efficient economy and more cost-effective technologies to remove CO2 from the atmosphere. Assumed societal/behavioural changes are similar to Headwinds.
Balanced Net-Zero Pathways	This scenario is informed by the range of solutions across the 3 previous scenarios that would put the UK on track to net-zero and would meet the recommended carbon budget. According to the CCC assessment, this scenario is considered plausible and is the basis of the advice in their report.
Tailwinds	This scenario assumes success of both innovation and societal/behavioural change and goes beyond the Balanced Pathway to achieve net-zero before 2050.

Figure 4: CCC low carbon hydrogen profile for domestic heat only (residential buildings), by scenario, year, 2020 – 2050



Source: Climate Change Committee – Sixth Carbon Budget – Dataset (Version 2 – December 2021)

[68] Scottish Renewables (2021) – Deployment Levels in the Sixth Carbon Budget.

Sources

No.	Source
1	Amion Consulting (2021) – Potential Economic Impacts of the HyNet North West Project.
2	Aurora Energy Research (2022) – Hydrogen Conference London.
3	Carbon Trustl/Imperial College London Consultants (2021) – Flexibility In Great Britain.
4	Climate Change Committee (2018) – Hydrogen in a low–carbon economy.
2	Aurora Energy Research (2022) – Hydrogen Conference London.
3	Carbon Trust/Imperial College London Consultants (2021) – Flexibility In Great Britain.
4	Climate Change Committee (2018) – Hydrogen in a low-carbon economy.
5	Climate Change Committee: Sixth Carbon Budget (2020) – Charts and data in the report.
6	Climate Change Committee: Sixth Carbon Budget (2020) – Sector Summary: Buildings.
7	Climate Change Committee: Sixth Carbon Budget (2020) – The UK's path to Net Zero report.
8	Delta EE/Climate Xchange (Robert Castek and Stephen Harkin) (2021) – Evidence review for hydrogen for heat in buildings.
9	Department for Business, Energy and Industrial Strategy (2018) – Clean Growth: Transforming Heating – Overview of Current Evidence.
10	Department for Business, Energy and Industrial Strategy (2021) – Heat and Buildings Strategy.
11	Department for Business, Energy and Industrial Strategy (2021) – Hydrogen Production Costs 2021 annex: Key assumptions and outputs for production technologies.
12	Department for Business, Energy and Industrial Strategy (2021) – UK Hydrogen Strategy.
13	Department for Business, Energy and Industrial Strategy (2022) – Hydrogen Investor Roadmap: Leading the Way to Net Zero.
14	Department for Business, Energy and Industrial Strategy (2022) – Hydrogen sector development action plan.
15	Department for Business, Energy and Industrial Strategy (2022) – Open consultation: Improving boiler standards and efficiency.
16	Department for Business, Energy and Industrial Strategy/ARUP (2023) – Hy4Heat Programme Website.
17	Department for Energy Security & Net Zero (2023) - Powering Up Britain.
18	Department for Levelling Up, Housing and Communities (2022) – Levelling Up the United Kingdom: executive summary.
19	Ecuity (2020) - Local green jobs – accelerating a sustainable economic recovery: An Ecu1ty Consulting report for the Local Government Association (LGA).
20	Element Energy (2019) – Analysis on abating direct emission from hard to decarbonise homes: A study for the Committee on Climate Change.
21	Element Energy (2019) – Hy-Impact Series Study 1: Hydrogen for economic growth Unlocking jobs and GVA whilst reducing emissions in the UK – A report for Equinor.

No.	Source
22	Element Energy (2021) – Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget: A study for the Committee on Climate Change.
23	Energy Networks Association (2023) – A hydrogen vision for the UK.
24	Energy and Utilities Alliance (2021) – Decarbonising heat in homes: Putting Consumers First.
25	Energy Systems Catapult (2023) – Guide to the decarbonisation of heat.
26	Eunomia Research and Consulting Ltd (2021) – Industry insights and analysis: Building Skills for Net Zero – Report prepared by Eunomia for CITB.
27	Gas Safe Register (2019) – News 2019: Ten years of keeping people gas safe.
28	H21 Leeds City Gate (2016) – H21 report.
29	H21 North of England report (2018) - H21 report.
30	House of Commons - Science and Technology Committee (2022) – The role of hydrogen in achieving Net Zero: Fourth Report of Session 2022-23.
31	House of Commons – Business, Energy and Industrial Strategy Committee (2022) – Decarbonising Heat in Homes: Seventh Report of Session 2021-22.
32	Hydrogen Taskforce (2020) – Hydrogen is ready to power the UK's Green Recovery: Economic Impact Assessment.
33	Jan Rosenow, Regulatory Assistance Project (2022) – 'Is heating homes with hydrogen all but a pipe dream'.
34	Local Government Association (2022) – Hard to Decarbonise Homes.
35	National Grid ESQ (2022) – Future Energy Scenarios 2022 Data Workbook.
36	Navigant (2020) – Decarbonisation Pathway for Greater Manchester Reaching carbon-neutrality in a balanced scenario by 2038. Prepared for: Cadent Gas and Electricity North West.
37	Office for National Statistics (2022) - UK input-output analytical tables: industry by industry.
38	Office for National Statistics: Nomis (2022) – Business Register and Employment Survey : open access, employees, 2021 latest data.
39	Regulator of Social Housing (2022) – Registered provider social housing stock and rents in England 2021 to 2022.
40	Rt Hon Chris Skidmore MP (2023) – Mission Zero: Independent Review of Net Zero.
41	Savills UK (2021)- Decarbonising The Housing Association Sector: Costs and funding options.
42	The Hydrogen Council (2021) - Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness.
43	Vivid Economics (2019) – Energy Innovation Needs Assessment: Overview report – Commissioned by Department for Business, Energy and Industrial Strategy.
44	Wood/Optimat (2022) – Supply Chains to Support a Hydrogen Economy.

Contacts

Vicky Parker

PwC UK - Power and Utilities Lead

victoria.x.parker@pwc.com

+44 7483 336 390

Nick Forrest

PwC Strategy& UK - Economics Consulting Lead

nick.forrest@pwc.com

+44 7803 617 744

Benjamin Gough

PwC Strategy& UK - Regulatory Economics Lead

benjamin.j.gough@pwc.com

+44 7483 354 061

Harsimran Arora

PwC Strategy& UK - Energy Economist

harsimran.arora@pwc.com

+44 7483 353 214

Paddy Schmidt

PwC Strategy& UK - Valuation Economist

patrick.y.schmidt@pwc com

+44 7483 422 259

strategy&

Strategy& is a global strategy consulting business uniquely positioned to help deliver your best future: one that is built on differentiation from the inside out and tailored exactly to you. As part of PwC, every day we're building the winning systems that are at the heart of growth. We combine our powerful foresight with this tangible know-how, technology, and scale to help you create a better, more transformative strategy from day one.

As the only at-scale strategy business that's part of a global professional services network, we embed our strategy capabilities with frontline teams across PwC to show you where you need to go, the choices you'll need to make to get there, and how to get it right.

The result is an authentic strategy process powerful enough to capture possibility, while pragmatic enough to ensure effective delivery. It's the strategy that gets an organization through the changes of today and drives results that redefine tomorrow. It's the strategy that turns vision into reality. It's strategy, made real.