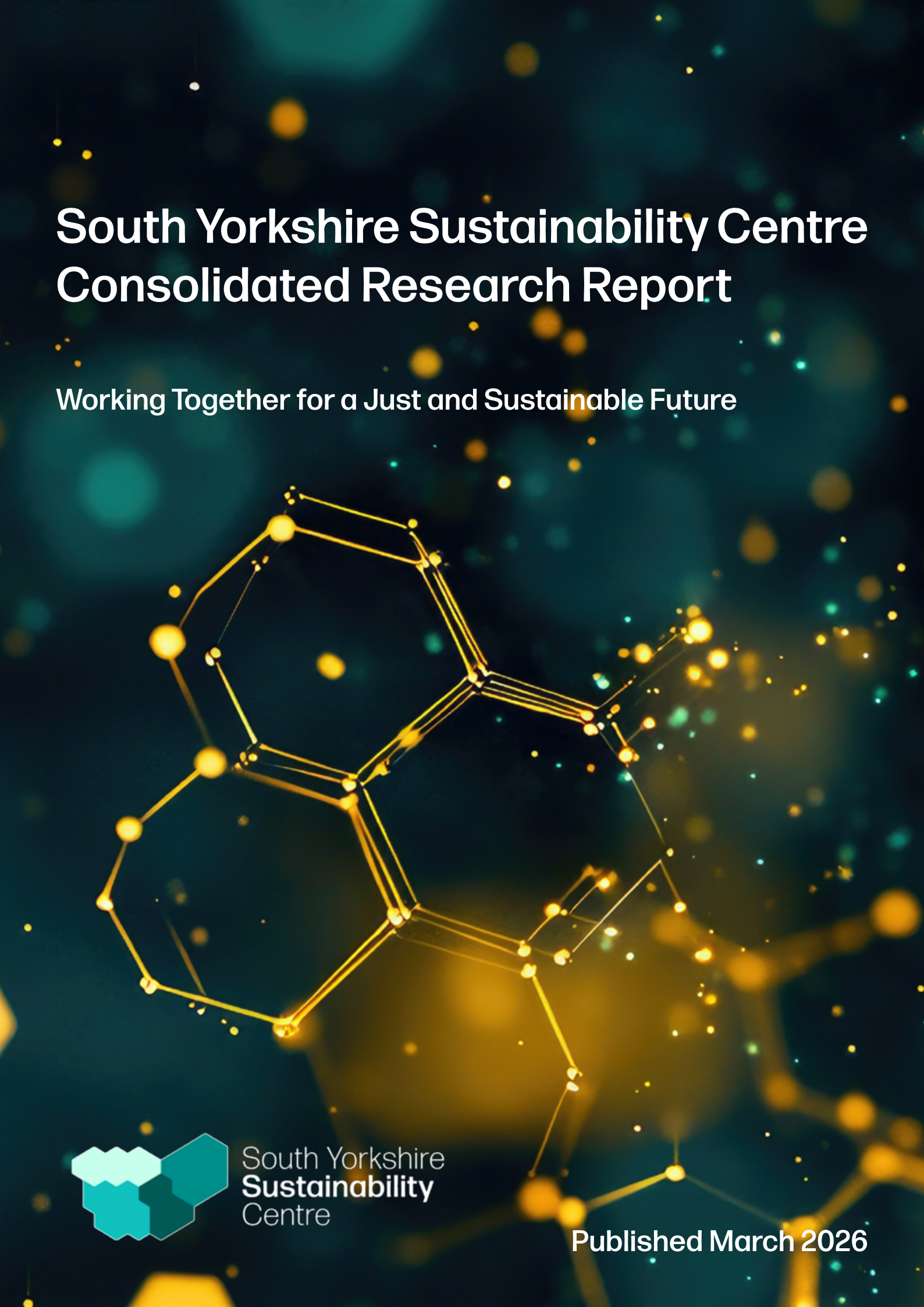
South Yorkshire Sustainability Centre Consolidated Research Report

Working Together for a Just and Sustainable Future



South Yorkshire Sustainability Centre

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Our focus is on working collaboratively to identify and respond to regional sustainability challenges through research that is rooted in South Yorkshire.

We would like to thank our core partners for their continued support: South Yorkshire Mayoral Combined Authority, The University of Sheffield and Sheffield Hallam University.

Additionally we would like to thank the four South Yorkshire local authorities for their continued involvement with the centre: Barnsley Metropolitan Borough Council, City of Doncaster Council, Rotherham Metropolitan Borough Council and Sheffield City Council.

We believe the partnerships, collaboration and knowledge exchange we have built and fostered have contributed robust, data driven and evidence-based solutions to the region's sustainability challenges.

The South Yorkshire Sustainability Centre Consolidated Research Report is published by the South Yorkshire Sustainability Centre and and features confributions from academics and researchers from the University of Sheffield and Sheffield Hallam University.

With thanks to the SYSC central team:
Prof. Rachael Rothman, Sylvia Moffatt, Jess Thomas, Emily Williams, Simon Archer, Dr Meg Lewis, Nicola Ross and Alexander Fletcher.

Prof. Rachael Rothman welcomes attendees to the SYSC Summit, January 2026.

Rachael Orr from Climate Outreach delivers a keynote speech to the SYSC Summit, January 2026.

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Foreword

Professor Rachael Rothman

As Academic Director for the South Yorkshire Sustainability Centre, I am incredibly proud of what we have all achieved together.

This report is the culmination of four years of hard work. However, the publication of this report is not the end and there is so much more that we could and should do together.

I am very excited to present this report showcasing the breadth and depth of the findings of the South Yorkshire Sustainability Centre. It seems like only yesterday, and yet also a lifetime ago, that we first started planning the Centre and asking how we could work together better across South Yorkshire to tackle the challenge of net-zero. What a lot we have achieved together since then.

We secured £5m funding from the Research England Development Fund in March 2022 to pilot a partnership model that aimed to **build stronger working relationships between the region's universities and public, private and third sector organisations.** The grant allowed us to establish a partnership that includes the two regional universities, the South Yorkshire Mayoral Combined Authority (SYMCA) and the four local authorities.

The core mission was to find successful mechanisms for co-producing interdisciplinary, place-based research that responds to real-life challenges in South Yorkshire. The goal was to produce research outputs that have real-world utility and can support regional actors to achieve their own strategic objectives. Whilst the South Yorkshire Sustainability Centre (SYSC) was focussed on supporting the region to **accelerate a just transition to net-zero**, the intention was always that the model and learnings could be applied to any challenge area such as public health or economic growth.

The funding enabled the delivery of a **large portfolio of sustainability research projects that were structured into the intersecting themes and work packages** shown in figure 1. Through these projects, we have been developing our interdisciplinary and collaborative practice whilst also seeking to deliver research findings that could tangibly support and enable South Yorkshire to **find decarbonisation pathways that are faster, fairer and supported by evidence that is rooted in place.**

The grant also provided £300k of flexible funding, which was generously matched by £600k from the South Yorkshire Mayoral Combined Authority. These **flexible funds enabled SYSC to be responsive** to the opportunities that were being identified through our interactions with partners, leading to exciting outputs such as the development of a soil carbon testing facility that will be used to support regional nature recovery, a collaborative demonstrator with the City of Doncaster Council analysing the indoor air quality impacts of retrofit, and the installation of a home heating demonstrator in the Gleadless Valley in collaboration with Sheffield City Council, Daikin and E.ON.

Such interdisciplinary and, moreover, transdisciplinary research is often not easy and we have learnt a lot over the past four years about how to successfully work together. **Facilitation of interactions and good communication between partners have been vital.**

This report comprises collections of policy briefs that distil key findings of our research portfolio. The report is structured so that our partners can engage selectively with the content; **each thematic chapter provides a summary of the centre's research as well as relevant policy analysis.** Following the summary, there are case studies that outline individual project findings as well as their scalability and regional relevance. Finally, for those wanting more granularity, each case study links to full findings and published research papers.

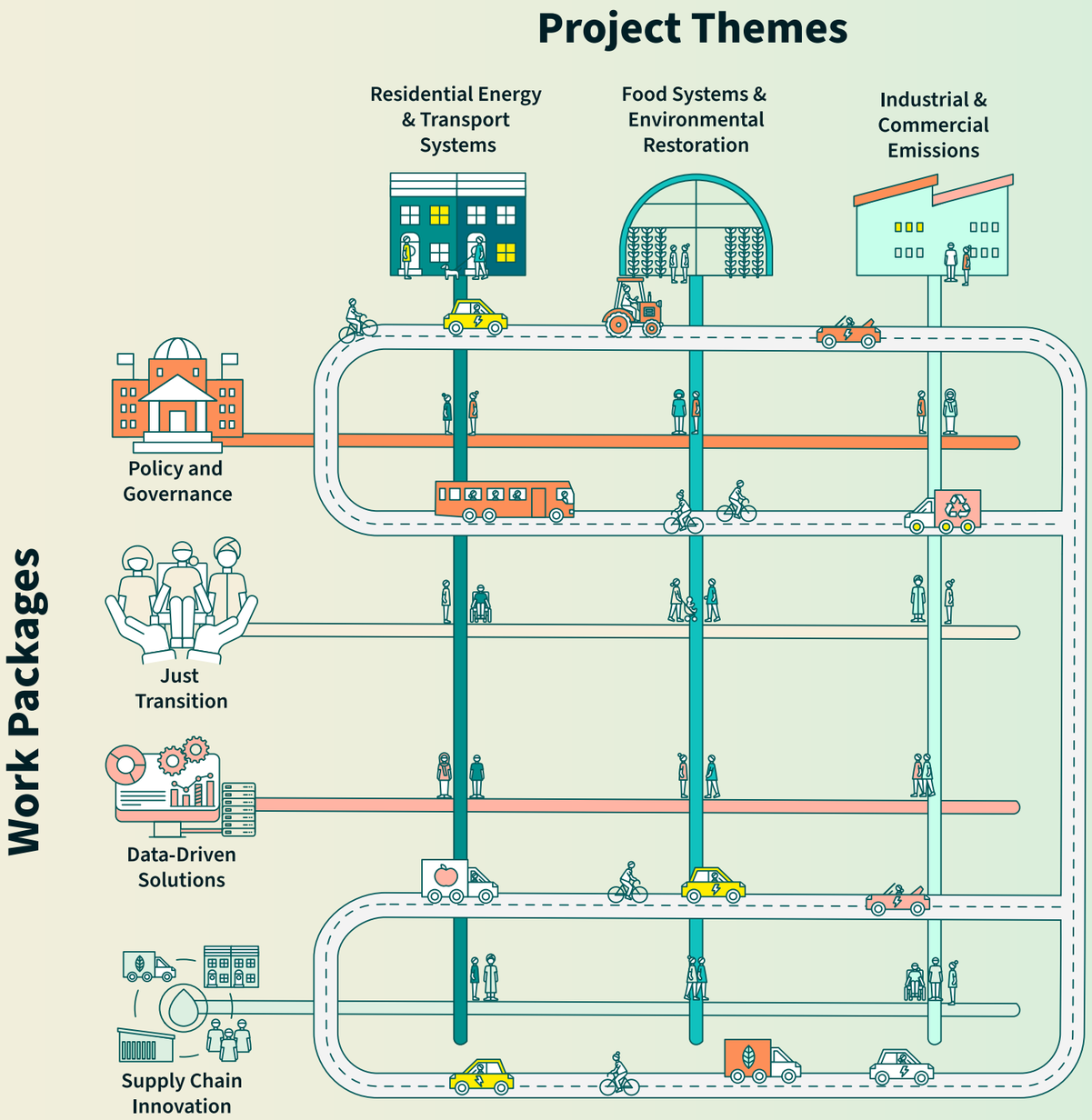

Figure 1: SYSC's organisational matrix showing the intersecting themes and work packages.

As I reflect on the last four years, I can't help but feel that the need for collaboration is even greater than when we submitted the SYSC bid. The world has grown significantly more volatile and uncertain since 2021 and net-zero goals can at times feel under threat. It is clear that the external environment has shifted and that we need to frame our research, and any future research projects, in terms that align with the policy environment; **this means talking about decarbonisation in terms of its co-benefits** i.e. affordable, warm homes, clean air, resilient businesses, healthy neighbourhoods, food security, good, green jobs etc.

I am also heartened by many significant leaps forward that have been made; the Great British Energy Act 2025 received Royal Ascent in May 2025, helping to establish Great British Energy as a publicly owned and operationally independent energy company with a mission to 'drive clean power deployment[1]; and the Warm Homes Plan, published early in 2026, sets clear commitment to ensure warm, safe and low-carbon homes to be the future of Britain.

South Yorkshire is also named as one of the advanced manufacturing clusters[2] in the UK's Modern Industrial Strategy. Furthermore, the Strategy recognised South Yorkshire's Investment Zone for growing the region's clean energy ecosystem[3]. The region's commitment to clean energy and green growth is further reflected in South Yorkshire Mayoral Combined Authority's Local Growth Plan vision, which focuses on these 'real sector strengths' of South Yorkshire[4].

Together we can seize these opportunities and build on the momentum provided by the central, regional and local government to design, test and implement effective interventions in South Yorkshire.

As Academic Director for the South Yorkshire Sustainability Centre, **I am incredibly proud of what we have all achieved together**. This report is the culmination of years of hard work. However, the publication of this report is not the end and there is so much more that we could and should do together. Whilst this report signals the end of the Research England period of funding, it is by no means the end of SYSC. And so I challenge readers, as you move through the report, to reflect on where research could support your own vital work and to reach out to SYSC. It is only through cross-sectoral collaboration that we can make a difference and **build a sustainable future together.**

How to use this Document

The 244 pages of this consolidated report contain the full breadth of our research portfolio, representing the findings across 34 projects delivered between 2021-2026. It has been divided into six thematic sections. Each section contains an in-depth overview of the challenges the region faces along with the SYSC research response. This is followed by recommendations for regional policymakers. Finally, each section then contains a series of detailed case study reports from our individual research projects.

The structure of this report mirrors the SYSC research themes, which were designed to respond to the challenges posed by South Yorkshire's highest emitting but most difficult to decarbonise sectors. While it is divided into six separate themes, each section draws on interdisciplinary research to give system aware analysis of the challenges and the potential solutions.

I hope you enjoy reading the report and learning more about our research. Do get in touch with us if you have ideas of how we can work together in future.

1 DESNZ (2025) Great British Energy Act 2025: factsheet.
2 UK Government (2025) The UK's Modern Industrial Strategy. Advanced Manufacturing Sector Plan.
3 UK Government (2025) The UK's Modern Industrial Strategy. Clean Energy Industries Sector Plan.
4 SYMCA (2025) South Yorkshire's Growth Plan. South Yorkshire's Vision for Business Growth and Greater Opportunity 2025-2035.

Executive Summary

The research compiled in this report highlights the extent to which climate and environmental action is fundamentally a public health imperative. Our internal and external environment increasingly poses a risk to human health. Moreover, whilst action is often framed as too expensive, the climate crisis poses significant economic risks to households and businesses, which will increase in severity as we move closer towards 2 degrees heating above pre-industrial levels. This has been made plain in a recent report by the University of Exeter and the Carbon Tracker, Recalibrating Climate Risk.

However, as this body of research shows, climate action contains significant economic, social and environmental opportunities. With increasing devolution, there is unprecedented opportunity for regional action, ensuring that change responds to place and benefits the people of South Yorkshire. The combined recommendations in this report demonstrate that, to harness these opportunities at a regional level, we urgently need to collaborate across sectors and disciplines, build trust, and channel targeted funding towards activities that could accelerate the transition to more sustainable forms of operating such as participatory engagement, trials, pilots and demonstrators, professional networks and working groups.

Any green transition must also be a just transition if we want to achieve improvements in public health and regional prosperity. Taken together, our just transition research has demonstrated that justice and inclusion are not an add-on to the already urgent list of tasks to be delivered in South Yorkshire but can provide an approach and set of values that underpin climate action and drive meaningful change. These changes rely on adopting new ways of working with citizens, communities, businesses and workers, which underpin our recommendations.

The sections that follow give a brief overview of our research findings, which are outlined in more detail in the thematic chapters laid out in the table of contents. Within the chapters, you'll also find the policy recommendations that have emerged from the evidence.

We hope you take something useful from this report and urge you to get in touch with us at sysustainabilitycentre@sheffield.ac.uk if you want to discuss our findings in more detail, or have an exciting idea for more research.

Residential Energy Systems

SYSC's regional energy model shows that the increasing load from Heat Pumps and Electric Vehicle deployments will cause overload at 50% of both primary and secondary substations by 2050, requiring upgrades at a cost of £940 per customer.

Implementation of network-level smart controls could reduce the proportion of overloaded substations by 2050 from 50% to 35%, and defer the requirement to upgrade in other cases. This would reduce the required investment in grid upgrades by around £300 per household.

Domestic thermal storage could also help to relieve grid pressure by charging energy stores during off-peak periods and supplying homes with electricity during peak demand. Installing a 10 kWh thermal energy store into 1 million of the UK's estimated 30 million homes could provide up to 10 GWh of thermal storage alone. Current SYSC research is exploring whether storage and control technologies can also bring the cost of heating in line or below that of a gas boiler.

The SYSC Home Energy Survey has found that 46% of South Yorkshire residents surveyed did not have and did not want solar panels, 57% did not have and did not want heat pumps and 27% answered that they did not have and did not want smart heating controls.

Resistance to heat pumps correlated with income, indicating a perception that heat pumps are more expensive than gas boilers. Attitudes towards district heat networks (DHNs), were more positive.

The survey also indicates that the respondents' opinion of climate change is not a significant driver of domestic energy use; most energy saving action is motivated by a need or desire to reduce costs. The respondents said that their decision to join a DHN would be mostly influenced by cost savings (65%) and reliability (42%), with only 25% saying that they would join a DHN because it is better for the environment and only 13% would join to help reach the net-zero.

However, 75-86% of respondents were concerned that the UK wasn't investing enough in alternative energy sources quickly enough, that power cuts would become more frequent, and that the UK was becoming dependent on energy from other countries.

Community energy could stimulate public acceptance towards low carbon energy technologies and also provide a mechanism for keeping wealth in the region. This is demonstrated by the fact that 40% of Energise Barnsley investors are located in Yorkshire.

Housing Retrofit

SYSC research indicates that if South Yorkshire is to prioritise carbon reduction and align with the 1.5 °C net-zero climate target, its existing housing stock - approximately 609,000 homes, including around 480,000 houses and bungalows - would need to be retrofitted at a substantial pace.

Specifically, meeting the 2050 net-zero target would require the retrofit of approximately 19,200 houses and bungalows per year, rising to around 32,000 annually to achieve the more ambitious regional 2040 net-zero target.

To maximise carbon savings, homes with higher operational energy demands - larger pre-1920s homes - should be prioritised. In South Yorkshire there are 46,000 homes that are both above 100m^2 and constructed pre-1919.

A typical semi-detached house emitting ~2.5 tonnes/year of operation carbon for heating, would require 5.7 tonnes of embodied carbon for a whole-house retrofit leading to a carbon payback period of 2.28 years with the average payback periods being around 2-4 years.

To avoid energy bill hikes, whole-house retrofit, including fabric insulation measures and replacing fossil fuel heating systems is the best option, ensuring highest carbon and cost savings. If whole-house retrofit is unfeasible due to high upfront costs, a fabric-first approach would yield more favourable economic and carbon savings results compared to a systems-first approach (electrification of home heating via heat pumps with no fabric alterations), which would result in high energy bills due to electricity being more expensive than natural gas.

4% of South Yorkshire homes in dense urban areas could benefit from being connected to a district heating network (DHN). DHNs utilising waste heat from industry and energy-from-waste is projected to save 3.5% of annual regional heating costs and reduce annual emissions by around 45,000 tCO_2.

Prior to connecting to a DHN, certain retrofit measures, such as loft insulation and cavity wall insulation would be cost effective and help to reduce energy costs.

Effective ventilation, passive or mechanical, is a key part of good retrofit - essential for ensuring indoor air quality and preventing overheating in future temperature rises scenarios.

Over 88% of respondents to our Home Energy Survey said that they set their thermostat to 18°C or higher, with 16.1% saying that they set it to 22°C or more. If energy bills decrease with increased efficiency, residents may just increase the thermostat, increasing the operational emissions. By increasing the heating set point from 18°C to 20°C, the average annual heating demands of existing homes could increase from 14,500 kWh/a to 21,500 kWh/a, a 48% increase.

Transport

In South Yorkshire, 2023 roadside monitoring in parts of Rotherham recorded peak annual average NO_2 concentrations of over 60 µg/m^3, which is more than six times the World Health Organization (WHO) guideline of 10 µg/m^3. Re-routing vehicle traffic using a pollution-optimal traffic assignment model (TA) can reduce congestion and achieve a 21% reduction in Sheffield-wide NO_2 concentrations, reducing the number of roads exceeding WHO recommended limits from 37% to 30%, whilst only increasing average journey time by ~20 seconds.

Traditional transport models often assume that travel time and monetary cost are the only determinants of modal choice. In reality, a range of factors such as comfort, convenience, safety, and reliability are equally influential. SYSC is developing a decision-support tool that models the complex dynamics between factors that determine people's transport choices. The tool will enable identification of specific roads and routes where current conditions and traffic patterns already create a high probability for people to choose walking or cycling over driving.

SYSC's e-cargo cycle research found a high economic feasibility in South Yorkshire's urban centres, in some cases across areas as large as 80 km^2, with average CO_2e emission reductions of 10.8 kg per delivery route. At scale, replacing one diesel van with an e-cargo bike performing three routes per working day would save around 8.2 tCO_2e per year.

Another SYSC project assessed regional job accessibility using the current public transport network of South Yorkshire, taking 'communities' as populations within lower-layer super-output areas (LSOAs). It found that age is the most important predictor of transport affordability, with younger people struggling to meet their transport bills significantly more than older people. Across South Yorkshire, 32% of the total Barnsley region, 38% of the total Doncaster region, 35% of the total of Rotherham and 44% of the Sheffield region are likely to struggle to pay for transport.

Significant disparities emerge between those who rely on public transport and those with access to private vehicles. This is particularly true for those who don't live near high demand routes and/or work during 'off-peak' hours, often in low paid sectors such as warehouses and hospitals. The analysis shows that accessibility of employment sites via public transport drops significantly during these shift-change windows.

Building Sustainable Food Systems

Sheffield Hallam University's Advanced Food Innovation Centre (AFIC) places the value of South Yorkshire's local food and drink manufacturing industry at around £434 million, with roughly 170 businesses and about 9,000 jobs tied to food and drink production. Including agriculture, catering, retail and wholesale, the total "agri-food" sector accounts for £1.58 billion in economic output and 68,500 jobs in the region, representing 11.6% of all jobs.

An SYSC study of 12 food manufacturers in South Yorkshire, representing 7.05% of the industry population, found that the annual total consumption of energy of all 12 businesses was 34.63 GWh. This amounts to 7.15 tCO_2e of operational emissions per year assuming that electricity generation follows the same grid energy mix contributions as the entirety of the Yorkshire region.

The emerging findings of our research project evaluating South Yorkshire's soil health suggest that regardless of land use, denser soils tend to store less carbon and that carbon decreases with depth, displaying declines in soil organic carbon (SOC) between surface soils (uppermost 10 cm) and lower depths – which is a typical pattern even in healthy soils. However, this decline was less obvious on land that is under conservation land management and on one site the total organic carbon stocks were greater than the UK national average.

The research also highlighted the vulnerability of surface soils to disturbances and compaction associated with unmanaged grazing, noting the importance of incorporating soil health assessments into grazing regimes for the mitigation of substantial carbon losses. With grazing farms being a predominant type in Yorkshire and the Humber, this is particularly relevant for the region.

We also found that remaining financially viable is the most pressing concern amongst farmers and, whilst many are willing to take some land out of production to participate in nature recovery schemes, to access funding and to support nature restoration, many felt driven to do this because of unstable markets for farm produce. Farmers and land managers need stable funding sources that support financial viability alongside pro-environmental interventions as well as support from trusted people and organisations to access and manage grants.

The South Yorkshire Food Network feasibility project surveyed 56 local businesses, policymakers and civil society organisations from all four local authorities in the South Yorkshire region to gauge regional need for the South Yorkshire Food Network. The survey demonstrated strong support, with high levels of perceived value, openness to change and depth of commitment. Survey respondents emphasised that any network would need to: have transparent governance and accountability, focus on practical outcomes and actionable objectives, add value to local initiatives, avoiding duplication. This vision was shared across all geographies and sectors.

Hydrogen and Industrial Decarbonisation

The steel industry in South Yorkshire has undergone significant change over the last 40-50 years. In 1971, 140,000 people were employed in the steel industry in Sheffield alone, accounting for half of all the city's jobs. In 1987 this number fell to 57,000 and continued to decline with only 15,000 remaining employed by the steel industry in the region by 2024.

Industry and manufacturing decarbonisation, especially of heat-intensive industries such as steel, ceramics and glass making, presents a substantial challenge that requires collaboration between local authorities, industry and academia to overcome. SYSC convened the Industry Decarbonisation Roundtables with key stakeholders and partners across the region - including SYMCA, Forgemasters, Marcegaglia, Ardagh Glass, Aggregate Industries, Chesterfield Special Cylinders, E.On, Cadent and others - to hold open discussions about key challenges and barriers to decarbonisation. These discussions revealed that the two most realistic pathways to decarbonisation are seen as electrification, followed by hydrogen. The main challenges to widespread hydrogen adoption were identified as the lack of clear, long term policy steer from the national government, high risk and operational and capital costs of hydrogen, hydrogen supply uncertainties, readily available volumes of hydrogen in the region and further large scale feasibility studies required.

SYSC research to ascertain hydrogen economy readiness benchmarked the hydrogen economy maturity of the UK against other G20 nations. The study found the UK to be one of the frontrunners, together with the US and China in hydrogen economy maturity. For the UK – and particularly regions such as South Yorkshire seeking to embed themselves in the hydrogen economy – this benchmarking provides insight into the country's competitive positioning relative to other G20 members

Although South Yorkshire is not within a hydrogen cluster at the moment, it is well connected to two large emerging hydrogen clusters at the Tees Valley and Hull, whilst also holding 0.37 GW (enough to produce ~1944GWh annually) hydrogen production capacity (albeit currently restricted by grid headroom availability). Still, SYSC's State of Hydrogen in South Yorkshire Report identified that the real strengths of the region and its leadership potential lies in hydrogen research, hydrogen use demonstrators and manufacturing for the hydrogen supply chain.

Another study utilised the regional optimisation model AENi to understand where hydrogen clusters could be established to achieve a cost optimal scale-up of hydrogen supply in South Yorkshire. The study considered 21 energy, heat and emission intense manufacturing companies of varying sizes in South Yorkshire. Although just an initial modeling exercise that requires further in-depth collaboration with partners, the project's findings show that a hydrogen network for industrial sites is likely feasible using existing electrical grid connections.

Successful hydrogen deployment depends not only on technical feasibility, but on societal and institutional readiness. Acceptance of hydrogen storage and distribution across different stakeholder groups within the region is broadly positive but strongly conditioned by perceptions of safety and risk. Across all stakeholder groups, safety emerged as the dominant determinant of acceptance with positive responses to enhanced monitoring and transparency. More than 80% of public respondents indicated that additional monitoring systems would increase their comfort with hydrogen storage and distribution. This suggests that visible, data-driven safety mechanisms can materially improve acceptance.

Just Transition

A just transition seeks to ensure that addressing the ecological emergency does not exacerbate existing inequalities, and instead seeks to reduce inequality through embedding inclusivity and equity within sustainability actions. This means supporting marginalised communities and sharing the benefits of transitions. It also requires recognition of the needs of current and future generations, for instance through providing space for youth participation as key stakeholders in a just transition.

Just transition is multi-faceted, requiring focus on fair distribution of costs and benefits, recognition of different identities, cultures and needs, and ensuring inclusive procedures for decision-making.

As well as practical challenges, there are cultural barriers to achieving a just transition, such as established ways of life: the daily rhythms and routines built around ways of heating homes, doing business, work, leisure and travel. These norms vary across generations and different households, reflecting complex emotional and behavioural responses towards what feels normal and acceptable for different people

South Yorkshire has already undergone significant change over the last 40 years, with the industrial change experienced during the 1980s and 90s being particularly difficult on some of the communities within the region. Tens of thousands of jobs were lost in the mining and manufacturing sectors. Today 20% of local areas in South Yorkshire are in the top 10% most deprived in England.

The region's industrial legacy also creates new challenges. Over 15% of workers in Yorkshire and Humber will need to reskill or find alternative employment as fossil fuel industries are being phased out and replaced by renewable energy sources. Recent research puts parts of the region among those most vulnerable to the economic implications of transition in the UK.

The transition to a low carbon economy also brings economic opportunities. For instance, clean energy has been identified as a key opportunity area for the region. Effective mechanisms will be required to ensure that the wealth created by such opportunities can be harnessed to provide opportunities to those that most need them, and to capture value for the region to invest in collective goods and services.

Residential Energy Systems

Case Studies in this section:

26 Residential Energy Systems Recommendations for Regional Policymakers

28 Demand Flexibility to Support the Electrification of Heat and Transport

32 Decarbonisation of Residential Heat for the South Yorkshire Region

36 Towards a Faster, Fairer and more Popular Transition to Clean Heat in South Yorkshire

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44 Enabling Community Energy in South Yorkshire

48 Domestic Energy Use: Drivers of Energy Decadence

52 Novel Storage and Control Technologies for Decarbonisation of Domestic Heat

58 Heat Network Zoning and the Alignment of Profit and Equity in District Heat Networks

Challenge

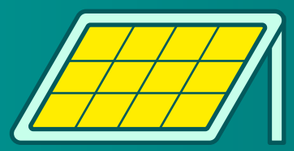
According to the National Audit Office, in 2021, the UK's 28 million homes accounted for 18% of all UK greenhouse gas emissions (GHGs)[1]. Most of those emissions derive from burning natural gas which is still used for heating and hot water in 86% of UK homes[2], with 90% of households having mains gas as the primary source of heating in South Yorkshire[3]. In the recently published Warm Homes Plan, the government aims to accelerate decarbonisation of home heating by tripling the number of solar panels by 2030 as well as increasing heat pump installation delivery to over 450,000 per year[4].

However, the vision of an electrified future for home heating is complicated by an electricity grid being under strain. Without significant reinforcement of the current national grid capacity, the nation-wide rollout of heat pumps and electric vehicles (EVs) will produce acute pressures for the grid. Whilst a typical house currently contributes 1 - 2 kW to peak demands, a heat pump by itself contributes around 2 kW, and a residential EV charger contributes around 1 kW. This leaves significant demand that needs to be met by South Yorkshire's electricity grid. However, SYSC's regional energy model shows that this increasing load from heat pumps and EV deployments will cause overload at 50% of both primary and secondary substations by 2050, requiring upgrades at a cost of £940 per customer.

There are also risks associated with the supply of electricity generated by renewable energy sources. The variability of solar and wind generation introduces fluctuations that complicate the integration of the power generated into the grid, which challenges system resilience. Even if the supply is secured, every kWh still carries high embedded impacts arising from manufacturing, raw materials extraction, and installation of renewable energy generators. Improvements in technology maturity are needed to reduce these impacts, such as the anticipated improvements in the efficiency of photo-voltaic cells for solar panels.

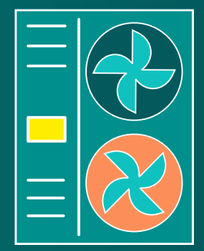
1 NAO (2024) Decarbonising home heating.
2 https://www.energy-uk.org.uk/fuelling-the-future/the-role-of-gas-heating-in-homes/
3 Carrick, J.and Wood, M. 2024. 'Consumption Habits: A report into household energy use in South Yorkshire'.
4 UK Government (2026) Warm Homes Plan.

The government aims to accelerate the decarbonisation of home heating



Triple the number of solar panels by **2030**

Increase heat pump installation delivery to over **450,000 p/a**

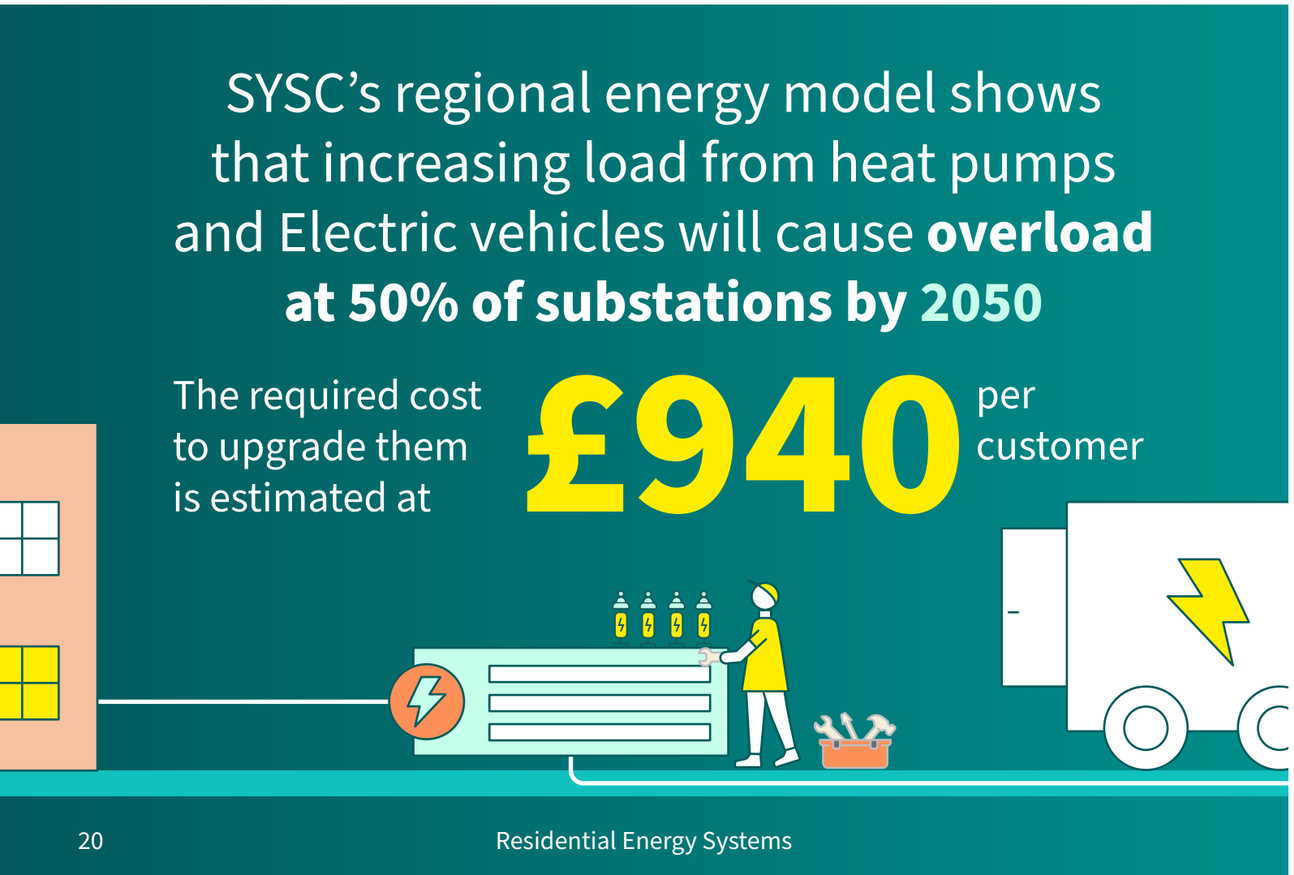


It is important to reduce overall energy consumption alongside any efficiency gains. In 2008, UK homes were kept, on average, 5 degrees warmer than they were in 1970[5]. Over 88% of respondents to the SYSC Household Energy Survey said that they set their thermostat to 18 degrees or higher, with 16.1% saying that they set it to 22 degrees or more. The same survey also found that, in South Yorkshire (as is elsewhere), energy use increased with income[6]. This may produce practical challenges as well as questions of equity as demand in more affluent parts of the city could cause surging grid pressure during peak hours.

Yet, we cannot expect all households to reduce their energy consumption to the same level due to differing needs; there is an issue of simultaneous overconsumption and underconsumption in the UK, with underconsumption being a particular issue in South Yorkshire. Fuel poverty within the region ranges from 14% (Rotherham, Sheffield) to 16% (Barnsley, Doncaster), according to 2023 data published by DESNZ[7].

Lastly, there is also a question of public acceptance of low-carbon home heating technologies. The SYSC Home Energy Survey has found that 46% of SY residents surveyed did not have and did not want solar panels, 57% answered that they did not have and did not want heat pumps and 27% answered that they did not have and did not want smart heating controls. Resistance to heat pumps was also correlated with income, indicating a perception that heat pumps are more expensive than gas boilers. Attitudes towards district heat networks (DHNs), however, were more positive once information about DHNs was given. The survey also indicates that the respondents' opinion of climate change is not a significant driver of domestic energy use; most energy saving action is motivated by a need or desire to reduce costs. The respondents said that their decision to join a DHN would be mostly influenced by cost savings (65%) and reliability (42%), with only 25% saying that they would join a DHN because it is better for the environment and only 13% would join to help reach the net-zero.

5 UK Government (2011) Great Britain's housing energy fact file.
6 Carrick, J.and Wood, M. 2024. 'Consumption Habits: A report into household energy use in South Yorkshire'. Sheffield: University of Sheffield, p.6.
7 DESNZ (2025) Sub-regional fuel poverty in England, 2025 report (2023 data). Interactive map.



SYSC Research Response

SYSC research aimed to address these significant technical, social and economic challenges to support and enable the delivery of a fair and effective low carbon heating transition in South Yorkshire.

Our research showed that, without flexibility measures, ~50% of both primary and secondary substations in the region will require upgrade by 2050. We estimated that the cost of carrying out these upgrades stood at a staggering £940 per customer. Furthermore, SYSC research found that time-of-use tariffs (TOUTs) by themselves would be insufficient to alleviate distribution grid issues. Although they can accomplish savings to emissions and energy costs, large spikes in demand will still arise, and can actually increase in magnitude if consumers all respond simultaneously to off-peak price incentives.

SYSC explored other technological options, such as smart grid controls and domestic thermal storage as ways to enhance grid flexibility and alleviate increasing pressure. We found that smart grid controls, which can coordinate all heat pumps and EV chargers on a network, can reduce demand peaks for residential areas by around 21%. Implementing network-level smart controls could reduce the proportion of overloaded substations by 2050 from 50% to 35%, and defer the requirement to upgrade in other cases. This would reduce the required investment in grid upgrades by around £300 per household. Smart controls were found to be the most effective for EV chargers, which offer the greatest flexibility, whilst heat pumps can be left under full user control and still retain ~80% of the cost benefits, provided EV charging is under smart control.

Increased opportunity to charge EVs at work could further even out EV charging demand, cutting peaks by an additional 5%, for an additional saving in grid upgrade costs of around £65 per household.

Domestic thermal storage could also help to relieve grid pressure by charging energy stores during off-peak periods and supplying homes with electricity during peak demand. These storage options can be deployed in various ways, for example to address space heating (SH) or domestic hot water (DHW) needs within an individual dwelling, or to provide additional flexibility within communal heating loops. Local storage systems could have significant benefits across the network, avoiding grid constraints during periods of peak electrical demand. Although more research and optimisation is needed, initial findings show that thermal stores could be suitable for direct use for either domestic

hot water or low temperature space heating. The potential is significant; installing a 10kWh thermal energy store into 1 million of the UK's estimated 30M homes could provide up to 10GWh of thermal storage alone.

Whilst electrification will be the dominant form of heat decarbonisation nationally and in South Yorkshire, heat networks remain part of the optimal future energy mix solutions. The Warm Homes Plan sets the ambitious government target to more than double the amount of heat demand met via heat networks in England to 7% by 2035, with the expectation that they'll provide a fifth of all heat by 2050[8].

SYSC projects also explored the economic viability and decarbonisation potential for district heat networks and their expansion within South Yorkshire. The research found that, for 4% of South Yorkshire's housing stock, connection to a district heat network was economically viable. Viability depended on housing density and proximity to high demand customers such as hospitals and schools.

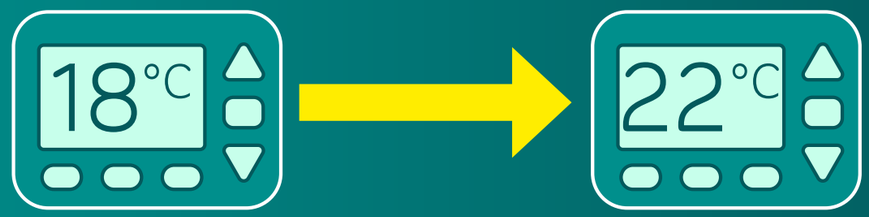
Researchers also applied different models of DHN development to the case study of Sheffield to understand how different policy approaches ('Profit-driven', 'Social Maximising' and 'Social-Leaning') might play out in terms of continuous network expansion and profitability. They found that a sustained growth trajectory was only possible under the Social-Leaning strategy, which describes centralised planning policies that balance commercial interest with social good. Network expansion under this strategy occurs in multiple phases over the 25-year simulation, enabling the development of larger, more integrated networks that connect a broader range of urban areas, achieving both the highest linear heat density (21,352 kWh/m/year) and the highest cumulative profit (£17.8M)

We also investigated the economic viability and achievable carbon reductions of different heat sources for the DHNs, such as waste heat and minewater. Utilising waste heat from industry and energy-from-waste is projected to save around 3.5% on the annualised cost of heating for the region, versus the scenario with pure electrification. Utilising these heat sources could also reduce annual emissions by around 45,000 tCO_2, or 3% of the total with electrification. Development of minewater sources was not found to be cost-optimal in this study with energy

8 UK Government (2026) Warm Homes Plan.

Over 88% of respondents to the SYSC Household Energy Survey said that they **set their thermostat to 18 degrees or higher.**

16.1% saying that they set it to 22 degrees or more



88% **16%**

of household energy survey respondents

prices around 1.5p/kWh more expensive than electrification resulting in a rise of circa £200 per annum for a typical house. Minewater sources could enable further cuts to emissions provided efficiency is high but this has not yet been demonstrated.

Where dwellings are connected to heat networks, certain fabric retrofit measures are also recommended to implement beforehand. These recommended measures are loft insulation and cavity wall insulation. These measures reduce energy peak loads which leads to network savings of ~10%, as well as reduced energy costs. Floor insulation and solid wall insulation were found to be borderline cost-effective (cost of installation vs. operational savings and DHN infrastructure savings).

The current costs of running low-carbon energy systems are linked to electricity tariffs, the price of which is largely dictated by wholesale gas prices rather than the true cost of delivering electricity. This means that space heating using an Air-Source Heat Pump (ASHP) without other interventions - for example, fabric retrofit, thermal storage or use of TOUTs - can be higher than the cost of heating the same space with a gas boiler. This is a key barrier to increasing the uptake of ASHPs in the UK and in South Yorkshire. Thermal storage has the potential to deliver reduced operating costs for ASHPs without the costs and disruption associated with deep fabric retrofit.

The housing retrofit section of this report provides more information and covers the benefits, including carbon and energy cost savings of retrofit.

Just Another Transition

Although the task ahead might seem overwhelmingly complex, heating transitions are far from novel and have occurred more frequently within living memory than at any other point in human history[9]. While the primary goal of the current transition is to reduce greenhouse gas emissions from buildings, it is not the first time heating practices have been altered for environmental and public health reasons. For example, shifts away from coal toward cleaner burning fuels, such as natural gas, were largely driven by the need to improve air quality. History provides a rich body of experience that can inform today's move towards sustainable domestic heating systems. The JustHeat project explored

9 Ambrose, A., and Davies, K. (2024), Was the Past More Sustainable? Keeping Warm.

District Heat Networks

Modelling shows that District Heat Networks can connect up to **4%** of South Yorkshire's housing stock

Over a 25 year period they can also...

deliver up to
£17.8 m
in profit

reduce the region's emissions by around
45,000 tco_2

the challenges faced by communities with strong historical ties to fuels now being phased out. These fuels often shaped the very development of communities, with dominant industries like mining providing employment, housing, fuel and leisure, and creating lasting loyalties long after their decline.

The project highlighted key themes that can help us understand how we might build consent for contemporary heating transitions. Firstly, comfort and homeliness were central to how people used heat. Secondly, households layered heat sources (e.g. gas, electric, heaters, log burners) to maintain flexibility and security during periods of financial or supply uncertainty. The SYSC's Household Energy Survey also found that 29% of the respondents said they used an alternative source of heating with 80% reporting that they did so to save on the cost of their primary source of heating. Finally, place-based identities count, particularly in former coalfield communities where coal symbolised pride, work, security and belonging.

The JustHeat project also uncovered narratives amongst participants which suggested that trust in the state regarding energy interventions has traditionally been high in Sweden, compared to the UK[10]. At a regional level, the Household Energy Survey also found that 69.4% of respondents scored their confidence in local councils as a source of information about energy savings between 1 and 4, with 1 representing no confidence and 7 a lot of confidence. Confidence rates were no better for either the Department for Energy Security and Net Zero (DESNZ) or the South Yorkshire Mayoral Combined Authority. Recommendations from family and friends were also more likely to influence respondents' decision to join a heat network than recommendations from an energy supplier, Ofgem or their local council.

This lack of trust in established bodies was reflected in broader concerns about the energy transition, with the majority of respondents (75%-86%) also concerned that the UK wasn't investing enough in alternative energy sources quickly enough, that power cuts would become more frequent, and that the UK was becoming dependent on energy from other countries.

One of the mechanisms that could help to address these barriers to low-carbon heating transitions and earn social acceptance is community energy schemes.

Community energy is broadly defined as a project that includes some degree of community involvement in a sustainable energy activities, i.e. an activity that results in reducing emissions from energy use, either by green energy supply (replacing fossil fuelled energy with renewable energy) or reducing energy demand (e.g. installing energy efficiency measures).

SYSC research found that community energy schemes provide economic benefits for individuals as well as the region. Since 2004, the UK has been a net importer of natural gas[11]. Community energy could provide a mechanism for keeping wealth in the region, as demonstrated by the fact that 40% of Energise Barnsley investors are located in Yorkshire. Community energy schemes can also reduce residents' bills alongside the payment of community dividends.

Community groups can also provide mutual support and advice on how a healthy and sustainable 'bricolage' approach can improve thermal comfort, experience and resilience. There are some great examples of community led initiatives, which don't often reach the biggest energy users (more affluent households) but are engaging sensitively with more vulnerable households that would benefit most from the support. For example, the Upper Don Community Energy Groups' Community Warming Project.

Community energy could also act as a positive interface for political representatives and the civil service to build trust with South Yorkshire residents. Initiatives such as the Sheffield Energy Hub show how community energy can broaden engagement by linking private, public, and third-sector organisations.

Finally, to increase social acceptance and willingness to transition away from fossil fuels, the promotion and marketing of co-benefits, such as better health and more resilient, cheaper home heating systems should not be underestimated. SYSC research into twentieth century energy transitions shows how the public sector led the marketing of the transition from coal to gas by selling the considerable benefits to housewives (i.e. reduced workload), delivering a programme that converted 40 million appliances in 14 million households in just 8 years between 1969 and 1977.

There are of course differences between the post-war and contemporary context; in the post-war period, the public was more accepting or used to centralised control, governments could more easily control messaging and the gas transition offered a more tangible difference to lives such as whole-house heating or instant heating. However, there are also similarities: change was stimulated by public health and environmental concerns, the thermal experience changed, the transition increased energy bills for some, and, although heavily subsidised (70% from national and local authority schemes), incurred costs for the homeowner.

10 Ambrose, A. and Palm, J. (forthcoming) Cheap and warm vs cold and expensive: the very different histories of home heating in Sweden and the UK, Insights - The Conversation

11 UK Department for Energy Security and Net Zero (2025) Digest of United Kingdom Energy Statistics.

Residential Energy Systems Recommendations for Regional Policymakers

1. Local policymakers should **implement heat zoning policies to provide the certainty and scale needed to de-risk the development of district heating networks in deprived areas**, and to create the conditions for strong network growth, securing more connections and higher profits.

   i. Heat Network Zoning and the Alignment of Profit and Equity in District Heat Networks.

2. Local authorities, in partnership with Distribution Network Operators, should **pilot smart grid technologies in South Yorkshire's residential areas** to better understand their potential to help mitigate future grid overload.

   i. Demand Flexibility to Support the Electrification of Heat and Transport.

3. Local policymakers should **support cross-sectoral partnerships that can deliver regional innovation (including demonstrators) in smart storage and control electrified heating systems, alongside retrofit**, in order to demonstrate cost competitiveness with gas boilers and to expedite the availability of smart storage and control systems in the home.

   i. Novel Storage and Control Technologies for Decarbonisation of Domestic Heat.

4. To help address anticipated grid overload as the deployment of heat pumps and electric vehicles (EV) gain pace, **local policymakers should collaborate with energy suppliers and employers to develop a workplace EV charging offer** that could reduce peak demand in residential areas.

   i. Novel Storage and Control Technologies for Decarbonisation of Domestic Heat.

5. **Local policymakers should pursue a fabric-first approach to the heating transition so that heat pumps are only installed in thermally efficient buildings**, helping residents to maintain warm homes at affordable costs. This is essential for building public consent and tackling fuel poverty.

6. **Local policymakers should prioritise community ownership to build trust with residents and generate greater buy-in for electrified heat and electric vehicles (EV).** Community energy schemes provide a feeling of ownership, whilst also providing energy security and helping to lower the bills, which could increase the appeal of electric heating and electric vehicles. The evidence shows that community energy projects and groups can also build more positive relationships between communities and local authorities.

   i. Enabling Community Energy in South Yorkshire.

7. In recognition of the multiple benefits provided by community energy (beyond MWh generated), and in anticipation of central government investment such as the Local Power Plan, local policymakers should provide **long-term, consistent, financial and coordination support to community energy groups**. This should include taking responsibility for convening diverse actors from across the region via connected energy hubs (i.e. the Sheffield Energy Hub) and actively targeting the expansion of community energy schemes in the region.

   i. Enabling Community Energy in South Yorkshire.

8. Research shows that local histories, needs and conditions shape the way in which energy policy lands in practice. In collaboration with community organisations and research partners, **local policymakers should adopt a localised, tailored approach to developing Local Area Energy Plans and Regional Energy Strategic Plans**. See Just Transition Recommendations for Regional Policymakers for details on a proposed Living Transitions Programme.

   i. Towards a Faster, Fairer and more Popular Transition to Clean Heat in South Yorkshire.

9. **Local policymakers should prioritise the retrofit of off-gas-grid homes to support a fair and accelerated transition** for those communities that were left behind during the transition to gas. Prioritising those previously left behind is not only just but may also provide 'quick wins' as these communities are more likely to see a transition to electrified heat as an improvement.

Further Research Opportunities

Flexibility measures: Further research or trials should assess the impact of flexibility measures on energy costs and the energy market, as well as the network. Flexibility measures are also not without cost, so a full cost-benefit analysis is recommended.

Demand flexibility: Peer-to-peer (P2P) trading of power can incentivise the adoption of EV chargers and heat pumps with photovoltaic generation; trials and studies that combine smart controls with an element of P2P could analyse: the physical and digital infrastructure needed, the real-world effects on demand profiles, and real-world human behaviour, including ease of recruitment.

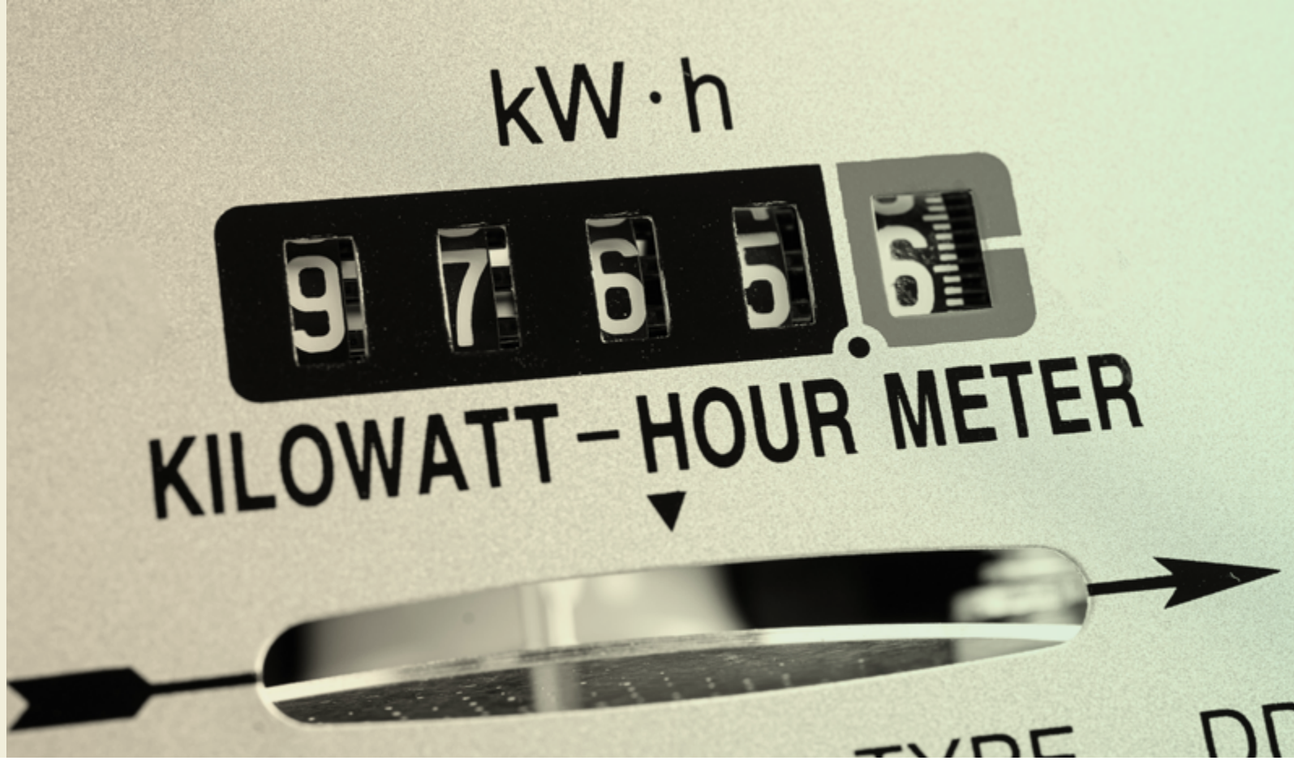
District heat networks: To better understand whether retrofitting prior to connecting a home to a heat network is economically viable, more real-world data collection is needed on thermal comfort, and the rebound effect following building fabric improvements.

Heat zoning planning: Future work could develop the existing analysis by incorporating additional real-world complexities, including multiple competing operators, evolving technology costs, fuel price volatility, and adaptive consumer preferences.

Community energy: More research should be conducted into inclusive models of participation and methods for capturing the wider impacts of community energy.

Demand Flexibility to Support the Electrification of Heat and Transport

Project team:
University of Sheffield: Prof. Solomon Brown, Dr Timothy Hutty



Challenge Statement

Heating the UK's homes accounts for approximately 18% of all UK greenhouse gas emissions, whilst domestic transport accounts for around 29%[1]. As such, decarbonisation of these sectors is a priority. Northern Powergrid expects the number of Electric Vehicles (EV) in the South Yorkshire region to increase from under 50,000 now to above 600,000 by 2050, with the number of residential heat pumps increasing from around 10,000 now to 360,000 by 2050[2].

Electrification will bring significant increases in peak electricity demands, presenting a challenge for the electricity system. Whilst a typical house currently contributes 1 - 2 kW to peak demands, a heat pump by itself contributes around 2 kW, and a residential EV charger contributes around 1 kW[3,4,5,6]. **Consequently, up to 42% of South Yorkshire's distribution substations may be overloaded by 2050 if not upgraded**, according to Northern Powergrid's distribution future energy scenarios[7].

To mitigate this challenge, EV and heat pump demand could be shifted away from peak times through incentives such as time-varying (time-of-use tariffs, TOUTs) that offer consumers cheaper unit rates outside of peak periods[8]. Smart EV chargers and heat pumps could also automatically adjust usage to alleviate stress to the grid[9].

1 Department for Energy Security and Net Zero (2025), Provisional UK greenhouse gas emissions statistics 2024.
2 Northern Powergrid (2025), Northern Powergrid DFES Local Authority Level.
3 UK Power Distribution (2017), Electrical Network Design Approval Application.
4 Customer-led Network Revolution (2015), After Diversity Maximum Demand (ADMD) Report.
5 Love, J., Smith, A.Z., Watson, S., Oikonomou, E. (2017), 'The addition of heat pump electricity load profiles to GB electricity demand: Evidence from a heat pump field trial'. Applied Energy, vol. 204, pp. 332-342.
6 UK Parliament, Scottish and Southern Electricity (2021), Written evidence from Scottish and Southern Electricity Networks.
7 Brown Group, The University of Sheffield, SYMCA, (2022), 'Hydrogen Conversion and Grid Capacity for South Yorkshire'.
8 Drax Electric Insights (2025) Electric vehicles and heat pumps are reshaping power demand.
9 Syla, A., Rinaldi, A., Parra, D., and Patel, M. K. (2024), 'Optimal capacity planning for the electrification of personal transport'. Renewable and Sustainable Energy Reviews , vol. 192, 2024.

Research Response

This research project aimed to address the following questions:

1. Can TOUTs in conjunction with smart controllers for heat pumps and EV chargers significantly defer the costs of upgrading South Yorkshire's distribution network?
2. Can TOUTs compete with direct control of appliances by the distribution network operator?
3. What is the role for EV charging at workplaces in facilitating the transition to EVs?

We modelled the demand for houses that would arise under three scenarios:

- Standard tariffs.
- TOUTs.
- Smart optimisation (with the DNO controlling devices to minimise peaks).

We used load profiles to model the anticipated demand for all South Yorkshire substations to understand if and when they would require an upgrade and the associated costs. Heat pump demand was modelled for buildings during a cold winter week. To predict the demand for charging EVs, we used real-world travel survey data and forecast EV uptake; we also explored a scenario where vehicles are incentivised to charge when parked at work.

Evidence and Outputs

Without flexibility measures, we find that circa 50% of both primary and secondary substations will require upgrade by 2050. The cost of carrying out these distribution grid upgrades is estimated at £940 per customer. 'Worst case' demand spikes are initially caused by EVs but will eventually be driven by heat pumps as heat electrification increases to 2050. It is worth noting that photo-voltaic (PV) solar has extremely limited impact on the highest demand peaks, as these occur in winter.

TOUTs by themselves are insufficient to alleviate distribution grid issues. Although they can accomplish savings to emissions and energy costs, large spikes in demand will still arise, and can

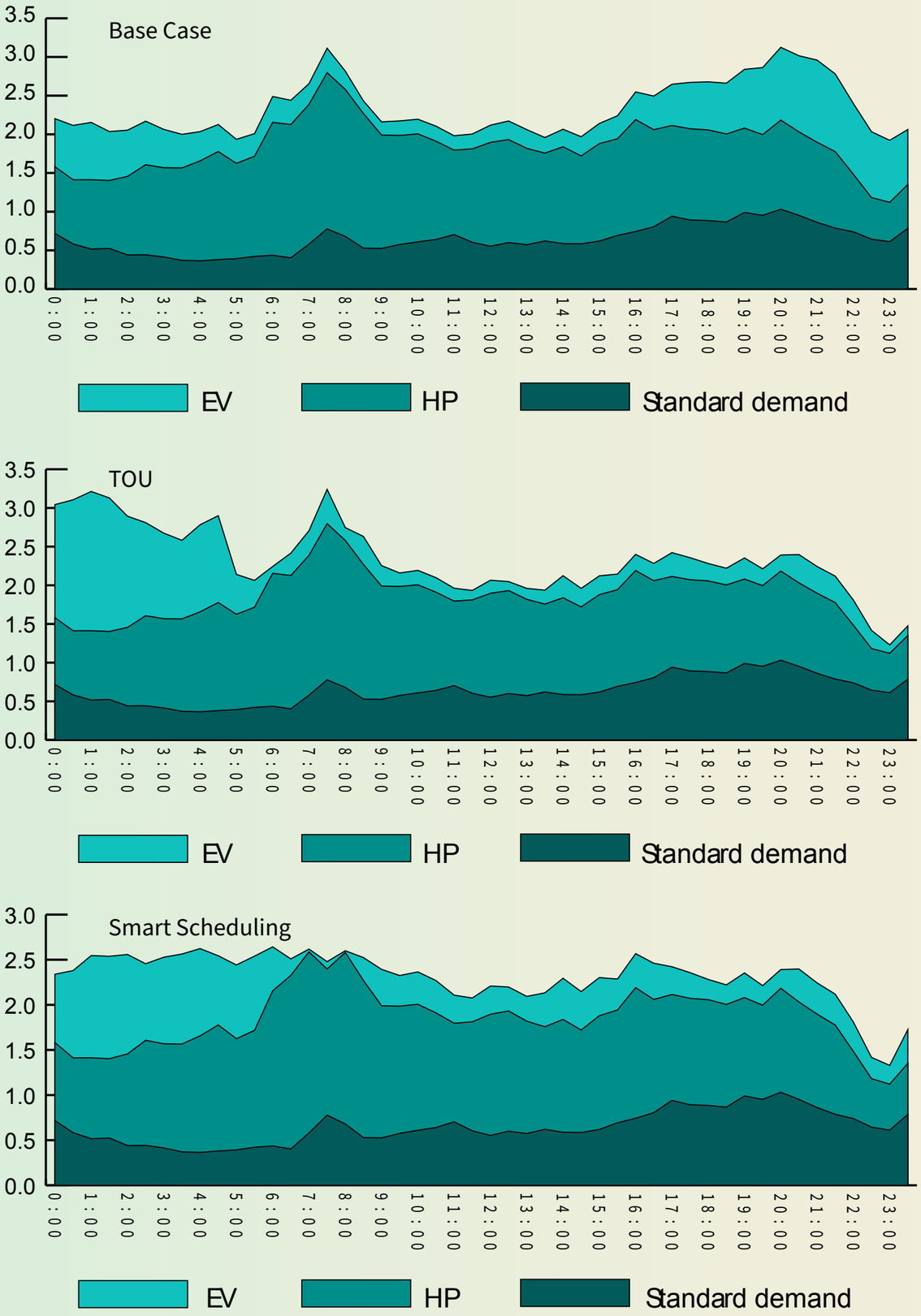


Figure 1: Electricity load on 'peakiest' simulated winter day; without flexibility measures; with TOU; and with smart scheduling.

actually increase in magnitude if consumers all respond simultaneously to lower prices. Smart controls which can coordinate all heat pumps and EV chargers on a network can reduce demand peaks for residential areas by around 21%. Implementing smart controls could reduce the proportion of overloaded substations by 2050 from 50% to 35%, and defer the requirement to upgrade in other cases. This would reduce the required investment in grid upgrades, by around £300 per household. Smart controls are most effective for EV chargers, which offer the greatest flexibility; heat pumps can be left under full user control whilst still retaining ~80% of the cost benefits, provided EV charging is under smart control.

Increased opportunity to charge EVs at work could further even out EV charging profiles, cutting peaks by an additional 5%, for an additional saving in grid upgrade costs of around £65 per household.

What does this mean for the region?

- Policy makers should seek to partner with the DNO to support trials of smart grid technologies for residential areas.
- Incentives for provision of workplace EV charging should be considered, especially where this can be coupled with PV and smart charging. Price incentives are required in tandem with this, as power is typically cheapest at night. Caveats: workplace charging has a possible tension with 'active travel'.

Next steps

The results of the study will be made available via the SYSC Residential Decarbonisation dashboard, enabling users to map results and compare different scenarios.

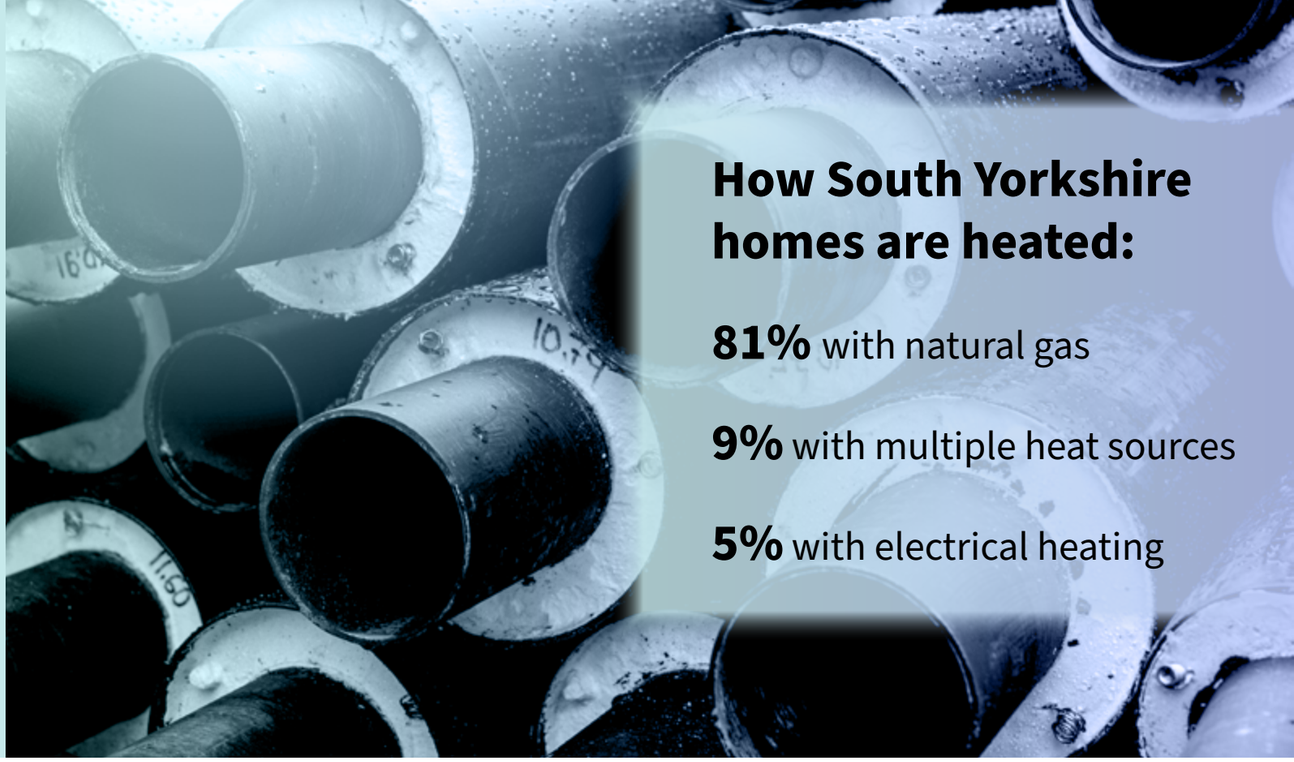
Peer-to-peer (P2P) trading of power can incentivise the adoption of EV chargers and heat pumps with PV generation. P2P could create microgrid communities that trade energy on a small scale, potentially saving households money and reducing the peak power requirement of the community. P2P was not covered in this case study; there is potential for trials and studies that combine smart controls with an element of P2P that could produce learnings on:

- The physical and digital infrastructure needed to support smart grid and P2P.
- The real-world effects on demand profiles (as opposed to modelled).
- The real-world human behaviour, including ease of recruitment.

This study focused on reduction of ***peak*** power demand in residential areas. There is a separate question around reduction of energy costs, which potentially unlocks more value for smart grid measures. Further research or trials should assess the impact of flexibility measures on energy costs and the energy market, as well as the network. Flexibility measures are also not without cost, so a full cost-benefit analysis is recommended.

Decarbonisation of Residential Heat for the South Yorkshire Region

Project team:
University of Sheffield. Prof. Solomon Brown, Dr Timothy Hutty



Challenge Statement

According to the National Audit Office, in 2021, the UK's 28 million homes accounted for 18% of all UK greenhouse gas emissions[1]. In South Yorkshire, 81% of homes are heated with natural gas, followed by 9% with multiple heat sources and only 5% with electrical heating[2]. Thus, decarbonisation of home heating is both a challenge and a priority in order to reach net-zero by 2050. Electrification of heat, by replacing gas boilers with heat pumps, is the cornerstone of the government's heat decarbonisation strategy. Heat networks, which supply heat to multiple buildings from one or more centralised heat sources, will also play a part, and are anticipated to supply 7% of the UK's heat by 2035[3], and 20% by 2050[1].

South Yorkshire currently has two major heat networks, the Veolia District Energy Network and the E.ON Blackburn Meadows Heat Network. Plans have been submitted to expand the latter to more than double its current size[4, 5]. The region possesses notable unexploited heat sources, including waste heat from industry, and low grade geothermal heat from old coal workings[6]. Large commercial and public buildings will be the most important heating loads supplied by heat networks; but more clarity is needed on the extent to which residential heat could also be decarbonised by this means[7, 8].

Research Response

This research project aimed to address key outstanding questions around residential heat decarbonisation in the region. Firstly, which parts of the region should be prioritised for heat network development, and to what extent is the connection of residential properties a cost-effective decarbonisation strategy? Secondly, where residential properties could connect to heat networks, should fabric retrofit be prioritised over heat network connection? Thirdly, how does the level of ambition for cutting Green House Gas (GHG) emissions affect the cost-optimal heating strategy?

We broke the whole South Yorkshire region down into sub-areas of around 100 buildings, and used computational methods to lay out heat network routes. We then computed the overall cost of supplying heat to the region, through to 2050, as well as the associated emissions. We compared different combinations of heat sources and fabric retrofit levels.

Evidence and Outputs

The majority of South Yorkshire's residential building stock should decarbonise via electrification. District heat network (DHN) developments are highly capital intensive and the economics for deployment to areas with average housing density are poor. Our results suggest that the proportion of residential dwellings that can most economically decarbonise by joining a heat network is around 4%, representing 9% of residential heat demand. It becomes cost-efficient to connect residential dwellings when they are in close proximity to large anchor loads such as schools and hospitals.

However, whilst electrification will be the dominant form of heat decarbonisation in the South Yorkshire region, heat networks remain part of the optimal mix of solutions. Utilising waste heat from industry and energy-from-waste is projected to save around 3.5% on the annualised cost of heating for the region, versus the scenario with pure electrification. Utilising these heat sources could also reduce annual emissions by around 45,000 tCO_2, or 3% of the total with electrification. Development of minewater sources was not found to be cost-optimal in this study with energy prices around 1.5p/kWh more expensive than electrification resulting in a rise of circa £200 per annum for a typical house. Minewater sources could enable further cuts to emissions provided efficiency is high but this has not yet been demonstrated.

Where dwellings are connected to heat networks, certain fabric retrofit measures are recommended to implement beforehand. These recommended measures are loft insulation and cavity wall

1 National Audit Office (2024) Decarbonising Home Heating.
2 Office for National Statistics (2023) TS046 - Central heating.
3 DESNZ (2026) Warm Homes Plan.
4 E.ON (2024) Net Zero Sheffield Energy Generation and Storage Decarbonisation Routemap 2024-26.
5 SYMCA (2022) South Yorkshire Mayoral Combined Authority Energy Strategy.
6 E.ON (2025) Blackburn Meadows District Heat Network.
7 DESNZ (2025) Sheffield Heat Network Zoning - Zone Opportunity Report.
8 E.ON (2023) Blackburn Meadows District Heating Network Connection and city wide heat decarbonisation.

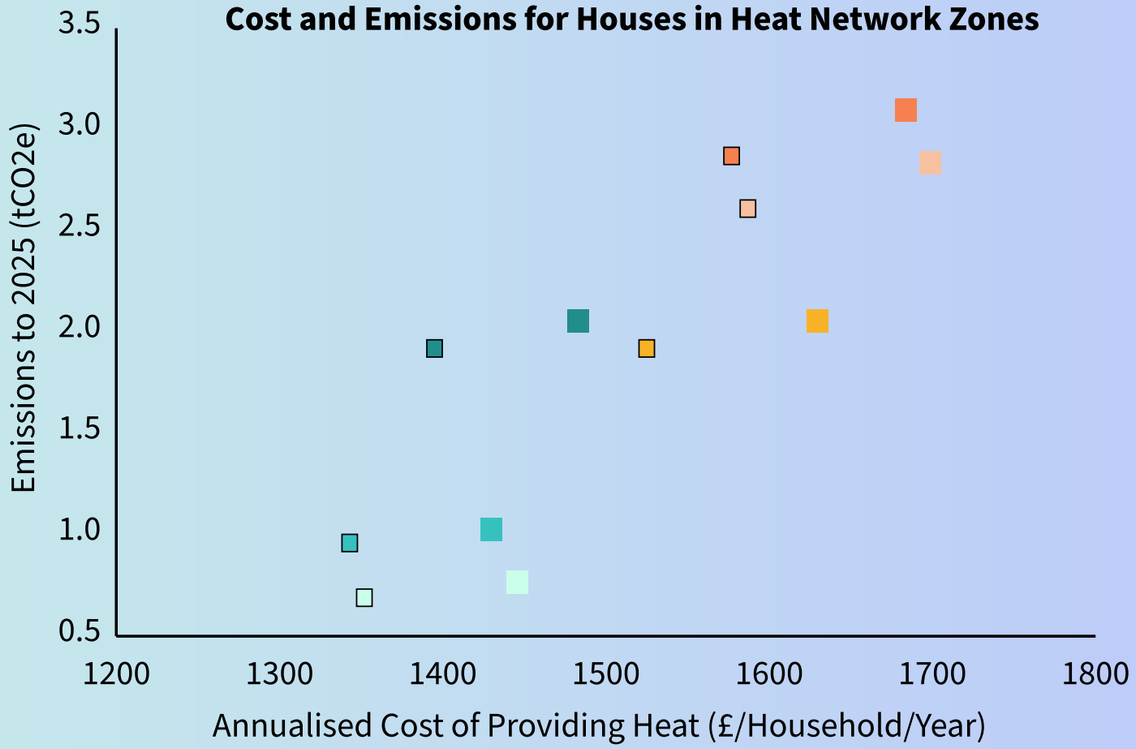


Figure 1: Cost and emissions for houses in heat network zones

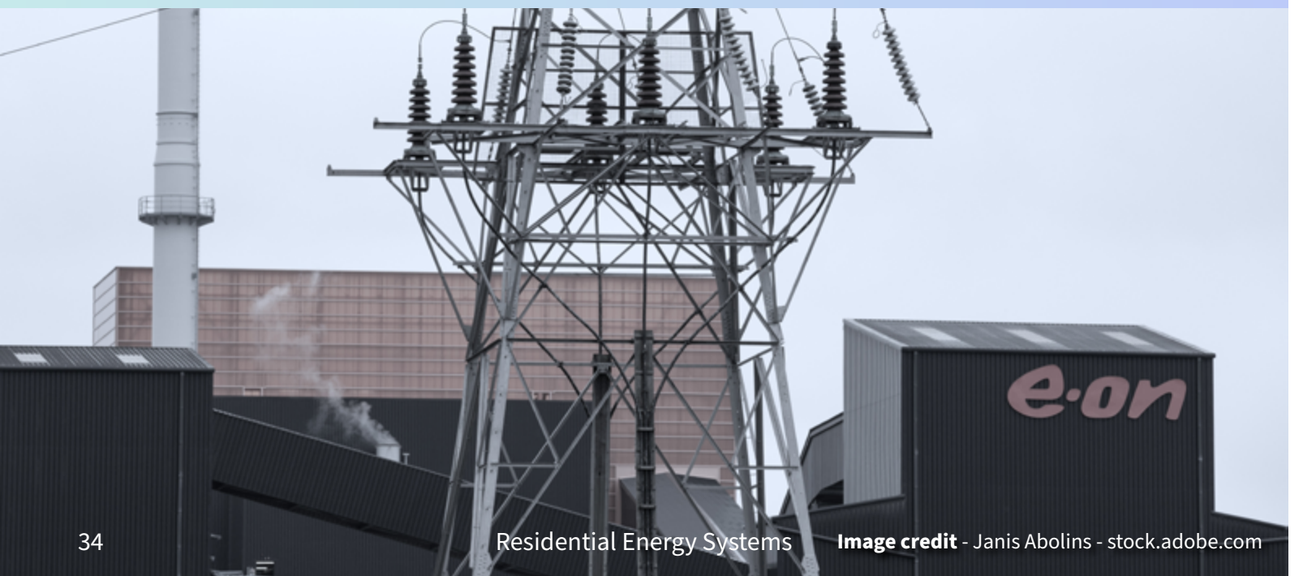


Image credit - Janis Abolins - stock.adobe.com

Utilising waste heat from industry and energy-from-waste is projected to **save around 3.5%** on the annualised cost of heating for the region

Utilising these heat sources could also **reduce annual emissions by around 45,000 tCO_2**

insulation. These measures reduce peak energy loads which leads to network savings of ~10%, as well as reduced energy costs. Floor insulation and solid wall insulation are found to be borderline cost-effective (cost of installation vs. operational savings and DHN infrastructure savings).

What does this mean for the region?

Usually, the local authority policy of pursuing fabric retrofit before heat network connection is sound. This finding applies to loft and cavity wall insulation. Economics for solid wall insulation or floor insulation are tight, and money may unlock quicker carbon savings if spent elsewhere.

The local authorities should continue to support the rollout of heat networks, with a particular priority to fully exploit existing energy-from-waste facilities and industrial heat resources. Exploitation of minewater is more costly but can achieve slightly deeper carbon savings.

Electrification will remain the dominant approach to heat decarbonisation for detached, semi-detached and terraced houses. Supporting electrification via investments in training and supply chains is critical.

Study Limitations

It is worth noting that this investigation did not look at the rebound effect where consumers respond to improved building performance by improving their thermal comfort, rather than saving energy. The rebound effect potentially weakens the case for fabric retrofit ahead of heat network connection.

The economics of residential heat network connections for new-build estates are known to be far better than for existing stock; this study focused only on existing stock.

Next Steps

The results of the study will be made available via the SYSC Residential Decarbonisation dashboard, enabling users to map results and compare different scenarios. The computed heat network layouts and their techno-economic metrics will be published as part of this.

The tools developed for this project are versatile and can be used to examine other decarbonisation strategies, such as small-scale local heat networks with communal heat pumps. There are also opportunities to look in more detail at emerging heat sources such as data centres, and to model decarbonised heat for new build estates. Models developed during this work are widely applicable and could be used for similar studies on any geographic area.

More studies are required on thermal comfort and the rebound effect from building fabric improvements; these would likely require real-world data collection.

Towards a Faster, Fairer and more Popular Transition to Clean Heat in South Yorkshire

Project team:
Sheffield Hallam University: Prof. Aimee Ambrose, Dr Kathy Davies, Dr Lindsey McCarthy

Birmingham City University: Prof. Becky Shaw

Project partners:
Site Gallery, Sheffield (Exhibition host)

Challenge Statement

This project supported the translation of key learnings from the international JUSTHEAT project to the South Yorkshire context, to enable more rapidly and sensitively delivered transitions to clean heat, rooted in community perspectives.

The project highlights that mainstream discourse on the transition from fossil-fuelled to low-carbon (clean) heating systems tends to focus almost exclusively on the present and future, often assuming little or no historical precedent. In fact, heating transitions are far from novel and have occurred more frequently within living memory than at any other point in human history[1]. While the primary goal of the current transition is to reduce greenhouse gas emissions from buildings, it is not the first time heating practices have been altered for environmental and public health reasons. For example, shifts away from coal toward cleaner burning fuels, such as natural gas, were largely driven by the need to improve air quality[2]. This history provides a rich body of experience that can inform today's move towards sustainable domestic heating systems—more than is often assumed.

Research Response

JUSTHEAT[3] and preceding studies[4, 5] have shown that communities with strong historical ties to fuels now being phased out – such as coal or wood - face particular challenges in adapting to and accepting transitions to clean heat. These fuels often shaped the very development of communities, with dominant industries like mining providing employment, housing, fuel and

1 Ambrose, A., and Davies, K. (2024), Was the Past More Sustainable? Keeping Warm.
2 Davies, K. (2024), Breathing Clean Air.
3 Ambrose, A., Shaw, B., Palm, J., Pelsmakers, S., Aho, H., Castano Rosa, R., Davies, K., Jiglau, G., Kilpelainen, S., Krishna, R., Labont, D., McCarthy, L., Sinea, A., Von Platten, J. and Vornicu, A. (2025). Looking back to move forwards: a social and cultural history of heating in Europe - A summary of key findings across the UK, Romania, Sweden, Finland. Centre for Regional Economic and Social Research, Sheffield Hallam University.
4 Darby, S. J. (2017), Coal fires, steel houses and the man in the moon: local experiences of energy transition. Energy research & social science, 31, 120-127.
5 Rohse, M., Day, R., and Llewellyn, D. (2020). Towards an emotional energy geography: Attending to emotions and affects in a former coal mining community in South Wales, UK. Geoforum,110:136-146

Four main themes emerged across South Yorkshire from JUSTHEAT

Heating as bricolage and resilience

"If I stayed up late or something ***I'd just flick the gas fire on for ten minutes and it does make a difference.*** But like at night, if that isn't on, cold air, you can feel it, but you know, I feel some nights if the wind's in that certain direction fair few be cold. So you put that on."

Thermal delight and wellbeing

"***You always used to feel secure sitting by a coal fire;*** you don't get that so much do you now? ***It's a strange sort of homely feeling you get.*** You'd look at the fire and imagine different shapes in the flames as a child."

Place-based identities and coal heritages

"***The coal was delivered to an outhouse.*** There were two brothers who ran the coal business in Whiston, Bennie and Eddie. They would come with 100 weight sacks, one each on the shoulders, and tip it into the outhouse. My parents had to go and get it as and when it was needed in a scuttle or a bucket. ***It was pretty hard work.***"

Affordability

"The Rayburn stove was quite a big old lump and a lovely thing to look at as well. ***Our cat used to love sitting in front of it.***

I also remember the day it got taken away... being a bit disappointed. It was a lovely old system but then as soon as we got the new system in realising ***how efficient the new system was compared to that.***"

Quotes taken from JUSTHEAT's oral history interviews in South Yorkshire.

leisure, and creating lasting loyalties long after their decline. We refer to these communities as “fueliverses”. Such former coalfield and wood reliant communities in Rotherham formed key case studies in JUSTHEAT.

The research found that home heating is shaped by personal memories and attachments, local history and household practice. Four main themes emerged across the South Yorkshire case study:

- **Heating as bricolage and resilience:** households layered heat sources (e.g. gas, electric, heaters, log burners) to maintain flexibility and security during periods of financial or supply uncertainty.
- **Thermal delight and wellbeing:** comfort and homeliness were central to how people used heat, with enduring affection evident for firesides and log burners, even among environmentally committed households.
- **Place-based identities and coal heritages:** in former coalfield communities, coal symbolised pride, work, security and belonging. Here, there was a risk of heating transition fatigue after the transition for gas arrived late for these communities and revealed new vulnerabilities.
- **Affordability:** household decisions were heavily shaped by energy costs, before consideration could be given to environmental concerns.

Support from the South Yorkshire Sustainability Centre (SYSC) enabled the team to undertake two complementary activities aimed at embedding key learning from JUSTHEAT at the South Yorkshire level. These comprised:

- **A ‘public conversation’** between research participants in the Rotherham area and local decision-makers responsible for shaping the region’s heating future. These facilitated discussions were designed to bridge the gap between households historically left behind by past heating transitions – due to their reliance on coal and in some cases, wood - and officers and elected members from local and regional authorities tasked with rapidly reducing emissions from domestic heating. You can read more about this event and the findings, here: https://www.shu.ac.uk/centre-regional-economic-social-research/publications/justheat-a-public-conversation.
- **A one-day interactive conference and exhibition of artworks** produced in response to the project’s findings. The event brought together policymakers, practitioners, academics and consumer advocates to hear about the project and, through a series of activities (listening to presentations, reading out oral history testimony etc), identify what the findings mean for the work they do in relation to the transition. The artwork encouraged delegates to reflect on the emotional attachments we form with heating fuels and sources and the profound ways home heating shapes our lives.

Together, these activities strengthened regional engagement with JUSTHEAT and raised awareness among practitioners, policymakers and the public that decarbonising heat is a complex social, cultural, emotional and political challenge - not just a technical or economic one.

What does this mean for the region?

Our research into past heating transitions highlights several lessons for regional and local authorities seeking to deliver an accelerated and just transition to net-zero.

1. **Prioritise community ownership to build trust and buy-in:**

   Heating fuels in the past were tangible, such as wood gathered from common land and coal provided as a salary to coalminers. By contrast, electricity is less tangible and its ownership more fraught. Community energy schemes solve this by allowing the feeling of ownership, as well as providing energy security and helping to lower the bills, encouraging the appeal of electric heating and EVs.

2. **Devolve and tailor approaches to reflect local histories and needs:**

   Experiences of past heat transitions varied hugely, even between neighbouring villages, and are likely to shape how consumers respond to the next transition. The level of granularity required to design effective programmes means that Westminster must devolve more power to regional authorities. Local Area Energy Plans and Regional Energy Strategic Plans must also resist treating entire authorities as homogenous units—such generalisation risks being counterproductive.

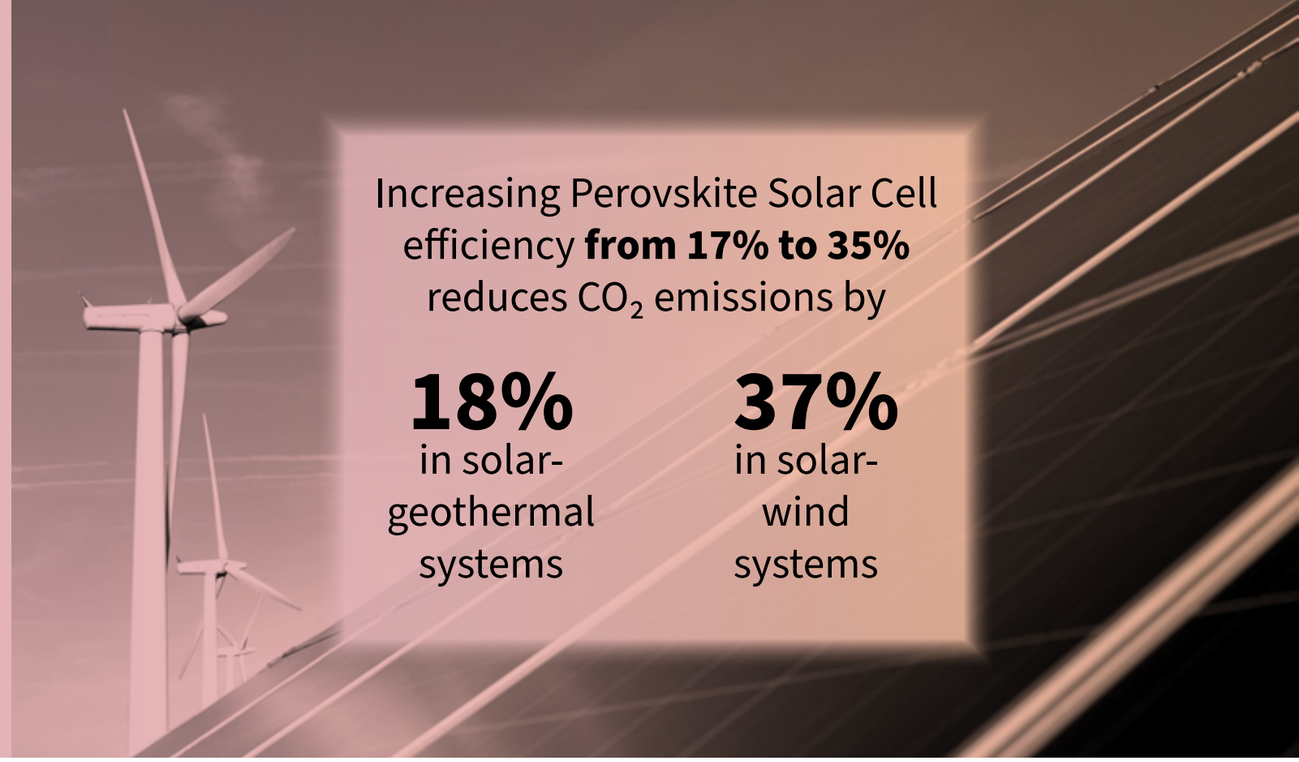
3. **Prioritise off-gas-grid homes to support a fair and accelerated transition:**

   In general, policymakers of the past decade have assumed that off-gas-grid homes will be the most complex and expensive to fit with decarbonised heating. Though the houses themselves may present technical challenges, communities that have not been through heat transitions in the past are more likely to see this one as an improvement. Moreover, this approach is inherently just - as it ensures that those left behind during the last wave of innovation are not left out once again.

Exhibition at Site Gallery, Sheffield, May 2025. All photos Copyright: Becky Shaw.

Hybrid Renewable Power Systems for Net-Zero: Life Cycle Evidence for Integrating Solar, Wind, Geothermal, and Perovskite Solar Cells

Project team:
University of Sheffield: Prof. Lenny Koh, Dr Moein Shamoushaki, Eleanor Borrill



Challenge Statement

The UK's net-zero transition relies heavily on the rapid expansion of renewable energy generation. While the deployment of renewable technologies is essential for decarbonisation, it also presents several challenges.

First, there are environmental trade-offs. Renewable technologies often carry high embedded impacts arising from manufacturing, raw materials extraction, and installation, particularly in hybrid power systems that combine multiple generation technologies.

Second, there remains a significant technology maturity gap. Perovskite solar cells (PSCs) are an emerging technology manufactured using alternative materials to conventional silicon solar cells. They offer advantages such as the capability to be manufactured on curved or flexible surfaces, along with rapid efficiency improvements over the last decade. However, they are currently constrained by short operational lifespans and toxicity concerns related to their material composition, particularly lead usage.

Additionally, the supply chains underpinning PSC deployment are vulnerable. Critical materials – including lead, silver, and indium tin oxide – face risks of scarcity, geopolitical disruption, and adverse environmental impacts from mining.

Finally, as renewable penetration increases, grid stability becomes a pressing concern. The variability of solar and wind generation introduces fluctuations in power supply that complicate integration and challenge system resilience.

Regional Relevance

Contribution of Research

Prior to this study, significant knowledge gaps existed: no comparative life cycle assessments (LCAs) had been conducted for integrated renewable-based hybrid power cycles, the integration of PSC technology into such systems had not been evaluated for sustainability trade-offs, and the effects of PSC lifespan and efficiency improvements on environmental performance were poorly understood.

This research addresses these gaps by delivering the first comparative LCA of three integrated renewable-based power cycles: combined geothermal-wind, combined solar-geothermal, and combined solar-wind. The study quantifies and compares the environmental impacts of these systems, explicitly incorporates PSC technology into solar-based configurations, and models system sensitivity to PSC lifespan (3-15 years) and efficiency (17-35%). It also identifies key environmental hotspots within hybrid systems and provides evidence to guide technology mix decisions that maximise sustainability and resilience.

Evidence and Outputs

Research Findings

In base case modelling, solar-wind systems demonstrate the lowest impacts on ozone depletion and climate change, while geothermal-wind achieves the lowest impacts in freshwater and marine ecotoxicity categories. Across all systems, improvements in PSC lifespan yield the greatest environmental benefits. Extending lifespan from 3 to 15 years reduces CO_2 emissions by 28% in solar-geothermal systems and 56% in solar-wind systems, with even a 7-year extension delivering a 49% reduction in greenhouse gas emissions in solar-wind. Efficiency improvements are also beneficial, though less significant. Increasing PSC efficiency from 17% to 35% reduces CO_2 emissions by 18% in solar-geothermal and 37% in solar-wind systems.

Environmental hotspots vary by technology. Geothermal well drilling is highly material-intensive, requiring steel, cement, and bentonite. Wind plant construction is dominated by impacts from steel, copper, and concrete. PSC manufacturing is a critical hotspot, with aluminium, chlorobenzene, and indium tin oxide glass contributing heavily to environmental burdens. Toxicity-related impacts, driven by lead, zinc, silver, and indium tin oxide, are less responsive to lifespan or efficiency improvements, underlining the need for material substitution strategies.

In best-case scenarios, certain environmental impacts - including terrestrial ecotoxicity, photochemical oxidant formation, and human toxicity - can be reduced by more than 88% relative to worst cases, demonstrating the significant potential of targeted interventions.

Published academic papers on this research project can be found here[1] and here[2].

1 Shamoushaki, M., Koh, S.C.L., Solar cells combined with geothermal or wind power systems reduces climate and environmental impact. Nature Commun Earth Environ 5, 572 (2024).
2 Shamoushaki, M., Koh, S.C. Lenny, Comparative life cycle assessment of integrated renewable energy-based power systems, Science of The Total Environment, 946, (2024).

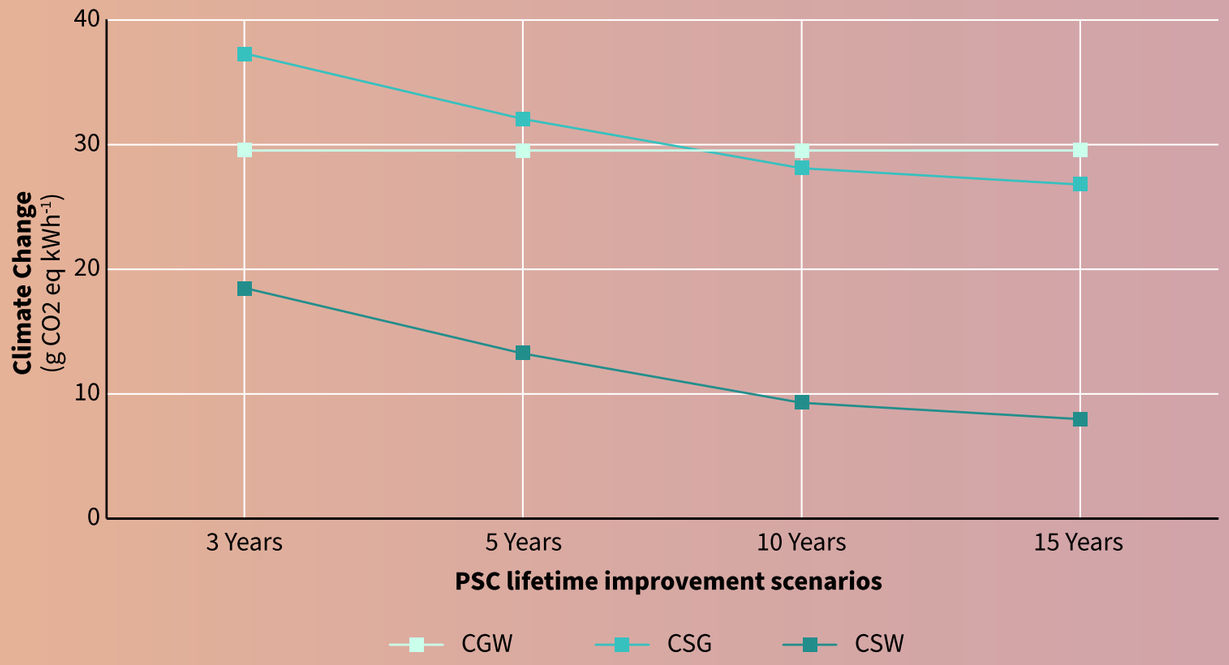


Figure 1: Variation in climate change impact per kWh electricity generated by each combined power system under scenarios of PSC lifetime improvement. Increasing the PSC lifetime from 3 to 15 years would reduce the climate change impacts of the solar-geothermal and solar-wind systems by 28% and 56%, respectively.

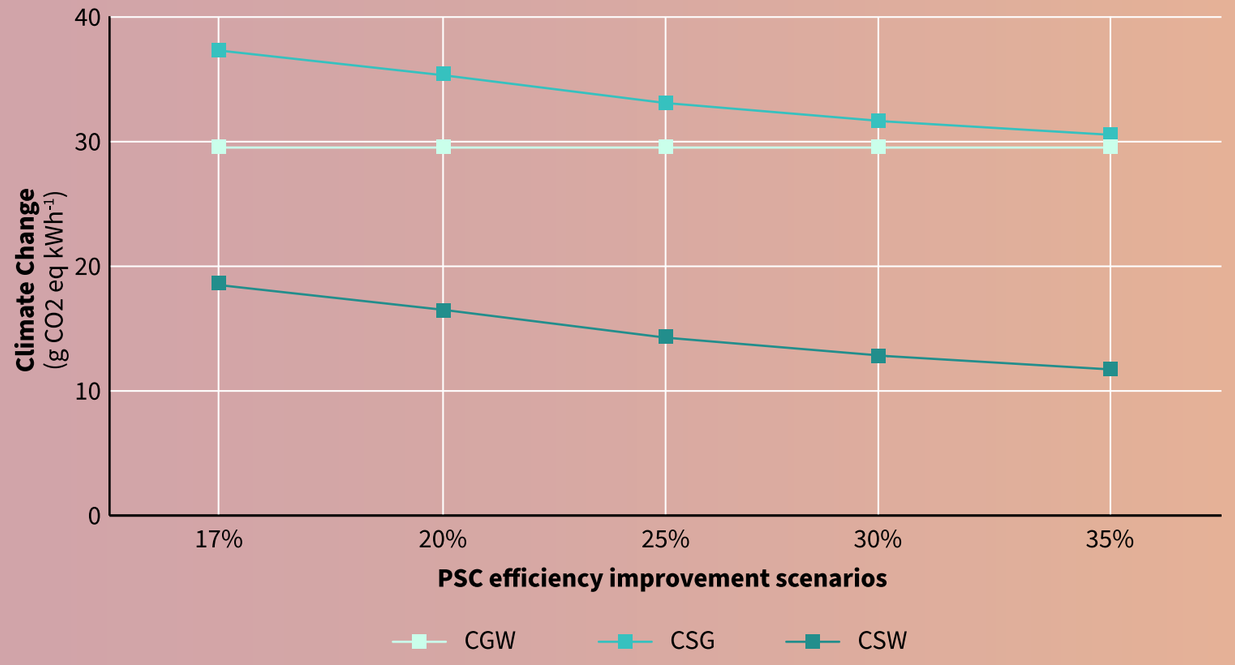


Figure 2: Variation in climate change impact per kWh electricity generated by each combined power system under scenarios of PSC efficiency enhancement. Increasing the PSC efficiency from 17% to 35% would reduce the climate change impacts of the solar-geothermal and solar-wind systems by 18% and 37%, respectively.

Scalability and Commercialisation

The study highlights global opportunities for scaling integrated renewable systems. In South Yorkshire, there is clear potential to develop local PSC component manufacturing and hybrid system assembly, drawing on the region's materials engineering expertise, established steel and advanced manufacturing base, and logistics infrastructure. Integrating this with the region's growing hydrogen and renewable energy capabilities would not only strengthen supply chain resilience and energy sovereignty but also provide the foundation for scaling deployment.

At the same time, scaling must account for the capacity requirements of both energy production and supply chains. Expanding hybrid renewable systems, particularly solar-wind and solar-geothermal, will require reliable access to critical materials, localised recycling pathways, and sufficient renewable energy generation to support manufacturing and operation.

Key Policy Insights

While the findings of this research hold global significance as renewable energy innovation and deployment accelerates worldwide, actionable recommendations can be drawn for South Yorkshire. The following section sets out key policy insights, building on the conclusions and recommendations drawn from the selected publications.

1. Continue to expand hybrid renewable energy systems.

   Build energy security and sovereignty by continuing to accelerate the transition to decarbonised energy systems using support from the UK government such as the Powering Up Britain: Net Zero Growth Plan (2023), the Powering Up Britain: Energy Security Plan (2023), the UK Renewables Deployment Supply Chain Readiness Study (2024), and the Strategy and Policy Statement for Energy Policy in Great Britain (2023).

2. Expand specialist skills training.

   The region should build on its strong academic and industrial base by working with Sheffield's universities, colleges, the AMRC Training Centre, and local industry to expand specialist skills provision. In order to ensure a skilled workforce capable of supporting large-scale deployment of hybrid renewable systems, the region should develop accredited courses and apprenticeships focused on PSC manufacturing, renewable energy integration, and sustainable construction. These initiatives will strengthen South Yorkshire's talent pipeline and position the region as a leader in advanced low-carbon technologies.

3. Develop circular supply chains

   The region should build on existing partnerships with the local steel, copper, and advanced materials industries, such as those demonstrated by Sheffield Forgemasters, Liberty Steel, and C F Booth Ltd in Rotherham, to further develop circular supply chains that recycle and repurpose key system components. In order to enhance resource efficiency and minimise waste, further regional initiatives should be established to repurpose PSC and hybrid system components at scale.

4. Position South Yorkshire as a national hub for hybrid renewable energy.

   In order to achieve net zero emissions by 2040, as outlined in the regional Energy Strategy, South Yorkshire should build on its strong engineering base, the AMRC's research infrastructure, the Energy Institute's capabilities, and the region's logistics network to pilot component production, develop PSC prototypes, and position itself as a national hub for hybrid renewable energy technologies.

5. Leverage housing retrofit and energy programmes.

   The region should continue to build on existing housing retrofit and energy efficiency programmes, such as the Home Upgrade Grant (HUG 2), Barnsley Council's Energy Efficiency Works, and the South Yorkshire Housing Association (SYHA) Retrofit Projects, to integrate locally manufactured PSC-enabled hybrid systems. This approach will stimulate local demand, support green manufacturing, and accelerate the region's transition to low-carbon housing.

Enabling Community Energy in South Yorkshire

Project team:
University of Sheffield: Dr Matthew Wood, Dr Jayne Carrick

Challenge Statement

Community energy is broadly defined as a project that includes some degree of community involvement in a sustainable energy activity / activities, i.e. an activity that results in reducing emissions from energy use, either by green energy supply (replacing fossil fuelled energy with renewable energy) or reducing energy demand (e.g. installing energy efficiency measures).

The potential for community energy to contribute to net-zero targets and facilitate public engagement is recognised in South Yorkshire Mayoral Combined Authority's (SYMCA) Energy Strategy (2022), which aims to "enable community energy schemes and encourage communities to be part of the transition". However, across the UK, community energy has been held back by poorer than expected uptake[1]. In South Yorkshire, uptake has been even lower than other regions, despite boasting the UK's largest community energy photo-voltaic (PV) solar and battery storage scheme, Energise Barnsley[2].

Inconsistent financial support policies[3], including the withdrawal of the Feed-in Tariffs[4] and subsequent short term grant schemes, have significantly affected uptake of community energy. However, policymaking to promote community energy is also hampered by the varying ways that 'community energy' is applied, defined and understood[5], especially as it has evolved from grassroots schemes initiated, funded, implemented and managed by people physically connected to a locality, to commercial offerings that enable citizens to invest in renewable energy schemes.

1 Kumar, C. Green Alliance (2019), Community Energy 2.0: The future role of local energy ownership in the UK.
2 South Yorkshire Mayoral Combined Authority (2022), South Yorkshire Mayoral Combined Authority: Energy Strategy.
3 Braunholtz-Speight, T., Sharmina, M., Manderson, E., McLachlan, C., Hannon, M., Hardy, J. and Mander, S. (2020), 'Business models and financial characteristics of community energy in the UK'. Nature Energy 5, 169–177.
4 OFGEM Feed in Tariffs (FiTs): a UK Government scheme that provided financial support for small scale (<5MW) renewable electricity generation, between 2010 and 2019.
5 Hicks, J. and Ison, N. (2018), 'An exploration of the boundaries of 'community' in community renewable energy projects: Navigating between motivations and context'. Energy Policy 113, 523–534.

Research Response

The research applies a just transitions lens, highlighting how community energy can help tackle inequalities by redistributing the benefits of energy development and giving communities a stronger role in decision-making. This is especially relevant in South Yorkshire, where the decline of coal and steel left deep social and health inequalities—life expectancy differs by up to 20 years between the richest and poorest areas[6]. Once a net energy exporter, the region now imports energy, sending millions out of the local economy. The project explored the extent to which community energy offers a pathway to address these challenges while building a fairer, locally rooted energy system.

To achieve this aim, we undertook a series of interviews with key informants from across the sector and 20 months of ethnographic observation with community energy groups in South Yorkshire.

Evidence and Outputs

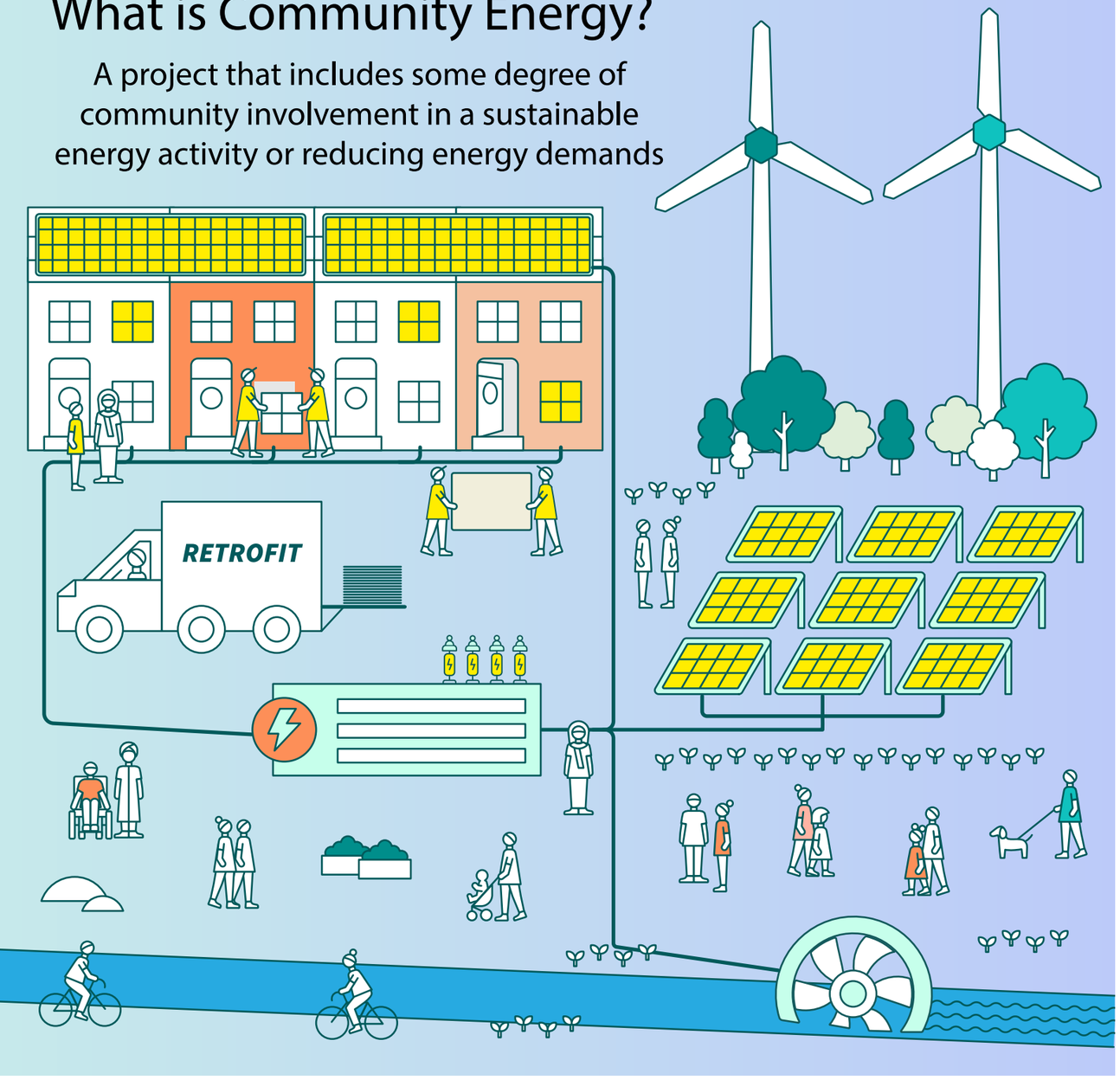
The research found that community energy has evolved from being rooted solely in place-based renewables, and shifted towards a broader focus on community as networks of relationships, shared values, and collective action. This shift creates new opportunities to advance a just transition, reframing energy as a space of collective care and intergenerational responsibility, echoing the communal ethic of former coal-mining communities.

The definition of community energy remains open to wide interpretation. Some use the term liberally, e.g. solar panels (paid for by the local authority) on schools, where community involvement is limited to building users using the solar powered electricity. In other cases, projects that could be defined as community energy were not being considered as such, especially those associated with retrofitting energy efficiency measures. Thus, energy efficiency projects are often not counted in measures of success for the sector, especially

6 South Yorkshire Mayor's Health Equity Panel (2024), 'Health Is Wealth in South Yorkshire: How to Become the UK's Healthiest Region'.

What is Community Energy?

A project that includes some degree of community involvement in a sustainable energy activity or reducing energy demands



because they prioritise kWh of renewable energy produced.

There is often an assumption that community energy initiatives are primarily driven by climate and energy targets, with the “community” element serving mainly as a delivery mechanism for low-carbon generation. However, this research highlights the potential benefits in reframing energy projects as vehicles to advance shared community values and deliver wider social benefits. Increasingly, community energy initiatives prioritise outcomes such as advice, support, and practical measures to improve household energy efficiency. These activities are typically delivered through volunteer-led groups working in partnership with public and private sector actors, creating opportunities for citizens to collaborate in pursuit of collective benefit.

Key findings for policymakers:

- **Beyond energy generation:** Many community energy initiatives foster social cohesion, volunteering, and mutual support, embodying principles of intergenerational justice. However, because they don’t produce measurable energy outputs - current success metrics (e.g. MWh generated) miss such contributions. Key observations include:

- **Participation and inclusivity:** While volunteers are often white, middle-class, and retired, initiatives such as the Sheffield Energy Hub show how community energy can broaden engagement by linking private, public, and third-sector organisations. More work is needed to involve marginalised groups as beneficiaries and participants so that community energy delivers equitable outcomes.

- **Connection:** People will support projects that they feel connected to, such as those that retain benefits locally, or that they can contribute to.

Overall, the findings suggest a quiet but significant transformation; community energy projects are redefining what energy transitions mean by embedding social justice, care, and community responsibility alongside decarbonisation.

The results of the research will be presented in a journal article ‘Can community energy deliver a just transition in former coal mining areas of Northern England?’[7]. Once published, the article will be available via the SYSC website.

What does this mean for the region?

To support the development of community energy in South Yorkshire, regional policy makers should:

- Recognise and support “softer” interventions that strengthen community resilience, volunteering, and mutual support.

- Encourage collaboration across public, private, and third-sector organisations, following models such as the Sheffield Energy Hub.

- Strengthen community energy as a networked ecosystem, not just isolated projects, for example, supporting the Sheffield Energy Hub as a nexus for community groups, public organisations and private companies and developing the hub concept across the region.

- Shape policies around the idea of community as a set of active, evolving relationships and shared values, rather than something defined only by location or demographics, for example Upper Don Community Energy’s Community Warming project, where simple draught excluders (door curtains and sausage dogs) were made - by volunteers at a series of sewing workshops - and fitted for people in fuel poverty or with damp related health problems.

- Support projects that rebuild communal responsibility and intergenerational connections, echoing traditions of mutual support and self sufficiency in former industrial communities.

- Support initiatives that promote reducing greenhouse gas emissions and a just transition.

- Provide long-term, consistent policy support to give community groups the stability to innovate and scale, e.g. by reducing uncertainty in funding and regulation.

- When measuring the success of community energy, move beyond purely technical measures (e.g., MWh generated) to also capture social value, intergenerational justice, and collective care outcomes.

Next Steps

The project has already fostered further SYSC funded research in collaboration with the Northeast and Yorkshire Net Zero Hub and Community Energy England on a community energy toolkit to encourage and guide local authorities to support and foster community energy groups and schemes.

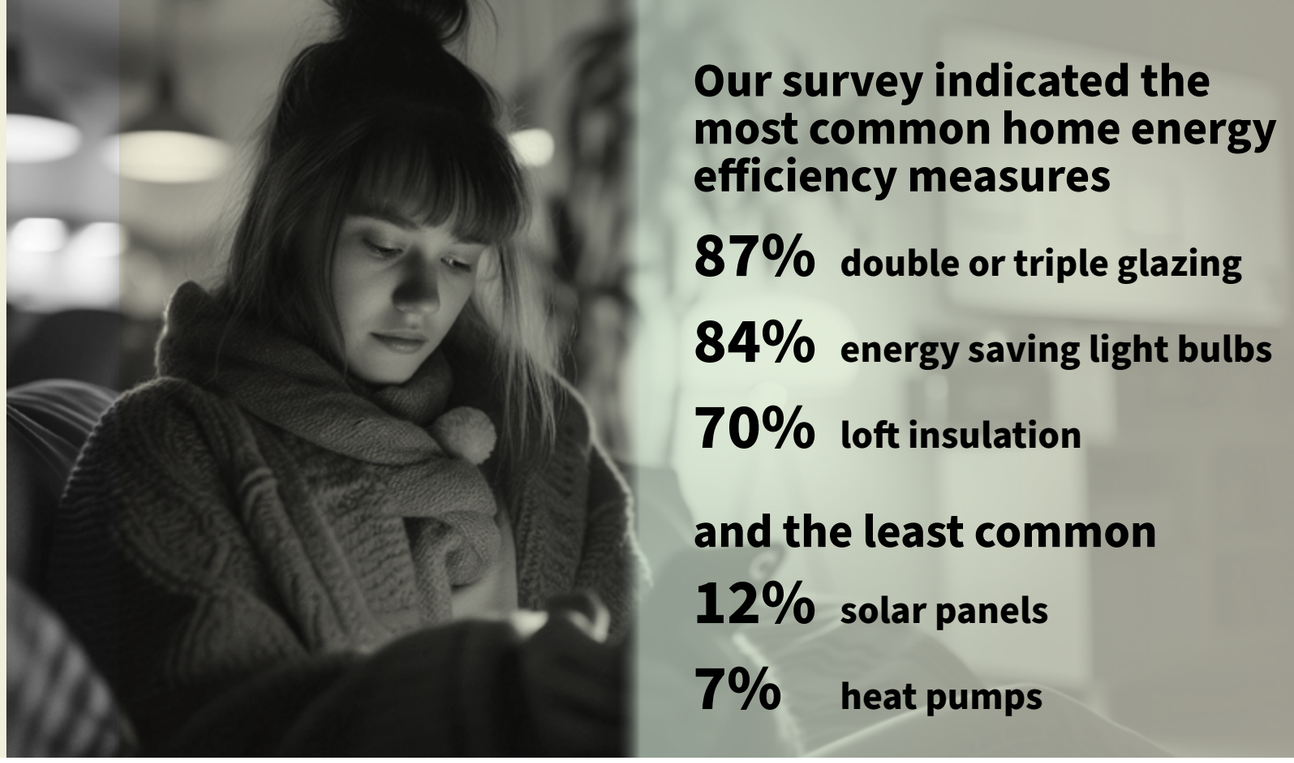
The results of the research have contributed to a call for evidence by the Energy Security and Net Zero Committee: Unlocking community energy at scale.

The project has identified the need for more research into inclusive models of participation and methods for capturing the wider impacts of community energy. This could include piloting new approaches that recognise the “quiet revolution” of unrecorded, socially embedded community energy initiatives.

7 Carrick, J. & Wood, M. (nd). ‘Can community energy deliver a just transition in former coal mining areas of Northern England?’. In production.

Domestic Energy Use: Drivers of Energy Decadence

Project team:
University of Sheffield: Dr Matthew Wood, Dr Jayne Carrick



Challenge Statement

Domestic energy use is a significant source of greenhouse gas emissions. In South Yorkshire, domestic energy use represents between 29% (Doncaster) and 39% (Sheffield) of total energy use in South Yorkshire. Reductions in domestic energy use could and should contribute towards meeting regional and national net-zero targets. This is reflected in one of the four goals in the regional government's Energy Strategy[1]:

"improve the energy efficiency and sustainability of our built environment, and encourage communities to be part of the transition"

To make enough savings in domestic energy to effectively contribute to net-zero targets, policies need to be directed at areas where the largest savings can be made, i.e. those using the most, and with the capacity to reduce their consumption the most.

To make enough savings in domestic energy to effectively contribute to net-zero targets, policies need to be directed at areas where the largest savings can be made, i.e. those using the most, and with the capacity to reduce their consumption the most.

Drivers of domestic energy use are complex, but previous studies show that those on higher incomes use disproportionately more energy than those on lower incomes, creating consumption inequalities[2]. However, more research was needed to explore the characteristics of high domestic energy users and drivers of 'over-consumption'.

Research Response

The project aimed to identify the areas where South Yorkshire could focus policy interventions to reduce domestic energy 'over consumption', thereby reducing emissions and tackling socio-economic inequalities. To achieve this aim, we explored the determinants of high domestic energy use, undertaking a systematised review of previous UK studies.

The results of the review identified a gap in the literature on region specific data; no previous empirical research on energy use had focused on the South Yorkshire region specifically. Moreover, up-to-date data was needed to reflect the post 2020 context, which has seen both increases in the cost of energy and rising awareness of climate change. To inform regional policy making, region and time specific data was required and so the systematised review[3] was followed by a survey of 622 residents[4] from across South Yorkshire.

Evidence and Outputs

Our analysis confirms that domestic energy use in South Yorkshire is linked to income; higher earners consume more energy, while lower-income households are more vulnerable to rising costs and worry more about bills. Energy consumption does increase with the size of the property (measured by number of rooms and occupants), however, even when we controlled for these factors, we found that income is still a significant driver of energy use.

Our analysis found that high energy consumption was not linked to lower concern for climate change or energy saving. In fact, high users expressed similar concern as lower users, suggesting attitudes are not the barrier. Instead, lack of control, poor understanding of household energy use, and the "invisibility" of consumption limit the translation of concern into action. This is supported by interview data from another SYSC research project led by PhD student Amy Grace that suggests high consumers are uncertain about their energy consumption, which they often underestimate.

Social influence also matters: both high and low users report that they could be encouraged by seeing others save energy. Moreover, as illustrated in Figure 1, friends and family were perceived as the most trusted source of advice on energy saving information, emphasising the importance of social networks. Energy suppliers were also among the most trusted sources of energy saving advice. In contrast, local authorities, regional governments (including SYMCA) and Government departments (e.g. DESNZ) were ranked the least trusted sources of energy saving information.

Thinking about ways to reduce energy use, the survey indicated that most homes in South Yorkshire have some energy efficiency measures. Most commonly, double or triple glazing (87%), energy saving light bulbs (84%), and loft insulation

1 South Yorkshire Mayoral Combined Authority (2022), 'South Yorkshire Mayoral Combined Authority: Energy Strategy'.
2 Kartha, S., Kemp-Benedict, E., Ghosh, E., Nazareth, A. and Gore, T. (2020), The Carbon Inequality Era: An Assessment of the Global Distribution of Consumption Emissions among Individuals from 1990 to 2015 and Beyond'. Oxfam, Stockholm Environment Institute.
3 Carrick, J. The University of Sheffield, (2023,) 'Review of Domestic Energy Use: Drivers of Energy Decadence'. Sheffield: The University of Sheffield.
4 Representative of South Yorkshire in terms of key demographics, income and attitude to climate change.

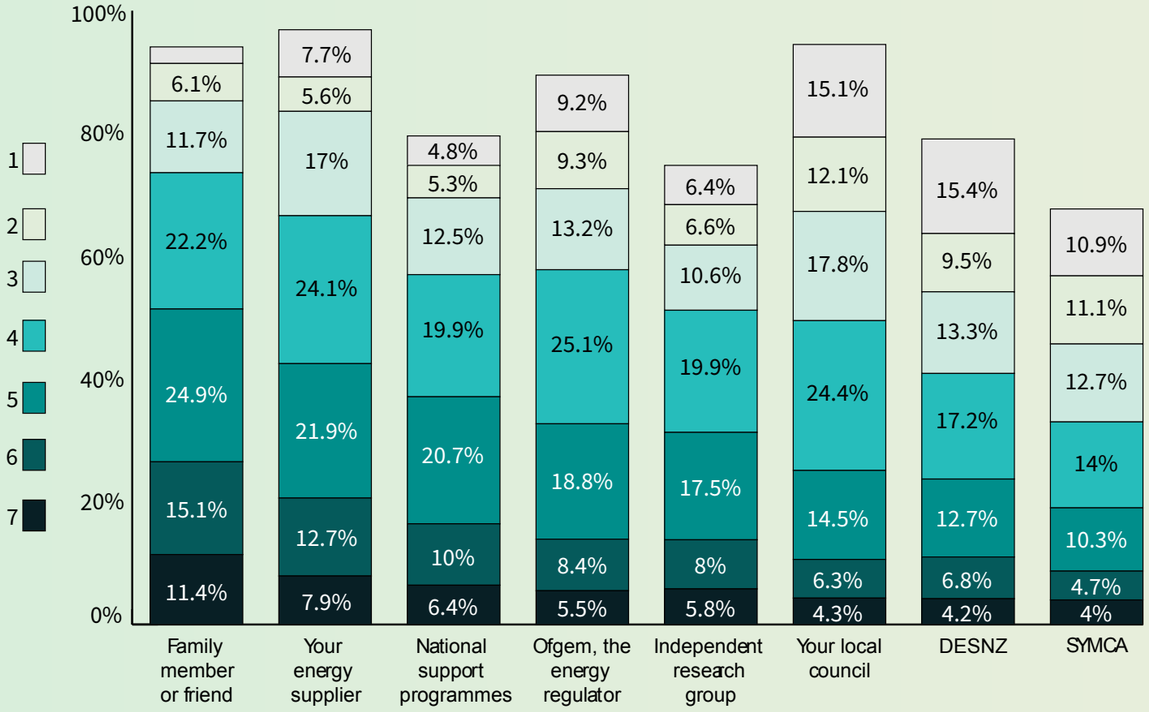


Figure 1: Confidence in sources of information on saving energy

(70%). The least common were solar panels (12%) and heat pumps (7%). Moreover, nearly half of respondents (48%) said they would not want to have solar panels and more than half (57%) said they would not want to have a heat pump, indicating resistance to these measures.

Further analysis shows that resistance to heat pumps reduces as income increases, indicating a perception that heat pumps are expensive. In contrast, resistance to solar panels increased with climate change scepticism. This suggests that policies to promote these technologies require different messaging, which appeals to those with least resistance. Perhaps heat pumps could be framed as a must have technology, whereas solar panels could be framed as a green technology.

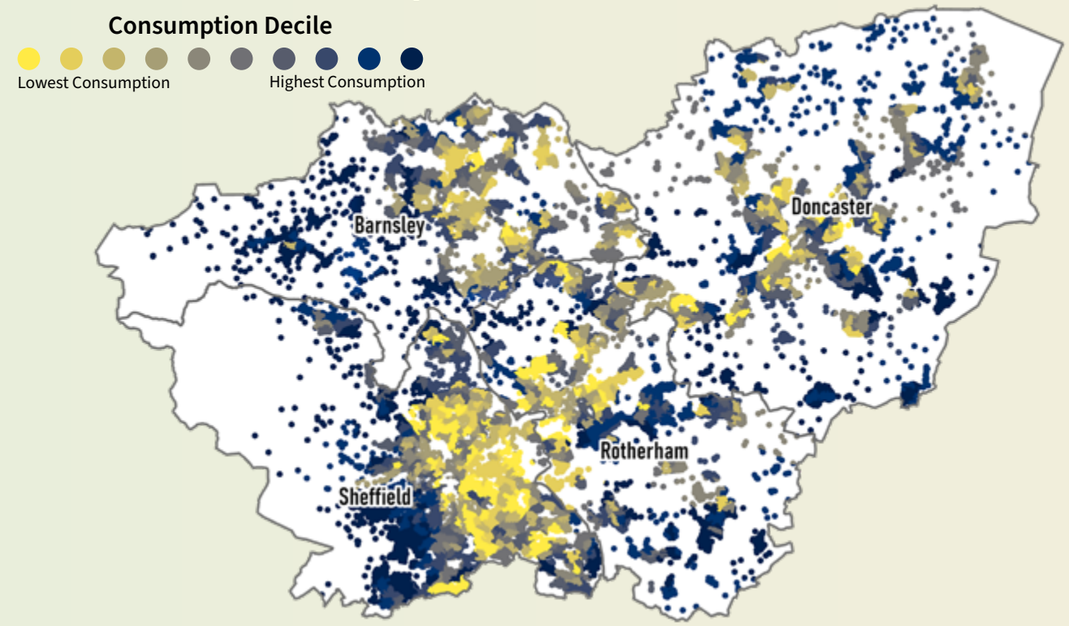
What does this mean for the region?

We recommend policy interventions focused on improving household energy literacy, making energy use more visible, and increasing residents' control over how energy is consumed. Such interventions may be more effective if delivered through or in partnership with trusted intermediaries rather than solely through government-led channels given that residents have low confidence in local and regional government, and DESNZ as sources of energy saving advice (see Figure 1).

Supporting previous studies[5,6], the results highlight the critical role of social networks in shaping behaviours; residents have most confidence in seeking energy saving advice from friends and family (see Figure 1) and could be encouraged to save energy by seeing others do so. Harnessing these norm-setting dynamics, alongside practical support, offers an opportunity to reduce demand among higher-consuming households.

Approaches could include easy to understand smart technologies and comparative tools that show households how their consumption compares to peers.

5 Bobrova, Y., Papachristos, G. and Fong Chiu, L. (2021,) 'Homeowner Low Carbon Retrofits: Implications for Future UK Policy'. Energy Policy 155, 112344.
6 Owen, A., Middlemiss, A., Brown, D., Davis, M., Hall, S., Bookbinder, R., Brisbois, M.C., Cairns, I., Hannon, M. and Mininni. G. (2023), 'Who Applies for Energy Grants?' Energy Research & Social Science 101, 103123



Visualising the distribution of household consumption across South Yorkshire by looking at household gas and electricity use, emissions from flights, distance travelled by car to work and a general consumption measure. These indicators were combined into a single measure and divided into deciles acros Lower Super Output Areas (LSOAs) in South Yorkshire

Figure 2: Distribution of energy consumption across South Yorkshire (Source: Grace, Leather and Parkes 2024).

Next Steps

Dissemination of the results among policy makers is required to optimise the impact of the research. The results have already been presented to the South Yorkshire Mayoral Combined Authority, Derbyshire County Council, and at the North East and Yorkshire Net Zero Hub's annual event in November 2024.

Analysis of the survey results explore transport inequalities across South Yorkshire; identifying areas where accessibility to jobs via public transport and affordability of transport is low, and where improved public transport links are most needed.

An ongoing EDRC funded project is also exploring perceptions of low carbon heating transitions among communities in South Yorkshire that are disconnected from, or late to connect to, mains gas.

Project Outputs

1. A Review of Domestic Energy Use: Drivers of Energy Decadence summarising the results of a systematised review of previous UK studies.
2. Consumption Habits: A report into household energy use in South Yorkshire summarising the results of a survey of 622 householders from across South Yorkshire.
3. What drives energy decadence? Survey evidence on energy consumption perceptions in South Yorkshire (journal article in review).

Our analysis also draws on research conducted by SYSC colleagues at Sheffield Hallam University as part of the Just Transition Work Package:

- Unequal and unjust? Visualising South Yorkshire's consumption distribution a journal article by Grace et al (2024), which mapped energy consumption across the region. See Figure 2.
- Preliminary findings from Amy Grace's PhD research, which is using qualitative interview data and ethnography to explore what drives and locks in high consumption lifestyles with South Yorkshire as its case study.

Novel Storage and Control Technologies for Decarbonisation of Domestic Heat

Project team:
University of Sheffield: Dr Rob Barthorpe, James Shaw, Dr Luke Boorman, Dr Sajan Preet

Project partners:
Sheffield City Council, E.ON and Daikin.

Challenge Statement

Domestic heating accounts for around 18% of UK carbon emissions[1]. Reducing this figure forms a key element of both national and regional approaches to meeting the UK Government's legally binding net-zero targets. Achieving an equitable transition to low-carbon domestic heating is also key to South Yorkshire's regional priorities around safe, secure and sustainable housing.

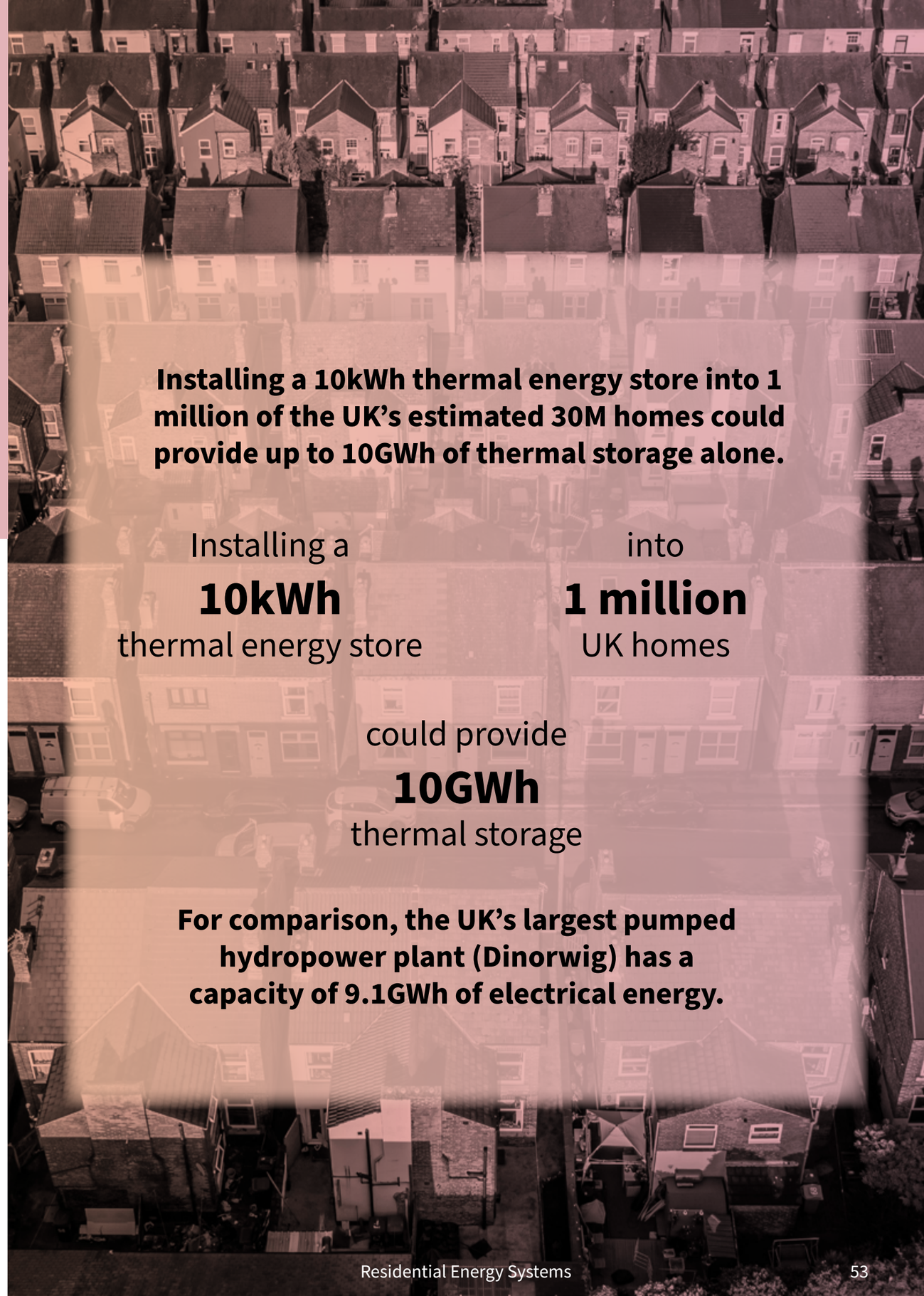
However, there are significant technical, social and economic challenges that must be addressed to deliver on a fast, fair and effective low carbon heating transition. Key challenges include low voltage (LV) network constraints, variation in the supply of low carbon energy generation (i.e. wind and solar generation), a perceived lack of public acceptance, increased operating costs for consumers, architectural challenges within the existing UK housing stock, and skills gaps.

Domestic thermal storage and automatic control technologies hold the potential to enhance the UK's energy flexibility by charging energy stores during off-peak periods and supplying homes with electricity during peak demand. These storage options can be deployed in various ways, for example to address space heating (SH) or domestic hot water (DHW) needs within an individual dwelling, or to provide additional flexibility within communal heating loops. Local storage systems could have significant benefits across the network, avoiding grid constraints during periods of peak electrical demand. This will become increasingly important as heat and transport electrify, adding burden to already challenged energy networks.

The potential is significant; installing a 10kWh thermal energy store into 1 million of the UK's estimated 30M homes (such as the phase change material store developed in the the first stage of the project, described below) could provide up to 10GWh of thermal storage alone. For comparison, the UK's largest pumped hydropower plant (Dinorwig) has a capacity of 9.1GWh of electrical energy.

Deployment of low carbon domestic energy systems with storage at scale has the potential to deliver substantial regional cost and carbon savings, as well as consumer comfort benefits without wholesale grid upgrades, facilitating the energy transition. However, further work is required in several areas in order to progress the technical, commercial and social readiness

1 https://www.nao.org.uk/reports/decarbonising-home-heating/?nab=0

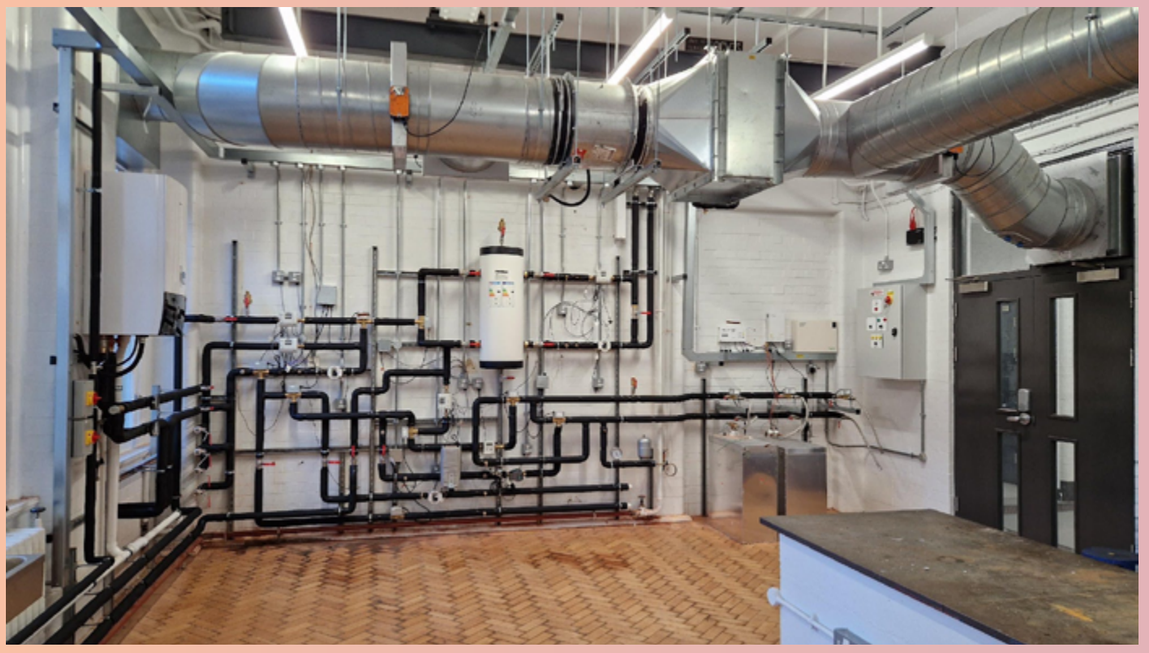


levels of these solutions. One of the key enablers for progress is testing and refinement at system level - i.e. with all components assembled into an integrated heating system - and in real-world operation once appropriate technical maturity has been demonstrated. This allows potential barriers to deployment to be revealed and addressed.

Research Response

Researchers within the Faculty of Engineering at the University of Sheffield are leading a muti-phase research programme that is developing, optimising and demonstrating how novel storage solutions (e.g. thermal, electrical) and control (principally hierarchical predictive control) technologies could be integrated with established low carbon heating solutions (e.g. heat pumps, solar PV) to address grid and end user challenges.

The inclusion of storage enables the end user to take advantage of time of-use-tariffs (TOUTs) as well as current and future flexibility services to reduce their energy bills and carbon impact. Interoperable predictive control allows such systems to operate at their optimum without requiring ongoing input from the end user.



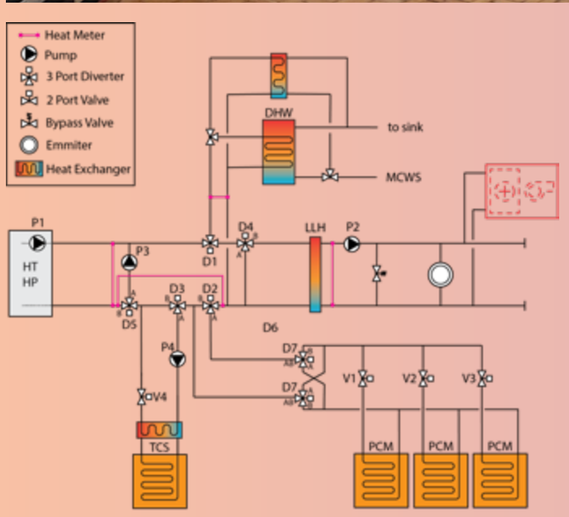


Figure 1a and 1b: ADSorB & Low Carbon Laboratory (LCL)

The LCL represents a replica of a domestic heating system installed within a set of trial properties in Nottingham, enabling developments in the design, operation and control of the storage systems and associated heating and emission equipment to be tested at system level prior to deployment.

The lab allows testing of an extensive set of system modes and offers extension to alternative heat sources and storage options. Extensive sensing and metering enables quantified testing of different technology combinations at system level, derisking in-home trials.

Thermal storage can be deployed in various forms, ranging from sensible storage - raising and lowering the temperature of the active material, as in a standard hot water tank – to advanced options that can enable higher energy storage densities and longer storage durations. These include phase change material (PCM) storage devices that involve melting and resolidifying an active material, and thermochemical storage (TCS) which involves drying out and rehydrating the active material.

The DESNZ-funded ADSorB project investigated the potential of TCS and PCM at a domestic scale as part of an automated low carbon home heating system. Both technologies offer energy storage at far greater densities than traditional hot water stores; both use materials with minimal environmental impact; both offer storage at extended durations - up to inter-seasonal in the TCS case - enabling storage of heat during the summer for later use in the winter.

During the project, trials were conducted in existing, real world testbeds at the University of Nottingham: a 1930s house retrofitted to modern standards, a low energy house and a small-scale District Heat Network (DHN) that provided a communal store to multiple properties.

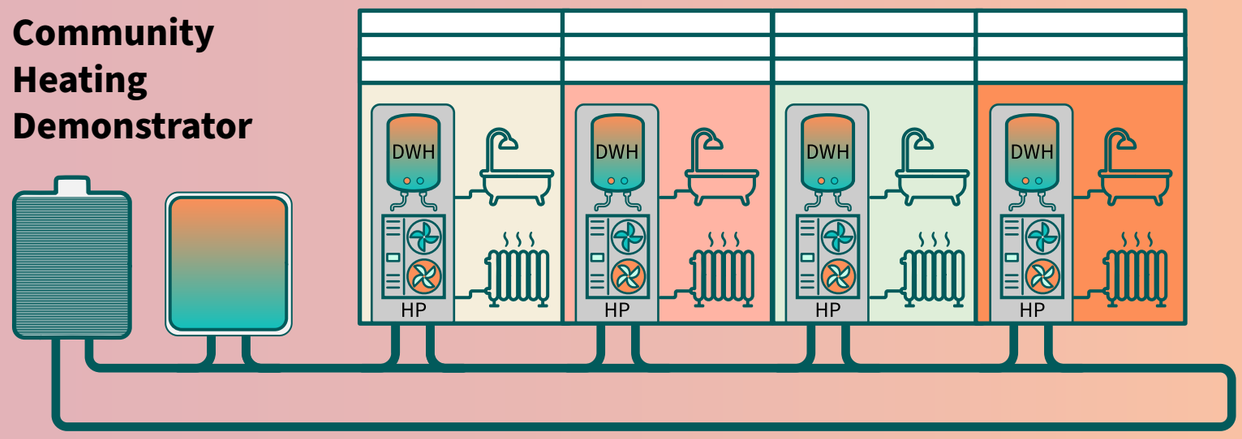
The performance of the individual stores was characterised in detail using the environmental test chamber facilities at the Laboratory for Validation and Verification (LVV) at TUoS. A further laboratory-based testbed - the Low Carbon Lab - was installed at TUoS to enable the evaluation and development of dwelling-level low carbon heating systems incorporating storage, enabling novel storage and control methodologies to be tested and refined.

Funded by the South Yorkshire Sustainability Centre (SYSC) capital fund (provided by the South Yorkshire Mayoral Combined Authority (SYMCA)) and the Grantham Centre for Sustainable Futures (GCSF) Regional Readiness Fund (RFF), the next phase of the project is currently underway and will:

- Develop the laboratory further to test dwelling level options appropriate to the region.
- Develop a new demonstrator focusing on community and district heating in the Gleadless Valley.

The latter has potential to work very well for high density building stock, minimising disruption within individual dwellings.

Community Heating Demonstrator



Community heating schemes can address decarbonisation of heat in both new and existing properties at scale, without requiring installation of entire low carbon heating systems (such as ASHPs) in each dwelling.

This minimises disruption and ongoing maintenance obligations for the end user and can address challenges around grid connection and energy flexibility (e.g. through peak shifting).

Community heat networks (CHNs) share many of the characteristics of large-scale district heat networks (DHNs), enabling research questions relevant to both to be addressed.

Evidence and Outputs

ADSorB Findings

- The research has shown that PCM stores could be suitable for direct use for either domestic hot water or low temperature space heating.
- The PCM stores have been demonstrated to be effective in enabling load shifting between peak and off-peak periods in real-world environments with scope for further development and optimisation.The commercial case could be strengthened by simplifying the product implementation and reducing costs.
- The research achieved a first-of-a-kind demonstration of a full-scale TCS device intended for use within a domestic setting. However, the TCS proposition remains some way from commercial viability, particularly in a domestic setting. More development and optimisation is needed.
- A simplified implementation method has the potential to aid commercial viability through improving system performance and minimising capital and operational costs, bringing the costs down below that for gas boilers[2]

The final report on the ADSorB project will be available here.

What does this mean for the region?

The current costs of running low-carbon energy systems are linked to electricity tariffs, the price of which is largely dictated by wholesale gas prices rather than the true cost of delivering electricity. This means that space heating using an Air-Source Heat Pump (ASHP) without other interventions - for example, fabric retrofit, thermal storage or use of TOUTs - can be higher than the cost of heating the same space with a gas boiler. This is a key barrier to increasing the uptake of ASHPs in the UK and in South Yorkshire. Thermal storage has the potential to deliver reduced operating costs for ASHPs without the costs and disruption associated with deep fabric retrofit.

Developing intelligent, low carbon systems with local thermal storage holds the potential to deliver a modern, sustainable heating system for residents at a comparable and potentially lower operational cost to gas heating. Without central government's actions to address the electricity and gas markets, implementing ASHP's on their own, without storage solutions or fabric retrofit to the buildings will increase energy bills in spite of the fact that they are more efficient than gas boilers during cold periods, particularly for properties that require a high system flow temperatures for space heating.

Innovation in these technologies is essential to secure a just transition to net-zero for those already grappling with fuel poverty and for those who may be tipped into fuel poverty if heat pump deployment increases energy bills. Moreover, to build public consent for low carbon heating systems, tangible benefits need to be identified and marketed, for example that the inclusion of storage may allow lower bills without requiring any additional input by the end user. Finally, innovation, development and optimisation in partnership with industry is needed. Innovation is particularly important in this space as a measure to mitigate the growing risk of grid overload during peak periods with more and more homes transitioning to electrified heat and electric vehicles.

However, equally important is the socialisation of the technology with residents and the demonstration of the benefits of the system, such as efficient, effective and affordable heat, with minimal maintenance requirements.

Next Steps

With funding from the SYSC (provided by SYMCA) and GCSF, this research is ongoing and features continued laboratory developments as well as the set-up of a demonstrator at the Gleadless Valley in partnership with Sheffield City Council, E.ON and Daikin.

The laboratory developments include the incorporation of solar PV generation, electrical battery storage, electric vehicle charging , and electrical plug loads alongside the existing ASHP-driven heating system, enabling development of optimal control techniques that span multiple low carbon technologies. The laboratory allows simulation of real-world behaviours, such as different space heating and hot water demand profiles, de-risking future deployments. In addition, a new thermal storage testing rig will facilitate further development of the prototype devices developed within ADSorB, and benchmarking against competing options. Next steps would be a range of in-home trials, ideally in South Yorkshire.

The demonstrator at Gleadless Valley will showcase a low temperature district heating system in the Tenants and Resident Association office. In addition to building a detailed understanding of the in-situ technical performance of this system, the project includes a Social Science work stream that will run Implicit-Association-Tests (IATs) to measure people's unconscious biases and attitudes towards low carbon heating technologies before and after engagement with the demonstrator. This will be followed by qualitative interviews to dig deeper into people's experiences, feelings and attitudes. In parallel, E.ON and Daikin will conduct a programme of public engagement activities to show residents the technology and provide information on how to manage costs.

The results from both the laboratory and demonstrator projects will be available from July 2026.

2 Winter 2025 energy prices and available Time of Use Tariffs.

Heat Network Zoning and the Alignment of Profit and Equity in District Heat Networks

Project team:
University of Sheffield: Thomas Cowley, Dr Timothy Hutty, Joseph Hammond, Prof. Solomon Brown

Challenge Statement

Achieving national net-zero targets requires the decarbonisation of heat. District heating is a proven decarbonisation option when supplied by low carbon or recovered heat sources, yet deployment across Europe is highly uneven. Uptake remains low in liberalised markets such as the UK, in contrast to coordinated municipal heat planning models that have supported higher penetration elsewhere[1] (for example, over 60% of households are connected to district heating in Denmark).

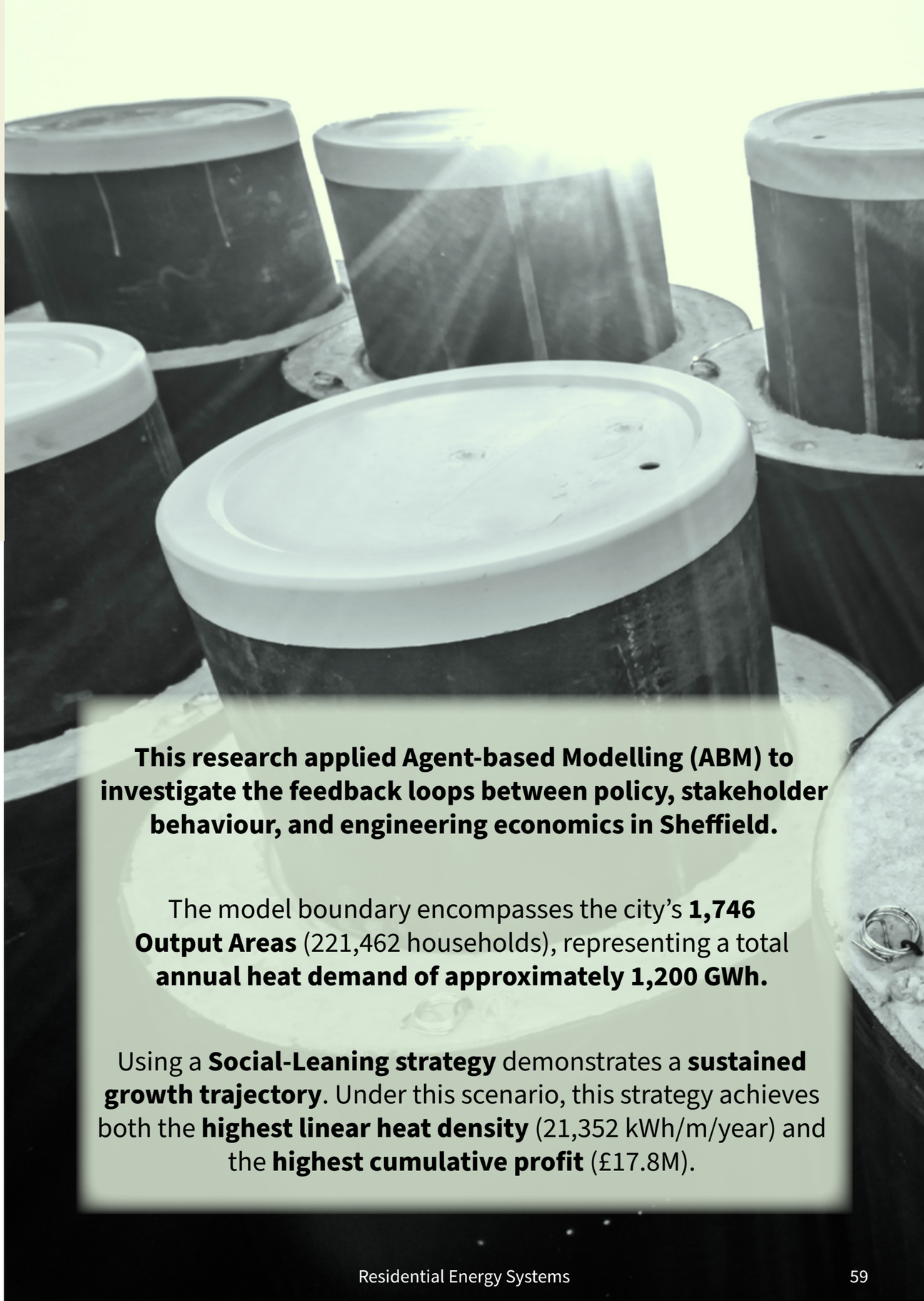
In liberalised markets, market-led rollout strategies can risk widening social inequality if less commercially attractive areas and customer segments are left unserved[2]. In response, governments including the UK are introducing policy frameworks and procedures inspired by more coordinated planning approaches, including mandatory heat network zoning[3] and area-based local energy planning[4].

The effectiveness of these top-down policies depends on how they interact with bottom-up stakeholder behaviour, resource allocation, and spatial constraints[5]. This interaction will be particularly important over the coming decade as heating policy and standards evolve to avoid locking buildings into costly or suboptimal heating pathways.

Response

This research applied Agent-based Modelling (ABM) as a means of investigating the feedback loops between policy, stakeholder behaviour, and engineering economics using the city of Sheffield as its case study. The city was selected for its diverse urban morphology, well-defined socio-economic geography, and its role as a participant in the UK Government's Heat Network Zoning pilot programme3 [12]. The model boundary

1 Hawkey, D. and Webb, J. (2014), 'District energy development in liberalised markets: situating UK heat network development in comparison with Dutch and Norwegian case studies'. Technol Anal Strateg Manag, vol. 26, no. 10, pp. 1228–1241
2 The Greenlining Institute (2019), 'Equitable Building Electrification: A Framework for Powering Resilient Communities'.
3 Department for Energy Security and Net Zero (2024), 'Heat network zoning: overview'.
4 Department for Energy Security & Net Zero (2025), 'Heat network zone opportunity report: Sheffield'.
5 Lockwood, M. and Devenish, A. (2024), 'Institutional context and the governance of heat transitions: The cases of the Netherlands and the UK'. Environ Innov Soc Transit, vol. 50, p. 100818.



This research applied Agent-based Modelling (ABM) to investigate the feedback loops between policy, stakeholder behaviour, and engineering economics in Sheffield.

The model boundary encompasses the city's **1,746 Output Areas** (221,462 households), representing a total **annual heat demand of approximately 1,200 GWh.**

Using a **Social-Leaning strategy** demonstrates a **sustained growth trajectory**. Under this scenario, this strategy achieves both the **highest linear heat density** (21,352 kWh/m/year) and the **highest cumulative profit** (£17.8M).

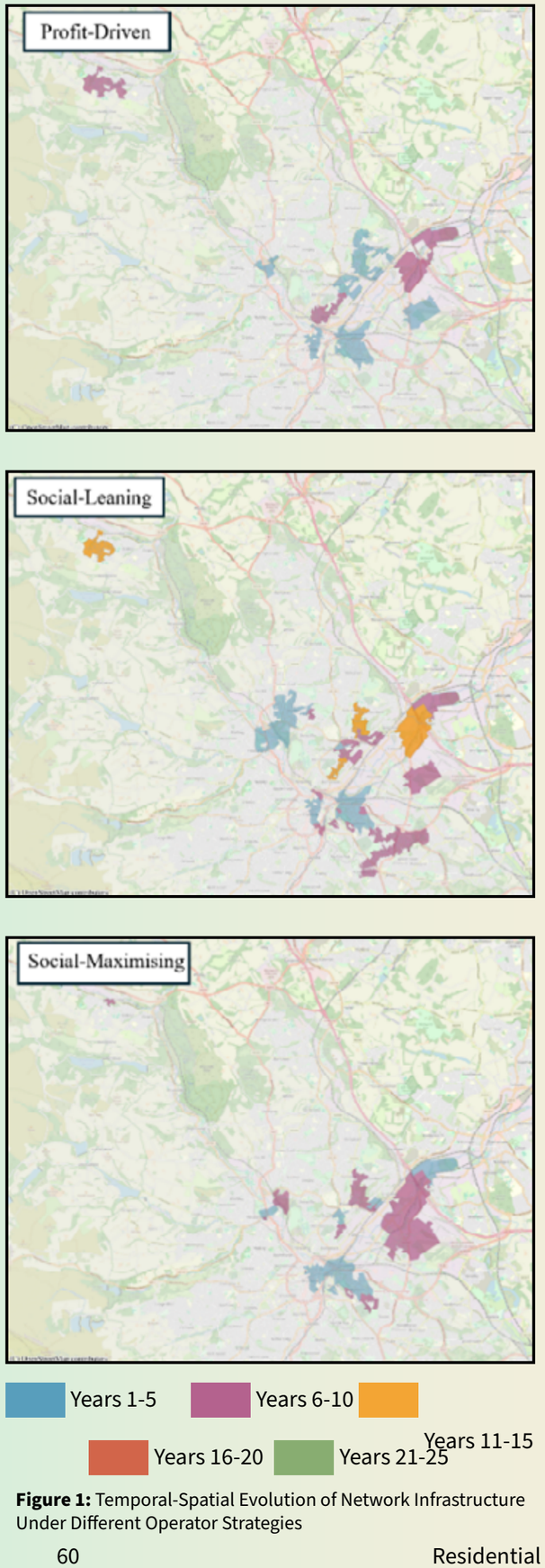


Figure 1: Temporal-Spatial Evolution of Network Infrastructure Under Different Operator Strategies

encompasses the city's 1,746 Output Areas (221,462 households), representing a total annual heat demand of approximately 1,200 GWh[6, 7, 8].

ABM was used to explore how competing planning strategies may shape spatially explicit network growth and equity outcomes in a UK case study context, comparing alternative operator investment priorities ranging from profit-driven to socially oriented objectives. The framework was also used to examine how stylised policy levers, such as heat network zoning, could influence development pathways over a 25-year simulation period (2025–2050), under two regulatory scenarios: a baseline market-driven case and a Heat Network Zoning case. The zoning scenario reflects current UK policy proposals, which introduce mandatory connection requirements for specific building types within designated zones[4].

The model explores six stylised operator strategies, represented by a single parameter (λ) that shifts investment priorities from purely profit-driven (λ=0) to strongly social-oriented (λ=5), with intermediate values representing more balanced approaches. These scenarios do not represent different organisations, but alternative strategic priorities applied within the same modelling framework.

Evidence and Outputs

The simulations identify two contrasting development pathways for district heat network (DHN) expansion under different operator strategies: early stagnation and sustained growth. Findings reflect stylised scenario simulations and illustrate mechanisms and feedback loops rather than real-world forecasts.

As illustrated in Figure 1, both the Profit-Driven and Social-Maximising strategies exhibit early stagnation, with no further network construction occurring after approximately Year 10 (an absence of orange, red, or green areas). Under the Profit-Driven strategy, deployment is limited to a small number of scattered networks that fail to achieve sufficient scale for continued growth and coverage.

6 Nomis (2021), 'Census 2021: Official labour market statistics'.
7 Department for Levelling Up Housing and Communities (DLUHC), EPC Datatables (2026), 'Energy Performance of Buildings Certificates: Live tables'.
8 Cambridge Energy (2025), 'Cambridge Housing Model (BEIS)'.

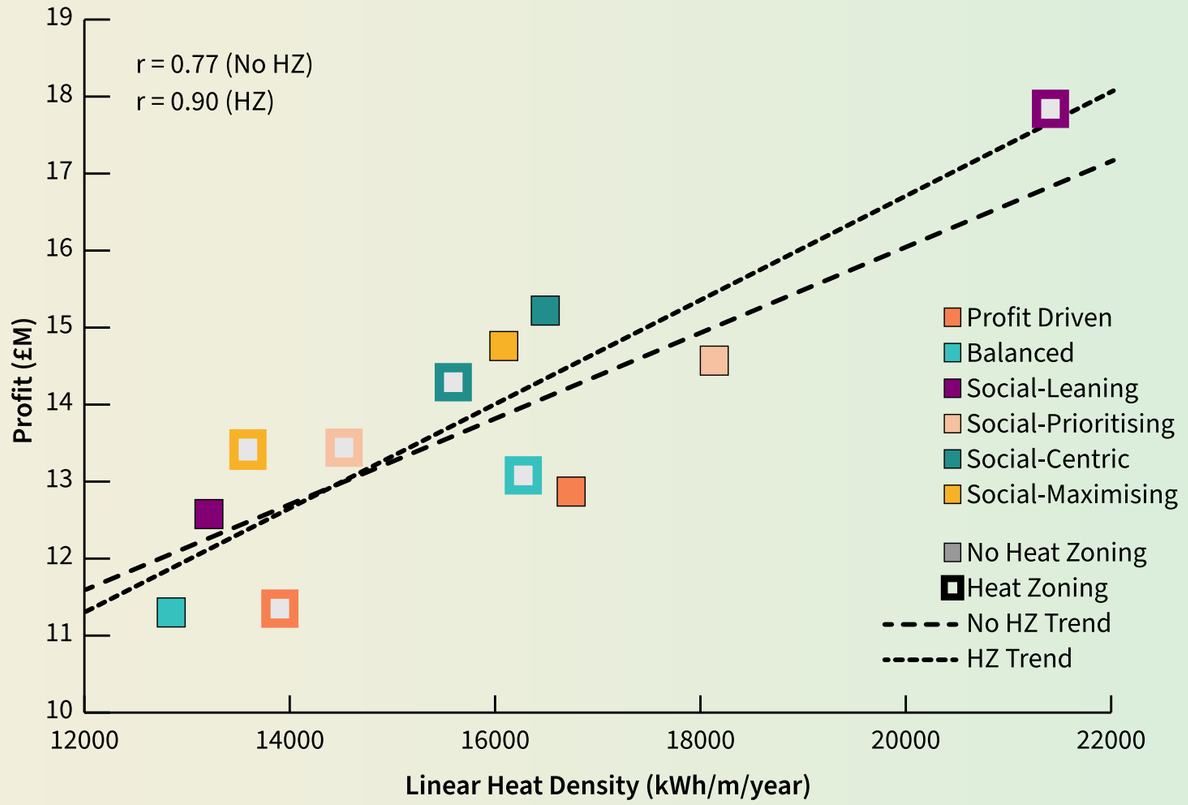


Figure 2: The Relationship Between Linear Heat Density and Financial Performance

In contrast, the Social-Maximising strategy produces an initial burst of expansion focused on high-deprivation areas, but this growth is not financially self-sustaining and subsequently stalls.

Only the Social-Leaning strategy demonstrates a sustained growth trajectory. Network expansion under this strategy occurs in multiple phases over the 25-year simulation, enabling the development of larger, more integrated networks that connect a broader range of urban areas. The mechanism in the model is that zoning increases demand certainty and scale, improving project viability and supporting continuous expansion. This reduces the tendency for purely profit driven strategies to stall due to insufficient early scale, and for purely social strategies to overextend into financially fragile buildouts. Under the zoning scenario, this strategy achieves both the highest linear heat density (21,352 kWh/m/year) and the highest cumulative profit (£17.8M) as shown in Figure 2. Cumulative profit is measured from the operator's perspective under assumed heat tariffs and costs in the model.

Figure 3 highlights how these operating differences translate into spatial equity outcomes. The Profit-Driven strategy predominantly routes infrastructure away from areas of high deprivation, resulting in fragmented networks that largely bypass higher-need communities. The Social-Maximising strategy concentrates deployment almost exclusively in the high-deprivation eastern sections resulting in two large, continuous networks that fail to expand and become isolated geographically from the rest of the city. By contrast the balanced strategy distributes infrastructure across the full socio-economic spectrum, with networks that serve both deprived and non-deprived areas within the same system.

Figure 4 illustrates a stylised household-level cost comparison under a scenario in which households are required to transition away from gas heating in 2035. The model compares the lifetime costs of individual heat pumps and access to a DHN over a 25-year period. In areas served by DHN infrastructure, households are modelled as facing lower lifetime heating costs relative to an equivalent household relying on a heat pump, with differences ranging from approximately £443 to £6,443 depending on location and assumed installation costs. In areas without DHN access,

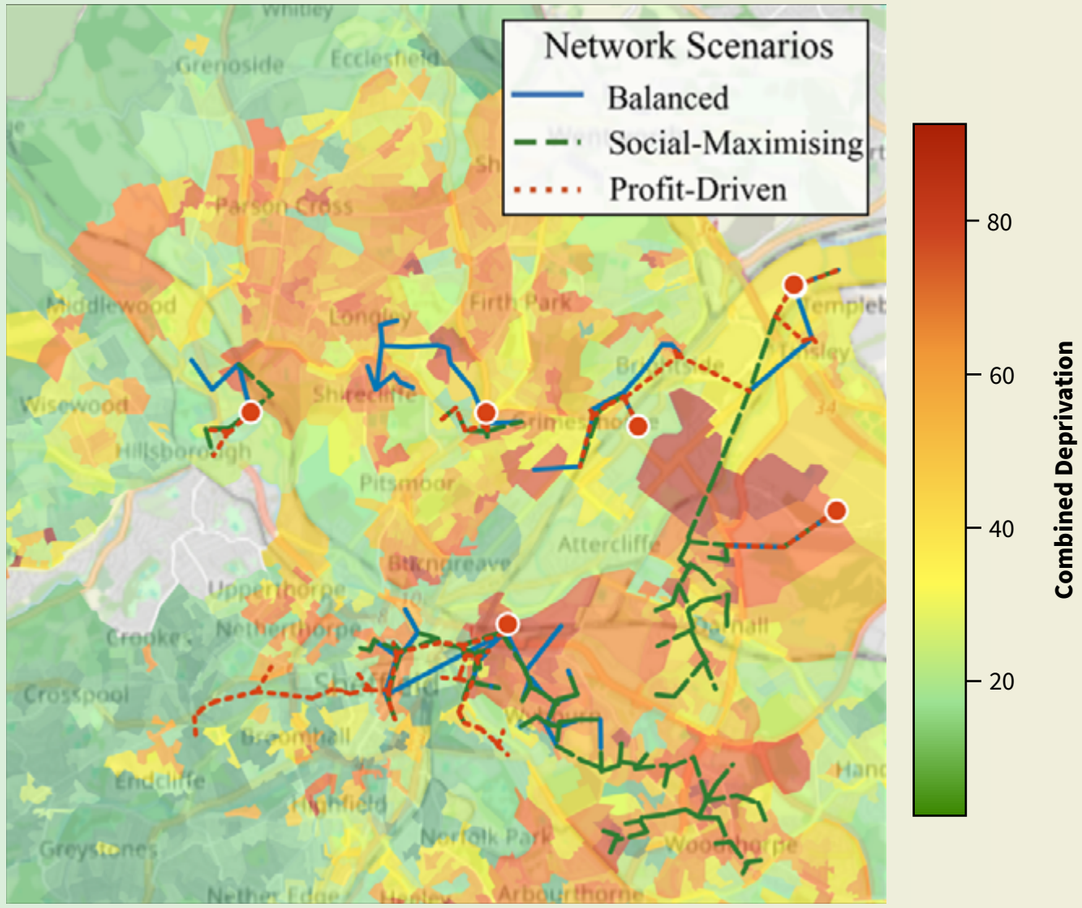


Figure 3: Spatial Distribution of Network Infrastructure Across Socio-economic Gradients

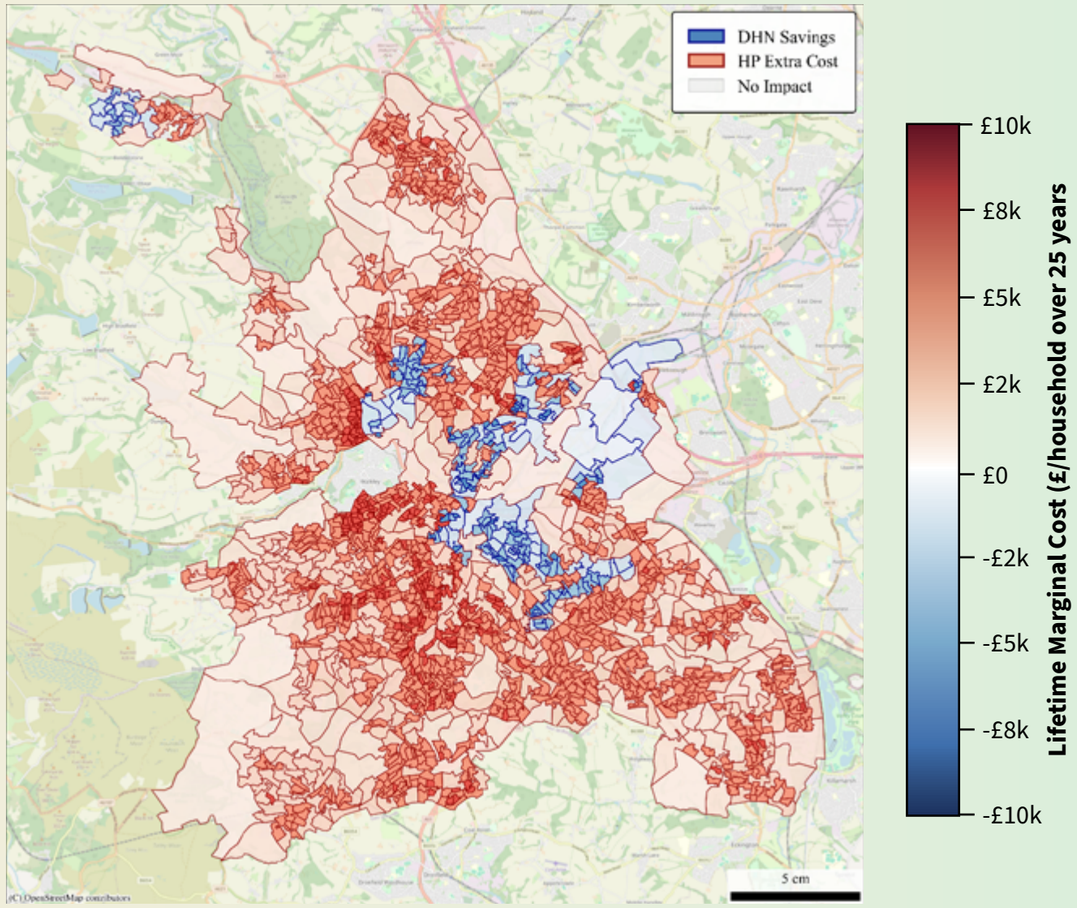


Figure 4: Illustrative Household Economic Impact of DHN Access Over a 25-Year Lifetime

households rely on individual heat pumps and face a corresponding opportunity cost relative to identical households with access to a DHN. These results are illustrative and reflect relative differences under the model's assumptions, rather than predictions of realised household savings. This comparison reflects household costs under assumed DHN tariffs and connection costs, and does not allocate wider system costs or distributional impacts beyond the household boundary.

Regional Policy Implications

The Sheffield case study indicates that coordinated spatial planning mechanisms, such as heat network zoning, can significantly influence how DHNs expand under different operator strategies and market conditions. Within the model, zoning alters investment incentives in a way that enables intermediate, social-leaning strategies to achieve both strong financial performance and broader spatial coverage, reducing the trade-off between profitability and social inclusion observed in uncoordinated market scenarios.

The analysis also highlights the potential for technology-neutral decarbonisation mandates to produce uneven, geographically determined inequities if deployed without coordination. Without planning mechanisms, commercially driven rollout may bypass less profitable areas, while early adopters of individual low-carbon technologies risk incurring higher lifetime costs or stranded investment as collective solutions later emerge.

Importantly, the results suggest that long-term financial sustainability and social equity are not inherently in conflict. Under coordinated policy frameworks, financially robust networks are better positioned to support wider inclusion through scale and cross-subsidisation. From a regional perspective, city-wide network growth emerges as a more meaningful indicator of social value than high connection rates within narrowly targeted areas.

Implications for South Yorkshire

- Use zoning to create demand certainty for anchor loads and high density corridors first, then expand into harder to serve areas once cashflows stabilise and use cross-subsidies.
- Define zoning alongside affordability and consumer protection measures, otherwise "mandated connection" can become politically fragile.
- Treat customer friction as a core delivery risk. Fund engagement and installation coordination should be seen as a programme, not a one off.

Limitations and Next Steps

Even with coordinated policy, social barriers remain important and effective delivery still depends on trust, disruption management, and service quality. Results are sensitive to assumed tariffs, subsidy levels, and household friction, so the absolute magnitudes are illustrative even where the directional effects are robust. Financial incentives alone are therefore insufficient; successful deployment requires ongoing engagement with customers and sustained focus on service delivery.

Future work could extend this analysis by incorporating additional real-world complexities, including multiple competing operators, evolving technology costs, fuel price volatility, and adaptive consumer preferences. These extensions would further support the translation of strategic insights into practical policy design.

Retrofit

Case Studies in this section:

72 Retrofit Recommendations for Regional Policymakers

74 What do Modern Methods of Construction mean for Housing Retrofit Jobs and Working Conditions?

78 Retrofit for a Healthy Building in a Warming World

82 Let Zero: A Retrofit One-Stop Shop for the Private Rental Sector

86 Archetype-Based Housing Stock Retrofit for Net-Zero South Yorkshire

90 Energy, Cost and Carbon Performance of Retrofit

94 Hydrogen and Heat Pumps in the Net-Zero Transition: Life Cycle Evidence for Building Sustainable Global Supply Chains

98 South Yorkshire's Path to Net-Zero: A Case Study on Decarbonising Regional Housing Stock

Challenge

In 2023, 1.6 Mt CO2e[1] of annual territorial greenhouse gas emissions were from domestic gas and electricity consumption in South Yorkshire. This was 25% of the total regional emissions in 2023. The Climate Change Committee (CCC), the government's advisory body, said the UK will not meet its emissions targets "without near complete decarbonisation of the housing stock[2]".

The government confirmed their commitment to the Future Homes and Buildings Standards to ensure that new homes have low-carbon heating, high levels of energy efficiency and solar panels by default[3]. However, considering that 80% of 2050's housing stock is already built[4], and that demolition is a better whole-life carbon option for only a very small subset of stock[5], there is an urgent need for housing retrofit on a national and regional scale to help to reduce household bills, cut carbon emissions, improve energy security and improve energy efficiency.

Currently, the energy efficiency of a dwelling is determined using the Standard Assessment Procedure (SAP), where energy consumption of the property is first estimated, then multiplied by the costs of energy and then divided by the property's floor area to give an energy cost factor per m2. Finally, this factor is converted to a scale from 1-100, where 1 is the least energy efficient and 100 indicates that the property has zero energy needs/costs. This scale is further divided into 7 bands (A-G), where A is given to the most efficient (92 and higher) and G to the least efficient (between 1 and 20) properties. These ratings are then used for the Energy Performance Certificate (EPC) rating accordingly[6].

The scale of the challenge is significant - 60% of homes in the UK are below an EPC band C. The combined average SAP score for South Yorkshire is 64.75, placing the region in Band D. Moreover, the current EPC assessment criteria is likely to become more stringent from mid-late 2026, with the new Home Energy Model, which is due to replace SAP[7]. Currently, EPC ratings are attached to energy costs from which energy efficiency is assumed. New standards will focus on establishing actual thermal and energy efficiency by assessing: fabric performance (insulation, draught-proofing, glazing standards), the efficiency of heating systems, smart readiness i.e. the use of smart meters and battery storage.

Retrofit is not solely a decarbonisation measure. There is a strong link between poor energy efficiency and the presence of damp and mould in homes. A 2007 meta-analysis showed a 30-50% increase in the likelihood of poor respiratory health for people living in homes with signs of dampness or mould[8]. In 2019, the presence of damp and/or mould in English residences was estimated to be associated with approximately 5,000 cases of asthma and ~8,500 lower respiratory infections among children and adults[9]. In South Yorkshire, around half of the SYSC's Household Energy Survey respondents said they had mould, mildew or damp in at least one room.

1 1 Mt = 1 000 000 tonnes
2 House of Commons Library (2024) Housing and Net Zero. Research Briefing.
3 UK Government (2026) Warm Homes Plan.
4 House of Commons (2025) Energy security and Net Zero Committee. Retrofitting homes for net zero.
5 Abbey, D., Arbabi, H. and Densley Tingley, D. (2025) Parametric contribution of building form to whole-life carbon decision-making. Royal Society Open Science, 12(7).
6 House of Commons Library (2025) Energy efficiency of UK homes.
7 Department for Energy Security and Net Zero (2025) Home Energy Model: replacement for the Standard Assessment Procedure (SAP). Consultation Outcome.
8 UK Centre for Moisture in Buildings (2019) Health and Moisture in Buildings.
9 GOV.UK. (2023). Understanding and addressing the health risks of damp and mould in the home.

The government's Department for Energy Security and Net Zero research programme 'Climate services for a Net Zero resilient world' found that a full fabric building retrofit (including wall and loft insulation, and double glazing with trickle vents) improved the consistency of indoor temperatures and reduced the presence of mould. Furthermore, the report calculated that these improvements would result in an increase of 12 Quality Adjusted Life Years (QUALYs) per 10,000 population, and a saving of around £0.3 billion to the NHS[10].

Retrofit is also a significant economic growth opportunity. The 2021 Heat and Buildings Strategy estimates that the transition to low-carbon buildings could add £6 billion Gross Value Added (GVA) and support 175,000 skilled jobs by 2030 and 240,000 skilled green jobs by 2035[11]. These estimates are also supported by more recent evidence. In February 2025, CBI Economics and Energy and Climate Intelligence Unit published The Future is Green: The economic opportunities brought by the UK's net zero economy report. The report found that the net zero sector grew 10.1% between 2023 and 2024, generating £83.1 billion in GVA, with each full time role generating 38% more in economic value than the average UK full time job[12].

One of SYSC's projects explored the opportunities and implications of pursuing Modern Methods of Construction (MMC) as a delivery system for regional retrofit. There is significant opportunity for growth in this sector; South Yorkshire has a strong array of MMC providers, 28 within 50 miles of Sheffield City region[13]. There are also existing commitments within the region to become leaders in MMC, and MMC forms a part of Sheffield's Housing Growth delivery plan (2025-2030).

There are clear advantages of MMC over traditional retrofit practice; more work is indoors, increasing productivity and improving working conditions; work places were found to be more inclusive environments for women; the required skillset tended towards generalist, problem solving skills, allowing entry from a more diverse range of careers; the shift to factory work means it's easier to positively manage the working environment and gives employees consistent commutes.

However, MMC does also risk creating repetitive, low paid work very different from the varied work that exists in parts of the construction sector. Factory work does also imply centralisation of functions, jobs are not located locally, with factory locations being based on transport links.

Overall, MMC retrofit may be easier for those outside of the construction sector to join, which is likely to be a significant benefit considering that, in the UK alone, 66,000 additional tradespeople per year are required to deliver retrofit at the pace and scale needed to meet decarbonisation goals[14].

10 Symonds, P. et al (2025) Health impacts of net-zero housing in England.
11 HM Government (2021) Heat and Buildings Strategy.
12 Energy and Climate Intelligence Unit (2025) The Future is Green: The economic opportunities brought by the UK's net zero economy.
13 Arcadis et al. (2020,) Sheffield City Region: Modern Methods of Construction (MMC) Audit: Eco System and Opportunity in the City-Region, p. 32.
14 PwC (2022), Green skills as an enabler of UK retrofit. Deep dive research report. PwC, p. 15

The scale of the challenge is significant

60%
of homes in the UK are below
EPC band C

The combined average SAP score for South Yorkshire is **64.75**

This places the region in **Band D**

If made attractive, these new jobs could create an opportunity for previously excluded groups to enter the sector[15, 16, 17] and to enjoy improved working conditions compared to traditional construction.

Along with the opportunities to bolster economic growth and create good jobs, retrofit helps alleviate fuel poverty. Improving building fabric energy efficiency reduces heat loss and thus reduces energy needed for heating, and associated energy bills. Most homes in England use gas central heating (86%), while 9% rely on other fossil fuels[18], all of which have seen significant price increases in recent years due to volatile markets and geopolitical instability. The Office for National Statistics reported that 41% of their 2024 survey respondents claiming it was very or somewhat difficult for them to afford energy bills[19]. In South Yorkshire, a SYSC Household Energy Survey found 26% of respondents in the 12 months up to January 2024 claim it was extremely or somewhat difficult to pay their home heating bills[20].

Lastly, as global temperatures rise, maximum summer air temperatures in South Yorkshire could increase by up to +7.6 C (change from the baseline period 1981-2000) by the 2080s in high emissions scenarios[21]. With 2025 being the third warmest year in UK, and all top 5 warmest years on record happening within the last decade[22], our homes will need to adapt as the risk of overheating will

15 Macrorie, R. et al. (2024), 'Support Place-Based and Inclusive Supply Chain, Employment and Skills Strategies for Housing-Energy Retrofit', in A. Crowther et al. (eds) Strengthening European Energy Policy. Cham: Springer Nature Switzerland, pp. 73–85.
16 Littig, B. (2017), 'Good Green Jobs for Whom?', in S. MacGregor (ed.) Routledge handbook of gender and environment. London New York: Routledge (Routledge international handbooks), pp. 318–330.
17 CITB and Eunomia (2021), Building Skills for Net Zero. Industry insights and analysis. CITB, p. 193.
18 HM Government (2021) Heat and Buildings Strategy.
19 ONS(2024) Cost of living insights:energy.
20 J.Carrick and M.Wood (2024) Consumption Habits - A report into household energy use in South Yorkshire.
21 https://www.ukclimateresilience.org/wp-content/uploads/2020/12/sheffield-city-pack_august-2022.pdf
22 Carbon Brief (2026) Met Office: A review of the UK's climate in 2025.

A 2007 analysis showed a **30-50% increase** in the likelihood of **poor respiratory health** for people living in **homes with signs of dampness or mould.**

In 2019, the **presence of damp and/or mould in English residences** was estimated to be associated with approximately **5,000 cases of asthma** and **8,500 lower respiratory infections** among children and adults

become increasingly more likely.

Retrofitting South Yorkshire's Housing Stock

SYSC research indicates that if South Yorkshire is to prioritise carbon reduction and align with the 1.5 °C net-zero climate target, its existing housing stock—approximately 609,000 homes, including around 480,000 houses and bungalows—would need to be retrofitted at a substantial pace. Specifically, meeting the 2050 net-zero target would require the retrofit of approximately 19,200 houses and bungalows per year, rising to around 32,000 annually to achieve the more ambitious regional net-zero target by 2040.

To maximise carbon savings, homes with higher operational energy demands, e.g. larger pre-1920s homes, should be prioritised. Using the Verisk GPS database, there are about 46,000 homes in South Yorkshire that are both above 100m2 and constructed pre-1919.

Moreover, how retrofit is designed and implemented matters enormously from an economic, social and environmental perspective. A system-first approach - where fossil fuelled heating systems (gas boilers) are replaced with electrified heating systems (such a heat pump(HP)) - would deliver a 73% operational emissions reduction but would result, on average, in 10% higher energy bills. Although heat pumps are 3.5 times more energy efficient than gas boilers, the electricity tariff is 3.9 times higher than the gas tariff (2025 prices). This approach could further exacerbate already high fuel poverty levels; 15% of South Yorkshire households live in fuel poverty according to Office For National Statistics 2023 data[23], which is unevenly distributed across the region and significantly higher in communities facing multiple disadvantages.

Our research confirms that the highest savings in both operational carbon emissions (96%) and energy bills (85%, heating temperature setpoint of 20°C) would be achieved with whole house retrofit deployment. Whole house retrofit is defined as replacing the central gas heating system with heat pumps and installing all insulation measures (wall, roof, floor) as well as high performance windows, as recommended in the UK's Building Regulations.

If whole-house retrofit is unfeasible due to the upfront investment needed, then a fabric-first (installing insulation measures, such as external, internal, cavity wall, roof insulation, triple glazed windows, etc.) approach should, in the immediate term, be prioritised over a system-first approach (replacing gas heating with heat pumps only), as it would result in higher operational emissions reductions (85%), reduce bills and make homes warmer. There will however be a tipping point before 2040 when the electricity grid is sufficiently decarbonised that systems retrofit results in the lowest whole life carbon solution, due to the additional materials being used in fabric retrofit and their embodied impacts.

Retrofit is a critical element of building a reliable and efficient low carbon energy system, but every kWh saved still carries environmental costs arising from manufacturing, raw materials extraction, transportation, installation and maintenance of the retrofit materials and systems.

SYSC research has calculated that for a typical semi-detached house emitting ~ 2.5 tonnes/year of operation carbon for heating, 5.7 tonnes of embodied carbon investment is needed to achieve a whole-house retrofit leading to a carbon payback period of 2.28 years with the average payback periods being around 2 - 4 years.

Decarbonisation of the grid would lower the embodied carbon investment of retrofit materials further. If heat pumps were deployed and all fossil fuel electricity generation was replaced, the majority of Scope 2 emissions associated with heating the home would be mitigated. However, with the government ramping up heat pump deployment, setting an installation target of over 450,000 heat pumps per year by 2030[24], and Northern Powergrid expecting the number of heat pumps in South Yorkshire to increase from around 10,000 now to 360,000 by 2050[25], the environmental impact of these technologies needs to be better understood. According to the Heat Pump Association, in 2024, based on UK sales data, the most popular type of heat pumps were air source heat pumps, specifically air to water systems (~83% of total UK sales[26]), which work with traditional radiators or underfloor heating. These types of heat pumps are preferred due to their comparatively low cost and ease of installation. SYSC life cycle assessments of different heat pumps - air-source (ASHP), ground-source (GSHP), water-source (WSHP) and hydrogen-source (HSHP) - show that air-source heat pumps currently show the highest overall environmental impacts, particularly in relation to global warming potential, ozone depletion, and ecotoxicity. An SYSC study conducted environmental impact forecasting against the UK net-zero targets, which revealed that ASHP are likely to achieve the largest carbon emission reduction over time (97% by 2050), while GSHP, WSHP, and HSHP are expected to reduce by 94%, 95%, and 59%, respectively. Across all technologies, key environmental hotspots include the use of copper and steel, refrigerant leakage, and the reliance on fossil-based electricity in manufacturing.

Furthermore, the deployment of heat pumps

23 ONS(2025) Sub-regional fuel poverty data 2025 (2023 data).

24 UK Government (2026) Warm Homes Plan.
25 Northern Powergrid (2025), Northern Powergrid DFES Local Authority Level.
26 HPA (n.d) Annual Heat Pump Sales UK.

into thermally inefficient homes risks electricity supply issues, grid overload and increased consumer energy bills that would increase fuel poverty rates. Fabric retrofit is needed to help reduce carbon emissions in the interim (until full grid decarbonisation is achieved) but also to help manage peak demand spikes and to control the costs of space and water heating for the consumer.

The heating source type is also relevant when considering fabric-first retrofit measures. A SYSC study considered whether properties should be retrofitted prior to connection to a district heat network. It found that a certain amount of retrofit interventions proved to be cost effective (cost of installation vs. operational savings and District Heat Network (DHN) infrastructure savings) for homes connected to district heat networks - loft insulation, glazing upgrade and cavity wall insulation reduce network load by 10% and energy bills, assuming thermostat temperatures were not increased. However, floor and solid wall insulation were borderline cost effective. It is important to note that these measures would still reduce heat loss and so could be considered an important intervention for alleviating fuel poverty; this recommendation is the result of an economic analysis only.

Measures to reduce bills and make homes warmer should also be prioritised in lower income households i.e. relatively cheap and easy, fabric first measures, such as draft excluders and loft insulation. For example, the Upper Don Community Energy group's 'Community Warming' project[27] provides free energy efficiency measures such as draught excluders and door curtains to people in fuel poverty and/or with ill health associated with cold and damp homes.

Retrofit, Overheating and Indoor Air Quality

Improving building fabric energy efficiency by adding insulation and establishing an airtight envelope could make a building more vulnerable to overheating and could trap indoor air pollutants, if retrofit interventions do not integrate the necessary passive and active ventilation measures or if ventilation is not installed correctly. Poorly executed retrofit can also increase the risk of damp and mould, reducing indoor air quality.

Our research found that without adding mechanical ventilation and cooling bedroom spaces, pre-and post-retrofit housing archetypes exceed various building standards' overheating thresholds for 2050 projected weather conditions[28]. Reversible heat pumpss, which could provide both heating and cooling, would be an option to reduce peak temperatures, particularly in vulnerable households.

Fabric retrofit also helps protect buildings from overheating and reduce grid demand. Homes with system-only retrofit or existing fabric construction are vulnerable to extreme summer temperatures and thus higher peak cooling loads, e.g. average of 31.2 kWh/day in 2050 weather. Fabric retrofit reduces this to 15.9 kWh/day.

However, fabric retrofit reduces background ventilation, which impacts temperature, humidity, CO2, particulate matter, volatile organic compounds and formaldehyde levels within homes. Most rooms in post-retrofit archetypes experience above the recommended indoor CO2 concentration levels (500ppm above outdoor) in cooler seasons. More research is being conducted in partnership with Doncaster City Council through a SYSC & Grantham Centre funded project that seeks to understand the health impacts that come with energy efficiency improvements, positive or negative.

Additional passive ventilation, e.g. trickle vents in windows, or mechanical ventilation, potentially with heat recovery, is recommended as part of retrofit measures in order to improve indoor air quality and help manage internal temperatures during hot weather.

27 Upper Don Community Energy group's 'Community Warming' project https://www.udcommunityenergy.co.uk/cwp.html

28 University of Exeter (2025) PROMETHEUS: Probabilistic Future Weather Research Project.

The Office for National Statistics reported **41%** of their 2024 survey respondents claimed it was **very or somewhat difficult for them to afford energy bills**

In South Yorkshire, an SYSC Household Energy Survey found **26%** of respondents in the 12 months up to January 2024 claimed it **extremely or somewhat difficult to pay home heating bills**

The Rebound Effect

Real-world energy use and carbon savings from post-retrofit homes could significantly diverge from theoretical models due to occupant behaviour and individuals' comfort needs. The rebound effect describes an increase in occupant energy consumption as a result of increased efficiency and decreased costs.

An SYSC study explored the sensitivity of operational carbon emissions and energy costs to changes to heating and cooling temperature set points. The results show that by increasing the heating set point from 18°C to 20°C, the average annual heating demands of existing homes could increase from 14,500 kWh/a to 21,500 kWh/a, a 48% increase.

Over 88% of respondents to our survey said that they set their thermostat to 18 degrees or higher, with 16.1% saying that they set it to 22 degrees or more . If energy bills decrease with increased efficiency, residents may just increase the thermostat, increasing operational emissions (compared to SYSC modelling) and causing a greater risk of grid overload, particularly in affluent areas.

Therefore, we recommend a retrofit policy that integrates behaviour change design for energy consumption (e.g., education and reward programs), user engagement strategies, and provides necessary information about retrofit sensitivities in different archetypes.

Retrofit Recommendations for Regional Policymakers

1. In order to **maximise carbon** savings from retrofit programmes in an environment where both finances and grid capacity is constrained, **local authorities should prioritise the retrofit of larger, pre-1920 properties (over 100m2), and the associated engagement with able-to-pay groups.**

   i. South Yorkshire's Path to Net-Zero: A Case Study on Decarbonising Regional Housing Stock.

2. **Working with local providers, a whole house retrofit approach (fabric and system) should be taken to best manage peak electricity demand periods** (avoiding substation overload) and to control the costs of space and water heating for consumers. This will also reduce operational carbon emissions until the grid is fully decarbonised.

3. In parallel with retrofit deployments, **local policymakers should support the deployment of relatively cheap and easy measures to low income households that could reduce bills and make homes warmer.** Measures could include draft excluders and loft insulation, delivered in partnership with Community Energy groups.

4. Regional retrofit initiatives must ensure that all retrofit designs include adequate ventilation (passive or active) to ensure good indoor air quality, and to avoid exacerbating existing health inequalities. **Local authorities should continue to collaborate with universities to understand and model the health risks and necessary mitigations to ensure safe retrofit.**

   i. Retrofit for a Healthy Building in a Warming World.

5. Local authorities should work with partners to produce **seasonal public education campaigns that support communities to become more resilient to extreme heat** by promoting summertime ventilation practices and relatively cheap adaptations such as external shutters.

   i. Retrofit for a Healthy Building in a Warming World.

Further Research Opportunities

Heat pump supply chains: Future research should extend life cycle analysis to include recycling and end-of-life pathways, alongside socioeconomic modelling of job creation. A comparative cost–benefit analysis of reshoring versus importing under different grid scenarios would also provide valuable guidance for investment and policy decisions.

Retrofit work pathways: Further research could compare findings on work implications for Modern Methods of Construction (MMC) with other retrofit pathways, for example, retrofit delivered by large incumbent organisations such as energy companies, community-led retrofit and SME led retrofit.

Retrofit deployment: Following on from the Let Zero project, more research is needed to understand the drivers, barriers and opportunities for other user groups such as 'able-to-pay' or homeowners that would need financial support.

Public consent: More research is needed in South Yorkshire to better understand the barriers and resistance to adoption of retrofit measures and develop strategies to unlock public consent for retrofit action in the region, particularly in local authority properties that might be prioritised for retrofit.

What do Modern Methods of Construction mean for Housing Retrofit Jobs and Working Conditions?

Project team:
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Challenge Statement

Increasing attention is being paid to implications of decarbonisation for economic activity, labour markets and worker experiences. In this project, we drew attention to the work involved in foundational activities that underpin the green transition. Retrofit has been promoted as a stimulus for creating quality green jobs[1], and the demand for labour to meet retrofit targets has been well documented[2, 3, 4]). In the UK alone, 66,000 additional tradespeople per year are required to deliver retrofit at the pace and scale needed to meet decarbonisation goals[5]. If made attractive, these new jobs could create an opportunity for previously excluded groups such as women to enter the sector[6, 7, 8]). However, little attention has been paid to the conditions and quality of such work.

There is a growing interest in 'good work' as a mechanism for increasing productivity, creating positive social outcomes and increasing innovation. A focus on the nature and quality of work is also central to those concerned with a just transition, in which communities previously excluded have new opportunities in a 'green economy'[9]. There is no single definition of good work, but many definitions include six key dimensions of job quality: pay and other rewards; intrinsic characteristics of work; terms of employment; health and safety; work–life balance; representation and voice[10].

The construction sector is below average in terms of quality work indicators due to lack of permanent contracts, long working hours[11], and a high rate of false self-employment[12]. There is a lack of societal prestige in retrofit and the construction sector[13], as well as a lack of diversity. Less than 10% of workers in construction are female, and only 6% Black and minority ethnic (BME)[14]. There is a need to diversify the workforce to drive innovation, create more welcoming work environments and boost productivity in retrofit (Jenkinson and Palmer, 2025).

Modern methods of construction (MMC) have been proposed to increase pace, scale, and quality of retrofit delivery through increased digitisation, automation and offsite manufacture. These include digital tools and techniques, offsite manufacturing and design approaches (e.g. platform approaches), and improved processes that improve the precision, predictability and efficiency of construction.

Similar to retrofit, it is framed as a response to the productivity and skills crisis in the construction industry, promising to bridge the skills gap and provide better quality jobs. While concerns have been raised about MMC removing regulatory barriers in construction, and 'uberizing' workers[15], alongside high profile exits and insolvencies of large MMC firms[16], the MMC literature has tended to be pro-innovation, lacking interrogation of implications for work[17].

1 Brown, D. et al. (2020), A Green Stimulus for Housing: The macroeconomic impacts of a UK whole house retrofit programme. New Economics Foundation, p. 35.
2 CITB and Eunomia (2021), Building Skills for Net Zero. Industry insights and analysis. CITB, p. 193.
3 PwC (2022) Green skills as an enabler of UK retrofit. Deep dive research report. PwC, p. 15.
4 Jenkinson, C. and Palmer, P. (2025), Policy Recommendations for a National Workforce Strategy. Bognor Regis: National Retrofit Hub, p. 71.
5 PwC (2022) Green skills as an enabler of UK retrofit. Deep dive research report. PwC, p. 15.
6 Macrorie, R. et al. (2024), 'Support Place-Based and Inclusive Supply Chain, Employment and Skills Strategies for Housing-Energy Retrofit', in A. Crowther et al. (eds) Strengthening European Energy Policy. Cham: Springer Nature Switzerland, pp. 73–85.
7 Littig, B. (2017), 'Good Green Jobs for Whom?', in S. MacGregor (ed.) Routledge handbook of gender and environment. London New York: Routledge (Routledge international handbooks), pp. 318–330.
8 CITB and Eunomia (2021), Building Skills for Net Zero. Industry insights and analysis. CITB, p. 193.
9 Atkins, E. (2023) A just energy transition: getting decarbonisation right in a time of crisis. Bristol: Bristol University Press.
10 Warhurst, C., Wright, S. and Lyonette, C. (2017), Understanding and measuring job quality. Research report. Part 1 – thematic literature review. London: CIPD, p. 42.
11 PwC (2022) Green skills as an enabler of UK retrofit. Deep dive research report. PwC, p. 15.
12 Taylor, M. et al. (2017) Good Work: The Taylor review of modern working practices.
13 PwC (2022) Green skills as an enabler of UK retrofit. Deep dive research report. PwC, p. 15.
14 Macrorie, R. et al. (2024), 'Support Place-Based and Inclusive Supply Chain, Employment and Skills Strategies for Housing-Energy Retrofit', in A. Crowther et al. (eds) Strengthening European Energy Policy. Cham: Springer Nature Switzerland, pp. 73–85.
15 Green, S.D. (2022), 'Modern methods of construction: reflections on the current research agenda', Buildings and Cities, 3(1), pp. 653–662.
16 Wallace, A. et al. (2025), Prefabs sprouting: Modern Methods of Construction and the English housing crisis, p. 42.
17 Ibid

South Yorkshire has a strong array of MMC providers, 28 within 50 miles of Sheffield City region[18]. There are existing commitments within the region to become leaders in MMC[19], and MMC forms a part of Sheffield's Housing Growth delivery plan (2025-2030). Barnsley College has opened the first dedicated MMC training centre in the UK[20].

Research Response

Retrofitting highlights particular challenges for MMC given the unpredictability and varied conditions of buildings, with consequent implications for work that might differ from new-build MMC. It is therefore a useful context to examine the claims of MMC and outcomes for work. Using a political economy lens, we examine implications of MMC-retrofit for work through a framework of three interlinked factors: context, conditions and experience of work. Our investigation is guided by three questions:

1. How does MMC change the context for work (e.g. workplaces and job location)?
2. What are the working conditions of MMC, and to what extent can MMC be used to create good quality retrofit jobs?
3. How do these aspects come together to shape experiences of work, including skills, intrinsic characteristics of work and workplace inclusivity?

Evidence and Outputs

Initial findings of qualitative research with MMC providers and stakeholders including trade unions, local authorities and combined authorities include a range of implications for MMC retrofit pathways on the quality and conditions of work:

Working indoors: MMC approaches to retrofit allowed a greater proportion of work to be conducted indoors. This not only enabled more work to be delivered (as there were less pauses due to inclement weather, and the ability to take on work all year round) but also created more pleasant and safe working environments.

More inclusive workplace cultures: Respondents noted that their workplace culture was less masculine, allowing them to attract and retain women in the business. More inclusive working environments were understood as beneficial for all employees.

Diverse career pathways drawing on a range of skills: Many employees came from careers outside of construction, including catering and animation. This included people retraining from a wide range of industries who were attracted by the mission and quality of jobs in MMC retrofit.

Focus on generalist skills, soft skills and 'deskilling': Respondents emphasised the role of soft skills, particularly problem solving, in MMC retrofit. They valued generalist skills in their employees. They described MMC as 'deskilling' retrofit, by simplifying the process and reducing reliance on skilled trades. However, the workflows developed were product-specific and could not be directly applied in other MMC businesses.

Relationship between good work and good retrofit: Respondents saw a link between good working conditions and good quality retrofit installation.

Limitations to being able to apply good work practices: One of the organisations had experimented with flexible working arrangements as a way of improving their offer to employees. However, it raised health and safety concerns for lone working; presenting challenges for clearing up at the end of each day, and there were limits to what work could be completed with one person. The specifics of retrofit installation therefore acted as a barrier to applying some good work practices.

This small sample size and focus on SMEs clearly does not paint a full picture of MMC retrofit working conditions. Through the project, we will investigate larger MMC companies, alongside the three additional retrofit pathways, to analyse the implications of different pathways on good work, aiming to produce a paper specifically on MMCs, retrofit and good work.

What does this mean for the region?

Using MMC to meet retrofit targets has significant implications for working conditions, and thus for the region.

- **Location of work:** MMC takes place in different work locations to traditional construction work. This includes a large focus on factory work. This has positive implications, such as making commutes consistent, and working environments safe and controlled. However, it can mean that jobs are not located locally, with factory locations being based on transport links, such as the M1.
- **Training provision and career pathways:** MMC requires different skills (and training) to traditional retrofit approaches. This can include the elimination of wet trades (such as plastering) and a focus on more general joinery skills. This means that current approaches to upskilling the construction sector and promoting construction career pathways may be inappropriate for MMC pathways.
- **Just transition:** MMC has the potential to create more inclusive workplace cultures. The opportunity for flexible working, predictable work patterns and consistent work locations can make the retrofit industry attractive for groups currently excluded from construction. However, MMC can also be repetitive and low-skilled, replacing the varied work that currently exists in some parts of the construction sector. Ensuring that existing construction workers are not excluded from MMC retrofit pathways whilst making it inclusive is a key concern for just transition in South Yorkshire.

Next Steps

We are carrying out additional research with MMC providers and key stakeholders in the region, including training providers. This could then be compared to the implications for work in other retrofit pathways, for example, retrofit delivered by large incumbent organisations such as energy companies, community-led retrofit and SME led retrofit.

18 Arcadis et al. (2020,)Sheffield City Region: Modern Methods of Construction (MMC) Audit: Eco System and Opportunity in the City-Region, p. 32.
19 Ibid.
20 Barnsley College (2025), ***UK's First MMC Training Facility. Barnsley College***.

Retrofit for a Healthy Building in a Warming World

Project team:
University of Sheffield: Dr May Zune, Dr Hadi Arbabi, Dr Danielle Densley Tingley

Introduction

Improving building fabric energy efficiency by adding insulation and keeping an airtight envelope could make a building more vulnerable to overheating and trap indoor air pollutants if the retrofit interventions do not integrate necessary active and passive ventilation measures[1]. Limited understanding of cooling and ventilation demand in system and fabric retrofit interventions, retrofit policy research and practice[2]. More robust overheating regulatory standards and indoor environmental quality guidelines are urgently required for the UK[3] to ensure heat decarbonisation and cooling resilience are achieved through net-zero retrofit delivery.

Focusing on South Yorkshire's climate context, our simulation-based research investigates overheating and air quality risks across fourteen low-rise housing types, and the results are compared for existing, system-only and whole-house retrofit.

The risks of overheating and lack of ventilation in system-only and whole-house retrofit homes

Overheating risks:

Without adding mechanical ventilation and cooling, for 2050 and 2080 projected weather years, bedroom spaces across pre- and post-retrofit models exceed various building standards' overheating thresholds, such as:

- **Passivhaus -** international energy performance standard for buildings, whose design aims to reduce the requirement for space heating and cooling.
- **CIBSE TM59 -** the UK's standardised methodology used to predict and assess

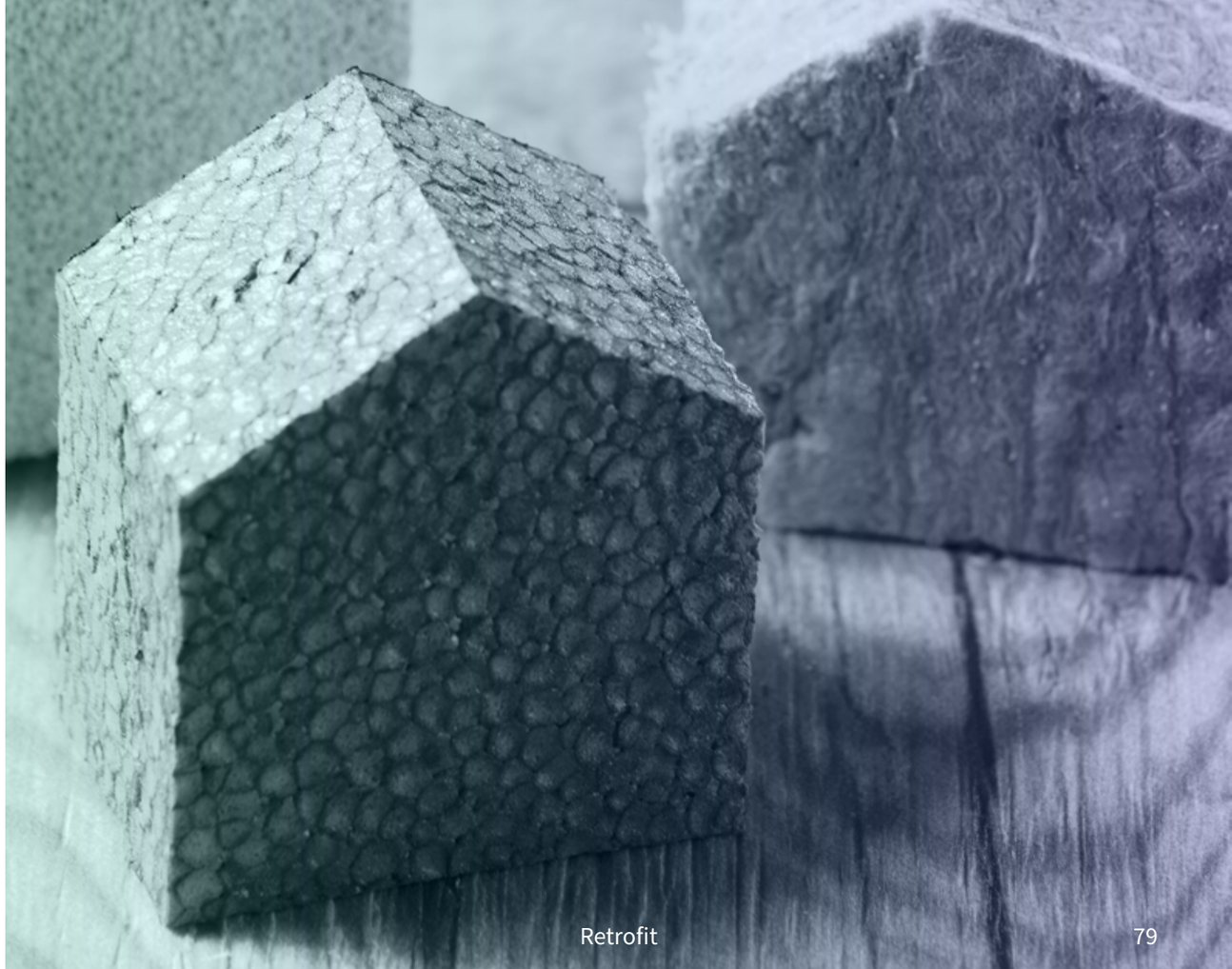
1 Coggins, A.M., Hogan, V., Mishra, A.K., Norton, D., Foster, D., Wemken, N., Cowie, H. and Doherty, E. (2024), Energy retrofits: Factors affecting a just transition to better indoor air quality. Indoor Environments, 1(4), p.100058
2 Khosravi, F., Lowes, R. and Ugalde-Loo, C.E. (2023), Cooling is hotting up in the UK. Energy Policy, 174, p.113456.
3 Attia, S., Benzidane, C., Ramin Rahif, Deepak Amaripadath, Hamdy, M., Holzer, P.J., Koch, A., Maas, A., Sven Moosberger, Petersen, S., Mavrogianni, A., María, J., Almeida, M., Akander, J., Hossein Khosravi Bakhtiari, Kinnane, O., Risto Kosonen and Carlucci, S. (2023), Overheating calculation methods, criteria, and indicators in European regulation for residential buildings. Energy and Buildings, 292, pp.113170–113170

To mitigate future overheating active cooling may be required.

Results highlight that homes with system-only retrofit or existing fabric construction are vulnerable to extreme summer temperatures and thus higher peak cooling loads.

Average of
31.2 kWh/day
in 2050 weather

Fabric retrofit reduces this to
15.9 kWh/day



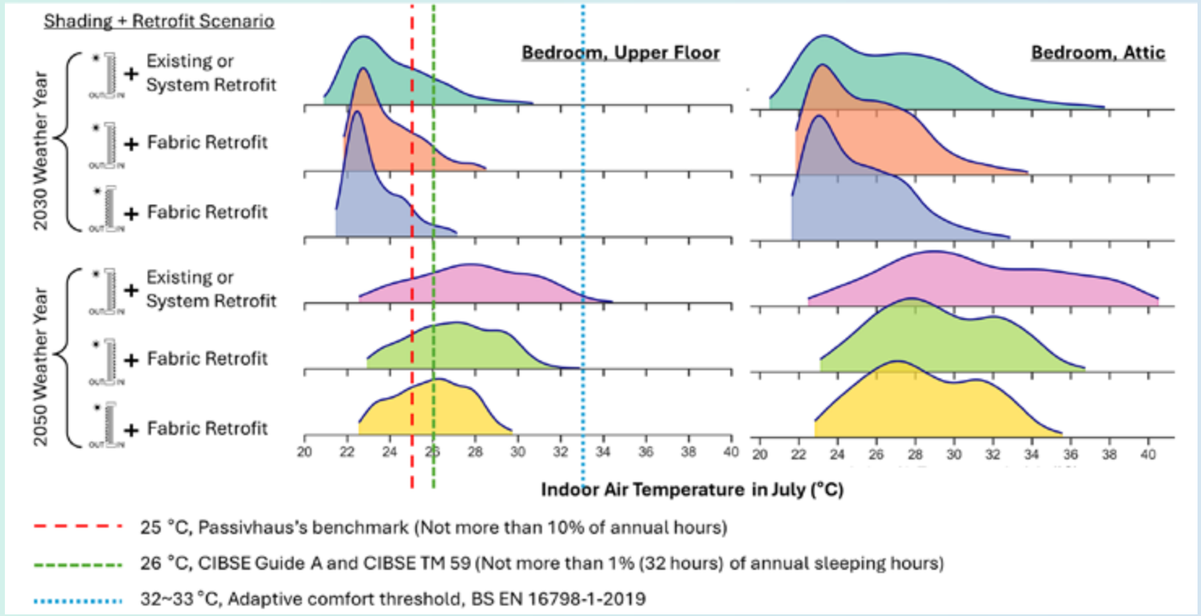


Figure 1: Indoor air temperature distribution in July, indicating the results of different retrofit and shading scenarios in the projected 2030 and 2050 weather.

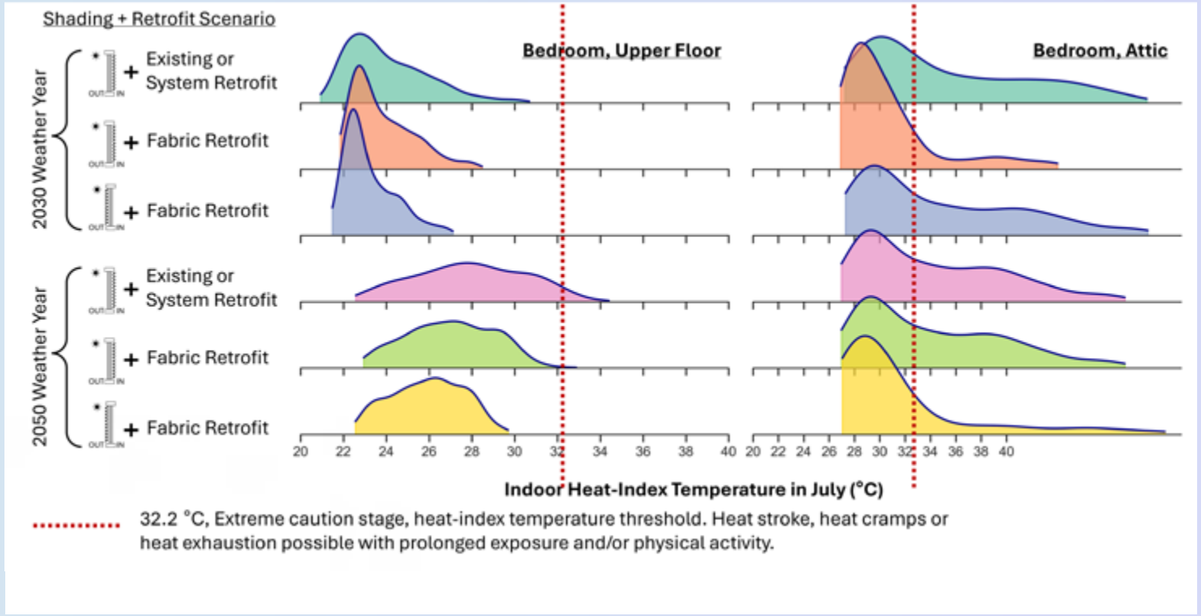


Figure 2: Indoor heat-index temperature distribution in July, indicating the results of different retrofit and shading scenarios in the projected 2030 and 2050 weather.

the risk of overheating in new and existing residential homes.

- **Adaptive thermal comfort model -** recommended in the European EN 16798-1, which defines the comfortable indoor temperature threshold in naturally ventilated buildings.

- **32.2 °C heat-index thresholds** - widely used in the US National Weather Service and Heat-health warning systems.

This means that, whilst the results of a typical end-terrace house show fabric retrofit mitigates extreme temperatures by providing a thermal barrier, it could also increase daily mean temperatures.

- Passive measures to reduce overheating: The effectiveness of opening a window at night (i.e., night-purge ventilation) is more profound after a fabric retrofit, as extreme and median indoor temperatures are reduced, but all housing types, pre- and post-retrofit, benefit from nighttime ventilation. However, noise and safety concerns could arise for this approach. The summer overheating hours can be further reduced by adding external shading, again, most effective when combined with fabric retrofit, although still hovering around recommended limits.

- Indoor air quality: Fabric retrofit typically aims to improve the air tightness of a building. Whilst this reduces heat loss, it also reduces background ventilation. As a result of this, most rooms in all post-retrofit scenarios in all building types experience above the recommended indoor CO2 concentration levels (500ppm above outdoor) in cooler seasons. Additional passive ventilation, e.g. trickle vents in windows, or mechanical ventilation, potentially with heat recovery, is recommended as part of retrofit measures in order to improve indoor air quality.

- Future cooling demands: To mitigate projected future overheating (in 2050 and 2080), active cooling may be required. The results highlight that homes with system-only retrofit or existing fabric construction are vulnerable to extreme summer temperatures and thus higher peak cooling loads, e.g. average of 31.2 kWh/day in 2050 weather. Fabric retrofit reduces this to 15.9 kWh/day.

Recommendations for South Yorkshire and the UK

- **Reversible heat pump:** Our results show that even with added passive measures, such as an external shutter for window shading or ventilation for passive cooling, all housing types in different retrofit scenarios could experience overheating in an additional one-degree (2.5 °C) warming scenario. As ongoing climate change alters the heating and cooling demands from homes, active cooling and temperature management represent a lasting challenge in the years to come. Given that the life spans of heat pumps vary between 15 to 20 years, a reversible heat pump is an option to provide both heating and cooling to maintain necessary building performance and reduce peak temperatures, particularly in vulnerable households.

- **Retrofit design:**

  - Whole house retrofit approaches, e.g. integrating fabric and systems retrofit, minimise heating and cooling needs, and are thus recommended.

  - All retrofit designs must ensure ventilation (passive or active) is adequate to ensure good indoor air quality.

  - Integrating external shutters to provide summer shading can be beneficial to reduce indoor air temperatures and cooling loads. Adjustable/movable shading is recommended so that daylighting and solar gain can be maximised during non-summer months.

  - Local Authorities could utilise various communication channels, e.g. their websites and social media pages, to run campaigns around effective summertime ventilation practices e.g. shutting windows during peak daytime temperatures and practising night purge ventilation, to improve indoor comfort and summertime overheating risks.

- **Retrofit policy:** We recommend that Mayoral Combined Authorities with devolved retrofit remit consider future heating, cooling and ventilation demands to improve indoor comfort and air quality levels now and in the future, especially within regional retrofit policy development and implementation.

Let Zero: A Retrofit One-Stop Shop for the Private Rental Sector

Project team:
Sheffield Hallam University: Prof. Will Eadson, Dawn Witherley, Dr Ella Hubbard, Dr Tom Archer, Dr Lindsey McCarthy, Dr Yael Arbel

All images in this section with thanks to James Morris/Nimble Photography

Challenge Statement

Retrofit One-stop shops (OSSs) aim to simplify the retrofit process for potential customers by coordinating the different actors involved, by offering independent advice, including technical measures and financing options, and by acting as a single point of contact for retrofit delivery. Proponents for OSSs see them as a way of generating demand; allowing the supply chain to invest in training and accreditation; overcoming poor quality work and building trust between customers and the supply chain; and simplifying the customer journey to minimise drop out.

Existing OSSs have largely targeted the owner-occupier market. However, a third of houses in the UK are privately rented and more than half of which have an EPC of D or lower[1]. 37.7% of homes in the private rental sector (PRS) in South Yorkshire fail the Decent Homes Standard[2].

The private rented sector (PRS) has proven difficult to engage with retrofit. This is often attributed to the 'split incentive' problem, where landlords bear the costs of property upgrades while tenants benefit from the reduced energy bills, resulting in limited incentives to retrofit their properties[3]. Similarly, the 'principal agent' problem, in which tenants are assumed to not be willing to pay a premium for energy efficient properties, limits demand[4]. There is a need to create new approaches to retrofit for the PRS, that go beyond current financial instruments[5].

Research Response

How can research contribute to confronting this challenge at a regional level?

The Let Zero project aimed to create an OSS for the PRS in South Yorkshire. This included piloting a face-to-face service for offering landlords and tenants retrofit advice, developing an online platform with innovative digital tools to support retrofit decision making, and a show home demonstrating retrofit measures designed to minimise disruption.

Research by Sheffield Hallam University investigated how a One Stop Shop (OSS) for housing retrofit in the PRS can be designed and implemented to inform a just transition in South Yorkshire, embedding the lived realities of local actors.

Research questions:

1. What is the current landscape of retrofit OSSs in the UK and Europe, and how can their shared experiences inform the development of an OSS for the PRS in South Yorkshire?
2. How do landlords and tenants perceive retrofit and the role of OSSs, and how can this inform the design of an OSS for the PRS?
3. What relationships have been built through the Let Zero OSS pilot, and how has the OSS changed the delivery of retrofit in South Yorkshire?

Evidence and Outputs

One-stop shops: The existing landscape and lessons for an OSS in South Yorkshire

Our research found that most existing OSSs offer advice and coordinate market players, but leave contracting to the homeowner (described as a coordination model[6, 7]). Few OSSs directly target the PRS, instead targeting the able-to-pay market.

While existing OSSs had a variety of organisational and business models, the most successful ones had clear objectives and values that aligned stakeholders and services offered, enabling good governance. They had also adopted strong customer management systems that tracked the customer journey (from advice to installation), which could take several years.

The project found that the key challenges for OSSs

1 Department for Levelling Up, Housing and Communities (2025), English Housing Survey 2021 to 2022: private rented sector.
2 Ibid.
3 Melvin, J. (2018), 'The split incentives energy efficiency problem: Evidence of underinvestment by landlords', Energy Policy, 115, pp. 342–352.
4 Ambrose, A. and McCarthy, L. (2019), 'Taming the "masculine pioneers"? Changing attitudes towards energy efficiency amongst private landlords and tenants in New Zealand: A case study of Dunedin', Energy Policy, 126, pp. 165–176.
5 Mininni, G.M. et al. (2024), 'Landlords' accounts of retrofit: A relational approach in the private rented sector in England', Energy Research & Social Science, 118, p. 103742.
6 Cicmanova, J., Esiermann, M. and Maraquin, T. (2020), 'One-stop-shop guide for sustainable home renovation: Setting up innovative local or regional renovation platforms'.
7 Bertoldi, P. et al. (2021), 'The role of one-stop shops in energy renovation - a comparative analysis of OSSs cases in Europe', Energy and Buildings, 250, p. 111273.

are additional costs associated with coordinating suppliers, known as transaction costs, and the risk and costs of contracting work or making referrals.

Landlord perspectives of retrofit and implications for OSS design

Landlords have varying motivations for improving the energy efficiency of their properties: these might include enhancing tenants' quality of life and addressing environmental concerns, but the predominant reason is to meet regulatory requirements.

There are major barriers to retrofit for landlords relating to property characteristics, planning and regulation, funding and finance, and deficits in knowledge. While financial products such as low/no interest loans will help some, others are daunted by the task of meeting new requirements and may exit the market.

There is a cohort of 'DIY landlords' who prioritise carrying out works themselves. These landlords may display resistance to advice on the best retrofitting options and working with preferred/ accredited contractors.

When presented with the value propositions of an OSS, landlords interviewed identified design advice, trusted trader schemes, and supporting access to grants, as the main services of value.

Tenant perceptions of retrofit and implications for OSS design

Tenants reported multiple barriers to improving energy performance, with some highlighting specific property issues, and others stressing their lack of influence with the landlord. Interviewees described the potential consequences of property improvements, which included both potential improvements to quality of life and energy bill savings. However, there were worries that this may be offset by higher rents.

Tenants would value an OSS advising them on their tenancy rights and moving-out processes/ costs. Others highlighted how an OSS might broker discussions between landlords and tenants, potentially offering guarantees and/or support to tenants if they were negatively affected. There was also a desire for scripts or templates to help tenants start conversations about retrofit with landlords as part of an OSS offering.

Changing relationships and delivery of retrofit in South Yorkshire

Stakeholders in the region felt that Let Zero has made good progress in embedding retrofit in South Yorkshire and the PRS. There is an increasing focus on retrofit within the region, and a growing network of retrofit practitioners. The project has been described as a 'centre of gravity' for retrofit in the region, shifting expectations around retrofit delivery. It has also experimented with new tools to scale retrofit, establishing a clearer understanding of how emerging technologies can be utilised. Through the project, partners have developed their businesses, grown networks and gained expertise in working with the PRS. Respondents felt that SYMCA is well positioned to take strategic oversight and drive retrofit through an OSS service such as Let Zero.

Outputs:

- Lessons from existing retrofit one stop shops in the UK and Europe: business model and governance design | Sheffield Hallam University (Sheffield Hallam University et al., 2025)
- Let Zero: One-Stop Shop Governance and Delivery for the Private Rented Sector. Research Findings (Sheffield Hallam University et al.)

What does this mean for the region?

OSSs offer value in helping potential customers navigate this complicated regulatory, funding and technical landscape. In doing so, they can build trust in the supply chain and generate demand. Let Zero has shown that OSSs can play a strategic role in embedding retrofit agendas and linking local authority work with combined authority strategies.

However, an uncertain funding landscape still remains. Income-based funding such as the Warm Homes Local Grant is not always appropriate in the PRS where landlords cannot control their tenants' financial circumstances, and there are gaps in funding for preparatory and remedial works involved in retrofit. There are commercialisation opportunities if a sustainable business model for the Let Zero service can be developed, including developing similar services in other regional and local authorities.

The Warm Homes Plan could have profound implications for retrofitting the PRS. It may tap into key regulatory drivers for landlords. However, it also puts increasing pressure on the sector, with some landlords threatening to sell their properties to the owner-occupier market (where regulatory drivers are weaker). In addition, this may generate large amounts of compliance work within local authorities, amongst their existing priorities (e.g. filling empty properties). There are further opportunities to develop Let Zero's value proposition in this context, such as being a service that is impartial and grounded in the lived realities of those engaged in retrofit delivery and uptake.

Let Zero has raised broader questions amongst project partners and regional stakeholders about the role of SYMCA in improving landlords' properties, the responsibilities of landlords for repair and maintenance, and the lack of incentives for local authorities to grant private suppliers access to properties in the region.

Next Steps

There is further work needed to maximise the impact of the project and secure its continuation. This includes:

- Evaluating landlord and tenant experiences of the service and of measures installed through Let Zero.
- Review available data collected through Let Zero providing valuable insights on retrofit conversion rates and/or retrofit related activity across South Yorkshire's PRS.
- Integrating the learnings from the show home, digital innovation and customer journey development to solidify the outcomes from the pilot phase of the Let Zero OSS.
- Refining the service aims and objectives to clarify the value proposition of the OSS, driving engagement and retention, and ensuring the project is contributing to regional priorities.

To maximise the impact of the research, further dissemination in the region and nationally will contribute to the development of retrofit OSSs, support the case for scaling retrofit in the PRS (National Retrofit Hub, 2025), and generate innovative finance models for retrofit.

Archetype-Based Housing Stock Retrofit for Net-Zero South Yorkshire

Project team:
University of Sheffield: Dr May Zune, Dr Hadi Arbabi, Prof. Danielle Densley Tingley

South Yorkshire has approximately

609,000 homes

4 in 5 homes that will be occupied in **2050** have already been built

Housing Archetypes of South Yorkshire[2]

Terraced **23%**

Semi-Detached **35%**

Bungalow **6%**

Detached **15%**

Other Archetypes **21%**
including Maisonette, Flats, Unknown and Domestic Outbuildings

Background

Four in five homes that will be occupied in 2050 have already been built. In South Yorkshire[1], 39.8% of all properties are likely to have been built before 1950, 42.9% between 1950-2002, and only less than 8.8% after 2002. The region's housing stock[2] is composed of houses and bungalows (78.9%), flats and maisonettes (1.4%) and unspecified (19.7%).

In 2023, 1.6 Mt CO_2e of annual territorial greenhouse gas emissions were from domestic gas and electricity consumption in the region[3]. This is 25% of the total regional emissions in 2023. Of more concern, this single year accounts for nearly a third of the region's remaining 4.3 Mt CO_2e housing carbon budget for the 25 years to 2050. This housing budget has been calculated based on the region's total carbon budget, which represents the total greenhouse gases the region should emit to stay within the Climate Change Committee's (CCC) pathway to net zero[4].

If South Yorkshire aims to champion carbon reduction and commit to meeting the 1.5 °C net-zero climate limit, its approximately 609,000 existing homes, including 480,000 houses and bungalows, must be retrofitted as fast as possible, whilst minimising the embodied emissions from the retrofits.

Recommendation for housing stock retrofit deployment

Retrofit must be made an urgent national and regional priority. In South Yorkshire, there is a need to retrofit at least 19,200 houses and bungalows annually to meet the 2050 net-zero target, or 32,000 houses and bungalows a year for net-zero by 2040.

However, the carbon budget to stay within 1.5°C is so limited that, in both deployment cases, the budget would be overshot. Only by retrofitting all homes in 2025-2028 could the region stay within budget. *Retrofitting homes with higher operational energy demands, e.g. larger pre-1920s homes, in the early years of retrofit deployment, should maximise carbon savings.*

Decarbonisation strategies in housing stock retrofit scale

In the immediate term, whole-house retrofit (i.e. fabric and systems measures) is essential to minimise carbon emissions and energy costs. Retrofitting all of South Yorkshire's stock by 2040 would result in a carbon overshoot of 7.2 MtCO_2e; this increases with slower deployment rates, e.g. up to 12.4 MtCO_2e if all homes are retrofitted by 2050. The comparison of the existing archetypes with a gas boiler and whole-house retrofit showed an average 85% reduction in energy costs for a heating temperature setpoint of 20°C, while also supplying necessary cooling during the summer and ventilation for fresh air throughout the year.

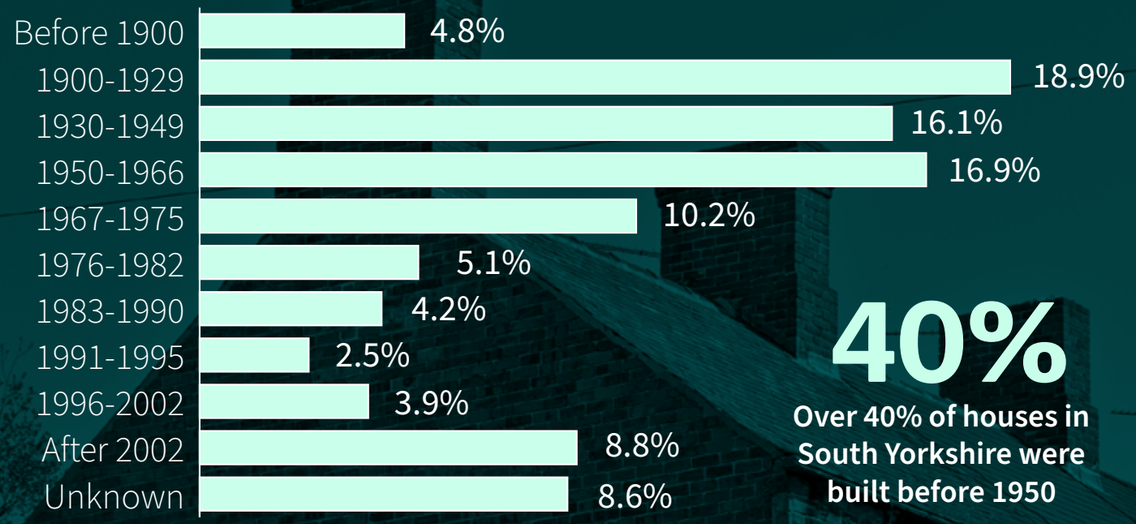
Fabric-only retrofit retains gas boilers, resulting in a very high carbon budget overshoot (17.9 Mt CO_2e if retrofit by 2050). Heat pump-only retrofit will minimise embodied carbon investment, but the lack of fabric measures will increase energy demand to achieve the same internal temperatures, and result in an average 10% increase in energy costs compared to a whole-house retrofit. The data shown here assumes materials will decarbonise in line with the electricity grid; if material decarbonisation is slower, this will result in higher embodied emissions. Material choice will also have an impact on carbon budget overshoot, with lower impact materials, e.g. recycled natural fibre insulation or glass wool, being preferable.

Summary Highlight

- Rapid retrofit of domestic homes is essential to meet regional climate ambitions.
- 32,000 houses and bungalows need to be retrofitted per year to meet the 2040 net-zero target,
- The electricity grid also needs to be decarbonised by 2040, faster than currently planned.
- Whole life carbon can be reduced by minimising the global warming potential of refrigerants for heat pumps.

1 DLUHC (2024), Energy Performance of Buildings Data: England and Wales.
2 Verisk (2024), UK Building Details for Decision Support. 3D Visual Intelligence.
3 DESNZ (2025), UK local authority and regional greenhouse gas emissions statistics, 2005 to 2023
4 Committee on Climate Change (2025), The Seventh Carbon Budget.

When were South Yorkshire Homes Built?[1]



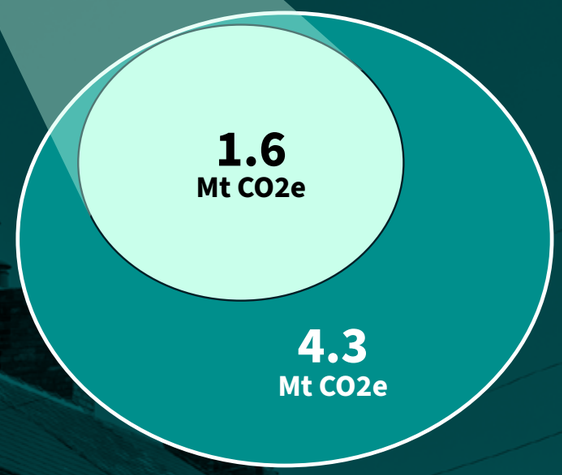
40%

Over 40% of houses in South Yorkshire were built before 1950

South Yorkshire's 2023 emissions

25%

in 2023, **1.6 Mt CO_2e or 25%** of South Yorkshire's total regional emissions were from **domestic gas and electricity consumption**



2023's

Domestic Emissions from gas and electicity consumption

SY's remaining housing carbon budget until

2050

Annual Operational Carbon Emissions

72%

System-first retrofit approach

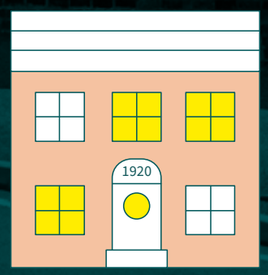
85%

Fabric-first retrofit approach

96%

Whole-house retrofit approach

Whole house retrofit results in an average **85% reduction** in heating costs for a heating temperature **setpoint of 20°C**



Retrofitting homes with higher operational energy demands, e.g. **larger pre-1920s homes**, in the early years of retrofit deployment, should **maximise carbon savings**

Whilst fabric first approaches offer higher carbon savings now, **by 2028, systems retrofit will offer higher savings** due to decarbonisation of the electricity grid.

Retrofit Deployment

19,200

houses and bungalows need to be retrofitted annually to meet the 2050 net-zero target

32,000

houses and bungalows need to be retrofitted annually to meet the 2040 net-zero target

Energy, Cost and Carbon Performance of Retrofit

Project team:
University of Sheffield: Dr May Zune, Dr Hadi Arbabi, Prof. Danielle Densley Tingley

Introduction

Implementing different decarbonisation strategies, such as building fabric and systems retrofit, in parallel with grid decarbonisation, aims to reduce domestic carbon emissions, improve housing quality, and tackle fuel poverty. However, many retrofit schemes and policies have not been oriented to achieve a net-zero target[1], and there is a lack of data that informs the relative change between energy demands, energy cost and carbon performance of different retrofit scenarios across various building typologies against their existing condition.

Focusing on South Yorkshire's climate context, our research investigates the effectiveness of different retrofit measures on fourteen low-rise housing archetypes and their contribution to net-zero retrofit.

Fabric-first and system-first retrofit

Heating energy savings of a system-only retrofit i.e. switching a gas boiler to a heat pump are relative to the coefficient of performance (COP) of the system. For instance, the heating energy demands from a typical existing semi-detached house with a gas boiler were 13,460 kWh/a, and this could change to 3,815 kWh/a by switching from a gas boiler (COP 0.85) to a heat pump (COP 3.0), indicating 3.5 times heating energy savings. Despite heat pumps being more efficient and using less energy, the overall household energy bills are likely to increase in the system-only retrofit scenario due to electricity being more expensive than natural gas (i.e. in 2025 the electricity tariff was 3.9 times higher than the gas tariff). If the heat pump is 3 times higher, our research found that once the requirements for cooling and ventilation were accounted for, there was an average increase of 10% in energy bills across all different housing types. However, this could be remedied by adding a fabric-retrofit first, reducing the energy demands of the building. In a whole-house retrofit scenario, an average of 85% of the heating energy cost savings can be achieved across all housing types. As illustrated in Case Study "Retrofit for Net-Zero and Healthy Buildings in a Warming World", it is also important to ensure adequate ventilation and cooling are provided, which, if mechanical rather than passive, will result in additional energy use.

1 Alabid, J., Bennadji, A. and Seddiki, M. (2022), A Review on the Energy Retrofit Policies and Improvements of the UK Existing Buildings, Challenges and Benefits. Renewable and Sustainable Energy Reviews, 159(1), p.112161.

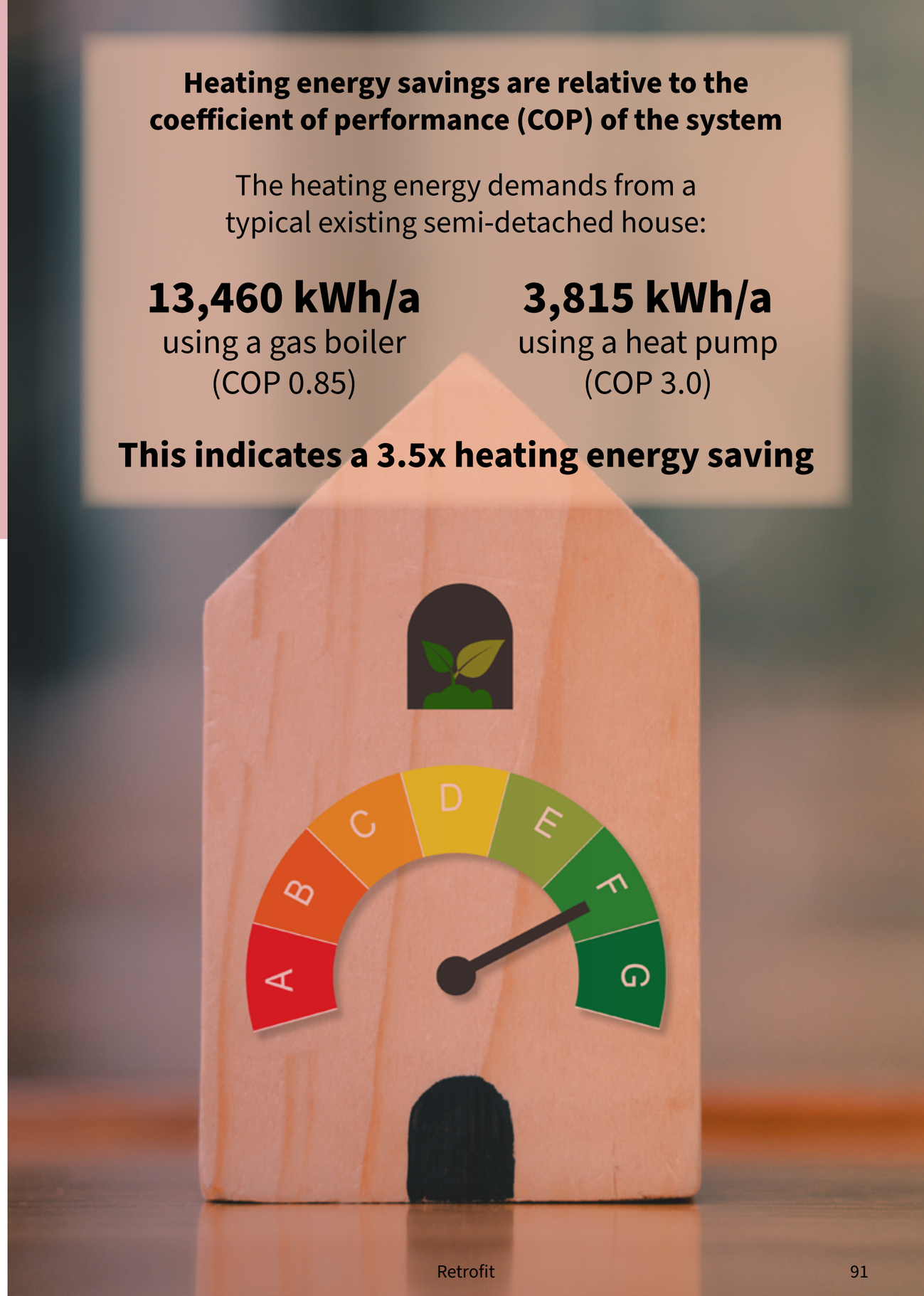
Heating energy savings are relative to the coefficient of performance (COP) of the system

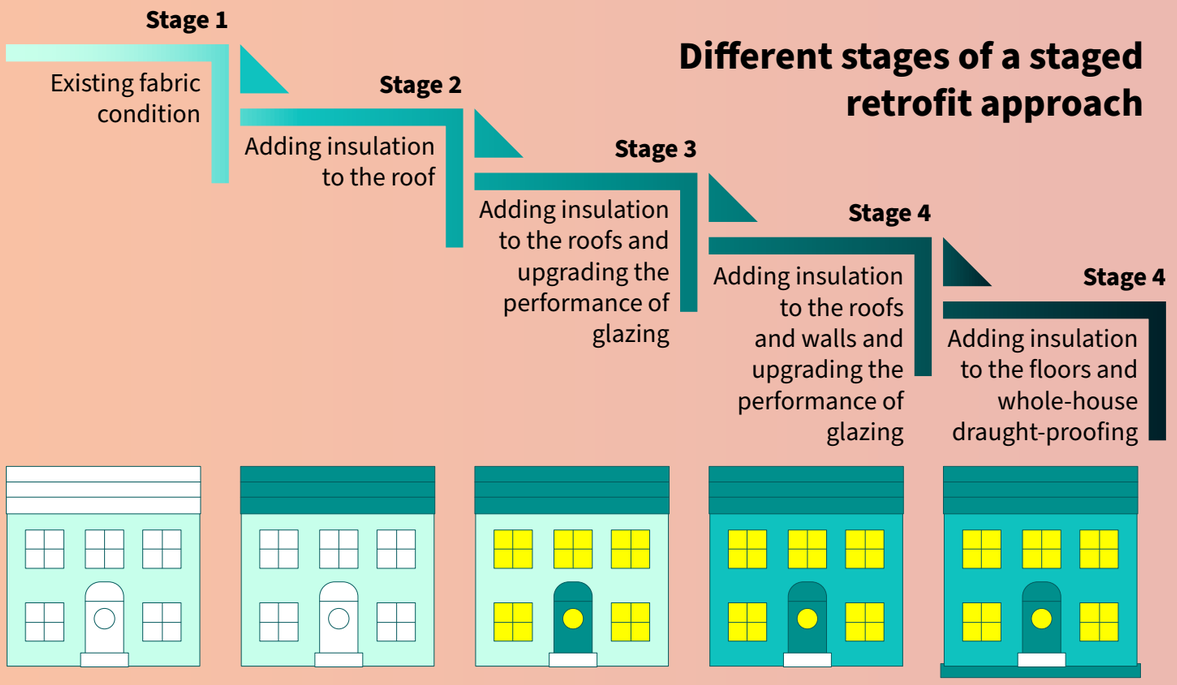
The heating energy demands from a typical existing semi-detached house:

13,460 kWh/a
using a gas boiler
(COP 0.85)

3,815 kWh/a
using a heat pump
(COP 3.0)

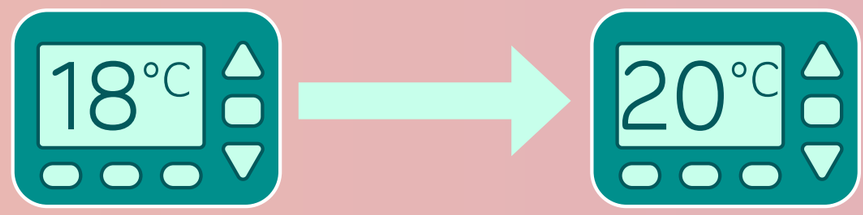
This indicates a 3.5x heating energy saving





Different stages of a staged retrofit approach

We compared the sensitivity of operational carbon emissions and energy costs that are changed by different heating and cooling temperature set points



14,500kWh/a **21,500kWh/a**

Increasing a temperature set point from **18°C to 20°C** results in a **48% increase** in energy demand

Our modelling study shows that an average of 85% of the total energy cost savings can be achieved across all archetypes by adding a whole-house retrofit while ventilation and cooling needs are provided. A system-first retrofit can significantly reduce operational carbon emissions across all archetypes by approximately 72% compared to the existing condition, encompassing both cooling and ventilation requirements, while the relative balance of gas and electricity carbon emissions (i.e. the carbon emission factor for gas is 3.4% higher than that for electricity in 2025) is also taken into account. A whole-house retrofit, which reduces residual heating demands and provides cooling and ventilation, has more profound operational carbon savings than energy cost savings, resulting in a typical semi-detached house with 2.28 tonnes of annual operational carbon savings.

Carbon Paybacks

The upfront embodied carbon investment for system and fabric retrofit in larger buildings is higher than in smaller ones. The material and system choices for retrofit influence the carbon payback year. A typical existing semi-detached house emits about 2.5 tonnes/year of operational carbon for heating, whereas about 5.7 tonnes of embodied carbon investment is required to achieve a whole-house retrofit. In general, the carbon payback year between embodied and operational carbon is found from 2-4 years if glass wool insulation for the roof and floor and EPS (Expanded Polystyrene) insulation for the wall, is considered in a fabric-first and whole-house retrofit across different building archetypes. Decarbonising the grid can facilitate a lower embodied carbon investment, as material decarbonisation can be achieved by electrification of industrial processes and transport. This will further reduce the carbon trade-off payback time between embodied carbon investment and operational carbon savings for a whole-house retrofit. Integrating passive (e.g., the whole life embodied carbon of external sliding shutters is 4.5 times higher than internal venetian blinds[2]) retrofitting approaches could further alter building performance, carbon payback and long-term energy and carbon savings.

Retrofit prebound and rebound sensitivities

Environmental payback times are quicker than economic payback times, and different requirements for comfort and socio-economic conditions could also influence both paybacks. In practice, when the building occupiers purposely set heating and cooling set point temperatures to reduce energy costs, the prebound effect occurs. Likewise, setting a higher heating set point or a lower cooling set point temperature causes the rebound effect. Considering this, we compared the sensitivity of operational carbon emissions and energy costs that are changed by different heating and cooling temperature set points. The results show that the average annual heating demands of the existing archetypes could increase from 14,500 kWh/a to 21,500 kWh/a, a 48% increase, by switching a 2°C difference of the heating set point from 18 °C to 20 °C. However, about a 19% change could be expected by switching a 1°C difference of the heating set point from 20 °C to 21 °C. As real-world energy use and carbon savings from post-retrofit homes could significantly diverge from theoretical models due to occupant behaviour and comfort needs for individual differences, we recommend a retrofit policy that integrates behaviour change design for energy consumption (e.g., education and reward programs), user engagement strategies, and provides necessary information about retrofit sensitivities in different archetypes.

Recommendations for South Yorkshire and the UK

This case study demonstrates that there are inequalities in energy demands and carbon emissions across different building archetypes. For instance, the oldest archetypes, such as the Victorian and Georgian ages, have higher energy demands due to poor fabric performance and typically larger floor areas to heat. Comparisons of fabric, systems and a combination of both retrofits inform the need to develop a future retrofit policy to:

- ensure residual energy demands are minimised by adding retrofit intervention,
- integrate grid and material decarbonisation for shorter carbon payback time from retrofit intervention,
- provide sufficient information about different types of retrofit intervention and address future retrofit rebound sensitivities across different archetypes.

This context-dependent dialogue example for the South Yorkshire housing stocks can be applied to similar housing stocks and the whole UK.

2 Edwards PT, Fordham M, Arnold M. (2023),Shading for housing: Embodied carbon of shading products. Good Homes Alliance.

Hydrogen and Heat Pumps in the Net-Zero Transition: Life Cycle Evidence for Building Sustainable Global Supply Chains

Project team:
University of Sheffield: Prof. Lenny Koh, Dr Moein Shamoushaki, Eleanor Borrill

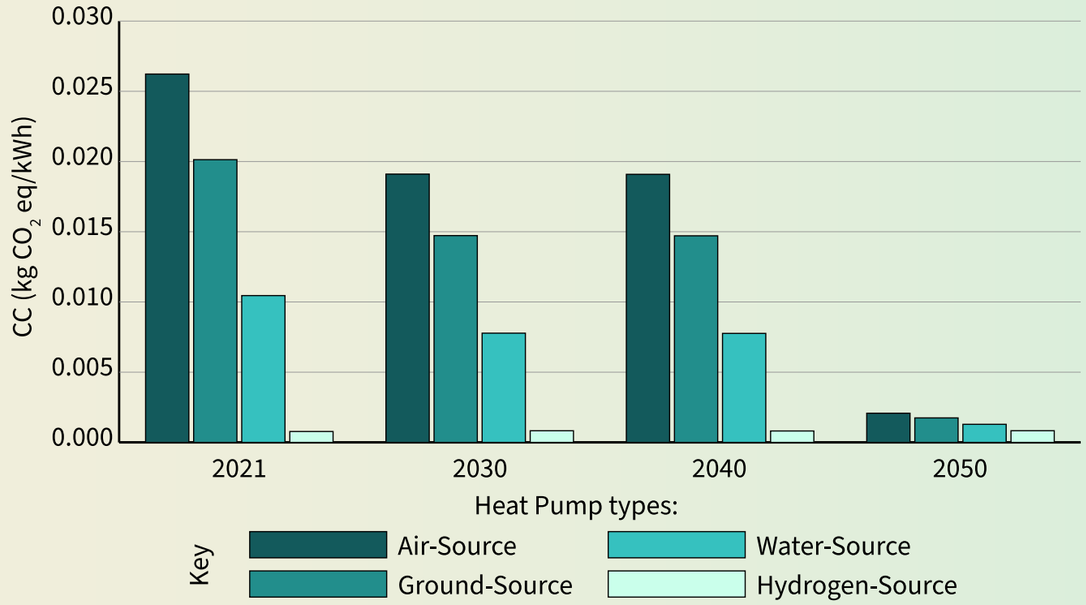


Figure 1: The UK heat pump supply chain climate change impact based on net zero plan forecast.

Challenge Statement

The UK has set ambitious targets to accelerate the deployment of low-carbon heating technologies. These include the installation of 600,000 heat pumps annually by 2028, the phase-out of fossil-fuel heating in new homes from 2025, and the achievement of net-zero emissions by 2050[1]. Meeting these goals requires a rapid scale-up of heat pump technologies, which in turn raises two major challenges.

The first challenge concerns the environmental footprint of the heat pump supply chain. At present, the majority of heat pump components are imported, often from carbon-intensive manufacturing hubs such as China. This reliance on overseas production increases lifecycle emissions and undermines the overall sustainability of the technology, acknowledged by the UK Warm Homes Plan which aims to achieve 70% domestic production of installed heat pumps by 2035[2].

The second challenge relates to regional industrial capacity gaps. The UK, including South Yorkshire, currently lacks domestic production for many critical components such as evaporators, valves, and refrigerants. This dependence on global supply chains exposes the sector to risks from geopolitical instability and logistical disruptions.

The literature reveals several evidence gaps that need to be addressed. Comparative lifecycle assessments (LCA) of entire supply chains for different heat pump technologies remain limited. To date, no LCA has been conducted for hydrogen-source heat pumps (HSHP) using green hydrogen. Furthermore, there has been insufficient focus on the resilience of regional supply chains and the policy mechanisms that could support localisation.

Regional Relevance

Contribution of Research

This research applies a comparative 'cradle-to-gate' LCA to quantify the supply-chain environmental impacts of four heat pump technologies: air-source (ASHP), ground-source (GSHP), water-source (WSHP), and hydrogen-source (HSHP). The analysis covers 56 supply-chain scenarios involving 15 manufacturer nations across Europe and Asia, supplying to the UK market. Additionally, environmental impact forecasting is incorporated with projected UK grid decarbonisation pathways for 2030, 2040, and 2050. This approach enables the evaluation of heat pumps within the context of long-term net-zero transitions.

Regional Relevance

South Yorkshire is well positioned to play a leading role in reshoring heat pump production. The region's strong manufacturing heritage and established logistics infrastructure, provide a foundation for developing local supply chain capacity. The findings of this research therefore provide an evidence base to inform industrial strategy, skills investment, and green growth planning in South Yorkshire and beyond.

Evidence and Outputs

Research Findings

The analysis highlights several important findings.

The geographic location of heat pump manufacturing significantly influences the environmental outcomes. Supply chains based in Sweden consistently demonstrate lower climate and particulate matter impacts due to the country's clean energy mix, while those centred in China have the highest impacts as a result of coal-heavy energy and long transport distances. Italy demonstrates the highest toxicity impacts among the GSHP, WSHP, and HSHP manufacturer nations, attributed to the use of more pollutant-containing materials and carbon-intensive electricity. Italy, China, and Austria show high ozone depletion impacts caused by greater pollutant impacts from refrigerant production and application. Partial or full reshoring to the UK offers the potential to reduce transport emissions and improve supply chain resilience.

HSHPs deliver the lowest lifecycle CO_2 emissions by avoiding reliance on grid electricity during operation. However, they exhibit higher land-use impacts due to the renewable energy infrastructure required for hydrogen production. In contrast, ASHPs show the highest overall environmental impacts, particularly in relation to ozone depletion and ecotoxicity, reflecting their reliance on refrigerants and high material intensity.

The environmental impact forecasting against the UK net-zero targets revealed that ASHP are likely to achieve the largest carbon emission reduction over time (97% by 2050), while GSHP, WSHP, and HSHP are expected to reduce by 94%, 95%, and 59%, respectively. Although all technologies achieve compliance with the UK net-zero target by 2050, HSHP may lead to higher impacts in certain environmental categories, highlighting the necessity for further technological developments, particularly in electrolysis.

Several trade-offs must be considered. Reshoring without continued grid decarbonisation could lead to higher carbon and particulate matter emissions from residual fossil-fuelled power. HSHPs offer strong climate benefits but require more land, raising concerns for biodiversity. Finally, while Sweden's clean energy advantage currently makes imports less carbon-intensive, UK manufacturing could outperform it if powered by 100% renewable energy. Across all technologies, key environmental hotspots include the use of copper and steel, refrigerant leakage, and the reliance on fossil-based

1 DESNZ (2023), Heat pump investment roadmap: Leading the way to net zero.
2 UK Government (2026), Warm Homes Plan.

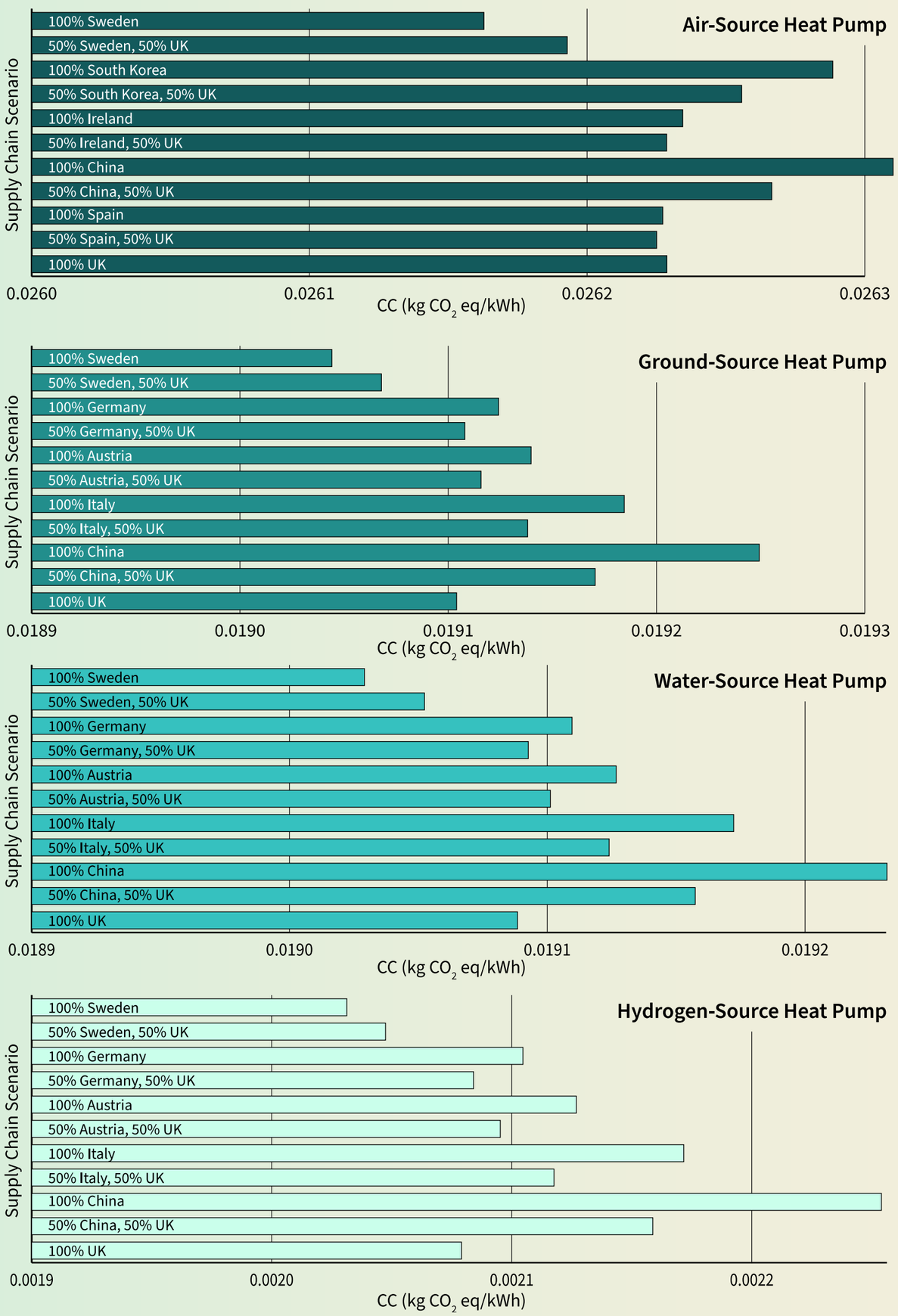


Figure 2: Climate change impact comparison for all supply chain scenarios.

electricity in manufacturing.

Published academic papers on this research project can be found here[3] and here[4].

Scalability and Commercialisation

The evidence supports strategies for scaling heat pump manufacturing both within and beyond South Yorkshire and the UK. Locally, the region can capitalise on its legacy of precision engineering and advanced manufacturing to transition to automated, high-capacity manufacturing lines. By integrating the Advanced Manufacturing Research Centre (AMRC)'s expertise in process and materials innovation, South Yorkshire can establish a resilient manufacturing hub. Nationally and internationally, this framework - linking localised supply chains, low-carbon manufacturing, and clean energy integration - can be applied to other industrial regions to accelerate heating decarbonisation while generating employment.

Key Policy Insights

While the findings of this research hold global significance as it focuses on global heat pump supply-chains, actionable recommendations can be drawn for South Yorkshire. The following section sets out key policy insights, building on the conclusions and recommendations drawn from the selected publications.

1. Continue to develop workforce and skills pipeline:
    - It is recommended to expand sector-specific training and apprenticeships (in partnership with Sheffield's universities, colleges, and Advanced Manufacturing Research Centre training centre) in low-carbon Heating, Ventilation, and Air Conditioning manufacturing and retrofit installation, aligned with the Green Jobs Taskforce, to build a skilled workforce capable of supporting large-scale decarbonisation, accelerating technology deployment, and ensuring long-term industry resilience.
2. Reduce pollution from material usage:
    - Invest in research into more sustainable and less polluting material alternatives; for example, finding substitutes for refrigerants, steel, copper, and insulation, particularly in ASHPs.
    - Where alternatives are not feasible, further regional initiatives are recommended to repurpose key heat pump materials and components, such as the recycling partnerships seen with Sheffield Forgemasters, Liberty Steel (Rotherham), and C F Booth Ltd (Rotherham).
3. Develop a reshoring policy in line with the UK's net-zero targets:
    - Alongside the UK Modern Industrial Decarbonisation Strategy (2025) and the UK Net Zero Investment Roadmaps (2023), which include frameworks for cutting emissions and attracting investment into UK manufacturing and supply chains, work with the government to create incentives and actionable strategies to accelerate reshoring of heat pump manufacturing.
    - Leverage local retrofit programmes, such as the Home Upgrade Grant (HUG 2), the Barnsley Council Energy Efficiency Works, and South Yorkshire Housing Association (SYHA) Retrofit Projects, to create demand for regionally manufactured heat pumps, ensuring strong market pull for local production.
4. Continue to increase the share of renewables in the energy mix:
    - Alongside the British Energy Security Strategy (2022) and UK Net Zero Investment Roadmaps (2023), ensure new manufacturing is supplied by low-carbon power by continuing to expand the share of renewables in the UK energy grid.

Next Steps

The research highlights practical steps for implementation and policymaking. In South Yorkshire, pilot manufacturing projects should be launched for priority heat pump components, embedding low-carbon and circular processes. Future research should extend life cycle analysis to include recycling and end-of-life pathways, alongside socioeconomic modelling of job creation. Comparative cost–benefit analysis of reshoring versus importing under different grid scenarios would also provide valuable guidance for investment and policy decisions.

3 Shamoushaki, M., Koh, S.C.L., Heat pump supply chain environmental impact reduction to improve the UK energy sustainability, resiliency and security. Nature Sci Rep 13, 20633 (2023).
4 Shamoushaki, M., Koh, S.C. Lenny, Net-zero life cycle supply chain assessment of heat pump technologies, Energy, 309, (2024).

South Yorkshire's Path to Net-Zero: A Case Study on Decarbonising Regional Housing Stock

Project team:
University of Sheffield: Prof. Vania Sena, Dr Bitrus Amos, Dr Ling Min Tan

Challenge Statement

This case study addresses the critical need for a regional-level analytical approach to evaluate decarbonization progress. By shifting the focus from national aggregates to regional interventions, this case study provides a granular understanding of how specific net-zero policies perform within local housing stocks. Ultimately, this approach allows for a more precise evaluation of decarbonization trajectories, ensuring that regional nuances are not lost in broad national modelling.

The lack of a unified, data-driven approach to South Yorkshire's sustainability challenges was the primary catalyst for SYSC-funded research. Currently, regional policymakers rely on fragmented datasets that fail to capture the 'whole-system' reality of South Yorkshire's unique industrial heritage and diverse housing stock. This case study uses a simulation tool, currently in development by SYSC-funded research, that bridges this gap by consolidating regional data into a single, comprehensive emissions profile.

Research Response

This research synthesised high-resolution, large-scale datasets to isolate the specific variables—such as housing age, tenure, and fabric type—that dictate decarbonisation success in South Yorkshire. By 'disentangling' these local nuances from national averages, the project evaluates the robustness of current data in predicting regional emissions trajectories. This provides a critical evidence base for Goal 3 of the South Yorkshire Energy Strategy[1], which mandates the improvement of energy efficiency in the built environment.

The primary aims of this case study are:

- To track temporal patterns and trends in energy efficiency, consumption, and potential CO2 saving trajectories across South Yorkshire Local Authorities (LAs).
- To forecast net-zero targets based on proposed national (2050) and regional (2040) energy policies.

1 SYMCA (2022) South Yorkshire Mayoral Combined Authority Energy Strategy

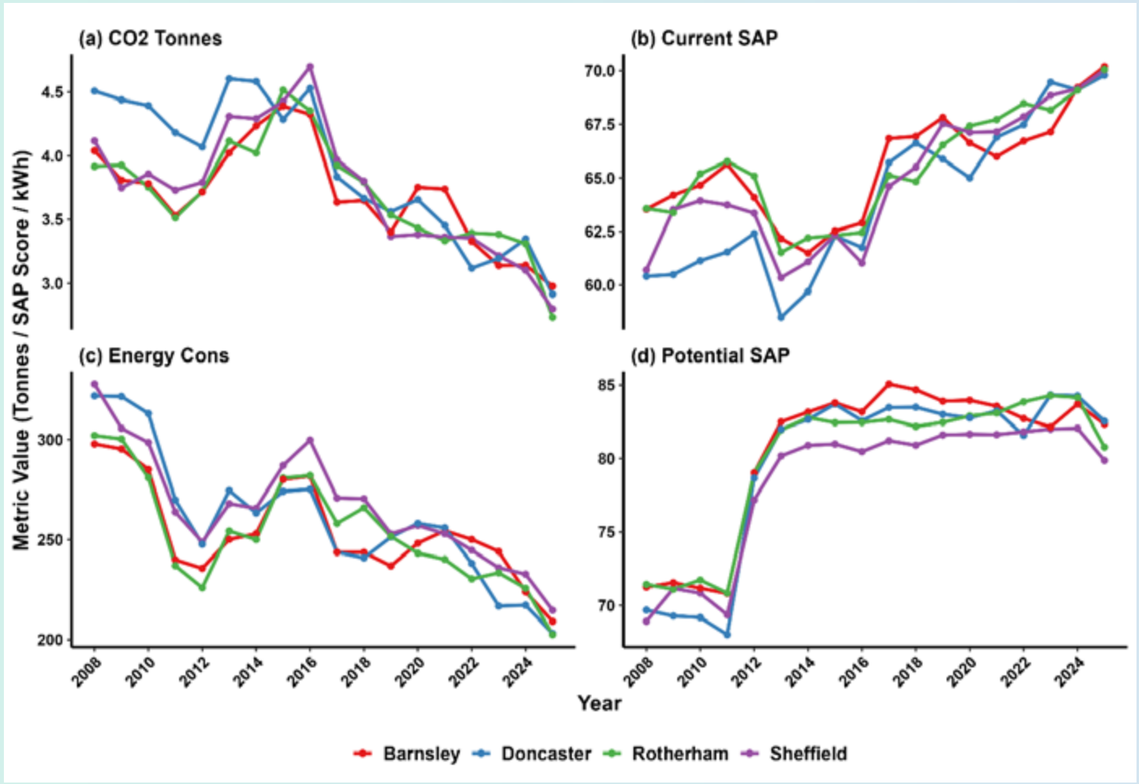


Figure 1: Historical variables exploration (2008-2025). Tracking SAP scores, energy intensity and total carbon tonnage

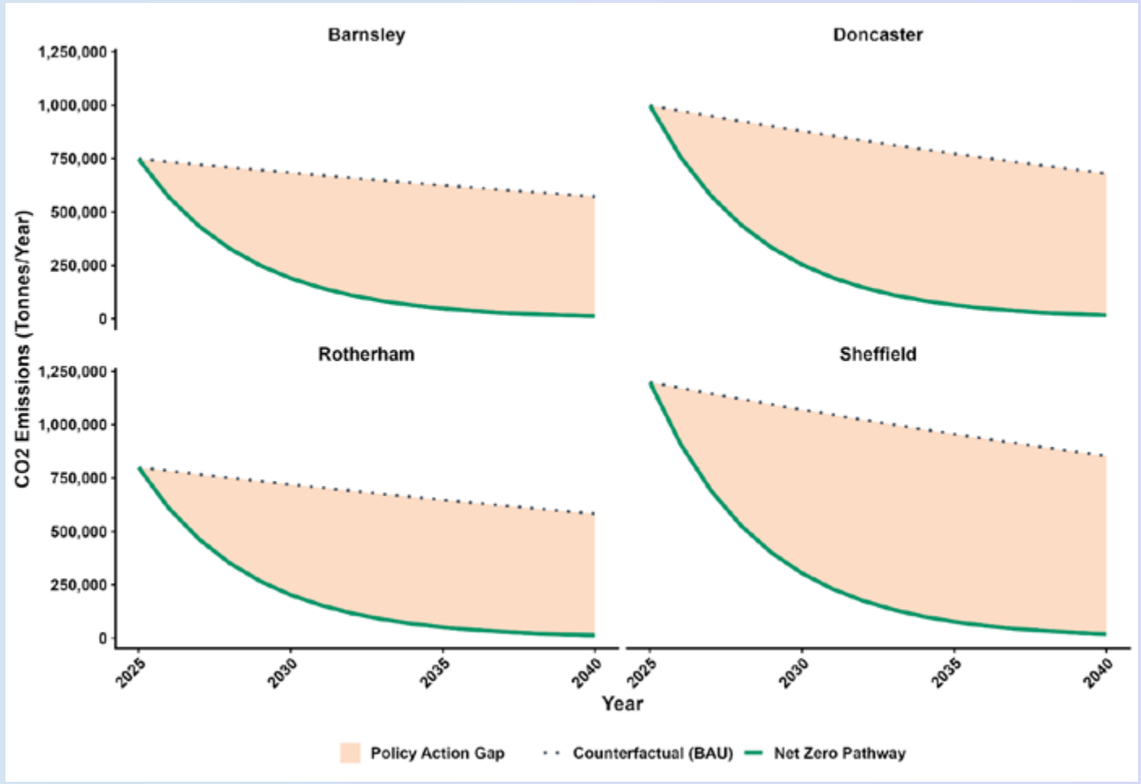


Figure 2: Residential CO2 emission decomposition and net-zero pathway. Required ~24% annual reduction vs. historical BAU efficiency trends

Evidence and Findings:

Descriptive Baseline

Descriptive analysis of the South Yorkshire EPC dataset[2] - measuring the intersection of building physics and carbon output - reveals three key regional trends:

- Dominance of Band D: EPC Band D is the modal rating across all four Local Authorities (LAs), peaking at 42.64% in Doncaster. This "average" middle-ground represents the primary retrofitting challenge for the 2030 Band C mandate.
- Sheffield's Head Start: Sheffield leads the region with 34.77% of homes already at Band C. Despite a lower mean SAP than Barnsley, its stock is most closely aligned with immediate net-zero targets.
- Doncaster's Efficiency Gap: With nearly 20% of homes in Bands E–G, Doncaster faces a "carbon penalty" characterised by the highest regional Median CO2 (3.5 tonnes) and a heightened risk of fuel poverty.

The combined average SAP score for South Yorkshire is 64.75, placing the region in Band D. While Barnsley leads with a mean efficiency of 65.38, Doncaster trails the regional average by nearly 1.5 points (63.80), highlighting a need for more intensive retrofitting to achieve Band C targets.

Regional Baseline Assessment: Housing Energy Performance and CO2 Mitigation Potential

Historical trends across South Yorkshire (Figure 1) reveal a significant divergence between housing efficiency potential and actual performance, particularly in Sheffield and Doncaster.

Figure 1C shows annual mean consumption intensity. This measure removes "size bias" by comparing energy use relative to building size rather than total energy cost. While intensity dropped from over 300 kWh/m² in 2008 to nearly 200 kWh/m² by 2025, a notable "Efficiency Relapse" occurred between 2012 and 2016. This spike highlights the housing stock's sensitivity to three critical factors: (1) a Market Price Rebound, where low global energy prices triggered a "rebound effect" as households prioritised thermal comfort over savings[3] (2) a Policy Gap caused by the 2013 transition to the "Green Deal," which slowed retrofitting rates and left the stock vulnerable[4] and (3) Environmental Sensitivity, as severe winters forced un-retrofitted buildings to increase consumption sharply to maintain habitable temperatures[5]. This combination temporarily masked earlier efficiency gains before more robust standards took hold later in the decade[6].

We observed a sharp rise in Potential SAP around 2012 (Figure 1A in the appendix), likely reflecting a Methodological Shift in how building efficiency is measured, such as more ambitious assessment criteria or the inclusion of high-efficiency technologies, such as heat pumps, rather than physical building improvements. Moving forward, the transition to new measurement methodologies will further redefine these ratings to better account for the decarbonization of the electricity grid, likely shifting potential benchmarks again. The Current SAP (solid black line) is rising steadily in all four districts, showing consistent improvement. However, a significant "efficiency gap" remains, representing untapped retrofitting potential.

2 DLUHC (2025). Energy Performance of Buildings Data: Open Data Communities (EPCs). Ministry of Housing, Communities & Local Government.

3 Singer, G. (2024) Complementary Inputs and Industrial Development: Can Lower Electricity Prices Improve Energy Efficiency? SSRN Journal

4 Howarth, C. and Roberts, B. (2018) The Role of the UK Green Deal in Shaping Pro-Environmental Behaviours: Insights from Two Case Studies. Sustainability, 10(6), p.2107

5 Bowen, A. (2010) Economic Growth, the Recession and Greenhouse Gas Emissions. Paper 3 in a series on Analytic Support for target-based negotiations.

6 Rosenow, J., Fawcett, T., Eyre, N. and Oikonomou, V. (2016). Energy efficiency and the policy mix. Building Research & Information, 44(5-6), pp.562–574

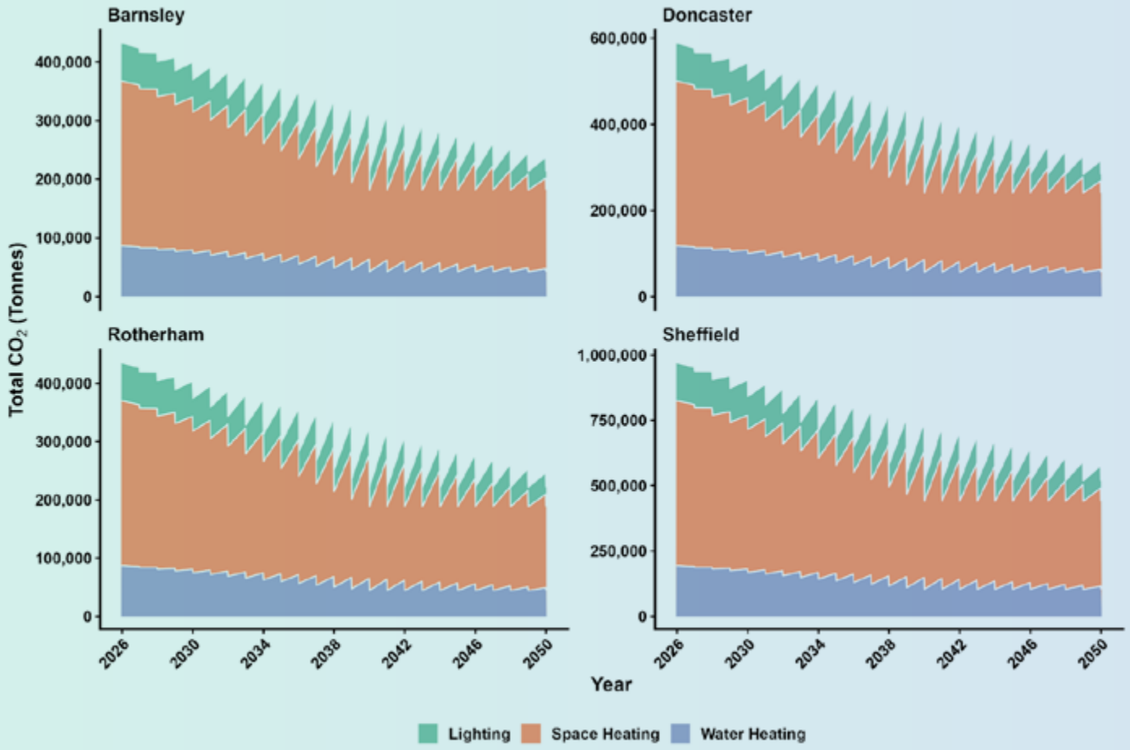


Figure 3: Residential CO2 emissions decomposition (2026-2050). Projected contributions: space heating, water heating and lighting.

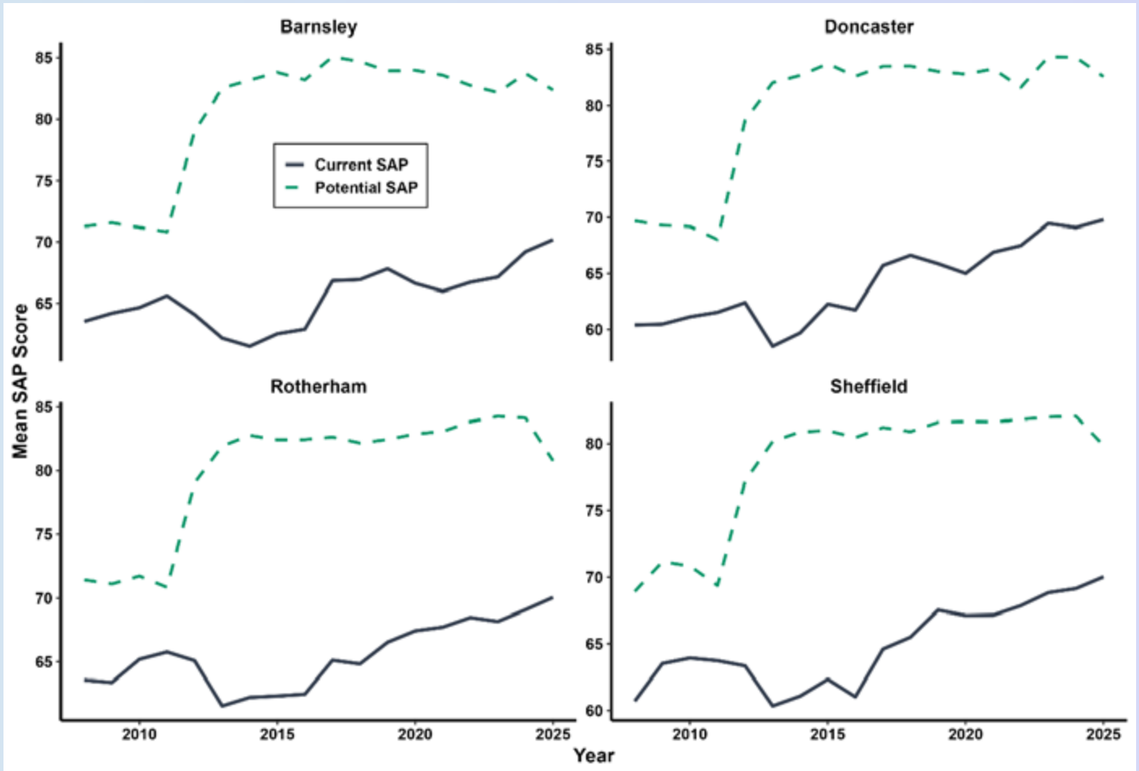


Figure 4: Historical energy efficiency trend (2008-2025). Gap between current performance and retrofit potential.

Forecasting Net-Zero Pathway Projections: Regional (2040) and National (2050) Mandates.

Figure 2 illustrates the critical divergence between South Yorkshire's historical trajectory and its 2040 climate mandates. The Counterfactual (business-as-usual) line projects a future based on 2008–2025 efficiency rates, assuming no radical shift in regional policy. In contrast, the Net Zero Pathway utilises an exponential decay model to visualise the scientifically required rate of decarbonization. The Policy Action Gap (shaded orange) quantifies the cumulative "missing effort" and the resulting carbon liability of maintaining the status quo. The analysis reveals an unprecedented acceleration requirement: to bridge this gap, the region must pivot from a marginal historical decline to a ~24% annual reduction rate in residential emissions. Current trends achieve only a fraction of this target, underscoring that incremental improvements are no longer sufficient to meet statutory carbon budgets.

As shown in Figure 3, across all four Local Authorities (LAs), Space Heating (orange) remains the primary driver of residential emissions. Unlike the UK electricity grid—which has seen emissions intensity fall by over 60% since 1999 due to wind and solar integration—natural gas is a fossil fuel with a fixed carbon floor. Every unit burned emits approximately 0.183kg of CO2, meaning efficiency gains in gas boilers can only provide incremental reductions. True decarbonization requires a technological "jump" to electrification via heat pumps to tap into the greening grid[7, 8]. This transition is essential to meeting the statutory requirements for residential decarbonization set out in the 6th Carbon Budget[9].

While Sheffield leads in absolute emissions due to its size, its consistent decline reflects a stronger baseline efficiency compared to Doncaster's shallower reduction curve and higher concentration of "hard-to-treat" properties. Barnsley and Rotherham show mid-range, identical trajectories, underscoring a regional dependency on large-scale retrofitting to overcome the stagnant "Space Heating" carbon block.

Recommendations for South Yorkshire and the UK

While South Yorkshire's intensity dropped from 300 to 200 kWh/m², the 2012–2016 "relapse" reveals a lack of thermal resilience; closing the "efficiency gap" requires shifting from incremental gains to deep fabric retrofitting to move homes from weather-reactive to energy-stable.

The 2012 jump in Potential SAP proves that the technical solutions for net-zero (e.g. heat pumps and solar) are already mathematically viable for the region. The bottleneck is not a lack of technology, but the pace of adoption.

As shown in Figure 3, to bridge the ~24% annual reduction gap, regional funding must be aggressively diverted away from generic "energy saving" and toward specific, high-impact heating electrification projects.

Next Steps

We will integrate high-resolution regional datasets and SYSC project outputs into the tool to ground emission scenarios in credible, South Yorkshire-specific evidence. This data will power the modelling of localised housing retrofit scenarios, enabling the precise, data-driven interventions required to close the identified Policy Action Gap.

7 HM Government. (2021). Net Zero Strategy: Build Back Greener.
8 DESNZ. (2021). Heat and Buildings Strategy.
9 Climate Change Committee. (2020). The Sixth Carbon Budget: The UK's path to Net Zero.

Transport

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Challenge

Domestic transport rose from 16% to 29% of UK territorial emissions, from 1990 to 2023, and has been the single biggest source of the UK's territorial emissions since 2014[1]. Provisional statistics for 2024 put transport at 30% of total emissions[2], a rise of 1% on 2023[3].

Reliance on private cars generates high levels of congestion, contributes significantly to regional greenhouse gas (GHG) emissions, and worsens air quality. In the UK, 68% of roadside NO_2 concentrations in 2023 originated from NO_x emissions from exhaust pipes[4]. In South Yorkshire, 2023 roadside monitoring in parts of Rotherham recorded peak annual average NO_2 concentrations of over 60 µg/m^3, which is more than six times the World Health Organization (WHO) guideline of 10 µg/m^3. Additionally, Sheffield City Council estimates that road transport in Sheffield is the *"most-significant overall single contributor"* to NO_2 emissions, citing around a 30% share of NO_x from motor vehicles[5].

Although the transition to electric vehicles (EV) will mitigate tail-pipe emissions, indirect emissions associated with car manufacture and the current grid energy mix will still occur. Electric vehicles still produce particulate matter pollution from tyres and brakes, affecting local air quality and ecosystems. Moreover, the carbon payback takes significant time. Life-Cycle-Analysis (cradle-to-grave) of battery EVs (BEVs) concluded that a medium-size car would need to be driven for 70,000 km before embodied and operational emissions fall below those of a vehicle with an internal-combustion-engine[6]. Given that Sports Utility Vehicles (SUVs), which are larger than a medium car, represented 71% of new electric vehicle registrations (an increase since 2021 of 28%)[7], the carbon payback will be even more delayed.

The 'autobesity' trend has social and practical implications as well as environmental. SUVs cause more road damage, more congestion, increase parking pressure, and pose significant safety risks to those who walk, wheel and cycle[8]. More generally, the requirement for on-street EV charging facilities may directly conflict with space for active travel lanes and bike/e-cargo cycle storage, not to mention adding demand that could cause grid overloading during peak times. Furthermore, the uptake of EVs could exacerbate social and economic inequalities. Considering the relatively high cost of an EV, and the need for a space for plug-in charging, they are more likely to be purchased by higher income households with off-road parking. The benefits of EVs are therefore unevenly distributed, whereas the costs of upgrading the electricity network to cope with the additional demand will be added to everyone's bills.

This shows that the reliance on private cars and conventional delivery vehicles, particularly in dense, urban environments needs to be reduced. However, the number of licensed vehicles in the UK is rising; in December 2024, there were 2,605,000 vehicles registered for the first time, an increase of 3% from the year before[9]. South

1 Department for Transport (2025) Greenhouse gas emissions from transport in 2023.
2 DESNZ (2024) 2024 UK Provisional Greenhouse Gas Emissions.
3 Department for Transport (2025) Greenhouse gas emissions from transport in 2023.
4 DEFRA (2025) Emissions of air pollutants in the uk – nitrogen oxides (nox).
5 Ivings, S., King, J.A., Roocroft, A., Ortiz, P., Willis, T., Martin, M.V., Arbabi, H. and Punzo, G. (2025) Origin–destination specific traffic emissions and data-driven NO2 pollution-optimal routing in urban environments. Environmental Modelling & Software, p.106813.
6 Styring, P., Duckworth, E.L. and Platt, E.G. (2021). Synthetic Fuels in a Transport Transition: Fuels to Prevent a Transport Underclass. Frontiers in Energy Research, 9.
7 Transport Environment (2025) UK's SUV Surge is Driving Up Road Risk and Costs - will HM Treasury Act?
8 Ibid.
9 Department for Transport (2025) Vehicle licensing statistics, United Kingdom: 2024.

Yorkshire's population is also due to rise from 1.4 million in 2025 to over 1.55 million by 2043[10], which could potentially increase the number of cars and congestion, particularly around urban centres.

This growing pressure on South Yorkshire's roads could be relieved by modal shifts for short distance journeys to minimise traffic congestion and improve air quality. Growing population density should also be seen as an opportunity to increase the use and economic viability, of public and active transport, and its infrastructure, in Sheffield, Rotherham, Barnsley and Doncaster. In line with national trends, South Yorkshire's population is also ageing, which only increases the need for efficient and reliable public transport. The Leeds Observatory data predicts that the number of 70-84 year olds (data not available over 84) will increase from 149,998 (2018) to 211,889 (2043)[11].

However, there are significant challenges to achieving modal shifts. A SYSC study on the recent history of transport in the UK, discussed how 'motornormativity' (a concept developed by Ian Walker and colleagues[12]) emerged from specific post-war policy choices that entrenched car use in the built environment. This trajectory was not always certain. In the 1930s, the Ministry of Transport sought the creation of around 500 miles of cycle paths alongside road building, inspired by the cycle lanes being created alongside new roads in the Netherlands. During this period, more miles were cycled than driven, although this was reversed by 1950 and the gap has widened ever since. It is worth noting that Amsterdam's trajectory has been famously different and the gap has widened. While Amsterdam opposed the vision of streets existing mainly for cars[13], the same did not happen in the rest of the world, Britain included[14].

Motornormativity has in many ways locked systems into car use. Research conducted in 2023, explored cycling experiences over the life course of a group of Sheffield based cyclists. The results showed that one of the key changes over the

10 Leeds Observatory (n.d.) Population projections.
11 Ibid.
12 https://doi.org/10.1504/IJENVH.2023.135446
13 BICYCLE DUTCH (2019) The battle for the Ferdinand Bolstraat.
14 Reid, C. (2017). How the Dutch Really Got Their Cycleways. Bike Boom. Island Press, Washington, DC.

Transport Emissions

Domestic transport has been the ***single biggest source*** of the UK's territorial emissions since **2014**

Percentage of transport in UK territorial emissions

16% in 1990 → **29%** in 2023

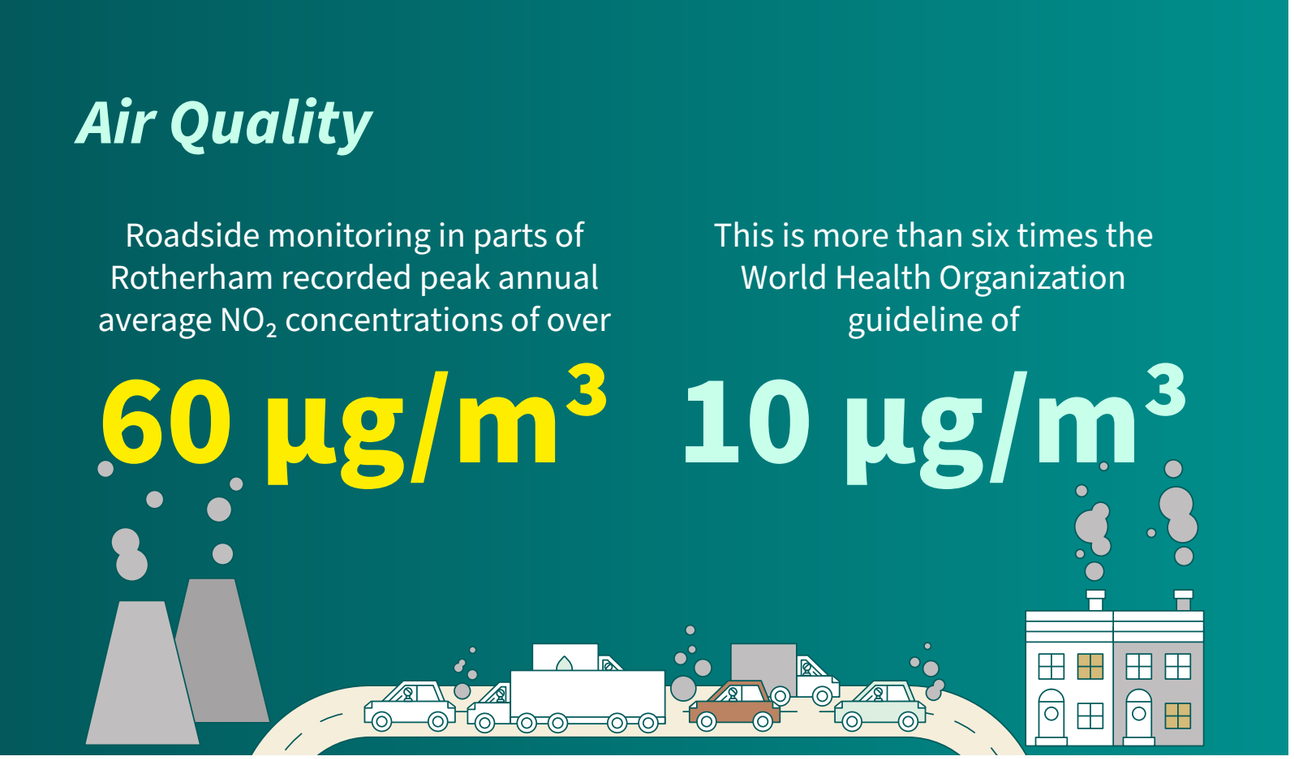
Provisional statistics for 2024 show a rise of 1% to 30% total emissions

1% in 2024

past decades was a perception that safety was worsening. Bigger vehicles, driving faster, and at times more aggressively, have contributed to a difficult environment for cyclists (and pedestrians) to navigate[15]. This perception is supported by the statistics. Whilst the proportion of fatalities for car drivers is declining (from 52% in 2004 to 45% in 2023), it is rising for pedestrians (from 21% in 2004 to 25% in 2023) and pedal cyclists (from 21% in 2004 to 25% in 2023)[16].

Furthermore, the congestion and street parking in city centres presents challenges for running reliable bus services[17]. Mobility and safety are also key to creating a vibrant local economy. Transport for the North (TfTN) attributes the 25% gulf in Gross Value Added (GVA) between the North and other areas of England to *"sub-optimal transport links and underinvestment in transport"*[18]. Accessible public transportation is at the heart of equitable societies; residents having equal opportunity to travel when, where, and how they want, at affordable costs. Moreover, high quality, high connectivity transport networks support regional development and regional economic growth. To determine how accessible and affordable the current public transport (PT) system is in South Yorkshire, SYSC assessed regional job accessibility using the current PT network of South Yorkshire, taking 'communities' as populations within lower-layer super-output areas (LSOAs).

15 Parkes, S. and Rafalowicz-Campbell, M. (in preparation) Cycling past and present: an oral histories approach in Sheffield, UK.
16 Ibid.
17 Sheffield City Council (2024) Connecting Sheffield: Abbeydale Road and Ecclesall Road.
18 Transport for the North (2019) Northern Powerhouse: Independent Economic Review Core Messages.



The study extracted three key metrics: (1) how many direct routes exist between all pairs of LSOAs; (2) modelled time spent travelling; and (3) minimum number of changes required to assess accessibility. It merged this analysis with SYSC's Energy Decadence project survey which provided five key outputs for this study: (1) age; (2) working status; (3) income; (4) education level, and; (5) whether or not respondents are struggling to pay for their transport bills.

We found that age was the most important predictor of transport affordability; younger people struggle to meet their transport bills significantly more than older people. Across South Yorkshire, our modelling predicted 32% of the total Barnsley region, 38% of the total Doncaster region, 35% of the total of Rotherham and 44% of the Sheffield region were struggling to pay for transport.

We also found that significant disparities emerge between those who rely on public transport and those with access to private vehicles. This is particularly true for those who don't live near high demand routes and/or work during 'off-peak' hours, often in low paid sectors such as warehouses and hospitals. The analysis shows that accessibility drops significantly during these shift-change windows.

Whilst public transport plays an important role in reducing GHG emissions and congestion as well as providing equitable access to workplaces, increasing active travel could play a significant role in improving public health (life expectancy for men and women in South Yorkshire is two years lower than the national average for England[19]), which also drives productivity. Still, care must be taken in the way that policies are designed to avoid a further entrenchment of motor-normativity and existing inequalities. For instance, a push to implement on-street EV charging infrastructure could affect pavement accessibility[20], hindering the government's targets for 50% of all the journeys to be completed via active travel methods such as walking, wheeling or cycling by 2030[21].

There is a need to uphold the rights of those who walk, run and wheel otherwise a 'green' EV policy may inadvertently entrench car use further. However, the EV transition also presents opportunities for community energy groups to co-own EV charging points so that financial benefits are retained locally, offsetting potential negative impacts and fostering a sense of local ownership.

19 NHS South Yorkshire (2025) A review of the health of South Yorkshire's population.
20 Possible (2023) Electric vehicle charging rollout poses growing threat to walking and wheeling targets and disabled access, warn charities.
21 Active Travel England (n.d.) About us.

Response

SYSC's research asked how we might build a more sustainable and equitable transport system that supports a thriving economy, society and environment. Whilst it is clear that private cars and vans will play a continued role in the transport systems of the future, it is only with fewer cars on the road, driving fewer miles, that we can deliver significant improvements in reducing carbon emissions whilst improving air quality, journey times and journey experiences.

The core question is how to facilitate modal shifts to active travel or public transport for a proportion of journeys. Traditional transport models often assume that travel time and monetary cost are the only determinants of modal choice[22]. In reality, a range of factors such as comfort, convenience, safety, and reliability are equally influential. Public transport users consider wait times and proximity to bus stops; active travel users are sensitive to hills, weather, and the availability of safe cycle routes.

SYSC is developing a decision-support tool that models the complex dynamics between factors that determine people's transport choices. The project seeks to understand the relationship between the enjoyability of a journey and the priority placed on the duration of the journey. The hypothesis posits that when a person's experience of moving is higher quality, they place a lower priority on time taken (within reason). An increasing positive experience of different travel modes helps broaden a person's alternative modal choice and increases the likelihood that they will select an alternative form of transport to the private vehicle.

Using the tool, it will be possible to pinpoint specific roads and routes where current conditions and traffic patterns already create a high probability that people will choose walking or cycling over driving. This shows us where the shift away from cars is already most likely to happen based on the real-world behaviour of the traffic network. Once the tool has been optimised, the project team will produce a series of scenarios tailored to regional priorities, such as:

- Shifting commuting trips from cars to public transport through service frequency improvements.

22 McFadden, D. (1974), 'The measurement of urban travel demand'. In: A. A. P. D. Hensher and P. R. Stopher (eds.), Behavioural Travel Demand Modelling. Lexington Books, pp. 279–318

- Designing active travel corridors between key employment centres and residential areas.

- Testing the impacts of low-traffic zones or car-free city centre policies.

There is also a need to explore opportunities for modal shifts from commercial delivery vans. SYSC funded interdisciplinary research to investigate the technical viability for e-cargo cycle deliveries across South Yorkshire as well as the socio-economic barriers to their adoption.

A modelling exercise found that there is great potential for e-cargo cycles to replace a significant proportion of last-mile deliveries in South Yorkshire's urban areas, especially where there is a high density of businesses and housing. Feasibility was found to be particularly high in Barnsley and Rotherham; across the areas of 80 km_2, e-cargo cycles still take less time than vans, despite making a mean of 5.9 and 6.2 subtours (between which more packages are picked up from the depot). In Sheffield, e-cargo cycles outperformed vans no matter the number of stops when the delivery area was 16km2 or less. In Doncaster, feasibility is high for e-cargo cycles up to 12 stops but is always outperformed by a van after 26 stops. This is due to lower business density and faster arterial routes that favour vans.

Whilst the modelling demonstrated strong potential for e-cargo cycle deployment, the accompanying qualitative research found significant challenges such as business resistance to change, the safety and security of both riders and e-cargo cycles, as well as a lack of local authority resources to support the transition. However, a clear role for local government emerged, alongside continued commitment to invest in cycling infrastructure; supporting the normalisation of e-cargo cycles through trials and their incorporation into internal fleets , with one interviewee noting *"People are not going to start seeing this as an alternative unless they start seeing them"*.

The combined study shows that there are strong use cases for Small and Medium-sized Enterprises (SMEs) and for certain delivery types (i.e. small parcels, groceries, medicines, documents). There could be additional value for those positioning themselves as sustainable businesses to their customers. Larger companies may also find value in partial adoption, with e-cargo cycles complementing vans for some types of deliveries.

Equitable Transport

Transport for the North attributes the **25% gulf in Gross Value Added** between the North and other areas of England to **"sub-optimal transport links and underinvestment in transport"**

Across South Yorkshire, our modelling predicted that

32% of Barnsley residents

35% of Rotherham residents

38% of Doncaster residents

44% of Sheffield residents

were struggling to pay for transport

This could reduce congestion pressure and improve air quality in dense urban areas.

Whilst some journeys can and should be shifted to alternative modes of transport, motorised vehicles will remain a significant part of the transport system. Therefore, policy and technical innovation is needed to temper the social and environmental costs associated with private and commercial motorised vehicles.

Researchers at The University of Sheffield found that re-routing vehicle traffic using a pollution-optimal traffic assignment model (TA) can reduce congestion and achieve a 21% reduction in Sheffield-wide NO_2 concentrations, reducing the number of roads exceeding WHO recommended limits from 37% to 30%. Traffic re-assignment could also reduce the number of roads exceeding 20µg/m3 - a level associated with elevated long-term health risks[23] - from 8% to 5%. Moreover, these gains are not accompanied by significant time penalties for drivers - the average increase in journey times is just ~20 seconds showing that health and environmental benefits don't need to come at the cost of major inconvenience.

Regional traffic policies may be implemented to encourage drivers to take the pollution-optimal routings. However, the transition to EVs will present new air pollution challenges; Particulate matter (PM) 10 and 2.5 from road, brake and tyre wear will increase due to the increased weight of EVs (compared to conventional vehicles) caused by large batteries[24], although advances in regenerative braking may eventually reduce pollution[25].

23 WHO (2021) WHO Global Air Quality Guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, World Health Organization, Geneva.
24 Parkes, S. and Rafalowicz-Campbell, M. (in preparation) Cycling past and present: an oral histories approach in Sheffield, UK.
25 Liu, Y., Chen, H., Gao, J., Li, Y., Dave, K., Chen, J., Federici, M. and Perricone, G. (2021). Comparative analysis of non-exhaust airborne particles from electric and internal combustion engine vehicles. Journal of Hazardous Materials, 420(126626), p.126626.

Transport Recommendations for Regional Policymakers

1. Working in collaboration with researchers, businesses and communities, local policymakers should include **communication and engagement campaigns that actively tackle 'motor-normativity'** in their delivery plans for promoting public and active transport. This should include creating **explicit statements of the benefits of multi-modal transport** in order to build public understanding of, and acceptance for, the need for change.

2. Planning departments should **change their focus from the optimisation of the flow of vehicles to the flow of people**, to give greater priority to alternative modes of transport that could deliver a more sustainable transport system, as well as a better experience for South Yorkshire's residents.

3. Acknowledging that transport-related economic and social exclusion limits regional growth ambitions, **local policymakers should use the transition to public control of buses by 2027 to implement an equity-based approach to service provision (in contrast to demand-driven models). This should occur alongside the introduction of a simplified distance-based fare structure** that eliminates the financial penalty of transferring between services.

   i. South Yorkshire's Public Transport Network and Distributive justice: Which Communities Face Poor Job Opportunities?

2. SYSC research has shown high feasibility for e-cargo cycles to replace last-mile deliveries in South Yorkshire's urban centres. **Local policymakers should work collaboratively with potential local providers** (such as a Different Gear, Evoloce or Russell's Bicycle Shed (all Sheffield based)) **to create a coherent, resourced, South-Yorkshire-wide e-cargo cycles scheme** that provides: a try-before-you-buy fleet, business change support, and support accessing subsidies and grants. In parallel, investment is needed in infrastructure such as sufficiently wide, segregated lanes, strategically placed distribution hubs and parking and storage facilities.

   i. Modelling the Impact of e-cargo Bikes for Last Mile Deliveries in South Yorkshire.

   ii. E-cargo Cycle Schemes: Lessons for Policy Design.

3. Regional transport planners should **include air quality as a design factor when developing local traffic policies** (i.e. speed limits or traffic light timings) as pollution optimal routing could reduce NO2 concentrations on major roads without significant increases to journey times (~20 seconds).

   i. Improving Air Quality: Re-Routing Sheffield's Commuting Cars Could Reduce City-Wide NO2 Concentrations by 21%.

Further Research Opportunities

The impact of EV charging infrastructure on urban spaces and accessibility, particularly conflict with walking, wheeling and cycling.

Factors influencing EV adoption beyond charging infrastructure - such as cost, range anxiety, vehicle choice, sensory (i.e. sound and feel of a petrol or diesel engine).

Best practices for integrating active travel, public transport, and EV use.

Effectiveness of various nudging techniques to promote sustainable transport.

The impact of urban planning and policy on travel behaviour and mode shift.

Research to understand the potential for regional policies to accelerate EV adoption.

Improving Air Quality: Re-Routing Sheffield's Commuting Cars Could Reduce City-Wide NO_2 Concentrations by 21%

Project team:
University of Sheffield: Samantha Ivings, Dr James A. King, Dr Alexander Roocroft, Dr Patricio Ortiz, Toby Willis, Dr Maria Val Martin, Dr Hadi Arbabi, Dr Giuliano Punzo

Challenge Statement

In the UK, roadside nitrogen dioxide (NO_2) - a pollutant closely linked to vehicle emissions - often exceeds recommended levels, contributing to respiratory issues and broader health inequalities. In 2023, 68% of UK roadside NO_2 concentrations originated from car exhaust pipes[1]. Black-box data from 2019 records an average daily traffic volume in Sheffield of 15,898 private cars per hour commuting during peak hours: weekdays 7-9am, and 4-7pm[2]. Sheffield's air quality is worsened by NO_2 during busy hours where traffic is congested - as stop/start traffic leads to more NO_2 output[3] - and due to under-utilisation of high-capacity roads. Therefore, by optimally re-routing traffic between origin and destination, it may be possible to improve local air quality even without reducing the number of cars on the road.

Research Response

To understand how best to re-route Sheffield's commuters, we developed a traffic assignment (TA) model, a tool predicting how vehicles moving between their origins and destinations (OD) will distribute on the road network. When paired with emission models, TA models allow the assessment of road-specific environmental impacts, providing critical information into the relationship between traffic distribution and air pollution.

The study develops a data-driven pollution function that calculates the direct relationship between traffic density and NO_2 levels. We have integrated three distinct datasets[4] so that we can optimise vehicle routing to reduce emissions without needing to change infrastructure or public transit habits.

While the method developed is applicable to any road network, the goal of this work is to provide a quantitatively robust strategy for minimising car-associated NO_2 pollution across Sheffield, allowing more roadsides to fall within acceptable NO_2 guidelines provided by the World Health Organisation (WHO).

1 DEFRA (2025) Emissions of air pollutants in the uk – nitrogen oxides (nox)
2 The Floow (an Otonomo Company). Smart mobility observatory, 2023.
3 Zhang, K., Batterman S., and Dion F. (2011), 'Vehicle emissions in congestion: Comparison of work zone, rush hour and free-flow conditions'. Atmospheric Environment, 45(11):1929–1939.
4 (1) traffic data gathered by the Sheffield City Council (SCC); (2) environmental sensor data from the Sheffield Urban Flows Observatory (SUFO); (3) readings from the Sheffield Hallam Athletics Stadium Weather Station.

Evidence and Outputs

To understand how people currently route their journeys between OD pairs, we assume road users will choose the fastest possible route for themselves (Sheffi, 1985). Thus, we create a TA model that is time-optimal for each individual user (i.e. minimising individual travel time). This is regarded as the current mobility scenario. We compare this with our TA model that is pollution-optimal city-wide (i.e. minimising overall NO_2). Many results arise from comparing these two scenarios.

The road-wise changes in traffic flows required to move from the current to the pollution-optimal

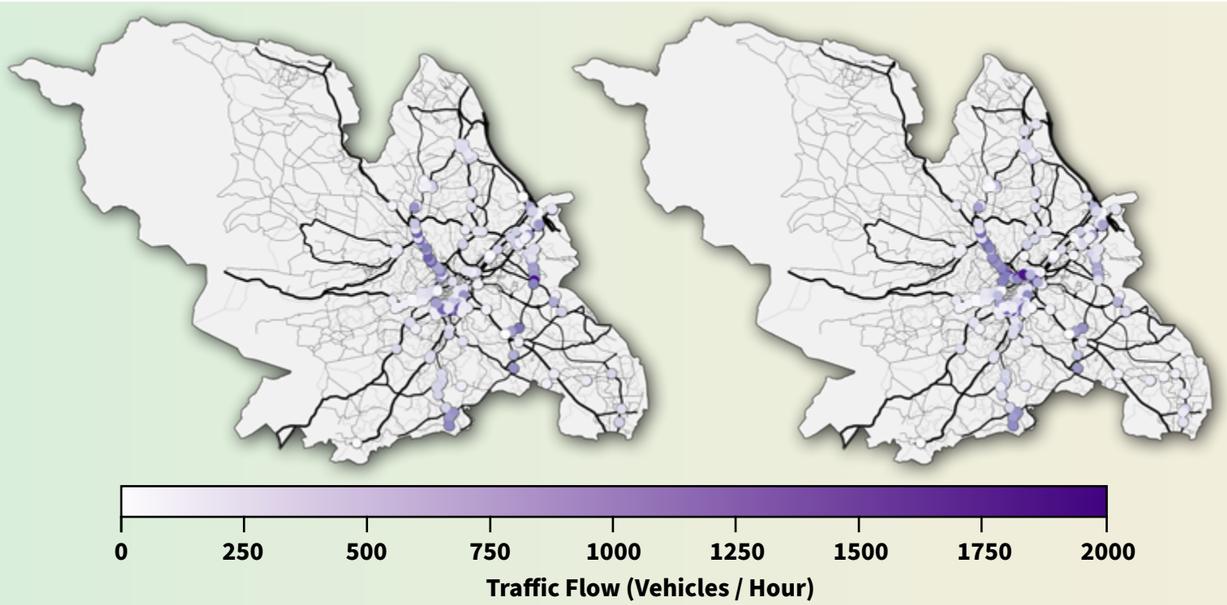


Figure 1 (a and b): Traffic flows during 2019 and 2023 in Sheffield, UK. Measurements are from Sheffield City Council traffic sensors. Plots show hourly averages across peak times (7-9am, 4-7pm) for Feb - Oct of each year.

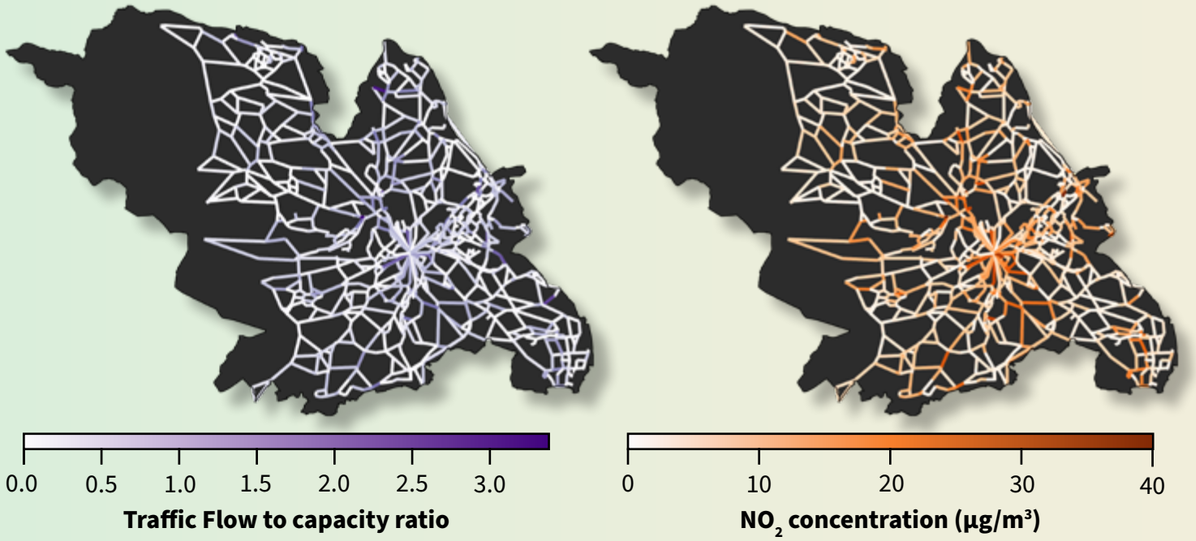


Figure 2 (a and b): Road-wise TA outputs for the current transport scenario in Sheffield, from Feb - Oct 2019 during peak hour.

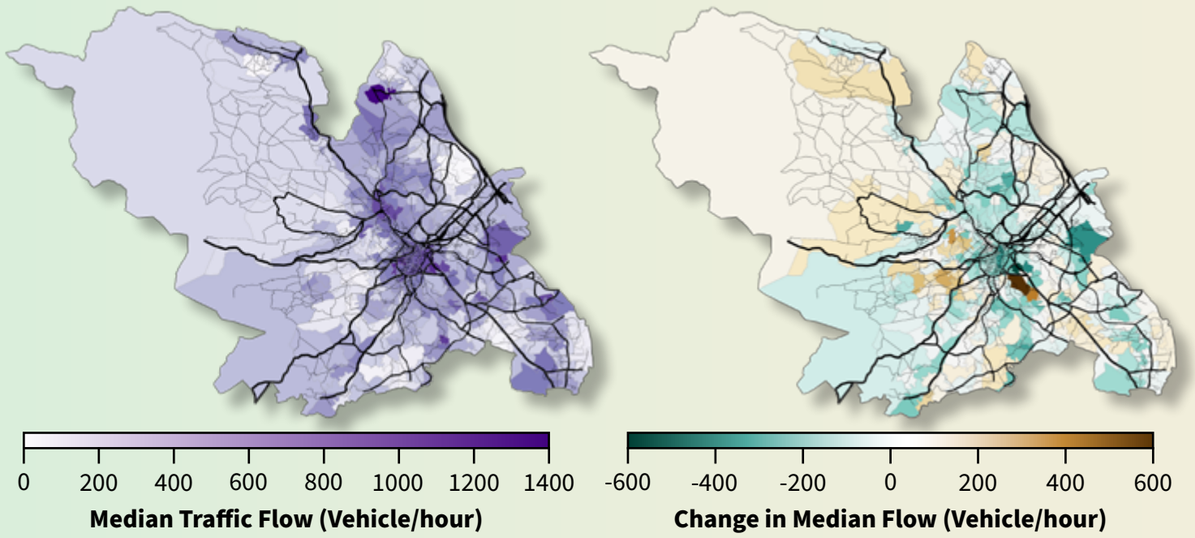


Figure 3 (a and b): LSOA-aggregated traffic flow results from two TA models: the current scenario, and the pollution-optimal. For each LSOA, the median road is visualised.

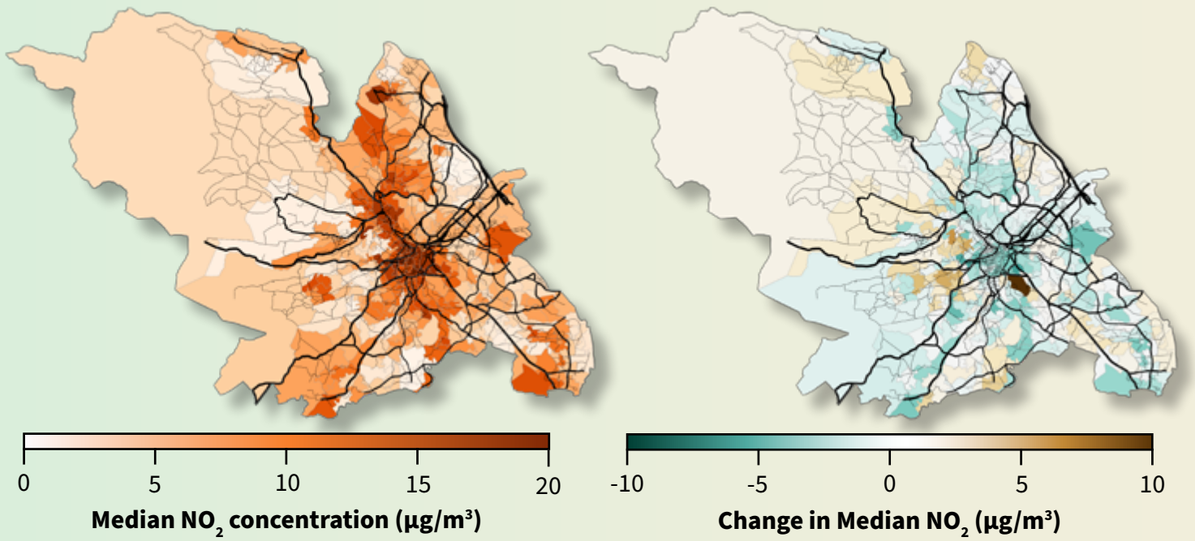


Figure 4 (a and b): LSOA-aggregated NO_2 concentration results from two TA models: the current scenario, and the pollution-optimal. The median road per LSOA is shown.

scenario is shown in Figure 2. In total, 981 roads (45.4%) require flow reduction, 1,039 (48.1%) require an increase, and 140 (6.5%) require negligible - i.e., modelled as zero - change to flows. Under pollution-optimal routing, increased traffic flows are assigned to major roads such as Barnsley Road, Firth Park Road, and Penistone Road. Meanwhile, roads within the same region as these, yet of a lower road class, require less flow.

In the current scenario, our TA output shows that flows on 671 (31.1%) of roads exceed their capacity, hence becoming congested. Many of these roads are situated at the city centre, extending through major arterial routes connecting the centre to the Northwest, Northeast, and Southern areas of the city in particular. In the pollution-optimal case, only 499 (23.1%) of roads exceed flow capacity: the city centre and the high-flow route towards the upper East of the city still experience congested roads, though the number of these is reduced. On average, roads in the current scenario are operating at around 71% capacity. In the pollution-optimal scenario, this figure is 69%, showing that minimising NO_2 concentrations desirably does not increase network-wide traffic congestion through flow management.

Roads modelled as currently having the highest flows - and highest NO_2 concentrations - are situated within and around the city centre, diminishing towards the West of the city. Much of the East shows low flow/NO_2, with the exception of very high results on the upper East route.

We have aggregated our road-based results to a Lower Layer Super Output Area (LSOA). The median road in each LSOA is reported. It is worth noting that LSOAs with very few roads passing through them may take a higher number of vehicles compared to those with high road counts.

Click here to open an interactive LSOA map for Sheffield in 2019 (HTML); Sheffield train station is marked with a red dot.

For the current mobility scenario, Figure 3(a) shows the median road's traffic flows within each of Sheffield's LSOAs. Several of the highest-flow LSOAs are situated around Sheffield's train station slightly East of the centre (such as Arbourthorne and Park Hill & Wybourn), with high flows also in directly bordering regions. Moving away from the centre, elevated flows remain along major arterial roads; particularly those connecting the North and East of the city with the centre.

In terms of commuting routes, we see that a route with some of the heaviest traffic flows in the current scenario is associated with commuting to/from the East of Sheffield towards both Rotherham and, further afield, Doncaster. Moreover, this route is situated very close to both Meadowhall and the Northern General Hospital. The highest flow LSOA along this route is an industrial area (company count 1,676, population 1,872), while other high-flow LSOAs are residential. These results suggest that residential LSOAs, located near major roads connecting industrial zones, are most impacted pollution-wise by through-traffic.

Shifting to a pollution-optimal case (Figure 3(b)), we find that the industrial district between Sheffield and Rotherham would see an increase of traffic away from the shortest route between the origin and destination, distributed instead along currently low-flow roads. Increased flows appear to facilitate flow reductions in neighbouring regions.

All of the ten highest-flow LSOAs in the pollution-optimal scenario would see lower median flows compared to the current scenario, achieving a 28% reduction. Across the whole network, an 8% total reduction in median road flows can be attained. This shows a redistribution of vehicles away from busy roads where traffic re-routing is feasible.

The analysis comparing the current (time-optimal) against the pollution-optimal routing scenario returns an Environmental Price of Anarchy (EPoA)[5]. This means that individual, self-interested behaviour results in higher environmental costs than socially optimal, centrally organised systems; in this case, selfish time-based routings are found to be 21% more environmentally costly than the pollution-optimal routings.

Figure 4(a) shows the median NO_2 concentration per road within each LSOA for the current scenario. As expected from the modelled traffic flow counts, the highest NO_2 concentrations are found in and around the city centre, and generally coincide with the highest traffic flows. Elevated concentrations are especially prominent along spatially connected North-South corridors and intersecting the centre. Some regions in the South, not experiencing excessive traffic flows, also show elevated NO_2 concentrations. This is likely due to the associated

5 Koutsoupias, E. and Papadimitriou, C. (2009), 'Worst-case equilibria', Computer science review, 3(2), 65–69.

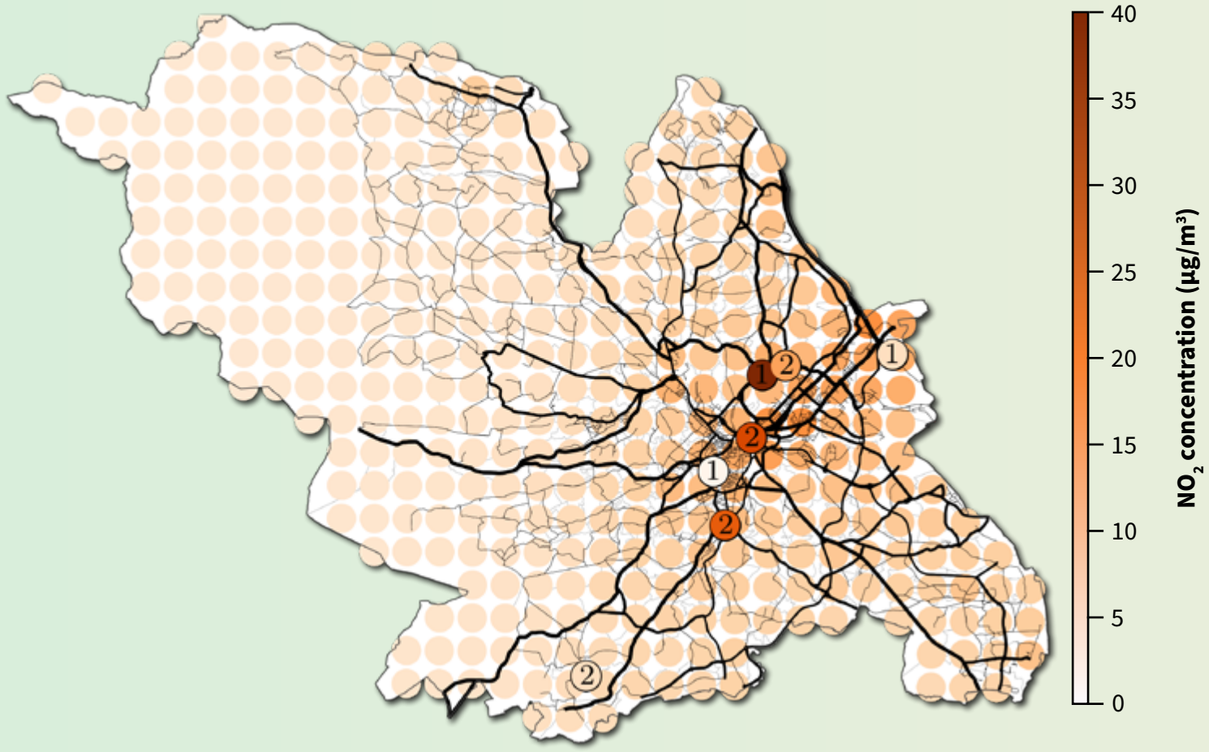


Figure 5: NO_2 concentration levels during 2023 in Sheffield, UK. City-wide background NO_2 concentrations are modelled by DEFRA, provided as hourly averages across 2023. Points labelled with (1) show measurements from Sheffield City Council (SCC) sensor datasets, averaged hourly across peak times (7-9am, 4-7pm) for Feb - Oct 2023, with NO_2 measurements provided in the unit µg/m3. Points labelled with (2) show additional SCC sensor readings, averaged hourly across the same time frame, with NO_2 measurements provided in the unit parts per billion (ppb). These measurements in ppb were then converted to µg/m3 using the ideal gas law.

roads operating near or above their saturation rate (flow/capacity), leading to high air pollutant outputs.

Figure 4(b) shows the difference in modelled NO_2 concentrations per LSOA between the current and the pollution-optimal scenario. We find that 204 LSOAs (59%) experience a reduction in median NO_2 concentration under pollution-optimal routing, while 141 LSOAs (41%) see an increase. Although some regions in the city show modest increases in NO_2, the largest air quality improvements are observed within the currently most polluted LSOAs. Conversely, some of the increases occur in low-pollution LSOAs, suggesting a re-distribution of pollution that results in a more balanced spatial distribution of NO_2 across the city.

Finally, using data from a University of Sheffield's Urban Flows Observatory automatic number plate recognition camera during Feb-Oct 2023, we found that, with the current fleet composition, passenger car flow alone predicted over 88% of the variation in NO_2 levels, even though features such as fuel type and vehicle age were accounted for.

What does this mean for the region?

By taking pollution-optimal routings, a 21% reduction in city-wide NO_2 concentrations could be achieved. These changes in NO_2 concentrations have significant implications for public health. Under the current traffic scenario, 37% of roads in the network are modelled to exceed the WHO annual mean guideline of 10µg/m3 during peak hours. In the pollution-optimal scenario, this proportion falls to 30%.

Additionally, the proportion of roads exceeding 20µg/m3 - a level associated with elevated long-term health risks[6] - declines from 8% to 5%. These results suggest that optimal traffic re-routing can meaningfully reduce population exposure to harmful levels of air pollution. Our model

6 WHO (2021) WHO Global Air Quality Guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, World Health Organization, Geneva.

especially reduces pollution within areas currently experiencing high NO_2 levels, such as along the route connecting the city centre to the Upper East of Sheffield, such as Burngreave and Tinsley & Carbrook.

In terms of road user satisfaction, these cleaner routes only add an average of ~20 seconds per journey (9% higher than in the current scenario), suggesting that health and environment benefits don't need to come at the cost of major inconvenience.

Local traffic policies may be implemented to encourage drivers to take the pollution-optimal routings, such as adapting speed limits on major roads where some increase of traffic is recommended, and/or altering the timings of traffic lights. As passenger car flow emerges as the main NO_2 predictor, promoting strategies to reduce car usage may be the single most effective action to consider.

Next steps

This study used a constant level of background NO_2. To further understand the spatial distribution of NO_2 across the city, we could apply a varying background level dependent on location to improve the accuracy of the model (see Figure 5). In this study Sheffield's Clean Air Zone (CAZ) and its implications were outside of scope. Further research could investigate the traffic flow rates within CAZ and its effectiveness and potential improvements to reduce air pollution.

This study could also be replicated for the remaining metropolitan areas in South Yorkshire to understand the opportunities for improving air quality through pollution-optimal traffic routing.

Finally, while our results suggest that the flow of private cars is the main contributor to NO_2, these are based on the current fleet composition, which the introduction of electric vehicles is quickly modifying. A refined analysis would then be needed to consolidate this output.

Cleaner Journeys, Smarter Cities:
A Multi-Layer Transport Model for Optimised Modal Shifts in South Yorkshire

Project team:
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Universidad de los Andes (Colombia): Prof. Andrés Medaglia Gonzalez, Pablo Medina, Maria Blanco

University College London: Maria Alejandra Wilches Mogollon

Challenge Statement

Reliance on private cars generates high levels of congestion, contributes significantly to regional greenhouse gas (GHG) emissions, and worsens air quality. The South Yorkshire Mayoral Combined Authority (SYMCA) has set ambitious goals for decarbonisation and modal shift[1], but there is a gap in the policy makers' toolkit for a model that integrates both the technical and psychological factors influencing how people choose to travel.

Traditional transport models often assume that travel time and monetary cost are the only determinants of modal choice[2]. In reality, factors such as comfort, convenience, safety, and reliability are equally influential[3,4]. Public transport users consider wait times and proximity to bus stops; active travel users are sensitive to hills, weather, and the availability of safe cycle routes[5,6]. Without capturing these nuances, regional planning risks underestimating both the barriers and opportunities for a shift away from private cars.

Research Response

We aimed to address this challenge by developing a decision-support tool that combines technical modelling with behavioural insights. Working in close collaboration with Professor Andrés Medaglia's research group at Universidad de los Andes in Bogotá, we drew on their expertise in system dynamics and decision science. Their team brought international experience of designing participatory approaches to transport modelling, which was central to our project's success.

Our work directly engaged with South Yorkshire stakeholders. On Tuesday 18 November 2025, a workshop took place in Sheffield with local transport experts, businesses, community representatives, and policy makers. This workshop, co-designed by the researchers in Sheffield and Bogotá, captured diverse perspectives on the most important factors shaping modal choice, such as travel time, economic cost, comfort, and safety. The workshop was followed by a four-day programme of in-depth interviews, led by the Bogotá researchers. These interviews provided a deeper understanding of the psychological and social drivers of travel behaviour, ensuring that our modelling reflects lived realities as well as technical constraints.

From these activities, we co-developed a Causal Loop Diagram that identifies the "unifying cost" people care about when deciding whether to drive, take the bus, walk, or cycle. This could be framed in terms of time, money, safety, or a combination of these. These insights will then be translated into empirically-informed cost functions that underpin a multi-layer traffic assignment model.

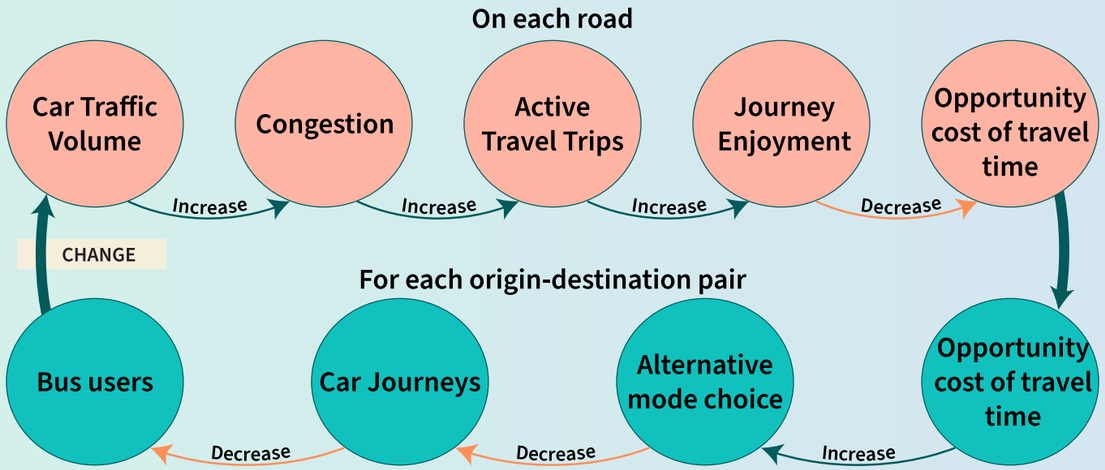
We began with the physical number of cars on the streets. When this volume of vehicles exceeds the roads' capacity, we experience congestion, slower speeds and lengthier journeys. This can drive a shift toward active transport trips, where people choose to walk or cycle rather than rely on vehicles. This change in behavior typically increases journey enjoyment, reflecting the personal satisfaction or pleasure felt while traveling. As someone enjoys their trip more, their opportunity cost of travel time - the priority they place on minimizing every minute of their commute - starts to feel lower because of the time spent moving being seen as higher quality.

An increasing positive experience of different travel modes helps broaden a person's alternative modal choice. This is their experience of having the freedom and practical ability to choose between different ways to get around. As these alternatives become more viable, we see a drop in car trips and an increased choice for public transport options in proportion of total travellers. A reduction in these car trips eventually leads to fewer vehicles on the road easing the initial congestion and closing the loop.

This model allows us to redistribute South Yorkshire's current origin–destination (OD) demand, currently dominated by private cars, across other transport networks, including public

1 SYMCA (2022) South Yorkshire Mayoral Combined Authority Energy Strategy
2 McFadden, D. (1974), 'The measurement of urban travel demand'. In: A. A. P. D. Hensher and P. R. Stopher (eds.), Behavioural Travel Demand Modelling. Lexington Books, pp. 279–318.
3 Beirão, G. and Sarsfield Cabral, J. A. (2007), 'Understanding attitudes towards public transport and private car: A qualitative study'. Transport Policy, 14(6), pp. 478–489.
4 Redman, L., Friman, M., Gärling, T., and Hartig, T. (2013), 'Quality attributes of public transport that attract car users: A research review'. Transport Policy, 25, pp. 119–127.
5 Ibid.
6 Pucher, J. and Buehler, R. (2008), 'Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany'. Transport Reviews, 28(4), pp. 495–528

Multi-layer transport model for South Yorkshire



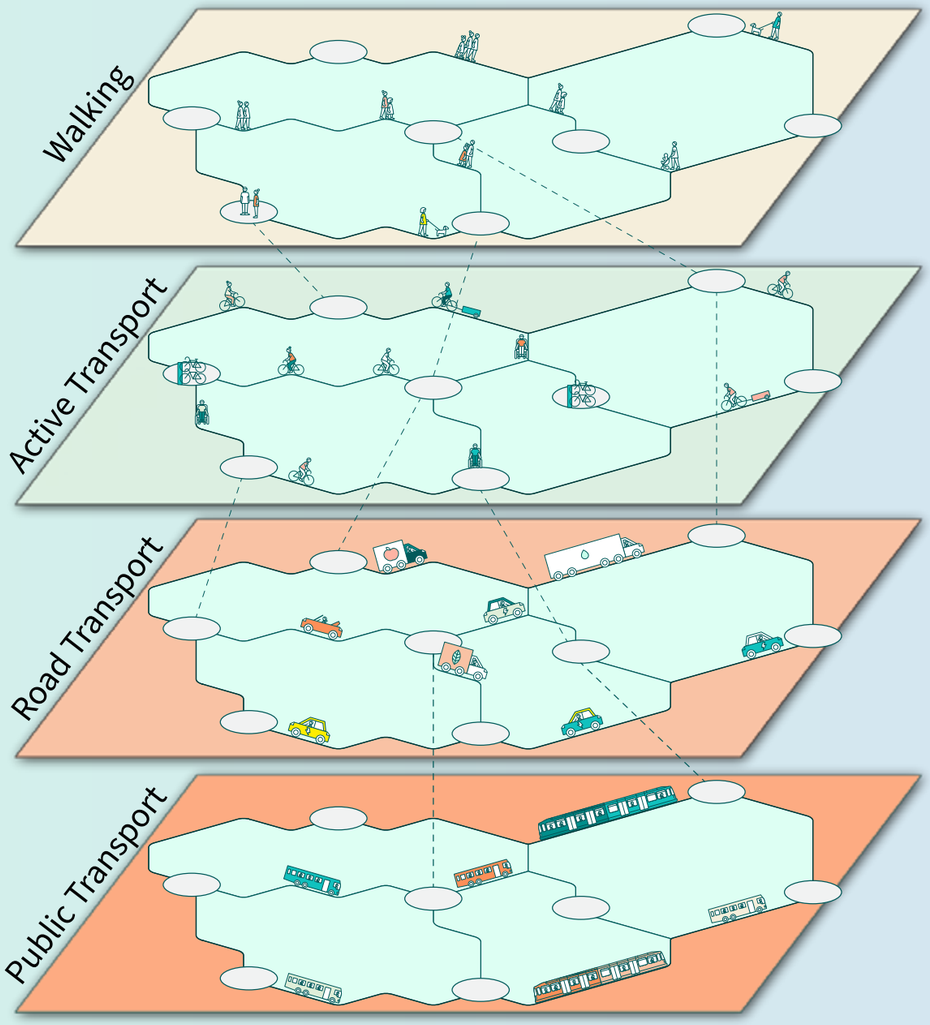


Figure 1: Simplified road network for South Yorkshire showing origin-destination active travel likelihood.

transport and active travel. Importantly, the model is not limited to time efficiency but incorporates the broader factors stakeholders identify as decisive. We refer to it as multilayer, as it deals with congestion at a road by road level and with mode preference at end-to-end journey level.

Evidence and Outputs

While full results are still in development, our approach is already producing tangible outputs. We are building a base case using Sheffield 2019 OD data from The Floow, which we will then scale to the entire South Yorkshire region. By integrating stakeholder-informed "cost functions" putting numbers to the causal relationships above, we will be able to simulate how journeys could shift from private cars to other modes under different policy scenarios.

The model can generate actionable insights, for example:

- Identify where public transport improvements (such as doubling bus frequency on main commuter corridors) are most likely to attract former car users.
- Highlight urban routes where the introduction of safe cycling infrastructure or cycle superhighways could lead to a strong uptake in active travel.
- Test Dutch-style interventions such as reallocating road space to buses and bikes, or creating low-traffic neighbourhoods[7].
- Produce heatmaps that reveal "low-hanging fruit" for intervention: OD pairs where car use is currently high but where active travel or public transport could become the lower-cost option with targeted investment.

In practical terms, this will allow us to say: "this particular flow between two neighbourhoods is currently dominated by cars, but could be most effectively shifted to cycling if dedicated lanes were added or this commuting route would likely see large mode shift if bus services were made more frequent or reliable".

7 Pucher, J. and Buehler, R. (2008), 'Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany'. Transport Reviews, 28(4), pp. 495–528

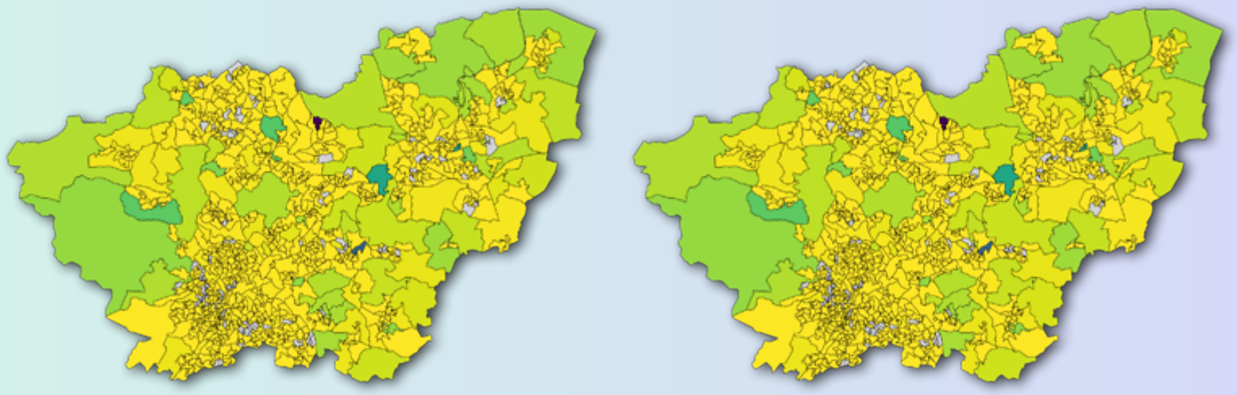


Figure 2 (a and b): ATT (a) and BU (b) after optimisation (UE)

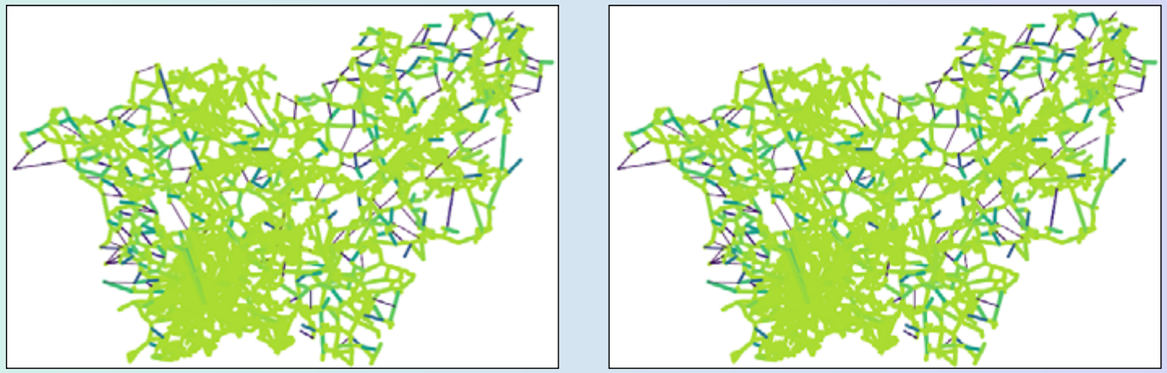


Figure 3 (a, b and c): AoN ATT (a), EU ATT (b), UE ATT - AoN ATT (c)

As a demonstration, we can start by identifying roads and routes where our prototype mode identifies promising expectation for people to choose alternatives to cars. Starting with existing data on car traffic flows between local areas, which tells us how many cars pass through each road, and then applying the relationships identified in our causal loop, such as how congestion impacts the choice to walk or cycle, we estimate the likelihood of a person choosing a car, a bus, or an active mode for any given journey. By isolating that "active" portion, we can pinpoint specific roads and routes where current conditions and traffic patterns already create a high probability for people to choose walking or cycling over driving. This shows us where the shift away from cars is already most likely to happen based on the real-world behavior of the traffic network.

What does this mean for the region?

For South Yorkshire, this project will provide a first-of-its-kind evidence base for designing transport interventions that are both technically optimal and socially acceptable. The model offers policy makers a tool to test interventions before committing resources, reducing uncertainty and improving decision-making.

The implications are wide-ranging. For example, by identifying routes most suitable for active travel, investment in cycle infrastructure can be targeted where it will have the greatest impact. Similarly, by simulating how bus service enhancements would shift demand, the region can prioritise investments that reduce congestion and emissions most effectively. These kinds of modal shift models have proven to be highly beneficial worldwide[8, 9, 10].

The benefits extend beyond efficiency. Shifting demand away from private cars will improve air quality, reduce GHG emissions, and promote healthier lifestyles through active travel. Crucially, by basing the model on stakeholder engagement, the project ensures that the recommended interventions align with local needs and values, making them more likely to succeed in practice.

Next Steps

The immediate next step is the workshop result refinement, consisting in optimising the formulations that translates preferences and propensities to quantifiable shifts across transport modes. After these activities, we will validate our model as an engine for understanding the potential effect of policies and structural interventions aimed at shifting the transport mode towards the most sustainable direction.

The modelling work will then produce a series of scenarios tailored to regional priorities, such as: (1) shifting commuting trips from cars to public transport through service frequency improvements; (2) designing active travel corridors between key employment centres and residential areas, and; (3) testing the impacts of low-traffic zones or car-free city centre policies.

These outputs will be shared with SYMCA and other stakeholders through visual tools such as heatmaps and dashboards. Over time, the model is positioned to be adapted for continuous use, supporting dynamic and responsive transport planning across South Yorkshire.

8 Shirzadi Babakan, A., Alimohammadi, A., and Taleai, M. (2018), 'An agent-based evaluation of impacts of transport developments on the modal shift in Tehran, Iran'. Case Studies on Transport Policy, 6(4), pp. 600–608.
9 Barbet, T., Nacer-Weill, A., Yang, C., and Raimbault, J. (2022), 'An agent-based model for modal shift in public transport'. Procedia Computer Science, 184, pp. 432–439.
10 Salazar-Serna, K., Cadavid, L., and Franco, C. J. (2024), 'Modeling urban transport choices: Incorporating sociocultural aspects'. Transportation Research Part F: Traffic Psychology and Behaviour, 99, pp. 234–248.

South Yorkshire's Public Transport Network and Distributive justice: Which Communities Face Poor Job Opportunities?

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Challenge Statement

Accessible transportation is at the heart of equitable societies; residents having equal opportunity to travel when, where, and how they want, at affordable costs. Moreover, high quality, high connectivity transport networks support regional development and regional economic growth. Transport for the North (TfN) names "sub-optimal transport links and underinvestment in transport" as one of the key attributes of the 25% gulf in Gross Value Added (GVA) between the North and other areas of England. In 2014, this gap equated to a £4,800 per person difference in income between the North and the UK average, and a £22,500 per person difference between the North and London[1]. According to the Centre for Cities 2021 report titled 'Measuring up: Comparing public transport in the UK and Europe's biggest cities', the productivity gap, due to weak public transport accessibility in Sheffield, stood at £2.3 million[2].

The South Yorkshire Public Transport (PT) network consists of buses, trains, and trams (see Figure 1). Tram services run primarily in Sheffield, but also connect Sheffield to Rotherham via the tram-train. Well-routed and affordable public transport (PT) services, running at sufficient frequencies, are key to minimising community exclusion and connecting people to the jobs, services and leisure facilities available in their area.

Understanding regional transport accessibility can reveal missed opportunities – particularly in terms of employment and economic activity – resulting from mobility barriers[3]. However, there is currently no analysis of South Yorkshire's PT network that reveals the spatial distribution of job accessibility for each community.

Moreover, assessing job accessibility is more complex than the presence or absence of PT infrastructure; socio-economic factors affect PT affordability for some communities. Therefore, the spatial distribution of job accessibility must be measured by quantity and types of job opportunities from a given location that can be accessed and are affordable using existing PT services.

1 Transport for the North (2019) Northern Powerhouse: Independent Economic Review Core Messages
2 Centre for Cities (2021) Measuring up: Comparing public transport in the UK and Europe's biggest cities
3 Crisp, R., Gore, T., McCarthy, L., (2017), 'Addressing transport barriers to work in low income neighbourhoods: A review of evidence and practice'. Sheffield Hallam University.

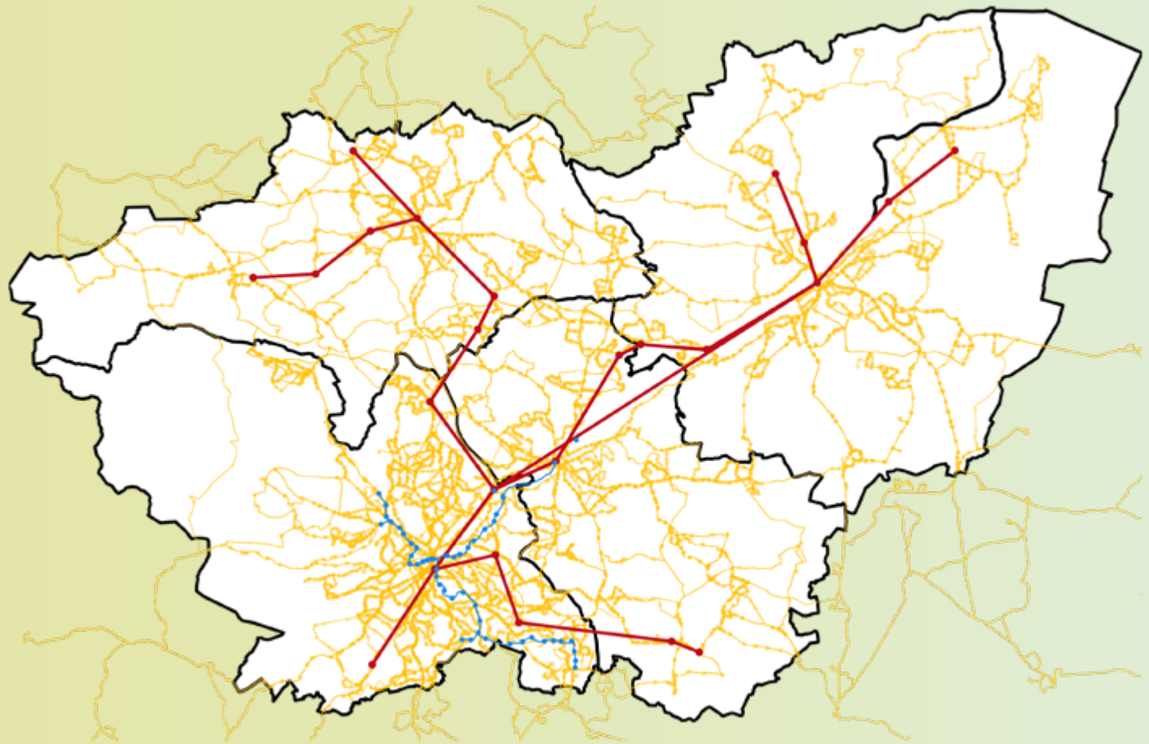

Figure 1: The public transport network of South Yorkshire, up to date as of May 2025.
Mode key: yellow - bus, red - train, blue - tram.

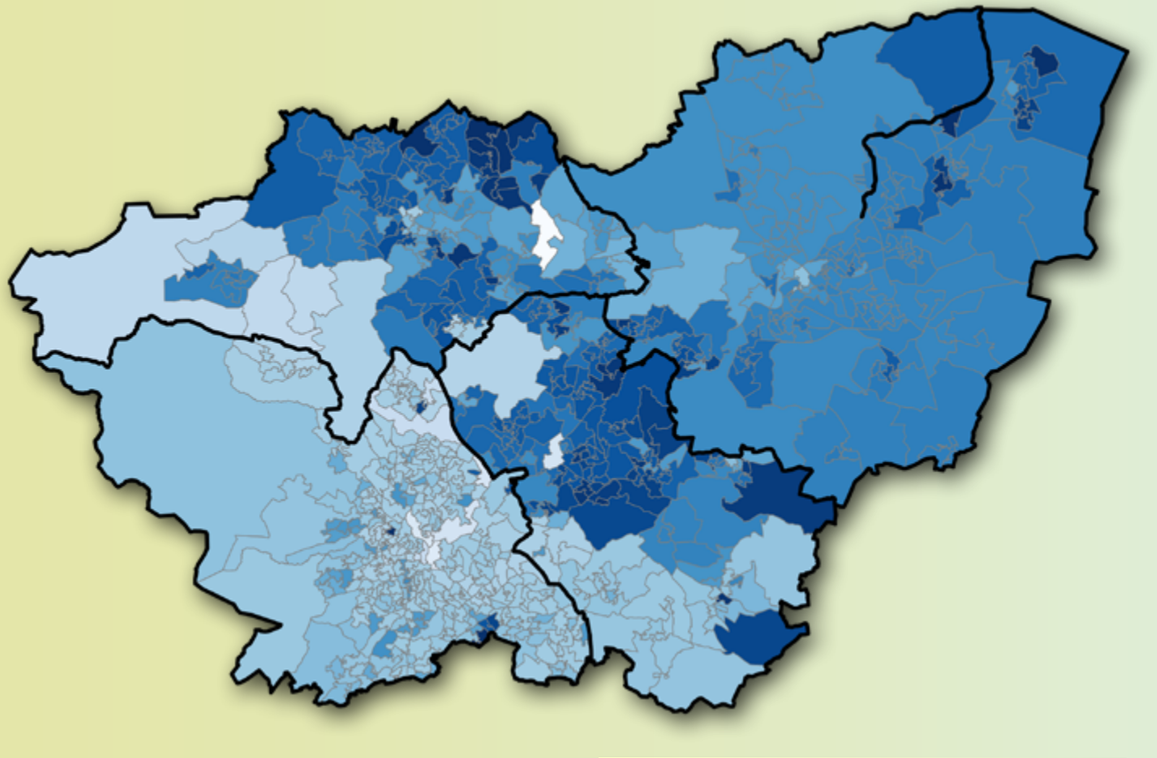

Figure 2: How many job opportunities are accessible from LSOA by public transport during peak commuting hours: weekdays 7-9am and 4-7pm. A maximum commuting threshold of 45 minutes is applied, with maximum 3 transfers.

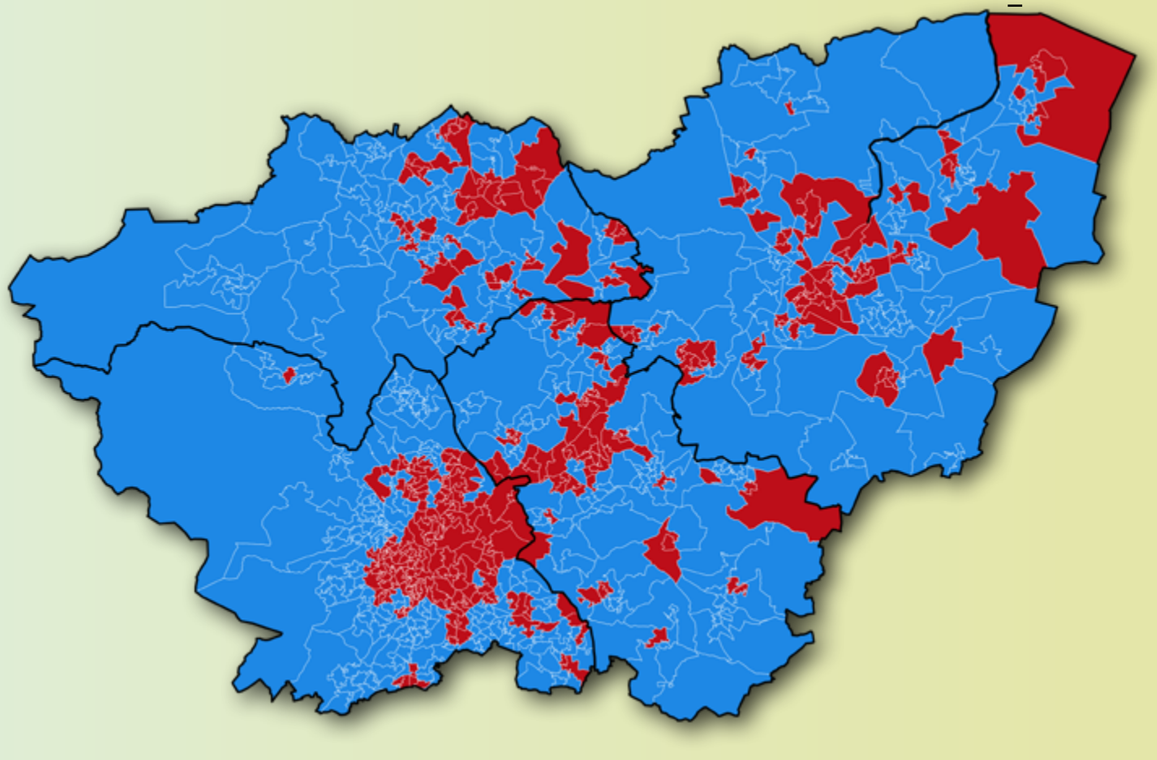

Figure 3: Transport affordability map of South Yorkshire, based on the outcome of a logistic regression model trained on a South Yorkshire survey, and applied to representative synthetic population data (Lomax et al., 2025).

Research Response

We assessed regional job accessibility using the current PT network of South Yorkshire, taking 'communities' as populations within lower-layer super-output areas (LSOAs). Spatial data for all current bus and tram services was provided by the South Yorkshire Mayoral Combined Authority (SYMCA), including service frequencies. Local train data was obtained from online service routes and timetables.

Different kinds of jobs require different in-person hours, and therefore, different commuting times. We provide our main analysis during peak commuting hours: weekdays from 7-9am and 4-7pm. To account for shift work, we also investigate PT options during typical hospital and warehouse commuting hours: all week from 5-7am, 3-5pm, and 9-11pm for hospitals, and all week from 4-6am, 12-2pm, and 8-10pm for warehouses. In doing this, we capture all key timebands where PT services run regionally across all three commuter scenarios.

We extracted three key metrics: (1) how many direct routes exist between all pairs of LSOAs; (2) modelled time spent travelling; and (3) minimum number of changes required. We assumed that transfers between all modes of PT can be taken within 800m, as this aligns with the maximum acceptable walking distance planning standard for train stops in the UK[4]. In alignment with SYMCA's bus service improvement plan[5], we assumed that commuters accept a maximum of a 45 minute commute each way. For tractability and realism, we adopted a cap of three transfers in our model.

To understand PT 'affordability', we used the household energy consumption survey undertaken by Jayne Carrick and Matthew Wood. This survey represents 623 respondents across South Yorkshire, who provided five key outputs for this study: (1) age; (2) working status; (3) income; (4) education level, and; (5) whether or not they are struggling to pay for their transport bills. The latter of these is a binary response, which we sought to characterise in terms of the first four respondent attributes.

By revealing how transport accessibility and affordability align with, or exclude, communities from economic opportunities, our framework empowers planners to design equitable transport systems that enable mobility.

Evidence and Outputs

Using our 45-minute limit for maximum acceptable travel time, we identify 'reachable' LSOAs during peak, hospital, and warehouse hours - see Figure 2 for results during peak hours. Comparing accessibility rankings to the number of registered companies in each LSOA, we find a visually intuitive overlap between areas of high economic activity and high accessibility.

Significant disparities emerge between those who rely on public transport and those with access to private vehicles. When these disparities are examined in the 24hrs cycle, it appears that existing transport strategies understandably focus on morning and evening peak travel times addressing high-demand routes. Yet this approach tends not to capture many lower-paid roles in sectors like healthcare and warehousing that require travel during "off-peak" hours. The analysis shows that public transport accessibility drops significantly during these shift-change windows, disadvantaging workers without cars in accessing these job opportunities.

Figure 3 shows the predicted transport

4 WYG/Rapleys (2020) How far do people walk? (CD3.38 WYG). Rapleys.
5 SYMCA (2024) Bus Service Improvement Plan Refresh 2024. South Yorkshire Mayoral Combined Authority, Sheffield.

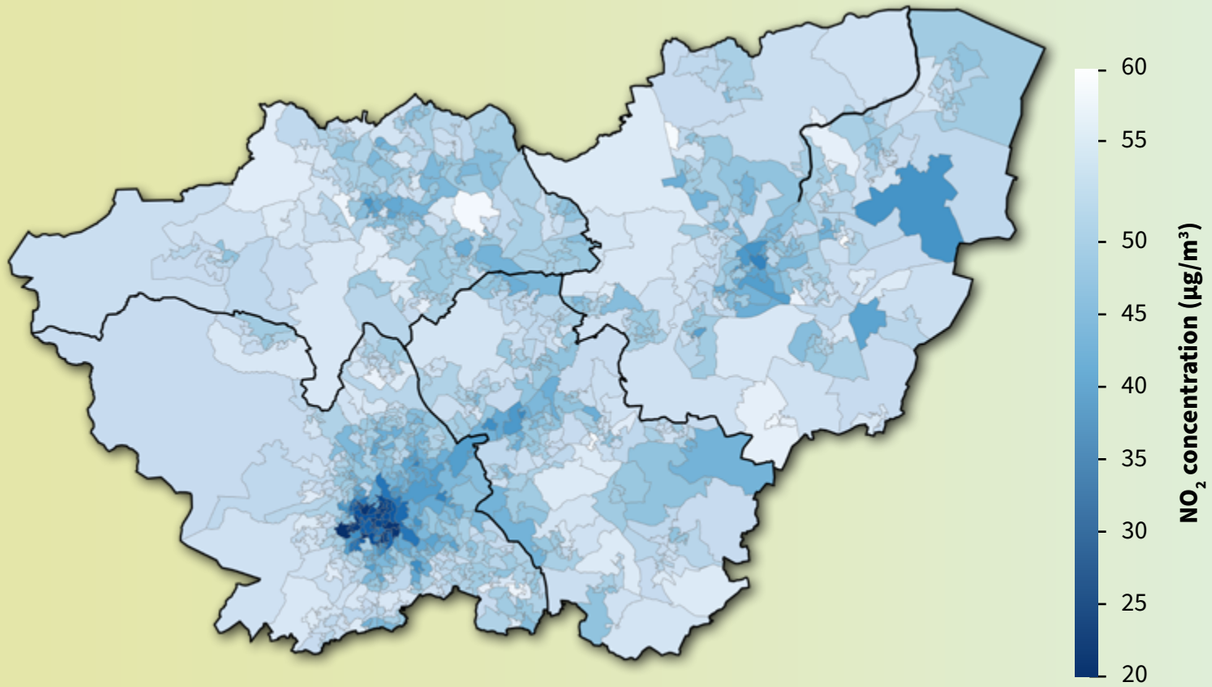

Figure 4: Map of the median age of residents within each LSOA, created from synthetic population data which matches actual census data when aggregated at LSOA level (Lomax et al., 2025).

affordability map for South Yorkshire at LSOA level. The number of LSOAs predicted to struggle paying for transport in each of the four local authorities are as follows:

- Barnsley: 47 (32% of total in region)
- Doncaster: 74 (38% of total in region)
- Rotherham: 59 (35% of total in region)
- Sheffield: 153 (44% of total in region)

This shows that Sheffield residents in particular may experience difficulties paying for transport. Doncaster is predicted to be the second most unaffordable region, followed by Rotherham, then Barnsley as the most affordable.

The key explanatory variable for this result is residents' age: the mean age for those struggling to pay was 21, while the mean for those not struggling was 54. Sheffield was found to be the most unaffordable because of the relatively large population of young people (university population) located within and around the city centre (see Figure 4), which is likely to explain the result.

However, when looking at personal report data, such as surveys, it's important to bear in mind that how each person interprets the response may differ. For example, an older person living rurally and who owns a private car may have a different perception of what 'struggling to pay for transport' looks like, in comparison to a young parent living near to the city centre who relies on PT. Understanding how much each respondent spends on transport per month could help to bridge this gap, especially in combination with household/ personal income data.

What does this mean for the region?

To meet the goal of increasing the proportion of economically active people living within 30 minutes of employment, findings suggest that current strategies must be adjusted. In particular, attention should be shifted towards the less economically active areas where PT access points are fewer than in high workplace density areas. PT stops are closely located to major attractors (e.g., workplaces) to promote accessibility. This generates a network that connects economically active areas, de facto excluding less affluent neighbourhoods in the region.

The transition to public control of buses by 2027 provides a mechanism to address these gaps. However, the research suggests that a demand-driven model, which prioritizes routes based on existing high usage, will not resolve the underlying inequalities. Attention should be shifted to link economically diverse areas to avoid islanding both geographically and temporally, across times of the day outside peak hours. The region could use an equity-based approach and also introduce a simplified distance-based fare structure to eliminate the financial penalty of transferring between services. Otherwise, the transport network will continue to limit regional economic growth by keeping a significant portion of the workforce without cars disconnected from the existing labor markets.

Our results align well with published deprivation statistics for South Yorkshire[6, 7], suggesting that communities with low socio-economic status and skills deprivation also experience the highest difficulties paying for transport.

6 Opportunity Sheffield (2023) Spatial mapping of South Yorkshire highlights areas of education, skills and training deprivation. Teacake Club / SYMCA blog, 13 Feb 2023.
7 South Yorkshire Fire & Rescue (2013) Community Profile. South Yorkshire Fire & Rescue, Sheffield.

Modelling the Impact of e-cargo Bikes for Last Mile Deliveries in South Yorkshire

Project team:
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Project partners:
Russell's Bicycle Shed

Challenge Statement

Urban logistics in South Yorkshire are dominated by fossil fuel delivery vans, which contribute significantly to congestion, poor air quality, and greenhouse gas (GHG) emissions. Last-mile delivery decarbonisation in particular was identified as an urgent challenge for the region by the South Yorkshire Sustainability Centre (SYSC), in order to meet regional net-zero targets. While e-cargo bikes are often highlighted as a promising solution to these challenges in European cities[1], there is little quantitative evidence on their feasibility in the United Kingdom outside of London.

This evidence gap makes it difficult for regional policymakers and businesses to make informed decisions about whether and how e-cargo bikes could realistically replace vans for local deliveries. E-cargo bikes currently remain a 'niche technology[2]', despite numerous and often promising trials with a range of large companies[3,4,5], as well as increasing private use[6]. There is a wide range of potential barriers to e-cargo bike use, including perceptions of rider safety[7], difficulty handling e-cargo bikes[8], a lack of familiarity or comfort with them[9], and limitations such as speed, range and capacity. Many barriers can be easily placed into one of two categories: difficulties transitioning to a novel delivery method (such as the need for training), and technical barriers (such as range and capacity). Implementation experiences and challenges were researched in more depth in a parallel SYSC Social Science study, e-cargo Cycle Schemes: Lessons for Policy Design.

Research Response

We set out to evaluate the technical feasibility and potential impact of e-cargo bikes compared with conventional vans for last-mile deliveries. To do this, we built a computational model of South Yorkshire's road network using open-source mapping data, Companies House business records, and traffic information provided by Sheffield City Council.

We combined this modelling with insights from local operators, including Russell's Bicycle Shed, who shared details of their experiences running e-cargo bike delivery services in Sheffield. Their input helped us ensure that assumptions such as average cycling speed and stop times were realistic for local conditions.

We modelled the distribution of businesses across South Yorkshire and developed a routing algorithm that allowed us to sample delivery points for both an e-cargo bike and a van, and simulate how long it would take each transport mode to deliver goods from the delivery depot, and the associated CO2 emissions.

Our work focused on four questions: (1) which businesses could benefit most from adopting e-cargo bikes; (2) how many delivery hubs would be required for viable operations; (3) how costs compared with conventional van services, and; (4) what scale of emissions reduction could be achieved through widespread adoption.

Evidence and outputs

Our analysis showed that e-cargo bikes can outperform vans in delivery efficiency across areas of up to 27 km^2, particularly in dense urban environments where vans are slowed by congestion and the need to find parking. Vans required on average four minutes of dwell time at each stop, compared with only one minute for an

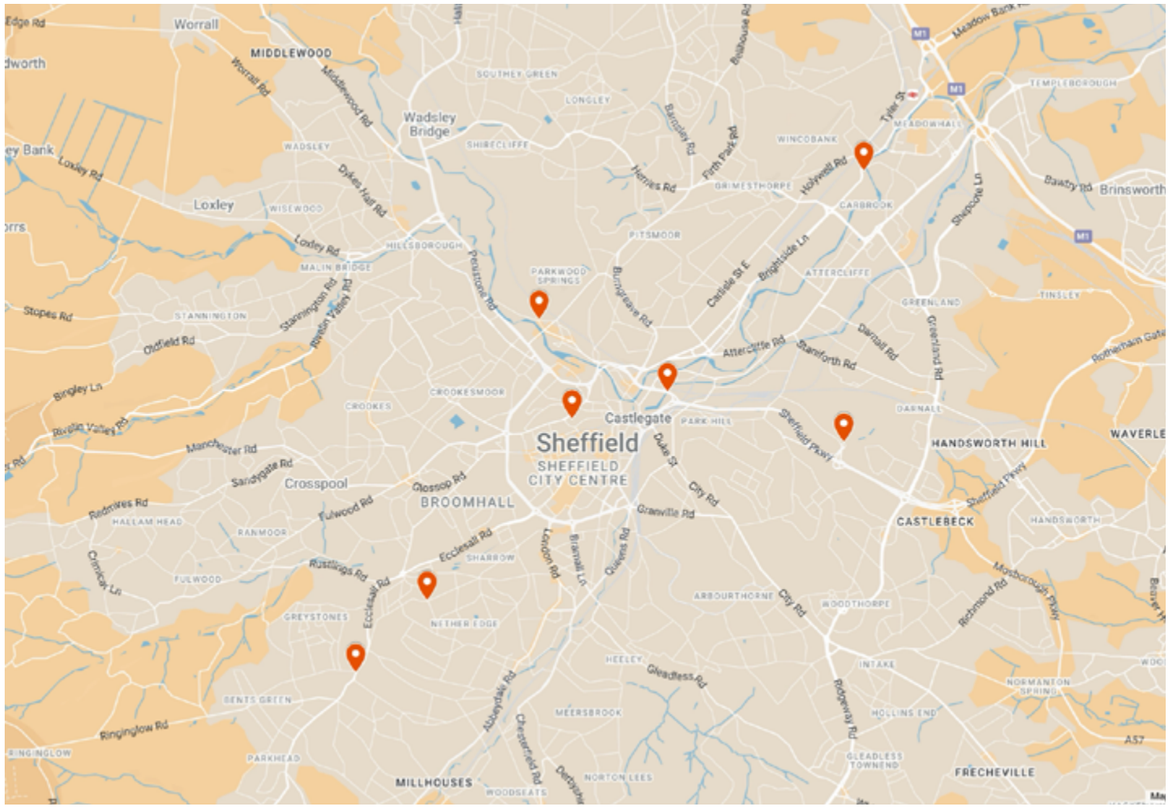

Figure 1: Map of the depots in Sheffield. Points are at the population weighted centroids of the seven LSOAs with largest numbers of businesses.

1 Gialos, A. and Zeimpekis, V. (2023) 'Dataset for the electric capacitated traveling salesman problem'. Data in Brief, 50:109464.
2 Sherriff, G., Blazejewski, L., and Davies, N. (2023), 'Why would you swap your nice warm van, where you can eat your butties and listen to the radio?' Mainstreaming a niche of cycle logistics in the United Kingdom. Energy Re-search & Social Science, 99:103062.
3 Sainsbury's (2018) 'Sainsbury's trials UK's first grocery delivery service by electric cargo bike'.
4 IKEA (2022) 'Solar-powered cargo bikes deliver lower climate footprint'.
5 DHL (2021) 'DHL supply chain trials e-cargo bike for home deliveries'.
6 CleanCities (2024) 'London sees dramatic increase in cargo bikes'.
7 Hess, A-K., and Schubert, I. (2019) 'Functional perceptions, barriers, and demographics concerning e-cargo bike sharing in Switzerland'. Transportation Research Part D: Transport and Environment, 71:153–168, 2019.
8 Bicycle Association (2024) 'Cargo bikes & cycle logistics'.
9 Sherriff, G., Blazejewski, L., and Davies, N. (2023), 'Why would you swap your nice warm van, where you can eat your butties and listen to the radio?' Mainstreaming a niche of cycle logistics in the United Kingdom. Energy Re-search & Social Science, 99:103062.

e-cargo bike. This gave e-cargo bikes a consistent advantage in high-density areas such as Sheffield city centre.

We found that at 31.5 km^2, both modes take an equal amount of time; we call this a 'critical point'. Below this critical point, e-cargo bikes are faster, whereas above this point, vans are faster. Figure 2 demonstrates how different size areas look across Sheffield, Doncaster, Barnsley and Rotherham.

In Sheffield the upper feasibility limit does not decrease below 16.6 km^2. This suggests that when delivery destinations are spread across areas smaller than this, e-cargo bikes take less time to complete routes than vans, regardless of the number of stops. A route of 30 stops takes approximately 4 hours to complete in Sheffield, while the time to complete feasible routes of 10 or fewer stops typically does not exceed 2 hours.

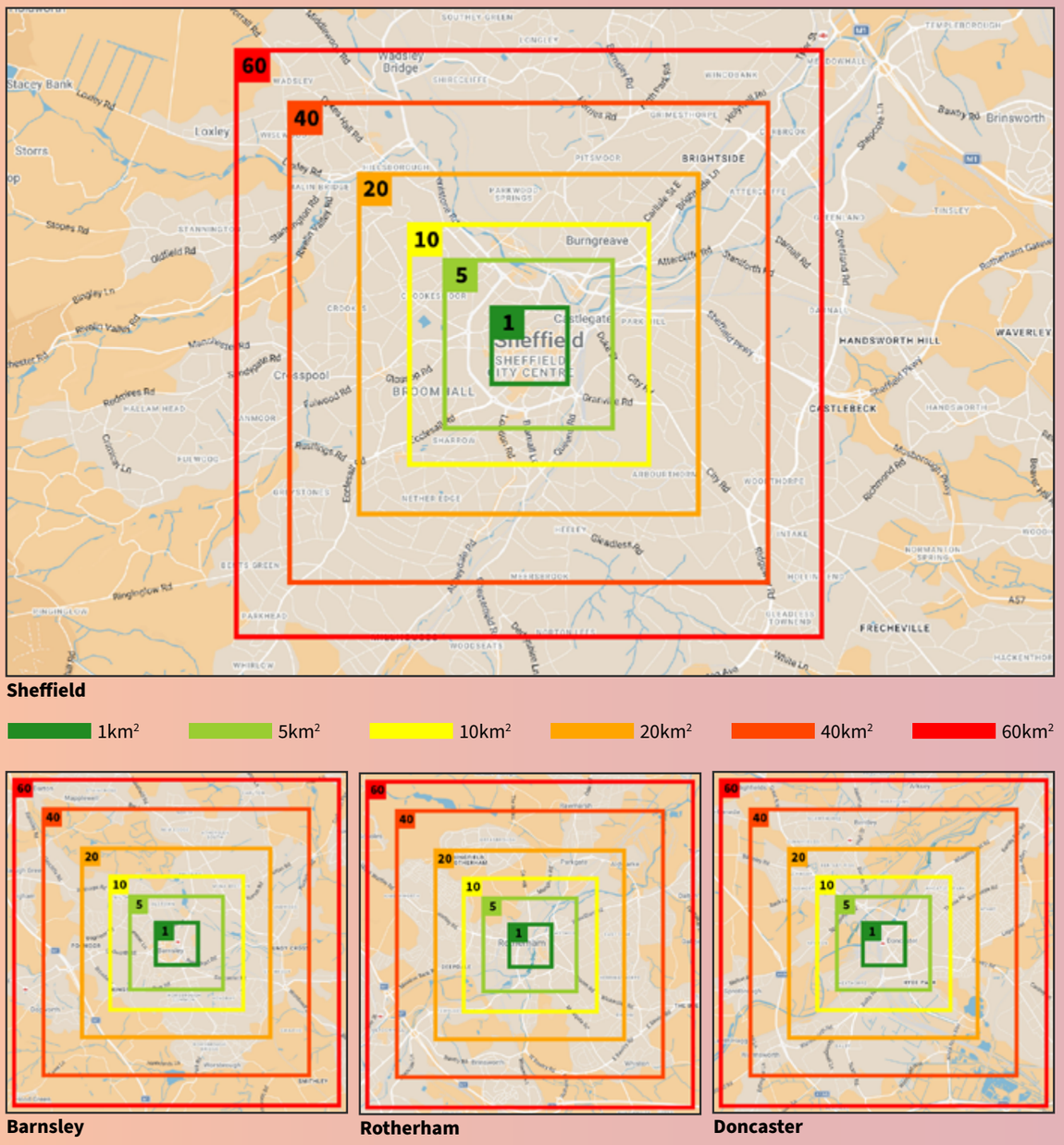

Figure 2: Maps to demonstrate how different size areas look across Sheffield, Doncaster, Barnsley and Rotherham. E-cargo bikes were found feasible: in Sheffield - areas ≤ 16km^2; in Rotherham and Barnsley - areas ≤ 50km^2; in Doncaster - with ≤ 25 stops across 25km^2

In Doncaster, feasibility for e-cargo bikes is high for up to 12 stops, but then decreases sharply, with vans always taking less time than e-cargo bikes to complete routes of more than 26 stops. The rapidly increasing lower limit shows insufficient business density to allow many stops in the area.

Feasibility is exceptionally high in Rotherham and Barnsley, with both local authorities having upper limits that do not substantially decrease with increasing numbers of stops. On routes of 40 stops spread across 80 km^2, e-cargo bikes take less time than vans despite making a mean of 5.9 and 6.2 subtours (between which more packages are picked up from the depot) in Rotherham and Barnsley, respectively.

In terms of environmental impact, switching from vans to e-cargo bikes reduced emissions by an average of 10.8 kilograms of CO_2 equivalent per delivery route, with potential savings of up to 20.1 kilograms depending on route length and density. At scale, replacing one diesel van with an e-cargo bike performing three routes per working day would save around 8.2 tonnes of CO_2 equivalent per year.

What does this mean for the region?

We found that small and medium-sized enterprises, particularly those located in central urban areas, stand to benefit most from adopting e-cargo bikes. Goods such as groceries, coffee, documents, and medical supplies are especially well suited to this delivery mode. Larger businesses may still find value in partial adoption, with e-cargo bikes complementing vans for some types of deliveries.

Our modelling also showed that cities the size of Sheffield would require around five strategically placed hubs, ideally located on arterial routes or near consolidation centres. This finding aligns with emerging models of urban consolidation hubs in other regions, where goods are transferred from large vehicles to smaller, cleaner modes for the final stage of delivery[10].

Our findings provide strong evidence that e-cargo bikes can play an important role in decarbonising logistics in South Yorkshire. For policymakers, the key message is that e-cargo bikes are not only viable but can in many cases be more time-efficient than vans. They also offer direct air quality and climate benefits through reduced emissions.

The transition will require supportive policies to overcome barriers such as perceptions of limited capacity and low demand. Financial incentives, such as grants or credits linked to clean air zone compliance, could help reduce the cost barrier for businesses. Investment in cycle infrastructure and the establishment of urban logistics hubs would further enhance feasibility and adoption.

Although we found strong potential in Sheffield and Rotherham, where business density is high, feasibility was lower in Doncaster due to faster arterial roads that favour vans. This suggests that regional adoption strategies may need to be tailored to local transport networks

Next Steps

The next stage for South Yorkshire could be to pilot e-cargo bike delivery schemes with local businesses, particularly small enterprises in dense urban centres.

Demonstration projects could help build confidence among businesses that remain sceptical of the service's capacity and reliability. Rich qualitative information was developed through a parallel SYSC study, e-cargo Cycle Schemes: Lessons for Policy Design.

There is also an opportunity to integrate e-cargo bikes into wider transport and decarbonisation strategies, including the development of urban consolidation centres. Additional research should focus on identifying thresholds of business density that determine viability, and on assessing how dedicated cycle infrastructure might further improve delivery efficiency.

10 Dreischerf, A. J. and Buijs, P. (2022) How urban consolidation centres affect distribution networks: An empirical investigation from the perspective of suppliers. Case Studies on Transport Policy, 10(1), 518–528.

E-cargo Cycle Schemes: Lessons for Policy Design

Project team:
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Challenge Statement

In South Yorkshire, urban logistics is dominated by fossil fueled delivery vans, which contribute significantly to congestion, poor air quality, and greenhouse gas (GHG) emissions. E-cargo cycles hold the potential to reduce emissions, improve inner city air quality, create 'green' jobs, and allow businesses to avoid the Clean Air Zone restrictions in Sheffield city centre. A report by climate charity Possible showed that e-cargo cycle deliveries in London are on average 1.61 times faster than vans, as well as saving significant CO2 and NOx emissions. Moreover, the annual running costs of e-cargo cycles were cited as £5,700 lower than for small diesel vans (£300 versus £6,000) based on research conducted by the Energy Saving Trust.

While e-cargo cycles are often highlighted as a promising solution in European cities, there is little quantitative evidence on their feasibility in the United Kingdom outside of London. This evidence gap makes it difficult for regional policymakers and businesses to make informed decisions about whether and how e-cargo cycles could realistically replace vans for local deliveries.

Significant challenges remain for this sector that has precluded them from entering the mainstream, remaining in the UK a "niche technology". There are also many barriers to e-cargo cycle use such as perceptions of rider safety, difficulty handling e-cargo cycles, a lack of familiarity or comfort with them, and limitations such as speed, range and capacity.

Research Response

The research addresses the following objectives: to synthesise what is already known about successful e-cargo cycle scheme implementation in terms of policy design and business perceptions, and to synthesise learning for implementation of future e-cargo cycle scheme development.

This complements a parallel study conducted through SYSC, Modelling the impact of e-cargo bikes for last mile deliveries in South Yorkshire, which investigates the technical feasibility (in terms of delivery time and delivery capacity) of e-cargo bikes in South Yorkshire as a means of replacing last mile or short distance deliveries currently conducted by fossil fueled HGV / LGV vehicles.

This project conducted a review of literature on e-cargo cycles as well as interviews with the representatives listed in Table 1.

Informal discussions were also held with representatives from City of York Council, London Borough of Hackney, Norfolk County Council, the latter's academic partner, as well as a Sheffield cycle shop with cargo cycle hire.

Evidence and Outputs

Successes

Overall, the try-before-you-buy schemes were considered the most successful - *"over half of the people who try one out actually go on to purchase one themselves"* (CaCC-PATO) - as it gave people the confidence to invest significant sums in the equipment, training and business process changes required.

In Colchester, an individual who obtained one of the Council's original fleet went on to launch Colchester e-cargo, which now employs 12 people covering pickups, deliveries, a city centre to home delivery service, and a contract with the e-scooter and ebike rental/sharing service to maintain and manage its Colchester fleet.

There were also strong use cases for Small and Medium Sized Enterprises. For example, a nursery in Brighton that used to send a member of staff in

Organisation	E-cargo bike fund	Interviewee role	Attribution acronym
Manchester City Council	£173,638.3 funded in 2021/22	Principal Resources and Programmes Officer	MCC-PRPO
Sheffield City Council	£158,360 funded in 2019/20	Senior Transport Planner	SCC-STP
Cambridgeshire County Council	£168,679 funded in 2019/20	Principal Active Travel Officer	CaCC-PATO
Colchester City Council	£135,988 funded in 2019/20	Transport and Sustainability Joint Lead	CoCC-TSJL
Zedify	n/a – delivery service partner	Brighton Hub Manager	Z-BHM

Table 1: Project interviewees

a taxi to deliver nursery meals was able to use an e-cargo bike to deliver the food to all stops in one hour.

Zedify was also contracted to visit SME clients with small rubbish loads, which they then delivered to a central collection point for a larger truck to collect. Businesses positioning themselves as sustainable found it was appreciated by customers too.

e-cargo cycles had also been used to replace some journeys by Council teams; cycles for internal use have largely been directed to the parks teams and others working outdoors, as *"those are the kind of people who are not fazed by having some outdoor clothes on and getting on a bike"* (MCC-PRPO). However, Sheffield City Council also found that *"it's quite difficult to get them [the cycles] out. It's still quite early days in terms of people feeling confident to use them"* (SCC-STP).

Challenges

The research identified a number of key challenges:

- business **resistance to change** in adoption of a new technology
- **safety and security** of both riders and the cycles
- **precarious working practices** in the cycle delivery sector
- generating sufficient **public awareness** and support
- **lack of local authority resources** in supporting this transition.

Resistance to change among businesses and the wider public was the number one challenge described by the interviewees. This resistance was encountered in the form of:

- **scepticism** or doubt around reducing costs
- **complications and confusion** around redefining operating models
- broader **uneasiness** relating to a new technology or change in general.

Furthermore, the research highlighted a cluster of concerns around the safety and security of both riders and cycles: the safety of the cycling environment and infrastructure in general, the ease of riding and control of e-cargo cycles, the storage and parking of the cycles and difficulties experienced obtaining adequate insurance.

The research produced rich qualitative findings, which can be found in the full report.

What does this mean for the region?

Recommendations about the shape of future trial schemes are as follows:

- Establish a try-before-you-buy fleet: there are a large variety of e-cargo cycles on offer, and end users often need help determining what will meet their needs.
- Streamline where possible and avoid running multiple different schemes at the same time.
- Ensure sufficient resources are allocated to management of schemes and maintenance of the fleet.

Collaboration between public and private sectors have also been key to the successful implementation of e-cargo delivery and logistics business models. To build successful partnerships we recommend:

- Seeking out those partners (or local champions) who are already helping to grow the presence of e-cargo cycles on the streets.
- Establishing a cross-sectoral alliance for information-sharing, mutual support, and lobbying power.

To overcome the varied challenges the research findings recommend:

- Working with successful e-cargo cycle operators, where available, in order to deliver sustained engagement and conversation with businesses, as well as an offer of support with redesigning operating models and practices.
- A renewed and continued commitment to investment in cycling infrastructure – to include e-cargo cycle parking and storage as well as sufficiently wide, segregated lanes.
- Targeting revenue funding to ensure sufficient resources for the maintenance, operation, and promotion of e-cargo cycle schemes.
- Incorporating public awareness campaigns into every stage of e-cargo bike programmes. At the same time, be prepared for some backlash.

Given local authority e-cargo cycle schemes have been dependent on external grant funding and are currently not sustainable into the long-term, the key question remains how to ensure future initiatives are able to survive beyond grant timescales to truly deliver a shift towards decarbonised transportation.

Next Steps

The second part of this research, "Modelling the impact of e-cargo bikes for last mile deliveries in South Yorkshire" has demonstrated quantitatively that there is a strong use case for e-cargo bike deliveries in some parts of the region. However, this research has shown that implementation is, in practice, challenging.

Based on the combined research conducted, we recommend that the region should build partnerships between interested parties in local government organisations, businesses, community groups and universities that can co-produce e-cargo bike projects and demonstrators using the results of viability modelling as a starting point.

Building Sustainable Food Systems

Published as part of the South Yorkshire Sustainability Centre Consolidated Research Report, March 2026

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The Challenge

It is estimated that the climate impact of the food system is such that, even if fossil fuel emissions were eliminated immediately, a business-as-usual food sector would put the target of restricting global warming to 1.5°C, or even 2°C, out of reach[1].

Unless there are major reductions to the climate impact of the global food system, including large scale decarbonisation and landscape restoration, we are unlikely to meet the central goal of the Paris Agreement in 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C'[2]. The Intergovernmental Panel on Climate Change (IPCC) predicts that even if warming is restricted to 1.5°C, it would be enough to destabilise whole ecosystems and impact weather patterns[3]. This calls for urgent action from all actors across the global food system to work together to limit the impacts of global temperature rises on climate and nature systems while preparing to adapt to coming weather uncertainties to build resilient food and nature systems fit for the future.

At the South Yorkshire Sustainability Centre (SYSC), our response to the food system emergency has been two-fold; to think globally - within the sustainable development framework laid out by the UN[4] - and to work locally with partners to build knowledge and capacity within our region around how to make South Yorkshire's food system, and the landscape it resides in, more sustainable.

South Yorkshire's Natural and Food System Landscape

The Natural Capital Solutions (NCS) report states that South Yorkshire covers 1,552 km² area and has a diversity of habitats within its boundary, but is dominated by improved grassland in the west and arable land in the east (44%)[5], with lowland areas around Doncaster and Barnsley supporting much of the farming activity. Although data for the South Yorkshire region only is not publicly available, according to OS MasterMap data for South Yorkshire, the area of agricultural land is 79,269 hectares (ha). South Yorkshire is included in the Yorkshire and the Humber geographical area for the Department for Environment, Food and Rural Affairs (DEFRA) agricultural statistics, which state that in 2024 the average farm size in the Yorkshire and the Humber region was about 91 ha, slightly above the English average of 87 ha. Around 26% of farms are 100 ha or larger, with most of the agricultural land area contained in these larger holdings. Smaller farms (less than 20 ha) are less prevalent by area, though more common in number. The predominant farm types were grazing livestock (41%) and cereal (20%) and the region's total income from farming was £582 million, with the average income per farm of £50,700 (a 43% decrease from the previous year)[6].

Whilst regional agriculture contributes to the rural economy through food production and related employment, South Yorkshire's food and drink manufacturing sector is an equally important

1 Clark, M.A., Domingo, N.G.G., Colgan, K., Thakrar, S.K., Tilman, D., Lynch, J., Azevedo, I.L. and Hill, J.D. (2020). Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets. Science, [online] 370(6517), pp.705–708.
2 UNFCCC (2015). Paris Agreement. United Nations.
3 IPCC (2018). Summary for Policymakers — Global Warming of 1.5°C. IPCC.
4 UNSDG (2019) UNITED NATIONS SUSTAINABLE DEVELOPMENT COOPERATION FRAMEWORK.
5 NCS (2021) South Yorkshire natural capital and biodiversity mapping.
6 DEFRA (2025) Agricultural facts: Yorkshire and the Humber region.

part of the regional food system. A report carried out on behalf of Sheffield Hallam Advanced Food Innovation Centre (AFIC) places the value of the local food and drink manufacturing industry at around £434 million, with roughly 170 businesses and about 9,000 jobs tied to food and drink production. Including agriculture, catering, retail and wholesale, the total "agri-food" sector accounts for £1.58 billion in economic output and 68,500 jobs in South Yorkshire. This represents 11.6% of all jobs[7]. The report also found the productivity of food and drink manufacturing workers matches that of key targeted sectors like advanced manufacturing and digital at approximately £65,000 per worker[8].

Furthermore, local universities including centres like Sheffield Hallam's AFIC are actively working on sustainable processing, efficiency improvements, and innovation in food manufacturing. There are also emerging efforts in controlled environment agriculture (CEA), vertical farming or glasshouse technologies, alongside urban agriculture and community growing which could enhance local production capacity, improve local food security[9], whilst also promoting sustainable land use. Collaboration between universities, urban growers and councils aims to support nature-friendly food production and strengthen local supply chains[10].

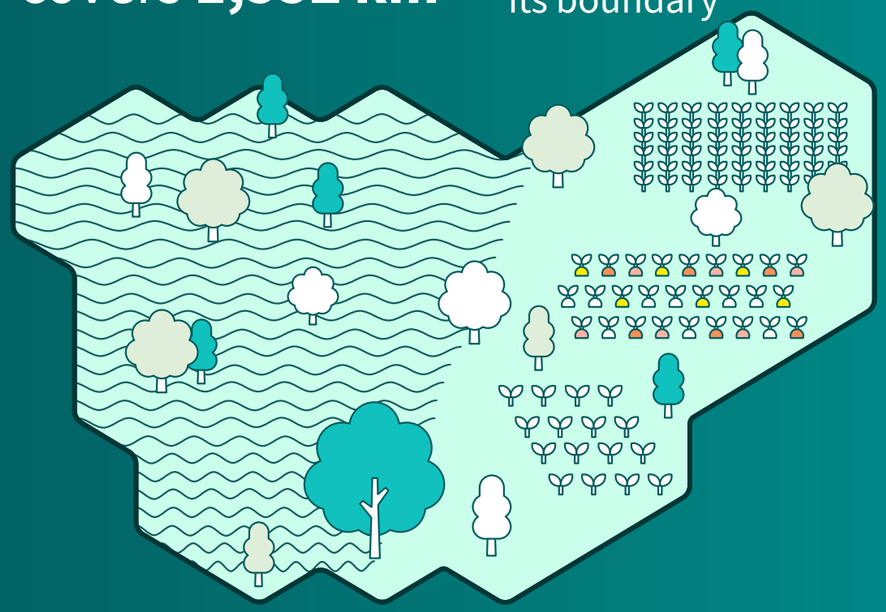
Overarching Challenges

The 2023 State of Nature report found the UK to be of the most nature-depleted countries on Earth, with significant nature and biodiversity degradation resulting in vast declines of many species of birds, plants, and insects that are crucial for keeping our habitats and ecosystems healthy[11]. According to the Green Finance Institute's analysis, the deterioration of the natural environment in the UK could lead to an estimated 12% reduction to Gross Domestic Product (GDP) in the years ahead - larger than the hit to GDP from the global financial crisis or Covid-19[12].

Outside of biodiversity loss, the UK is also facing significant soil degradation. Soils are the largest terrestrial carbon reservoirs and provide fundamental ecosystem services, including the provision of food and habitats and the regulation of water and climate[13, 14]. Soil organic matter (SOM) is a fundamental component of soils and a major determinant of soil health, containing stores of carbon and nitrogen bound together with other mineral nutrients. Soil organic carbon (SOC) makes up about 40-60% of SOM, and strongly influences the physical, chemical and biological structure and function of soils[15, 16]. The UK Centre for Ecology and Hydrology's Countryside Survey found an 11% increase in SOC on arable and horticulture land between 1978 and 2007[17]. Completed in 2007, the survey did not find an overall SOC decrease due to increase of woodland areas and improved grassland soils[18], however, the survey comprised of relatively small soil sampling (1,197 plots within 256 1km squares in 1978, 1,098 plots within 256 squares in 1998 and 2,614 plots within 591 squares

7 Food and Drink Technology (2023) South Yorkshire's hidden gem: food and drink manufacturing sector valued at £434m, reveals report.
8 Sheffield Hallam University (2023) South Yorkshire's 'overlooked' food and drink manufacturing sector worth £434m – new report.
9 South Yorkshire Sustainability Centre (n.d.) Establish South Yorkshire green infrastructure to enable delivery of the net-zero food system roadmap.
10 The University of Sheffield. (2023) South Yorkshire Sustainability Centre Launch.
11 State of Nature (2023) STATE OF NATURE 2023.

12 Green Finance Institute (2025) Assessing the Materiality of Nature-Related Financial Risks for the UK.
13 Harden, J.W., Sanderman, J. and Hugelius, G. (2017). Soils and the Carbon Cycle. International Encyclopedia of Geography, Wiley, pp.1–14.
14 Haygarth, P.M. and Ritz, K. (2009) The future of soils and land use in the UK: Soil systems for the provision of land-based ecosystem services. Land Use Policy, 26(1), pp.S187–S197.
15 Lal, R. (2016). Soil health and carbon management. Food and Energy Security, 5(4)
16 Lal, R. (2025). Soil organic matter: The heart of soil health. Journal of Soil and Water Conservation, 80(4), pp.320–326.
17 ONS (2022) Habitat extent and condition, natural capital.
18 UKCEH (2007) Soils in UKCEH Countryside Survey.



in 2007[19]) and used the Loss on Ignition (LOI) method which can estimate, but not measure, exact organic matter content. According to the Environment Agency, in 2010 soil degradation was calculated to cost £1.2 billion every year[20]. Since then to 2020, land used for organic farming, which helps to promote and restore soil health, decreased by 32%[21].

In South Yorkshire, the NCS evaluation of 91% of the region, found the majority (~57%) of the region's natural habitats to be in poor condition, due to the predominance of arable and improved grassland habitat and the extent of domestic gardens and amenity grasslands. The ecosystem services provided by the South Yorkshire's natural capital were carbon storage and sequestration, air purification, noise, local climate, water flow and water quality regulation, food production, timber production, recreation and accessible nature, with the demand focussed in the urban centres of Sheffield, Barnsley, Rotherham and Doncaster. The value of these services was estimated to be £550 million per annum, with air quality regulation (£237 million annually), recreation (£188 million annually), and physical health (£68 million annually) being particularly large. Despite this, the region is overall a net emitter of carbon at 105,300 tCO_2e per year at a cost of £8 million annually[22].

Furthermore, South Yorkshire faces the same soil degradation issues as has been observed nationally. Natural England Agricultural Land Classification (ALC), which maps agricultural land and assesses its fertility according to multiple factors, such as texture, structure, depth and chemical composition, shows that although a lot of South Yorkshire's agricultural land falls into 'good' to 'moderate' condition, there are big parcels of land rated as 'poor' or 'very poor' condition[23]. It is also important to mention, that the ALC methodology has its limitations, e.g. it only assesses the levels of soil inorganic carbon (SIC) in terms of calcium carbonate and does not measure or take into consideration SOC, thw importance of which was described previously[24].

19 UKCEH (2007) Countryside Survey: Soils report from 2007.
20 Environment Agency (2023). Summary of the state of the environment: soil.
21 ONS (2022) Habitat extent and condition, natural capital.
22 NCS (2021) South Yorkshire natural capital and biodiversity mapping.
23 Natural England (2010) Agricultural Land Classification Yorkshire and The Humber - ALC003.
24 DEFRA (2025) Agricultural Land Classification of England and Wales. Guidelines for grading the quality of agricultural land

The value of the local food and drink manufacturing industry in South Yorkshire is estimated at **£434m**

9,000 jobs and **170 businesses** are tied to food and drink production in South Yorkshire

In South Yorkshire, including agriculture, catering, retail and wholesale, the **total "agri-food" sector** accounts for

£1.58bn in economic output and **68,500 jobs**

This represents **11.6%** of all jobs

SYSC Research Response

The SYSC has worked to identify ways of addressing these challenges whilst also making the regional food system better for the people of South Yorkshire. Using local knowledge and local partnerships, our projects have a regional focus, but can offer perspectives with national relevance, with implications for local, regional and national strategies and policies.

As described previously, currently there is a very limited understanding and insufficient data on soil health nationally, with the Environment Agency claiming that more investment is needed to monitor soils effectively[25]. To address this knowledge gap in South Yorkshire, a SYSC research project is sampling and analysing soils from sites under agricultural and conservation land management to generate better insights into how different land uses influence soil carbon storage across distinct carbon pools. Across South Yorkshire farms, soils were collected from arable, long-term arable, mixed arable-pasture, long-term pasture and woodland sites, with some sites being sampled at different depths. Carbon content and bulk density of soils from both agricultural and conservation settings were measured, and SOC, black carbon and total organic carbon stocks calculated. Whilst this research project and result analysis is still ongoing, the emerging findings suggest that regardless of land use, the denser soils tend to store less carbon and that carbon decreases with depth, displaying declines in SOC between surface soils (uppermost 10 cm) and lower depths – which is a typical pattern even in healthy soils. However, this decline was less obvious on land that is under conservation land management and on one site the total organic carbon stocks were greater than the UK national average.

The research also highlights the vulnerability of surface soils to disturbances and compaction associated with unmanaged grazing, noting the importance of incorporating soil health assessments into grazing regimes for the mitigation of substantial carbon losses. With grazing farms being the predominant type in Yorkshire and the Humber, this is particularly relevant for South Yorkshire.

However, placing land under management plans, requires resources, knowledge and skills that may be inaccessible to some farmers. Whilst there is commitment in legislation to support new environmental management via the Agricultural Act (2020) and Environment Act (2021), there is

25 Environment Agency (2023). Summary of the state of the environment: soil.

Ecosystem Services in South Yorkshire

~57% of South Yorkshire's natural habitats are in poor condition

The value of ecosystem services is estimated to be £550m per annum

£237m/a
Air quality regulation

£188m/a
Recreation

£68m/a
Physical health

Despite all this, the region is a **net emitter of carbon** at **105,300** tCO_2e/a

considerable uncertainty about how policy and legislation will translate into a tangible funding regime. Although current government grants to increase productivity and manage land to benefit the environment exist via different funding streams of environmental land management (ELM) scheme, these can also be difficult to navigate and require time and know-how to apply for and administrate successfully.

Another SYSC project explored nature recovery farming in South Yorkshire, by interviewing people working in land management and farming in South Yorkshire and the Peak District National Park about their experiences of navigating the current funding and policy landscape. The research found that remaining financially viable is the most pressing concern amongst farmers and whilst many are willing to take some land out of production in order to access funding and support nature restoration, many felt driven to do this because of unstable markets for farm produce. Farmers and land managers need stable funding sources that support financial viability alongside pro-environmental interventions as well as support from trusted people and organisations to access and manage grants so that they can carry out the day to day work of producing food and ecosystem services for the region. Whilst collaboration is welcomed, there is also wariness about it leading to a loss of control over land, and decision making being transferred to the collective.

The importance of agency, the ability to participate in decision making and accessible support was also evident in SYSC research that focused specifically on micro and small scale growers in the region. The project conducted fieldwork in rural and peri-urban areas around South Yorkshire to understand the decarbonisation journeys for small growers and asked how these pathways could be designed so that they were fair-for-all. The research found that there was a need for greater inclusion in sustainability and decarbonisation policy and regulatory frameworks. Study participants noted their distinct characteristics which brought specific challenges 'due to their size'. Growers made an urgent call for a greater focus on the ways they operate, as well as on the vital role they play at ensuring a more sustainable agri-food system, and supporting the local economy.

Food Production and Manufacturing

Nature, agriculture and farming is where our food system often begins, but food production and manufacturing forms another branch of this system and has a set of its own unique challenges. South Yorkshire is a hub for food production and manufacturing, with 170 businesses including bakeries, breweries, ready-meal producers, distilleries and others. Along with its economic significance, the sector causes negative environmental impacts, with the most frequently reported impacts being high greenhouse gas (GHG) emissions and high water and energy consumption. On a national level, approximately 30.31 TWh of energy is used each year to support the industry[26]. However, this data is aggregated from multiple manufacturers of different size and type of manufacturing and lacks specificity that would help to address decarbonisation and resource efficiency challenges in South Yorkshire, especially in terms of small and medium-sized enterprises (SMEs), that form a large part of the region's economic landscape.

To properly target funding and interventions and to understand where energy, water, and emissions arise in day-to-day operations, regional policymakers and support programs require actual site-level data. This is urgently needed because SMEs are under immediate pressure to reduce expenses and emissions, but they frequently lack the information and standards necessary to support workable solutions. To address this gap in data, SYSC collected and analysed the environmental impact of products from 12 different food and drink manufacturing facilities in South Yorkshire (11 of them being SMEs), including annual energy use, water consumption, and carbon emissions. Out of approximately 170 food and drink manufacturing businesses, this study covered 7.05% of the industry population. The study found that the annual total consumption of energy of all 12 businesses was 34.63 GWh, the majority of which (32. 51 GWh) attributed to the one large manufacturer, with the remaining

26 DEFRA (2025) Food Statistics in your pocket.

contribution coming from a diverse group of SME manufacturers with lower, yet still significant, energy demands. This amounts to 7.15 tCO_2e of operational emissions per year, assuming that electricity generation follows the same grid energy mix contributions as the entirety of the Yorkshire region, as currently there is no South Yorkshire specific dataset - a limitation that the study discovered. The study also discovered a higher than the UK average reliance on natural gas in the overall energy consumption of the 12 study participants - this has important implications, as gas-fired equipment typically consumes more energy than electric alternatives. Although gas-fired equipment heats rapidly, it is generally less efficient and is associated with greater heat losses. Energy efficiency could also be improved by replacing gas-powered boilers, ovens, stoves, and steamers with renewable energy sources or by implementing heat recovery on dryers, wastewater steam, refrigeration systems, and ovens. The greater emphasis on natural gas in South Yorkshire is likely related to the kind of businesses operating and the age of the appliances. Many sites are still reliant on gas-fired systems because they were historically the most affordable option. Simultaneously, limited budget and practical concerns about switching to electric alternatives cause gas to remain the key energy resource in daily operations in this region.

The study also collected and analysed the data and energy performance from the three study participants that already implemented various measures to decarbonise and improve environmental performance, such as solar PV, aerobic food waste disposal system and a combined heat and power system, with the results described in the “From Data to Impact: Quantifying Environmental Footprint and Transforming Sustainability in South Yorkshire’s Food and Drink Manufacturing Industry” case study.

The study highlighted the importance of local, site-specific data collection and analysis, as well as barriers, such as reluctance of businesses to participate in research. There is a long-term opportunity to shift the culture and behaviour of food and drink manufacturers towards renewable resource use and energy efficiency. During SYSC’s research, many SMEs rejected participating because they were unconvinced of the benefits, lacked awareness of energy-saving opportunities, and faced practical barriers, including limited expertise, insufficient time, and a lack of internal capacity or resources to collect data and undertake energy-efficiency tasks. By actively engaging with the industrial community and continuing to collect data to encourage energy efficiency, this work prompts factories to check in on their energy and encourages integrating decarbonisation into supply chains, which can shift cultural assumptions about sustainability in food production.

The Case for a South Yorkshire Food Network

The key question is how can the region tackle these challenges whilst also benefitting from the opportunities available in a way that is fair for all of the region’s residents? It is clear that the food system is highly complex, nature recovery and conservation, farming and food production and manufacturing, health, education, economy and social wellbeing are intertwined. Trying to detangle and address only one of these strands risks incurring damage to others and thus a unified, holistic approach is needed.

Despite the vital work of local food partnerships in each of the four local authorities, South Yorkshire currently lacks a unified regional food network that brings together large-scale producers, small businesses, and community groups, allowing them to speak with a common voice on key issues of mutual concern.

SYSC’s South Yorkshire Food Network feasibility project aimed to address these issues whilst building on previous work on public procurement in Sheffield, that showed how the city’s ‘anchor institutions’ such as hospitals, schools and colleges could improve the health and sustainability of the food they serve to the public by increasing their purchasing from local small- and medium-sized producers.

The South Yorkshire Food Network feasibility project explored the idea of extending this work to a regional scale, evaluating the prospects of establishing a regional food network that could bring together key food system actors from across South Yorkshire. The study included a survey of 56 local businesses, policymakers and civil society organizations from all four local authorities in the South Yorkshire region. The survey demonstrated strong support for a regional food network, with high levels of perceived value, openness to change and depth of commitment. This vision was shared across all geographies and sectors.

While confirming their strong support for this initiative, participants expressed the importance of transparent governance and accountability, focusing on practical outcomes and actionable objectives. Respondents wanted a function that added value to local initiatives and avoided duplicating what already exists, emphasising that there should be a clarity of purpose with a focus on tangible benefits.

This multi-partner approach is ambitious and challenging, it is difficult to build coherent shared goals and objectives with tangible outputs and outcomes where partners have different competing priorities, pressures and resources available. However, another SYSC project, the Urban Agriculture Task Force (UATF), demonstrates how this can be achieved and the value it could have for

the region. The Task Force, which initially focused on the Gleadless Valley ward, and then the wider South Sheffield Local Area, aimed to contribute to a food system that is both socially just and environmentally sustainable, while demonstrating methods that can be replicated elsewhere in the region.

A core feature of the UATF's approach has been to work across nested governance structures: beginning at neighbourhood level, and building outward to wards, Local Area Committees, the local authority, regional networks, and national campaigns. This has allowed the UATF to develop a grounded understanding of local issues, identify systemic gaps, and design interventions that can be strategically scaled.

The UATF has also prioritised a multidisciplinary and multi-partner approach, combining practical farming, landscape design, education, research, and policy advocacy. By connecting community groups, public institutions, and academic research, the UATF has acted as a connector and enabler, bringing coherence to a fragmented food system and working towards the shared goal of a sustainable, fairer, and more accessible food system.

The UATF work programme revolved around 3 clusters:

1. **Developing a layered approach to urban horticulture, linking research, policy advocacy, infrastructure reuse, and hands-on design.** This involved mapping Sheffield's existing growing spaces, assessing socio-economic dynamics, and identifying new opportunities for food-growing using Geographical Information Systems (GIS); contributing to the national Right to Grow campaign, led by Incredible Edible; responding to the Sheffield Local Plan consultation noting equitable food access as a core component of good landscape design and management policy; supporting the Growing and Composting Working Group and playing a key role in helping the social enterprise Food Works to secure the lease for Norton Nurseries - the only large-scale glasshouse site in Sheffield and thus helping to bring underutilised infrastructure back into productive use.

2. **Focusing on education, training, and the cultivation of food system literacy across age groups and professions.** The UATF hosted a month-long Social Accountability Placement for four medical students from the University of Sheffield; worked with Year 6 SEN pupils from Woodlands Primary School on a bespoke farm-based education programme; members of the UATF have become approved practitioners to the national Climate Ambassadors scheme which connects climate and environmental sustainability volunteers with nurseries, schools and colleges across the UK.

3. **Connecting urban neighbourhoods with peri-urban farms, demonstrating the value of a joined-up landscape approach.** The UATF has contributed extensively to the Gleadless Valley regeneration programme, advocating for the integration of agroecological urbanism and nature-based solutions as well as supporting smaller interventions such as a raised herb and wildflower bed at the Gaunt Shopping Precinct in Sheffield.

By working through nested governance structures, the UATF has shown how local initiatives can inform ward-level, city-level, regional, and even national strategies. This offers a practical alternative to "bigger is better" models, and aligns the findings of international research on food system transformation.

Taken together, the projects featured in the case studies supporting this Building Sustainable Food Systems narrative provide a vision for the future. The UATF demonstrates concrete and scalable steps to support this vision for the region - where communities in rural, peri-urban and urban spaces are happy, prosperous and healthy. Everyone has access to food sufficient for nourishment and personal taste, with excess food redistributed rather than wasted. The whole regional food system is decarbonised, from on-farm production to distribution to food processing and manufacturing.

A vibrant, robust and sustainable local food economy is flourishing, attracting inward investment from innovative green businesses. A sustainable regional food system is helping to regenerate the landscape, working together with nature, and bringing benefits to human health and wellbeing for every resident in South Yorkshire.

Building Sustainable Food Systems Recommendations for Regional Policymakers

1. Local policymakers should use the delivery of the Local Nature Recovery Strategy to allocate funding for a **'One-Stop-Shop', delivered through trusted partners, for farmers and growers that aims to enable successful engagement with nature friendly farming grants and subsidies.** SYSC research shows that practical support is needed to access and administer grants that reward environmental action, as well as advice, knowledge sharing and advocacy to support farmers and growers to maintain financial viability alongside environmental action i.e. supporting new entrants into the sector through the creative use of land leasing and tenancies.

   i. Nature Recovery Farming: Supporting Regional Landscape Scale Resilience.

2. Local policymakers should recognise the importance of soil health, as well as other ecosystem services, for building landscape scale resilience and regional prosperity in South Yorkshire. **As part of the Local Nature Recovery Strategy delivery, local policymakers should initiate a South Yorkshire Resilient Landscapes programme that aims to build resilience through nature recovery** by bringing together key regional stakeholders through research, knowledge sharing events and collaborative projects. This should include coordination with existing alliances such as Connected by Water.

   i. Soil Carbon Storage Across South Yorkshire: Understanding Soil Carbon Stocks Across Pools in the Context of Agricultural and Conservation Land Management.

3. **Support electrification and efficiency in the food processing and manufacturing industry:** Policymakers should consider ways of providing financial and business change support to food processors and manufacturers to replace gas-powered equipment (boilers, ovens, steamers) with renewable energy sources or implement heat recovery systems on dryers and refrigeration units.

4. **Local policymakers should commit resources to set-up and service a South Yorkshire regional food network** that aims to establish a "common voice" for the regional food system, providing a space for innovation, confronting shared challenges (i.e. funding and policy gaps), knowledge exchange and mutual support. Research on horticultural SMEs suggests that sub-groups could be effective in addressing specific needs of different types of actors within the network.

   i. South Yorkshire Food Network Feasibility Study.

5. **Local authorities should adopt a "Right to Grow" model,** replacing a permissions-based with a rights-based model for land access. This would allow community groups to apply for licenses to utilise underused council assets for food production (e.g. land, glasshouses, public spaces).

   i. Urban Agriculture Task Force: Building a Just and Sustainable Food System in Sheffield.

6. Public sector landowners should **support peri-urban agroecological clusters to establish viable businesses** by providing secure land tenure, providing or facilitating investment in infrastructure, and supporting the set-up of public procurement contracts.

   i. Urban Agriculture Task Force: Building a Just and Sustainable Food System in Sheffield.

7. **Integrate food into regional health strategies, recognising the critical role it plays in public health:** Embed food-growing and food education initiatives into broader health, climate, and greenspace strategies to address health inequalities in deprived areas such as the Gleadless Valley.

   i. Urban Agriculture Task Force: Building a Just and Sustainable Food System in Sheffield.

Further Research Opportunities

Sustainable agriculture: Further research could consider how we can effectively incentivise and compensate farmers and land managers to deliver valuable ecosystem services such as biodiversity restoration, natural flood management, and carbon storage.

Landscape Resilience: Collaborative research is needed to determine how landscape scale resilience can be effectively monitored and evaluated, which should include exploration of the metrics and indicators that would satisfy the demands of environmental, social and economic resilience for our region.

Landscape Resilience: Collaborative research needed to determine how effective collaboration can be fostered between different actors within the farming and land management sector in order to deliver regional landscape resilience.

Soil health: More research is needed to determine how quickly organic carbon stocks in disturbed/compacted soil recover through restorative measures i.e. through well-managed conservation grazing or appropriate agricultural management practices.

Soil health: Further research could explore how effective conservation grazing is at enhancing and maintaining high-quality soil organic carbon stocks in South Yorkshire grasslands.

Food Processing & Manufacturing Processing: Work with businesses to identify which production stages are most energy intensive and strategies to improve efficiency and implement alternative low carbon technologies.

Horticultural SME decarbonisation: Further research could bring together policy-makers, SMEs, and stakeholder organisations to build relationships and start the process of co-creating a net zero transition plan for the sector.

Urban Agriculture Task Force: Building a Just and Sustainable Food System in Sheffield

Project team:
Regather: Gareth Roberts, Alice Farmery, Fran Halsall
University of Sheffield: Prof. Jill Edmondson, Prof. Peter Jackson

Project team:
Gleadless Valley Wildlife Trust, Incredible Edible, Food Works, ShefFood, Sheffield City Council, schools, GP medical centres, and community groups

Challenge and Response

South Yorkshire's food system faces a familiar set of challenges that mirror wider national trends: insecure land tenure, underutilised assets, fragmented governance, diet-related health inequalities, and a lack of consistent policy support for sustainable local food production. In Sheffield, these challenges are felt acutely in areas such as Gleadless Valley, where health inequalities, food poverty, and limited access to appropriate green space intersect.

The Urban Agriculture Task Force (UATF) was created to interrogate and intervene in this system, focusing initially on the Gleadless Valley ward, and the wider South Sheffield Local Area. The Task Force's aim is to contribute to a food system that is both socially just and environmentally sustainable, while demonstrating methods that can be replicated elsewhere in the region.

A core feature of the UATF's approach has been to work across nested governance structures: beginning at neighbourhood level, and building outward to wards, Local Area Committees, the local authority, regional networks, and national campaigns. This has allowed the UATF to develop a grounded understanding of local issues, identify systemic gaps, and design interventions that can be strategically scaled.

The UATF has also prioritised a multidisciplinary and multi-partner approach, combining practical farming, landscape design, education, research, and policy advocacy. By connecting community groups, public institutions, and academic research, the UATF has acted as a connector and enabler, bringing coherence to a fragmented food system and working towards the shared goal of a sustainable, fairer, and more accessible food system.

Findings and Potential Impacts

The work of the UATF can be grouped into three achievement clusters, each of which demonstrates progress at different scales of intervention.

Cluster 1: Urban Horticulture – Evidence, Policy, Infrastructure, and Design

A major contribution of the UATF has been to develop a layered approach to urban horticulture, linking research, policy advocacy, infrastructure reuse, and hands-on design.

- Urban Horticulture Mapping Project: In partnership with Jill Edmondson at the University of Sheffield, UATF researchers mapped Sheffield's existing growing spaces, assessed socio-economic dynamics, and identified new opportunities for food-growing using Geographical Information Systems (GIS). While the research highlighted the potential for expansion, it also revealed systemic barriers: lack of secure land tenure, inadequate funding, limited training opportunities, and insufficient policy support.

- Right to Grow Campaign: Building on this foundation, the UATF contributed to the national Right to Grow campaign, led by Incredible Edible. Working with local authorities in Sheffield, Hull, Leeds, and Liverpool, the project explored pathways to move from a permissions-based to a rights-based model of access to land for food growing. This work has seeded practical conversations with councils about embedding food growing into health, climate, and greenspace strategies.

- Sheffield Local Plan: The UATF responded to the Sheffield Local Plan consultation, noting each instance where food growing was omitted from greenspace, urban renewal and housing development proposals, and suggesting new phrasing that positions equitable food access as a core component of good landscape design and management policy.

- Norton Nurseries: The UATF also played a key role in bringing underutilised infrastructure back into productive use. After years of advocacy, Sheffield City Council tendered the lease of Norton Nurseries, the city's only large-scale glasshouse site (1,650 m^2). In 2024, the social enterprise Food Works successfully secured the lease and began transforming the site into a hub for community food production, volunteer training, and sustainable catering.

- Growing and Composting Working Group: Supported by the UATF, this ShefFood working group provides a platform for growers, community groups, and researchers to collaborate on scaling agroecological food production and composting in Sheffield. Early meetings in 2025 built momentum on land access and circular waste systems, fostering new partnerships, policy engagement, and knowledge-sharing. The model offers strong potential for replication across South Yorkshire.

- Landscape Design and Installation Projects: Complementing these systemic interventions, the UATF has also designed and implemented a range of smaller-scale projects: orchards and sensory gardens at schools, edible beds at GP medical centres, raised planters in public spaces, and green infrastructure in regeneration schemes. These projects show how food-growing can be embedded into everyday community environments, linking education, health, and neighbourhood renewal.

Taken together, these initiatives show how research evidence, policy advocacy, infrastructure recovery, and practical design can be integrated to build a supportive environment for urban horticulture.

Cluster 2: Education & Training – Building Food System Literacy

A second strand of UATF's work has focused on education, training, and the cultivation of food system literacy across age groups and professions.

- Medical Student Placement: In 2024, the UATF hosted a month-long Social Accountability Placement for four medical students from the University of Sheffield. Students were immersed in local food system challenges in Gleadless Valley, contributing to projects at Regather Farm, S6 Foodbank, and Gleadless Valley Wildlife Trust. A Community Needs Assessment undertaken by the students generated new data on barriers to healthy eating and access to green space. The placement deepened the students' understanding of the social determinants of health and the role of food systems, while building practical skills in community engagement and interdisciplinary collaboration.

- Woodlands School Farm Education Pilot Project: Also in 2024, the UATF worked with Year 6 SEN pupils from Woodlands Primary School on a bespoke farm-based education programme at Regather Farm. Over two months, students participated in food-growing, habitat creation, and creative activities. Teachers reported remarkable gains in confidence, teamwork, and problem-solving, while families observed positive changes at home. The project culminated in a celebratory farm picnic, underscoring the value of hands-on, nature-based education. This programme has been repeated in 2025, and will continue in the future supported by DEFRA subsidy.

- Climate Ambassadors: Members of the UATF have become approved practitioners to the national Climate Ambassadors scheme which connects climate and environmental sustainability volunteers with nurseries, schools and colleges across the UK. The UATF participated in the Good Life Schools Summit (June 2025), and advice has been offered and/or workshops delivered at the following schools: Newfield School, Woodlands School, King Egbert's Secondary, Anns Grove Primary & Arbourthorne Primary.

- School and Community Designs: Complementing these programmes, the UATF has developed orchards, sensory gardens,

and edible beds in school grounds and public spaces. These projects provide outdoor classrooms for environmental learning, while supporting children and communities to connect with food and nature.

This cluster demonstrates how the UATF contributes to a lifelong learning pathway - from primary school children, to university students, to professional training - embedding sustainability, health, and food awareness into education at multiple levels.

Cluster 3: Connected Landscape – Neighbourhood to Peri-Urban Integration

The third cluster of activity has focused on connecting urban neighbourhoods with peri-urban farms, demonstrating the value of a joined-up landscape approach.

- Gleadless Valley Landscape Strategy: The UATF has contributed extensively to the Gleadless Valley regeneration programme, advocating for the integration of agroecological urbanism and nature-based solutions. Proposals include community orchards, composting sites, rain gardens, swales, wetlands, and green travel corridors. The newly acquired Regather site at 181 Blackstock Road will act as an anchor hub for coordinating these initiatives, linking food, nature, and community wellbeing.
- Moss Valley Cluster: Adjacent to Gleadless Valley, the Moss Valley is home to a cluster of agroecological enterprises, including Regather Farm, Moss Valley Market Garden and Sheffield Organic Growers, contributing to South Yorkshire's nature friendly farms, smallholdings and community gardens and allotments cultivate nearly 40 hectares, employ nearly 100 staff with a collective turnover of £8m, engage nearly 2,000 volunteers contributing 200,000 volunteer hours and support over 1,000 vulnerable people annually. They provide a working demonstration of how peri-urban agroecology can support local economies, health, and biodiversity.
- Food Growing in the Public Realm: Smaller interventions, such as a raised herb and wildflower bed at the Gaunt Shopping Precinct, illustrate how edible landscapes can be woven into regeneration schemes, making sustainable food visible and accessible in everyday spaces.

By linking neighbourhood initiatives with peri-urban farming, the UATF has developed a model for a resilient, regenerative city-countryside partnership, where local production, ecological restoration, and community wellbeing reinforce one another.

Scaling and Governance Insights

A cross-cutting theme of UATF's work is the question of scale. Traditional models of "scaling up" risk diluting the local connections and values that underpin food system transformation. The UATF has instead explored the potential of:

- Scaling out: replicating successful approaches in different localities.
- Deep scaling: embedding changes in cultural norms, behaviours, and institutional practices.

By working through nested governance structures, the UATF has shown how local initiatives can inform ward-level, city-level, regional, and even national strategies. This offers a practical alternative to "bigger is better" models, and aligns with international research on food system transformation[1, 2].

Recommendations

Based on the evidence and experience of the UATF, the following recommendations are made to policymakers:

1. Embed rights-based access to land for community food growing in planning and governance frameworks.
2. Audit and repurpose underutilised assets (e.g. land, glasshouses, public spaces) for food production through community or social enterprise leases.
3. Integrate food and farming education into school curricula, medical training, and health/social prescribing pathways.
4. Support peri-urban agroecological clusters with secure land tenure, investment in infrastructure, and public procurement contracts.
5. Adopt nested governance structures for food system policy, ensuring neighbourhood-level insights shape regional and national strategies.

Next Steps

The next stage of this work will be delivered through the INNATURE project (2025–2029), which represents a four-year continuation and expansion of the UATF's mission. INNATURE will:

- Establish eco-social hubs (such as 181 Blackstock Road) to anchor neighbourhood action.
- Deliver landscape connector demonstrators, linking urban regeneration sites with peri-urban farms.
- Scale education programmes into structured, accredited pathways for schools, universities, and professionals.
- Develop monitoring frameworks to evidence impacts on health, biodiversity, and economic resilience.

Through INNATURE, the work of the UATF will move from a series of pilots and prototypes to a connected regional model for just and sustainable food systems.

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A Just Transition for Small and Medium Enterprises: The Case of Small-Scale Horticulture Growers in South Yorkshire Area

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Challenge and Response

Horticulture is a branch of agriculture that encompasses the growing of fresh fruit, vegetables and ornamental plants. Decarbonising horticulture is a fundamental element towards achieving net-zero futures, since it is an energy dense and vulnerable to climate change sector[1, 2]. Embedding Small and Medium Enterprises (SMEs) on the decarbonisation agenda, is also important, as smallholder agriculture accounts for over 80% of global agriculture - including horticulture[3] - and play a vital role in providing locally produced food, supporting local economies and sustaining sustainable livelihoods[4]. According to ONS data[5] in the UK, fruit, vegetable and flower businesses are predominantly SMEs; while according to the Horticulture Trades Association[6] over 90% of environmental horticulture businesses are also SMEs.

However, net-zero/sustainability transitions create a plethora of socio-economic and spatial inequalities, and fairness concerns are constantly raised for smaller actors, across different geographies[7, 8]. Nevertheless, very scarce research has previously focused on how horticultural SMEs are positioned within decarbonisation pathways and just transition frameworks; leaving a significant gap around justice considerations in this sector.

This PhD study aims at uncovering the just agri-food transition narrative through the lens of SMEs, and more specifically small and medium horticulture growers. For this study, we define small and medium horticulture growers, in line with the EU recommendation for SMEs i.e. employing <250 persons and having an annual turnover ≤€50 million[9]. Drawing upon empirical findings from our fieldwork in rural and peri-urban areas around South Yorkshire we develop an in-depth understanding on both what decarbonisation entails for small-scale growers, and also on how it can be designed in a fair-for-all manner. Focusing on the South Yorkshire Area specifically and building upon the existing community growing culture and rising number of agro-ecological market gardens[10], we further explore the opportunity for promoting horticulture food production in urban areas[11], simultaneously uncovering the potential for revitalising South Yorkshire's post-industrial landscape.

Via in-depth semi-structured interviews we: (i) shed light to the growers' vulnerability to climate change and current climate and decarbonisation action, (ii) uncover the transition-induced opportunities and challenges for smaller growers, and (iii) explore their visions of a just transition.

Through this qualitative research, we aspired to create a space of empowerment for the under-researched and under-represented groups, where they can share their perspectives and have their voices heard. Via re-thinking the just agri-food transition narrative, we position small-scale growers and local communities, at the epicentre of the net-zero transformation. This provides a creative pathway towards designing a resilient, equitable, and sustainable agri-food system.
In order to provide a broader spectrum on the just transition planning process, we have also conducted additional interviews with specialists across Regional Authorities and City Councils, as well as local stakeholder organisations.

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Findings and Potential Impacts

Whilst data analysis is still in progress, below is a summary of key findings emerging from our research:

- **Vulnerability to climate change and adaptation:** Growers have expressed their concerns over the impact of unpredictable weather patterns on crop yields - as most of them are growing outdoors - which they see as an important challenge in their efforts to adopt more sustainable practices, whilst also building adaptation and resilience.

- **Feelings towards net-zero:** Growers' feelings and attitude towards decarbonisation vary. Decarbonisation is perceived as a major challenge for growers who lack the necessary resources and technical know-how; thus, triggering reluctance and problematisation. In other cases, growers feel more optimistic and feel that the net-zero transition is an opportunity to move towards a more sustainable operation, focusing on a more conscious use of natural resources, ensuring more equitable benefits for the planet and the people.

- **Identities of small-scale:** Operating at a micro and small-scale, growers talk about their distinct characteristics, but also highlight numerous challenges that they are currently facing due to their size. Growers make an urgent call for a greater focus on the ways they operate, as well as on the vital role they play at ensuring a more sustainable agri-food system, and supporting the local economy. Growers also share a strong desire for greater accessibility and representation in the decision-making processes, as well as a greater inclusion in policy and regulatory frameworks related to sustainability, climate action and decarbonisation.

This research holds significant potential for scaling, by embedding different types of SMEs of the horticulture sector, such as processors, distributors, and retailers. Expanding the research to these actors will allow for a more holistic understanding of the opportunities and the challenges posed by decarbonisation across the horticulture supply chain, also providing a more solid foundation for an appropriate design of a just transition of the sector. Using a comparative case study approach allows the research to generate insights that can inform policymakers and foster more targeted interventions, whilst also enabling the replication of successful strategies across sectors and regions.

Recommendations

A key recommendation involves the development of tailored policies for horticulture SME growers. To support small-scale horticulture businesses in the transition toward low-carbon and sustainable practices, policies need to be specifically designed to address their unique needs. This might include financial support, such as grants and incentives for adopting low-carbon technologies, as well as guidance on the range of decarbonisation options that are available for fruit-vegetable growers and flower farmers operating at a smaller or micro scale. Implementation should involve tailored funding schemes, advisory services, and capacity-building programmes, which take into consideration the sector, scale, and business models of small growers; all of which at the moment are highly underserved by existing policy and regulatory frameworks. By providing this targeted support, small-scale horticulture businesses would be able to adopt sustainable practices more easily and without facing financial constraints, facilitating in this way the transition towards net-zero, whilst also fostering more equitable and achievable outcomes for SMEs, which are vital actors in the agri-food system.

A second recommendation revolves around the promotion of shared learning and the creation of collaboration networks within the horticulture community, in the form of peer-to-peer learning initiatives, information-sharing platforms, and structured networks that enable small growers to exchange knowledge on sustainable growing practices and low-carbon strategies. Facilitation of local collaboration networks - led by SMEs, and supported by the Local Councils - can aid growers to share insights, experiences, and practical solutions, fostering a sense of community, and reducing isolation. These collaborative spaces will not only enhance the collective capacity of small-scale growers to transition effectively but will also provide a supportive environment that encourages innovation and continuous improvement. This will ultimately strengthen the sector's resilience and contribution to a just and sustainable agri-food system for all.

Next Steps

In order to maximise the impact of this research, next steps need to involve the replication and expansion of the study. On this note it is important to highlight that this study has already been expanded to include the Western Greece Region. The City of Patras, which is the capital of the Region, was strategically chosen as it is also a post-industrial area and provides a robust comparative case study that will allow to extrapolate shared lessons, whilst also enhancing relevance and transferability findings.

The follow up will include data analysis and exploration of emerging findings, in order to initiate a comparative discussion and uncover lessons learned in different geographical settings. This will allow for a more in-depth understanding of small-scale growers' experiences across different regions, but will also provide a more robust foundation towards planning for a just transition.

A final step includes engaging stakeholders, through participatory approaches. In this study, we have targeted and conducted research with different groups of participants, separately. Future research should seek to take a further step towards bringing together policymakers, SMEs, and stakeholder organisations, in order to establish direct lines of communication, promote engagement, and enhance co-creation in the net-zero transition planning. Co-creation will foster a truly equitable decarbonisation, by equally taking into consideration the views of all actors involved, and by promoting a green regional transition, built upon sustainability and solidarity.

South Yorkshire Food Network Feasibility Study

Project team:
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University of Sheffield: Prof. Peter Jackson

Challenge and Response

The South Yorkshire food sector makes a significant but often overlooked contribution to the regional economy. Food and drink is the UK's largest manufacturing industry, contributing more to the economy than automotive and aerospace combined. In South Yorkshire, the sector employs 9,000 people across 170 businesses and generates £434 million in Gross Value Added (GVA)[1], making it second only to advanced manufacturing. Barnsley leads the region in both employment and business density, while Sheffield's high proportion of micro-businesses offers substantial growth potential. Regionally, food and drink manufacturing is expanding faster than sectors such as digital, advanced manufacturing, health, and low-carbon, highlighting its strategic significance[2]. Nationally, the food sector is also critical in facing up to the current challenges around climate change (accounting for around one-third of the region's greenhouse gas (GHG) emissions[3]), public health, environmental sustainability and biodiversity loss.

Taking a "food systems" approach highlights the inter-connections between these issues and the importance of addressing them in an integrated and interdisciplinary way.

Despite the vital work of local food partnerships in each of the four local authorities, South Yorkshire currently lacks a unified regional food network that brings together large-scale producers, small businesses, and community groups, allowing them to speak with a common voice on key issues of mutual concern.

This project builds on previous work on public procurement in Sheffield which led to the publication of Feeding the Future[4], showing how the city's "anchor institutions" such as hospitals, schools and colleges could improve the health and sustainability of the food they serve to the public by increasing their purchasing from local small- and medium-sized producers.

The present project explored the feasibility of extending our previous Sheffield work to a regional scale, focusing specifically on the prospects for developing a regional food network, bringing together key food system actors from across South Yorkshire. The study included a survey of 56 local businesses, policymakers and civil society organizations from all four local authorities in the South Yorkshire Mayoral Combined Authority (SYMCA) region. The survey demonstrated strong support for a regional food network, with high levels of perceived value, openness to change and depth of commitment. This vision was shared across all geographies and sectors. Four clusters were identified among the survey respondents: champions, pragmatists, as-yet-unconvinced, and critics (the latter representing less than 3% of respondents). The results show a high degree of consensus on the need for a regional food network and suggest how different groups might be targeted to secure their further engagement in the process.

Our quantitative analysis of the survey data was followed up by 22 in-depth interviews, allowing us to probe respondents' views in more depth and detail. The interview data suggested a range of key areas that were of concern to our participants:

1. The current food system presents significant challenges to all stakeholder groups, including policy gaps and competing priorities; access to funding; resource and capacity constraints; and specific challenges for small businesses and struggling communities.

2. The legacy of the COVID pandemic has resulted in cash flow issues for small businesses as well as supply issues for charities and food retailers.

3. The vision for a food network shared by stakeholders prioritises people-centred challenges (health, equity, food security), with systemic and growth-focused priorities (sustainability, economic development) being secondary but still integral to the food system vision.

4. Stakeholders see the value of a regional Food Network as a cohesive, adaptive, and action-oriented platform for collaboration, knowledge sharing, and systemic change. However, success is contingent on overcoming practical, financial, and perceptual barriers, including stakeholder trust, resource allocation, and ensuring tangible impacts.

5. Respondents point to the fact that collective

1 Economic Analysis of the South Yorkshire Food and Drink Sector, A final report to the National Centre of Excellence for Food Engineering at Sheffield Hallam University, KADA, June 2023. Available upon request.
2 Ibid.
3 WRAP(2026)Tracking UK food system greenhouse gas emissions: 2015-2023 UK Food system GHG Emissions model 2015-2023.
4 Boys, J. and Benstead, S. (2025) Feeding the Future. Centre for Local Economic Strategies.

action is essential to address regional food system challenges. Knowledge-sharing, networking, and collaboration are seen as core enablers, while equitable representation, strategic prioritisation, and resource coordination strengthen the network's potential impact. Funding and the ability to be heard are key levers to turn collective intent into tangible outcomes, ensuring the network achieves meaningful change rather than isolated or fragmented efforts.

6. Shaping an effective regional food network is not just about convening stakeholders; it requires strategically assembling the right people, structuring governance, facilitating meaningful interactions, and embedding feedback loops. The network's credibility and sustainability will rely on the interplay between these dimensions; ensuring it is inclusive, practical, and capable of translating dialogue into action.

7. Stakeholders are willing to contribute time, expertise, and resources to the food network, but only if it delivers clear value. Engagement is driven by relevance, collaboration, and tangible outcomes, while limited capacity - especially for smaller organisations - makes clarity of purpose essential. Participation is therefore conditional: the network must be action-oriented and impactful rather than a "talking shop".

8. Understanding past experiences - both successes and failures - is critical for designing a resilient, effective, and inclusive regional food network.

9. A successful regional food network requires clarity, inclusivity, action-oriented design, and strong connections with both local participants and regional structures.

While confirming their strong support for this initiative, participants expressed the importance of transparent governance and accountability, focusing on practical outcomes and actionable objectives. They sought to add value to local initiatives and to avoid duplicating what already exists. They warned that the time commitments of participants should be acknowledged (and compensated where appropriate); that we should learn from other regions; and that there should be clarity of purpose (with a focus on tangible benefits).

What does this mean for the region?

This project found that there is strong support for the development of a regional (South Yorkshire) food network and that such a network has the potential to create a "virtuous circle" simultaneously addressing key issues of economic growth, environmental sustainability, public health, social justice and equity.

Scalability

The research also suggests how these ideas might be relevant to other regions beyond South Yorkshire. The question of how to "scale up" local initiatives to regional or national scales has been of widespread interest to food researchers in the UK and beyond (see, for example, Connelly & Beckie 2016). Various models have been proposed including "scaling out" (replicating successful initiatives in other localities) and "deep scaling" (making fundamental changes to cultural norms, behaviours and practices at the local, regional or national scale). These ideas are explored in more detail in a recent policy brief, produced by the Sheffield-based H3 project, which could be read here.

Recommendations

Our recommendations for establishing a regional (South Yorkshire) food network are consistent with the Local Growth Plan (creating the potential for a food system innovation hotspot/sector cluster within Advanced Manufacturing, improving health outcomes and reducing labour market inactivity and carbon emissions) and with the UK Government's recently-published Food Strategy[5] which emphasised the need for policy to be "grounded in place", and "supporting work at local and regional level delivered by local councils, strategic authorities, local food partnerships, civil society and citizen groups". Similar aims were expressed in Tim Lang's recent report for the National Preparedness Commission where he heralded the emergence of a new form of bottom-up regionalism for food system resilience, citing the potential role of England's 10 metro mayors in leading the development of a city-regional food focus[6]. Our work supports these policy directions, uncovering a consistent picture across diverse places and sectors within the region, providing a solid launch pad for further work in this area, leading to the successful development of a regional food network.

Next Steps

This project provided a robust strategic case for establishing a food network in South Yorkshire.The next steps will be to produce a blueprint, detailing how these ideas can be taken forward in the most practical and cost-effective way.

5 DEFRA (2025) A UK government food strategy for England, considering the wider UK food system.
6 Lang, T. (2025) Just In Case: 7 steps to narrow the UK civil food resilience gap.

From Data to Impact: Quantifying Environmental Footprint and Transforming Sustainability in South Yorkshire's Food and Drink Manufacturing Industry

Project team:
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Context and Project Rationale

The food and drink industry is the UK's largest manufacturing sector, employing over 486,500 people and generating £148 billion in turnover, with a gross value added (GVA) of £37 billion[1]. Along with its economic significance, the sector causes negative environmental impacts, with the most frequently reported impacts being high greenhouse gas (GHG) emissions and high water and energy consumption. To support the industry, approximately 30.31 TWh of energy is used annually[2]. Achieving the UK's legally mandated climate goals, 68% emissions reduction by 2030 and net-zero by 2050, will be impossible without accelerating decarbonisation in high-emitting and energy-intensive sectors such as food and drink manufacturing[3]. South Yorkshire (SY) is a hub for production, with food and drink manufacturing generating £434 million GVA and providing 9,000 jobs across 170 businesses, including bakeries, breweries, other food producers, meat companies, and distilleries[4].

However, most of the currently available evidence is aggregated from multiple manufacturers of various sizes and on a national scale. This data lacks specificity that would help to address the unique decarbonisation challenges of small and medium sized (SME) businesses in SY, which account for 11 of the 12 sites analysed in this study. To properly target funding and interventions and to understand where energy, water, and emissions arise in day-to-day operations, regional policymakers and support programs require actual site-level data. This is urgently needed because SMEs are under immediate pressure to reduce expenses and emissions, but they frequently lack the information and standards necessary to support workable solutions.

This study has collected and analysed the environmental impact of products from 12 different food and drink manufacturing facilities in SY, including annual energy use, water consumption, and carbon emissions. Collecting operational data from multiple businesses is challenging because many are reluctant to participate in surveys. However, we overcame these challenges through persistent effort: we contacted more than 150 food and drink factories in SY and made repeated in-person visits to explain our project, taking the time to build relationships.

Out of approximately 170 food and drink manufacturing businesses, this study covers 7.05% of the industry population[5].

Table 1 presents summary characteristics of the facilities included in the survey. For ethical and confidentiality reasons, the names of the participating organisations are not disclosed. Instead, each facility is anonymised and identified using case study labels (A–L)

Results

Energy use

The aggregate annual energy consumption for the 12 manufacturers is 34.63 GWh, shown in Figure 1. The graph illustrates that a considerable amount of industrial energy demand is present in the food and drink industry in SY. One large manufacturer contributes 32.51 GWh due to their size and

Name	Product	Employees
A	Candy	15
B	Coffee	23
C	Bread	0-10
D	Traditional Bread	0-10
E	Milled grain (rice, barley, malt)	0-10
F	Ready meals	1000+
G	Potted meat	21
H	Ice cream	0-10
I	Beer	29
J	Milk	10
K	Beer	0-10
L	Multi-product in a commercial kitchen	50

Table 1: Characteristics of the food manufacturing facilities participating in the survey.

1 Food and Drink Federation (2026). Industry at a glance.
2 DEFRA (2025) Food Statistics in your pocket.
3 Ladha-Sabur, A., Bakalis, S., Fryer, P & Lopez-Quiroga. E. (2019). Mapping energy consumption in food manufacturing. Trends in Food Science & Technology, 86, 270-280.
4 Advanced Food Innovation Centre. (2023). South Yorkshire's 'overlooked' food and drink manufacturing sector worth £434m – new report.
5 Ibid

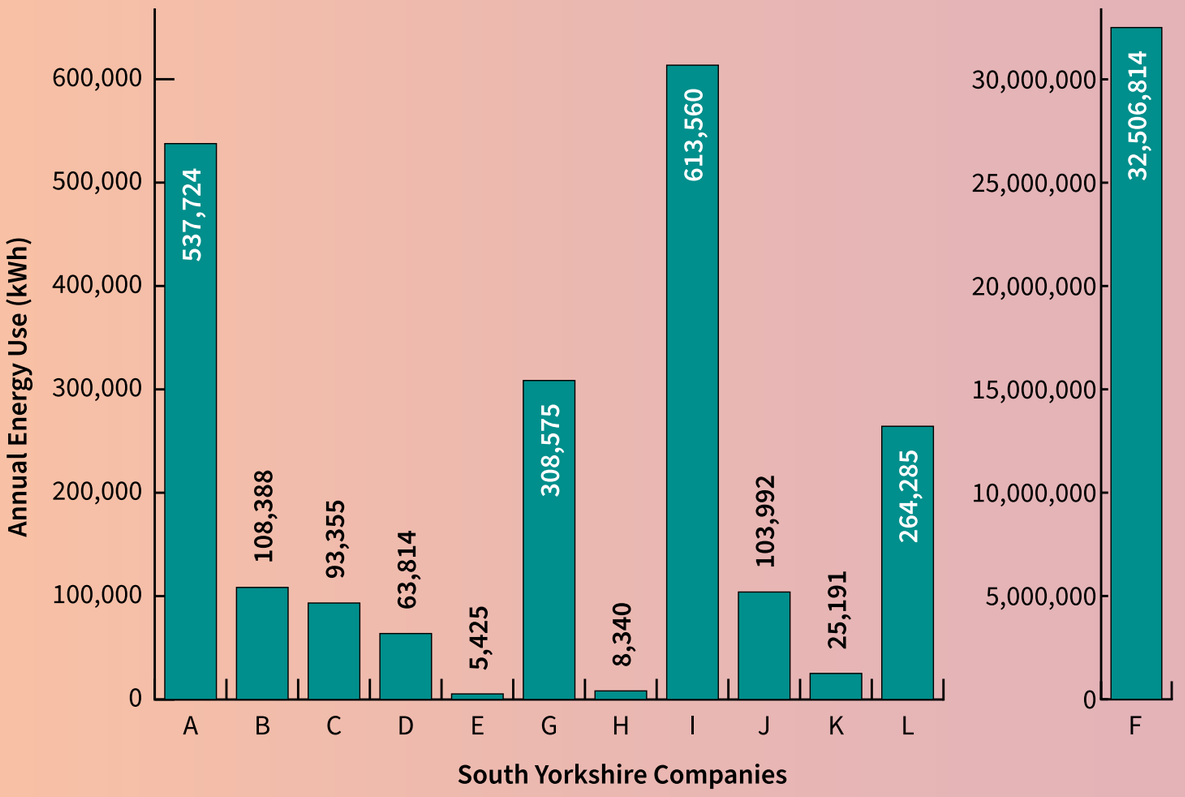


Figure 1: Total annual energy use from 12 food and drink manufacturing firms.

industrial intensity, whereas the remaining contribution comes from a diverse group of SME manufacturers with lower, yet still significant, energy demands. To put this data into perspective, a typical UK-based electric vehicle with a small battery size has a projected annual energy demand of approximately 1,900 kWh, and thus the collective annual energy demand for the twelve companies could theoretically support the annual operation of approximately 18,331 vehicles[6].

Annual energy use is divided between different energy sources, including fossil fuels and renewable energies, which is known as the energy mix. Determining the energy mix has two primary benefits: (a) understanding energy security and (b) enabling the calculation of carbon emissions. Energy security is important, as a diversified mix of energy types being used protects industry from supply disruptions and volatile prices. More relevant to this work, carbon emissions per kilowatt-hour of energy can be calculated to assess the environmental impact.

Based on our results, SY food and drink manufacturing facilities are using more natural gas than on average in the UK. The greater emphasis on natural gas in SY is likely related to the kind of businesses operating and the age of the appliances. Many sites are still reliant on gas-fired systems because they were historically the most affordable option. Simultaneously, limited budget and practical concerns about switching to electric alternatives cause gas to remain the key energy resource in daily operations in this region.

This has important implications, as gas-fired equipment typically consumes more energy than electric alternatives: although it heats rapidly, it is generally less efficient and associated with greater heat losses. Energy efficiency could be improved by replacing gas-powered boilers, ovens, stoves, and steamers with renewable energy sources or by implementing heat recovery on dryers, wastewater steam, refrigeration systems, and ovens. Additionally, the application of modern technologies such as artificial intelligence and machine learning can also help identify other

6 Subaru. (2025) How much does it cost to charge an electric car?

energy recovery resources. Recovered heat can be used for preheating air, products, or generating hot water, especially where switching to electric equipment is not feasible.

Following privatisation in 1989, the electricity system in the UK became highly fragmented between producers, suppliers, and distributors. Producers generate electricity and sell it to suppliers; however, some suppliers are also producers. Distributors are partnered with suppliers to maintain the infrastructure of the electricity grid. As of 2023, there were 56 major energy producers and 32 major energy suppliers spread across the regions[7]. **Determining which energy producers and suppliers currently supply the SY region is not straightforward**. The single distributor, Northern Power Grid, is consumer-facing and provides pricing options. If consumers wish to know who their energy supplier is, they must ask their network distributor. As such, it is extremely difficult to determine the energy mix used in SY. This is a major concern, as the decarbonisation agenda depends on clean electricity production. Therefore, future research should focus on determining the energy mix of the SY electricity grid to support sustainability assessments.

This represents a clear feasibility and system barrier: the lack of transparent, SY-specific grid-mix data limits precise attribution of electricity-related impacts. Instead of attempting to estimate site-specific electricity provenance, this study addressed this challenge by applying the same reporting boundary and UK Government electricity emission factors to all participating sites. Despite variations in the local grid mix, this ensured that carbon results were computed consistently and could be reliably compared across businesses.

In the Yorkshire region, electricity is generated from gas (55.6%), biomass (30.2%), wind (11.6%), and nuclear (1.8%)[8]. In some seasons, biomass stands higher than gas. If SY is assumed to follow broader Yorkshire trends, a substantial proportion

7 Neely, Hugo. (2023) Competition in UK electricity markets 2023. Department for Energy Security and Net-Zero.
8 National Energy System Operator. (2026) Carbon Intensity.

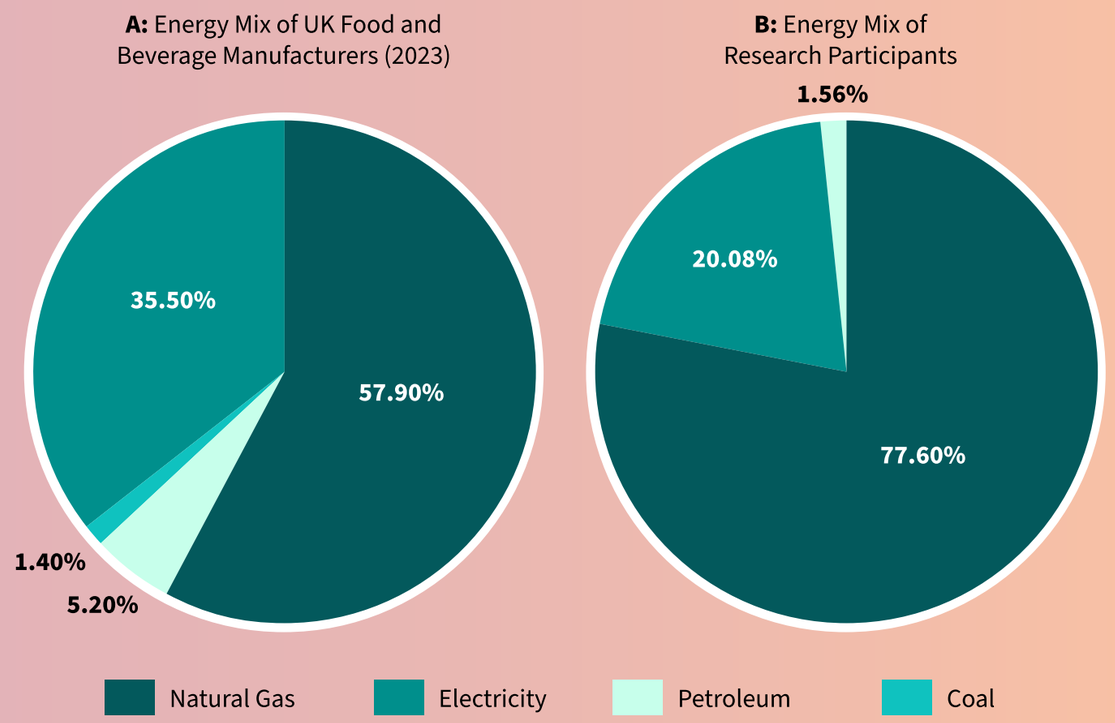


Figure 2: Energy mix of food and drink manufacturing: (a) UK national industry energy mix in 2023; (b) energy mix of the 12 SY food and drink manufacturers included in this study.

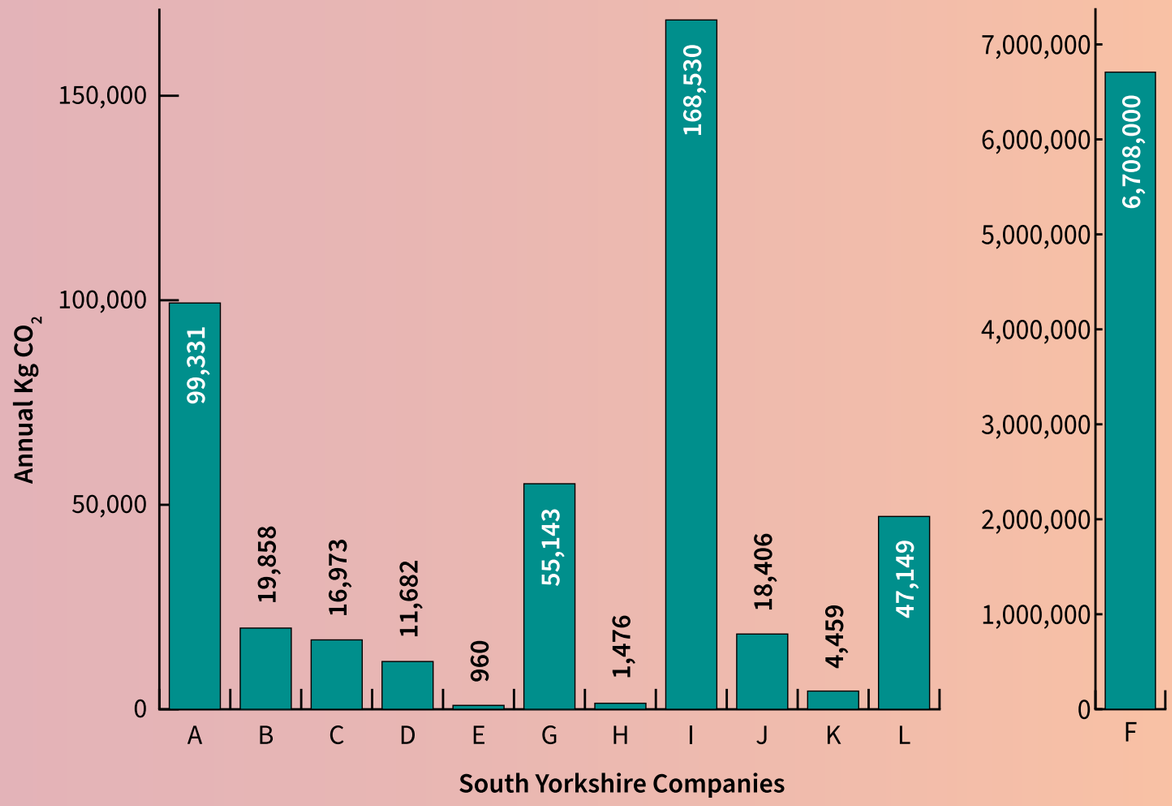


Figure 3: The annual carbon emissions for 12 food manufacturers from electricity and fuel use (Scope 1–2 only).

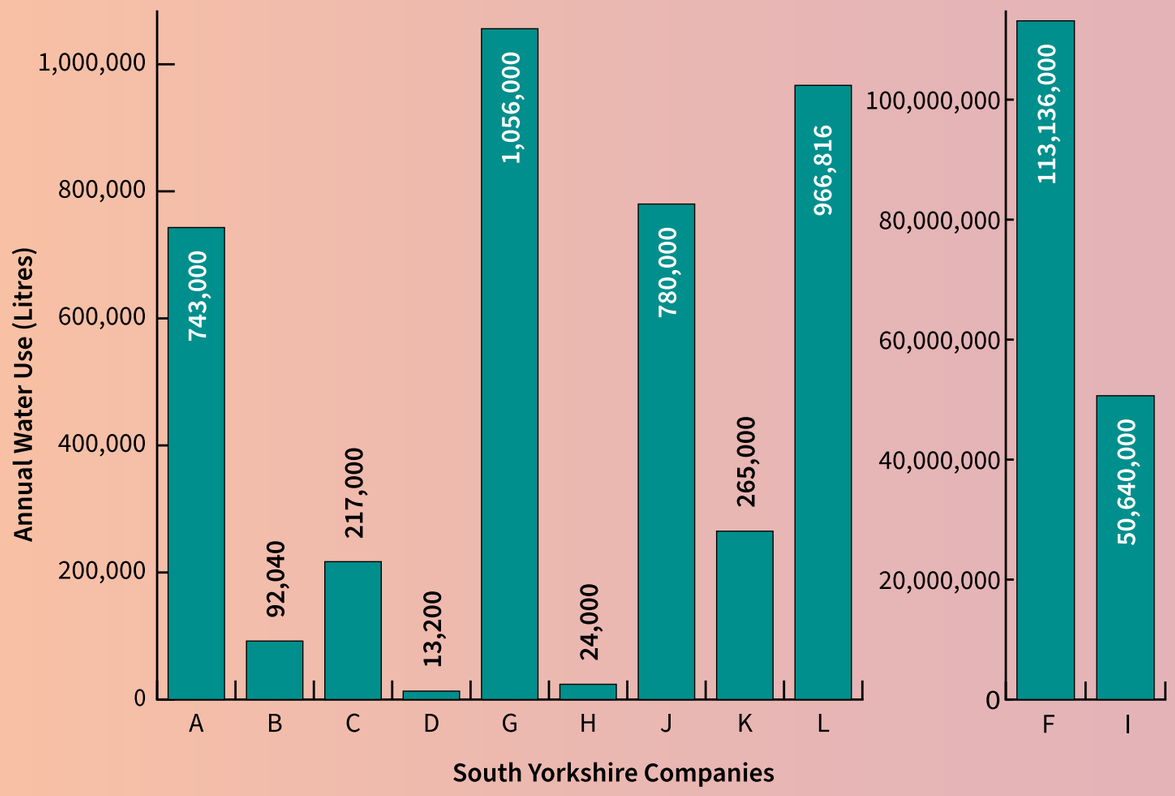


Figure 4: Annual water use for 11 companies. Company E is an experimental case, which does not consume water.

of electricity generation is likely to be imported, severely increasing associated emissions. With less than 15% of electricity coming from truly renewable energy sources, it is evident that there is an opportunity to decarbonise the grid for the entire region, including SY.

Understanding this background is essential to comprehending our findings. This background refers specifically to the regional electricity generation mix in Yorkshire and its likely implications for SY. In a regional grid dominated by gas, the carbon benefit of electrification may be restricted or time-dependent, underscoring the significance of tactics like demand reduction and on-site renewables. By combining actual operational data from SY manufacturers with regional grid context, this study provides helpful evidence to support practical decarbonisation decisions even in circumstances where system transparency is limited.

Carbon Emissions

Carbon emissions from research participants fall into both Scope 1 and Scope 2 categories. Scope 3 emissions, such as transportation, embedded carbon, etc., were outside of the study boundary. Scope 2 emissions come from the use of purchased electricity to run electric appliances, whereas scope 1 emissions come from the on-site burning of fuels, mainly natural gas used in boilers, ovens, and other thermal equipment[9]. We intentionally report Scope 1 and 2 operational emissions only (combustion/grid generation), excluding electricity transmission and distribution (T&D) and fuel well to tank (WTT), to keep a consistent boundary across all sites and utilities and to avoid mixing operational reporting with lifecycle accounting.

To convert energy use into carbon emissions, the UK government provides carbon emission conversion factors, which calculate and standardise energy consumption into carbon dioxide (CO_2). In 2025, the UK conversion factors for carbon dioxide equivalent (CO_2e) were 0.18494 kg CO_2e/kWh for natural gas, 0.177 kg CO_2e/kWh for electricity, and 2.661 kg CO_2e/L for Diesel[10].

In total, annual emissions amount to 7.15 tCO_2e. Figure 3 shows the carbon emissions from the 12 research participants. This figure only accounts for emissions from onsite fuel use and purchased electricity. Since these 12 firms represent only 7 percent of food and drink manufacturers in SY, the reality is that the sector's total contribution to regional emissions is much higher, which requires focused support for decarbonisation.

Water Consumption

Annual water use was another environmental indicator calculated for our research participants. Figure 4 shows that total annual water use is 166.96 million litres of water and that consumption differs widely across the food and drink manufacturers studied. These differences largely reflect the type of products made, as products that use water as an ingredient, such as beer, will have higher consumption, as well as the level of cleaning and processing required. Direct comparisons between facilities should be treated with caution. In many cases, water is only measured at the site level rather than by individual processes. This makes it difficult for businesses to see where water is being used. Better monitoring would help identify avoidable losses and inefficiencies. Improving water efficiency can also reduce energy use and associated carbon emissions.

We attempted to benchmark the findings of water consumption in this study against existing water-use assessments in Yorkshire or SY. However, regional water reports by providers such as Yorkshire Water focus on aggregate supply and demand metrics, without sector-disaggregated industrial water use. Additionally, economic analyses of the regional food sector do not include environmental or water consumption data. This constraint highlights a significant evidence gap in the systematic assessment of water consumption

9 United Nations. (2022) Category 3: Fuel- and Energy-Related Activities Not Included in Scope 1 or Scope 2.

10 UK Government (2025) Greenhouse gas reporting: conversion factors 2025.

within the food and drink industry at regional and sub-regional scales in Yorkshire.

Understanding and evaluating alternative approaches for highly efficient, low energy consumption/low carbon emissions

To understand the sustainability implications of the electricity grid, we are collecting data from three companies that have already implemented sustainability measures to improve how they use energy and other resources. We examine how these different approaches reduce environmental impacts in practice.

Case study J: Rooftop Solar photovoltaic (PV) Integration in a Dairy Processing Facility

The first case study examines the implementation of a rooftop solar PV system at a dairy processing facility located in SY. The intervention aims to reduce grid electricity consumption and associated operational carbon emissions through on-site renewable electricity generation. A combination of feasibility study data and real operational measurements from 2024 is used to evaluate system performance, electricity savings, and carbon emission reductions.

The PV system, consisting of 52 modules, supplies approximately 10.5% of the facility's annual electricity requirement. As a result of the PV installation, grid electricity consumption decreased to 93.06 MWh/year compared with the pre-installation period (from 103.99 MWh/year, with 10.93 MWh/year displaced by on-site PV generation). From an environmental perspective, the reduction in grid electricity consumption associated with on-site PV generation leads to an estimated annual saving of approximately 1.93 t CO_2e in operational emissions. Overall, the results indicate that rooftop PV provides clear energy, economic, and carbon benefits for the dairy processing facility. However, because the system supplies only a limited share of total electricity demand, further emission reductions through rooftop PV alone are constrained by site electricity requirements and available roof area, indicating the need for complementary decarbonisation measures.

Case study L: BioHiTech Eco-Safe Digester at a commercial kitchen

The second case study assesses changes in operational GHG emissions from food-waste management at a commercial kitchen following the installation of a BioHiTech Eco-Safe Digester. Annual food-waste generation was estimated at 5.2 t/yr. Two scenarios were compared: a baseline scenario in which food waste is collected and transported by Biffa to a landfill, and a post-installation scenario in which waste is treated on-site by the digester.

Overall, comparison of the two scenarios shows a net reduction of approximately 2.52 tCO_2e/year, corresponding to a reduction of around 69% relative to the baseline waste management pathway. These results demonstrate that the BioHiTech digester substantially reduces food waste–related operational emissions by avoiding the high methane emissions associated with landfill disposal.

Case Study F: Combined Heat and Power (CHP) in a Ready-to-Eat Food Manufacturing Facility

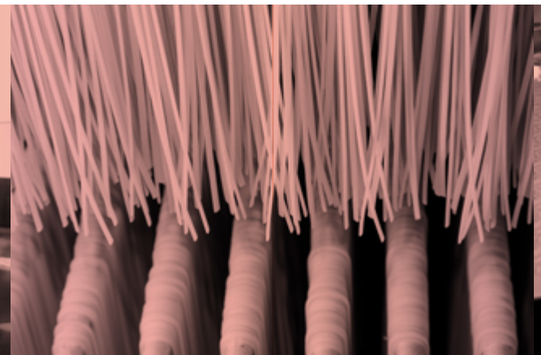
The third case study assesses the impact of a combined heat and power (CHP) system which simultaneously generates electricity and useful heat from a single fuel source, typically natural gas at a ready-to-eat food manufacturing facility, by comparing the current operation with CHP to an alternative scenario in which the CHP system is not in use. The analysis focuses on changes in fuel consumption and associated operational carbon emissions.

The results show that the total operational carbon emissions are higher when the CHP system is in use (5,960 tCO_2/year) than when it is removed (3,168 tCO_2/year). Although operating the CHP reduces emissions from grid electricity, this saving is offset by a significantly larger increase in emissions from natural gas consumption, resulting in higher overall emissions under current conditions.
This finding is consistent with previous research showing that CHP does not automatically reduce carbon emissions. Studies have shown that when electricity is supplied from a relatively low-carbon grid, replacing it with gas-fired on-site generation can increase total emissions.[11, 12] These findings underline that the carbon benefit of CHP is strongly context-specific rather than guaranteed.

Recommendations and Next Steps

1. Shifting corporate behaviour
    - There is a long-term opportunity to shift the culture and behaviour of food and drink manufacturers towards renewable resource use and energy efficiency. By actively engaging with the industrial community and continuing to collect data to encourage energy efficiency, this work prompts factories to check in on their energy and encourages integrating decarbonisation into supply chains, which can shift cultural assumptions about sustainability in food production.
    - However, as noted by Jackson et al. (2024) and the H3 Policy Brief, scaling up efforts may risk losing the local trust and relationships that are critical to project effectiveness[13]. During our research, many SMEs rejected participating because they were unconvinced of the benefits, lacked awareness of energy-saving opportunities, and faced practical barriers, including limited expertise, insufficient time, and a lack of internal capacity or resources to collect data and undertake energy-efficiency tasks.
2. Expand the survey to include more SY food manufacturers
    - A larger dataset will improve the accuracy of regional sustainability planning and provide stronger benchmarking evidence for businesses and policymakers.
3. Strengthen and maintain collaboration with politicians and business partners
    - Improved cooperation will ensure that findings affect funding decisions, support mechanisms, and objective guidance for industry.
4. Explore and address emerging research questions
    - Identify which production stages are most energy intensive.
    - Assess how regional insights can be integrated into a national energy and carbon map while preserving local specificity.
    - Determine the energy mix of the SY electricity grid to determine sustainability implications.

11 Dorer, V., Weber, R., & Weber, A. (2005) Performance assessment of fuel cell micro-cogeneration systems for residential buildings. Energy and Buildings, 37(11), 1132–1146.
12 Hawkes, A. D., & Leach, M. A. (2007) Cost-effective operating strategy for residential micro-combined heat and power. Energy, 32(5), 711–723.
13 Jackson, P., Yap, C., Parsons, K., Treuherz, S & Roberts, G. (2025) Values-based food systems: the role of local food partnerships in England. Agriculture and Human Values, 42, 1379–1393.



Soil Carbon Storage Across South Yorkshire: Understanding Soil Carbon Stocks Across Pools in the Context of Agricultural and Conservation Land Management

Project team:
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Challenge and Response

Soils are the largest terrestrial carbon reservoirs and provide fundamental ecosystem services, including the provision of food and habitats and the regulation of water and climate[1, 2]. The delivery of such services is dependent on soil health – their continued capacity to function as a vital living ecosystem that sustains plants, animals, environmental quality and human needs[3]. Soil organic matter (SOM) is a fundamental component of soils and a major determinant of soil health, containing stores of carbon and nitrogen bound together with other mineral nutrients. Soil organic carbon (SOC) makes up about 40-60% of SOM, and strongly influences the physical, chemical and biological structure and function of soils[4, 5]. The long-term stability of these carbon stocks depends on how it is partitioned across different pools - total organic carbon (TOC), particulate organic carbon (POC), and mineral-associated organic carbon (MAOC)[6]. Land management involved in restorative conservation and regenerative agriculture aims to restore the biodiversity and soil health of degraded lands for the continued provision of ecosystem services; for UK grasslands, this can be achieved through well-managed conservation grazing, which is being implemented in Shire Brook Valley Nature Reserve. Restoring and maintaining soil health plays a key role in enhancing the sustainability of food production in regenerative agriculture (whether that be arable, pasture or a combination). Whilst both agricultural and conservation land management practices can influence carbon pool distribution, the direction and magnitude of these effects remain unclear for many UK landscapes, including South Yorkshire.

Black carbon (BC), the product of the incomplete combustion of fossil fuels and biomass, is ubiquitous in soils globally. It is deposited onto soils from naturally occurring wildfires and fire management of vegetation – for example in the moorlands of South Yorkshire – and from human activity from industry, domestic heating and transport. This poorly understood carbon pool occurs in addition to the organic carbon pools in soil derived from natural ecosystem processes. Research suggests BC can locally contribute >20% of total carbon in urban and some agricultural ecosystems. However, the overall contribution of BC to total carbon stocks in soils is not routinely quantified. In addition, there is increasing evidence that BC plays an important role in soil biogeochemical cycling and in particular soil carbon sequestration. For example, our recent soil microcosm experiment found that BC-soot reduced soil carbon loss by 18%, suggesting that BC can increase carbon sequestration into soils. Hence quantifying BC pools, and the effects of land management on them, is hugely important for a fuller understanding of soil carbon sequestration capacity.

These projects responded to three key challenges:

1. Limited understanding of how different land uses in South Yorkshire influence soil carbon storage across distinct carbon pools. Furthermore, while total SOC is often measured, the distribution between POC and MAOC - which differ dramatically in stability and turnover - is rarely assessed at a regional scale.

2. Uncertainty about how soil physical properties, particularly bulk density, constrain carbon sequestration potential. Compaction is widespread in agricultural soils and in degraded lands targeted for restoration, yet its effect on long-term carbon storage (especially in MAOC) is poorly quantified.

3. Ensuring that conservation management of grasslands for improved biodiversity through conservation grazing at Shire Brook Valley also conferred benefits for soil health and carbon sequestration. As unmanaged grazing can reduce carbon storage, baseline soil carbon assessments should be incorporated into grazing regimes and subsequent monitoring.

1 Harden, J.W., Sanderman, J. and Hugelius, G. (2017) Soils and the Carbon Cycle. International Encyclopedia of Geography, Wiley, pp.1–14.
2 Haygarth, P.M. and Ritz, K. (2009) The future of soils and land use in the UK: Soil systems for the provision of land-based ecosystem services. Land Use Policy, 26(1), pp.S187–S197.
3 Lehmann, J., Bossio, D.A., Kögel-Knabner, I. and Rillig, M.C. (2020) The concept and future prospects of soil health. Nature Reviews Earth & Environment, 1(10), pp.544–553.
4 Lal, R. (2025) Soil organic matter: The heart of soil health. Journal of Soil and Water Conservation, 80(4), pp.320–326.
5 Lal, R. (2016) Soil health and carbon management. Food and Energy Security, 5(4), pp.212–222.
6 Prairie, A.M., King, A.E. and M. Francesca Cotrufo (2023) Restoring particulate and mineral-associated organic carbon through regenerative agriculture. PNAS, 120(21).

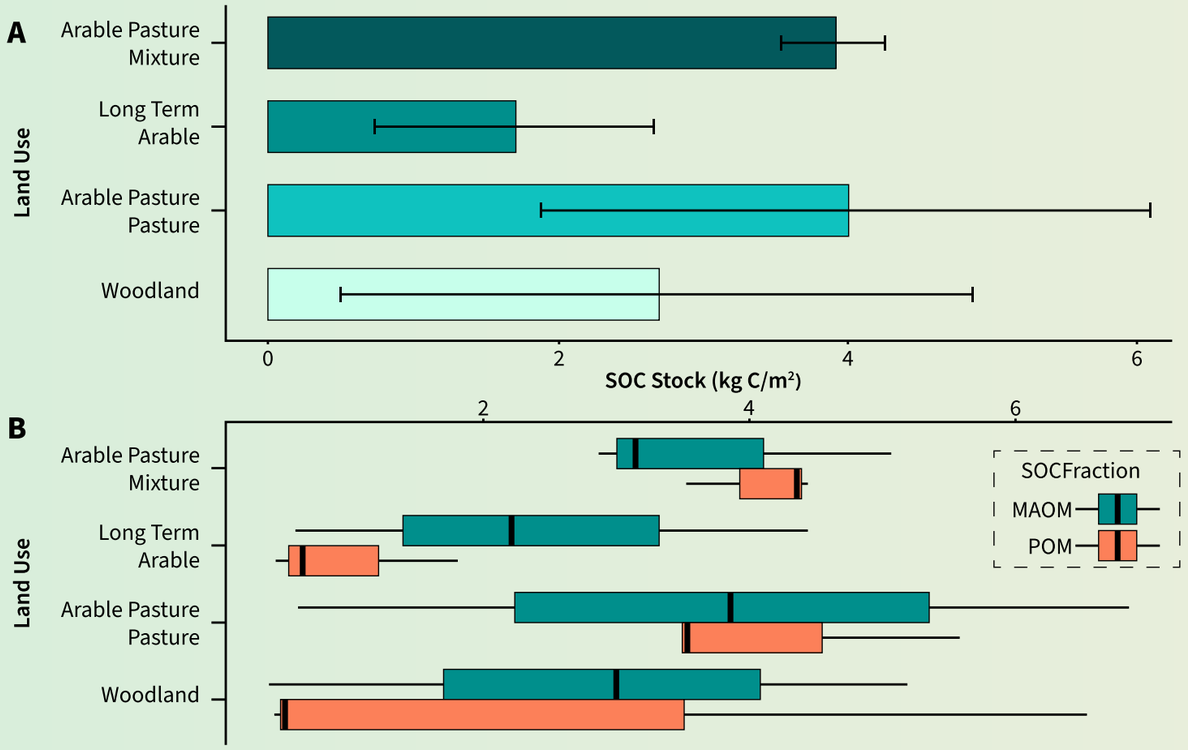

Figure 1: A) Whole-soil SOC stocks by land use. B) SOC stock variation by land use and fraction.

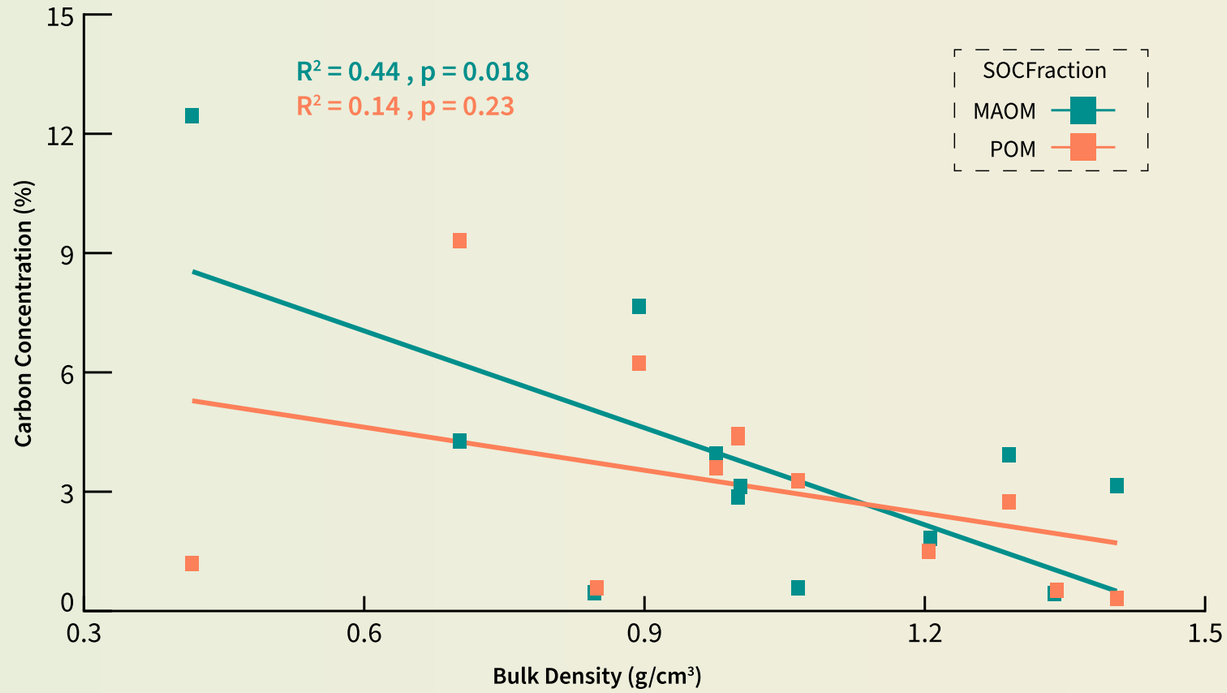

Figure 2: Correlation between carbon % vs bulk density.

What the work did:

- Soils were sampled across multiple land uses from both agricultural and conservation contexts. Across South Yorkshire farms, soils were collected from arable, long-term arable, mixed arable-pasture, long-term pasture and woodland sites. At Shire Brook Valley Nature Reserve, soils were collected at different soil depths across three selected fields: Rainbow Meadows and Sally Clarks which are semi-natural grasslands with agricultural land-use histories, and Linleybank which is a recently reclaimed landfill site.
- Carbon content and bulk density of soils from both agricultural and conservation settings were measured, and SOC, BC and TOC stocks calculated.
- In conservation soils, TOC stocks in the top 30 cm of soil were compared to UK national averages (for semi-natural grasslands and pastures (Bradley et al., 2006) and SOC stocks were compared across depth increments (0-10 cm, 10-20 cm, 20-30 cm) to assess carbon distribution and stability.
- Agricultural soils were fractionated into POC and MAOC to quantify carbon distribution between these pools. Bulk density measurements were also used to assess the relationship between soil compaction and carbon concentration in these soils.
- SOC stocks and pool distributions were compared across land uses (within agricultural and conservation settings separately) to identify management-relevant patterns.

Findings and Potential Impacts

Under agricultural land management:

Research is ongoing and final results will be reported in summer 2026. The key emerging findings are summarised below:

1. **Land-use differences in total SOC were small.** Across a sub-set of sampled sites, total SOC stocks showed only modest variation among land uses: long-term arable soils tended to have lower SOC, while mixed arable–pasture and long-term pasture systems displayed similar SOC levels.
2. **Mineral-associated organic matter (MAOM) consistently dominated carbon storage.** Fractionation revealed a clear and consistent pattern: MAOM held substantially more carbon than particulate organic matter (POM) across all land uses. This aligns with global evidence that MAOM is the primary long-term carbon pool due to its mineral protection and slower turnover.
3. **Soil compaction strongly limited carbon persistence**. Carbon concentration in MAOM showed a strong negative correlation with bulk density ($r \approx -0.67$, $p < 0.01$). Denser soils stored less carbon in MAOM, regardless of land use. This suggests that soil physical condition - not just management category - is a major determinant of carbon sequestration potential.

Under conservation land management (in Shire Brook Valley):

1. **Surface soil layers contained the most carbon.** Carbon decreased with depth in all fields, with Rainbow Meadows and Sally Clarks displaying sharp declines in SOC between surface soils (uppermost 10 cm) and lower depths - these patterns are typical of healthy soils. This decline was less obvious in Linleybank. Surface soils are highly vulnerable to disturbances and compaction associated with unmanaged grazing, highlighting the importance of incorporating soil health assessments into grazing regimes for the mitigation of substantial carbon losses.
2. **TOC stocks were generally consistent with UK national averages.** Carbon in soils is a key indicator of soil quality. The carbon content in Rainbow Meadows and Sally Clarks indicated these soils were of good quality, with TOC stocks greater than the UK national average for pasture soils and almost on par with semi-natural soils. Monitoring soil carbon stocks over time will provide an indication of whether these soils have capacity to store more organic carbon over time with the change in management to conservation grazing. Linleybank soils stored less carbon, as TOC stocks fell below both national averages.
3. **Land-use history had a significant impact on soil carbon stocks.** Soils in Linleybank were less healthy, more disturbed – as shown

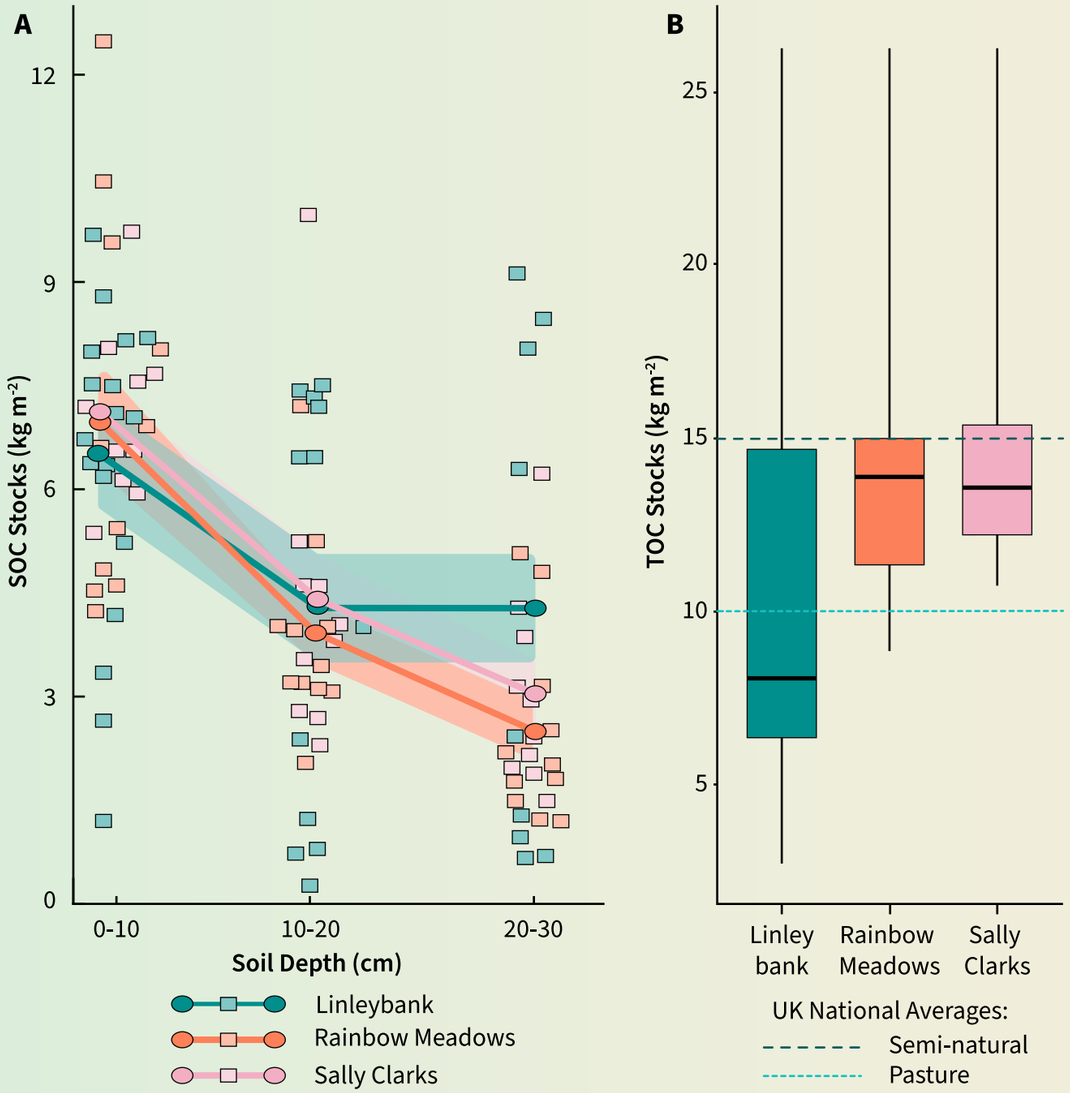

Figure 3: Distribution of carbon stocks across fields under conservation management in Shire Brook Valley: A) Depth profile of soil organic carbon (SOC) stocks across fields. B) Total organic carbon (TOC) in the top 30cm of soils compared to UK national averages (Bradley, 2006).

by less obvious declines in SOC with depth and highly variable SOC and TOC stocks – and stored less carbon compared to the other fields. This is likely indicative of its relatively recent landfill history and incomplete recovery since, showing that land-use histories can significantly influence soil health and carbon sequestration capacity. This may also identify Linleybank as a potential site that may benefit from conservation grazing.

Applicability Beyond South Yorkshire

These findings are highly transferable to other UK regions under either mixed agricultural management or conservation land management. Our research highlights the need to incorporate soil health assessments into land management regimes, as maintaining good soil health is fundamental to the long-term sustainability of agricultural and conservation practices.

Scaling the impact:

- **Scaling out:** Baseline soil health and carbon stock assessments can be replicated within other ecosystems, and are particularly relevant when changing land-use or management – for example when converting to either regenerative agricultural or restorative conservation land management practices – to ensure schemes have beneficial outcomes for soils. The sampling and fractionation approach can be applied outside of agriculture to conservation sites, and replicated across other UK regions to build a national picture of MAOC-based carbon storage.
- **Scaling up:** Insights can inform regional soil health frameworks, carbon accounting schemes, and advisory services at the individual level for farms and conservation practitioners.
- **Deep scaling:** Challenging the assumption that agricultural land-use change alone drives SOC gains, and highlighting the need for cultural and behavioural shifts toward soil-structure-focused management. Overall highlighting the importance of soil health assessments for both agricultural and conservation-based land management.

Recommendations:

1. **Integrate carbon pool measurements (POC/MAOC) into soil monitoring frameworks.** Move beyond TOC alone to include fractionation in soil carbon assessments where feasible in both agricultural and conservation contexts.
   Expected improvement: More accurate assessments of long-term carbon sequestration potential.

2. **Support farm clusters, local demonstration farms and nature reserves (e.g., Shire Brook Valley) as hubs for soil carbon learning.** Facilitate knowledge exchange between farmers, researchers, and land managers.
   Expected improvement: Wider adoption of soil-structure-focused practices across South Yorkshire.

Next Steps:

- Resampling in the next 3-5 years in Shire Brook Valley to assess impacts of grazing regime implementation on soil carbon stocks. Resampling over multiple years in agricultural sites to investigate temporal dynamics of carbon pool distributions (TOC, POC and MAOC).
- Co-develop management trials with local farmers to test interventions that support enhancement of MAOC storage.
- Explore policy integration, ensuring findings inform local climate strategies, soil health action plans, advisory programmes for farms and conservation practitioners.

New Research Questions:

- How quickly can SOC stocks –in particular MAOC– in disturbed/compacted soil recover following compaction amelioration? (E.g. through well-managed conservation grazing or appropriate agricultural management practices.)
- How effective is conservation grazing at enhancing and maintaining high-quality SOC stocks in UK grasslands? How might carbon pool distributions be impacted?
- How might microbial communities mediate MAOC stabilisation under different management regimes?
- How does black carbon influence carbon stocks and distribution across pools in soil?

Notes:

‘The question of ‘scaling up’ local food initiatives has been a recurrent theme in research on food system transformation. ‘Scaling up’ to regional or national scales may present a challenge to maintaining these close connections to the locality. Other models are being explored. These do not assume that ‘bigger’ is always ‘better’ and include ‘scaling out’ (replicating successful initiatives in other localities) and ‘deep scaling’ (making fundamental changes to cultural norms, behaviours and practices at the local, regional or national scale). This issue of scale — how and under what conditions the values of local food partnerships might be ‘scaled up’, without compromising their founding values —represents another important area for future research’.

More on this can be found in our publications here and here

Nature Recovery Farming: Supporting Regional Landscape Scale Resilience

Project team:
Sheffield Hallam University: Dr Anna Hawkins, Dr Joseph Glentworth, Dr Catherine Hammond, Dr Ellen Bennett, Dr Emma Cary, Stephanie Webb

Challenge and Response

We are currently at a crucial transition point for English land management with the trailing out of European Union farming subsidies, changes to the legislative frameworks for farming and environmental policy, and the launch of the ambitious Environmental Improvement Plan 2023. Nature Recovery land management has been recognised as an essential part of our carbon strategy as well as addressing the biodiversity crises.

Despite promising ambitions from Defra to support new environmental management through the Agricultural Act (2020) and Environment Act (2021), we know from our work with local and national stakeholders, that there is considerable uncertainty about the how policy and legislation will translate into a tangible funding regime, with many current land owners and managers fearful that their livelihoods will become unviable and feeling unable to participate in the transition to new and more sustainable ways of managing land producing food, and enhancing biodiversity. This creates tensions around the long-term future of rural communities and their connection with land-based industries that to date has received limited attention from researchers. What we do know is that farmers make a significant contribution to the social, cultural and economic makeup of rural communities[1] meaning that farmers are central to securing a sustainable future of rural areas, with the support of appropriately designed policy and schemes[2,3].

This project responds to these challenges by interviewing people working in land management and farming in South Yorkshire and the Peak District National Park about their experiences of navigating the current funding and policy landscape. We gathered and present a range of expert opinions about the opportunities and threats they face when trying to contribute to regional environmental and economic resilience with the aim of informing regional and national policy and funding strategies, as well as speaking to a global community of people working towards a sustainable and equitable transition of land management for people and nature.

1 McCarthy, J., Meredith, D. and Bonnin, C. (2023) 'You have to keep it going': Relational values and social sustainability in upland agriculture. Sociologia Ruralis 63(3), pp. 588–610.
2 Holt, A. and Morris, J.(2022) Will environmental land management fill the income gap on upland-hill farms in England? Land Use Policy 122, p. 106339.
3 Ogawa, K., Garrod, G. and Yagi, H.(2023) Sustainability strategies and stakeholder management for upland farming. Land Use Policy 131, p. 106707.

Findings and Potential Impacts

Our findings highlight a wide range of issues and approaches to sustainable land management, but the key messages fall into four categories:

1. The need for sufficient and stable funding regimes so that farmers and land managers can plan for long-term viability whilst supporting restoration of nature and improved environmental and economic resilience for South Yorkshire and the Peak District.

Uncertainty and a need to work towards greater stability is a strong theme emerging from our interviews and analysis of agricultural funding and policy. Funding schemes for farmers have become much more complex and uncertain, with many farmers struggling to navigate the range of schemes and understand the eligibility criteria and what they need to do to access the payments. This complexity is leading to mistrust and putting some farmers off accessing funding for environmental land management.

"I feel as though they keep changing the rules as they go along" - *"[We] did look at woodland grants, but…we physically couldn't do what they wanted us to do with the trees. If we put all the arable land into it, it needed deer fencing, and you've got to deer fence before you can plant your trees, and they wanted all that doing in the first year, and then it's on a reclaim basis, so you've gotta have the capital upfront. And we just didn't have enough money in the bank to be able to do that."* - SY Farmer

"So at the moment, where we are [is] we don't have any concrete support from the rural payments agency as to what's next… An incredibly vulnerable situation. So… My next move was to put the arable land up for sale. That was the only way I could secure the rest of the farm. But we're in a situation now when nobody is buying because there is no incentive to invest in farmland." - SY Farmer

2. The need for stable support from trusted people and organisations for farmers and land managers so that they can access and engage with funding and strategy whilst carrying out the day to day work of producing food and ecosystem services for the region.

Many of the people we interviewed named people and organisations they trusted and valued as

part of their support infrastructure. Many of these trusted individuals and roles within organisations were seen as precarious because of funding cuts. Without the right kinds of support many farmers will fail to access funding because of the complexity involved in applying and reporting compliance to funders. Charities such as the National Trust and Wildlife Trusts are often better equipped to access funding than more traditional farmers, but this was named as a cause of tension between larger organisations and more traditional farming families.

"And of course, most of us are completely ignorant of what's going on, so we're just trying our best… Going around in circles and I come to the conclusion is that I have to get some sort of professional help to pay and of course when you mention professional help [it] means money and of course that does put me off of it, but it works." - SY Farmer

"I've always believed that for a long time now, that they're not interested in small family farms [be] cause what we contribute to the food pile is very small." - SY Farmer

3. Whilst collaboration is welcomed, there is also wariness about collaboration leading to a loss of control over land, and decision making being transferred to the collective. Policymakers should be mindful of these tensions when designing engagement strategies.

There is an assumption that collaboration is necessary to deliver landscape restoration at scale, but this conflicts with many farmers' sense of independence and autonomy. The commitment to enter into a land management scheme that could last up to 30 years is a daunting prospect for many individual landowners. There is some mistrust about handing over decision making to a collective; many farmers and growers enjoy the opportunity to meet other farmers in their area, to share ideas and discuss problems, but not everyone wants to formalise this "clustering". The presence of large third sector land management organisations further complicates the opportunities for collaboration, because the governance structures, expertise and scale of these organisations lends itself well to collaboration and agility to respond to changing funding and policy regimes, this can cause resentment for some farmers who feel that these organisations take funding away from more traditional farmers.

"[In] 30 years time. I'll be 70. You know what I mean? It's like a long old time. And at that point, I ain't doing any, like, starting up any new businesses. Maybe I will, but very unlikely. So are we doing the right thing by that?" - SY Farmer

4. Remaining financially viable is the most pressing concern amongst farmers and whilst many are willing to take some land out of production in order to access funding and support nature restoration, many felt driven to do this because of unstable markets for farm produce.

Remaining financially viable was a significant challenge for all farmers and growers we spoke to, and in the case of larger farms this was attributed to uncertain markets, as well as an unstable climate. In the case of smaller growers, viability depended upon access to local food systems for storage, distribution and processing as well as variable weather conditions. Taking land out of food production was sometimes seen as risky because the land could become unsuitable for cultivation quite quickly, and the reliance on unstable funding streams was a deterrent for some. But for some farmers, livestock farming had become unviable and unmanageable, and so taking some land out of production for tree and hedgerow planting, or planting wildflower hay meadows was seen as a financial lifeline for others.

Whilst the prospect of taking land out of food production may be challenging for some farmers because it is core to their identity, funding that allows them to retain their farms and keep working the land is an attractive prospect, especially for farmers operating in less favourable landscapes such as upland areas.

"I'm always willing to try things… It's the way it's going, isn't it? But I do want food production as well… because you're making it viable. It's another income stream, isn't it? But because you're a farm and you've still got to do that, I don't mind being a park keeper a little bit. I don't want to be a park keeper for myself." - SY Farmer

Scaling Up Our Findings

We analysed our regional findings against national consultation reports and found many similarities in these key messages, suggesting that whilst South Yorkshire has a unique set of challenges and opportunities for landscape transformation at scale, it would make a good demonstrator for projects that would have national and international relevance and applicability. Policies that work here would be likely to work elsewhere, and conversely we could learn from as well as shaping best practice in other regions.

Recommendations

Many farmers and growers are financially precarious, and strategies that require their cooperation and collaboration need to be accompanied by a funded delivery plan, or robust support to help farmers and growers access funding.

Local food systems need to be operationalised in ways that are tangible and beneficial to food producers at different scales, helping them to access local markets for their produce that are stable and financially rewarding. Agricultural and horticultural work is demanding and low paid, so collaboration needs to be targeted and clearly beneficial. Our research findings have produced the following recommendations:

1. Develop regional policies and strategies that support farmers, growers and land managers to deliver environmentally, economically and culturally resilient landscapes that include clear implementation strategies for delivering desirable outcomes.
2. Provide practical support for farmers wishing to access funding that supports the regional agenda as part of a regional implementation plan.
3. Develop a regional food strategy that:
    - Provides support for new entrants into the farming, growing and environmental land management sector through the creative use of land leasing and tenancies.
    - Develops a support infrastructure for producers that includes production, distribution and processing so that regional food producers are able to remain viable in a challenging financial climate.

Next Steps

To maximise the impact of this work, regional farmers, growers and land managers need to be involved in the development of strategies and policies for landscape scale environmental, economic and social resilience. This provides opportunities for ongoing collaborative research with regional stakeholders to co-produce policies and support packages that will be accessible and effective, as well as ongoing evaluation.

New research questions include:

- How can we effectively incentivise and compensate farmers and land managers to deliver valuable ecosystem services such as biodiversity restoration, natural flood management, and carbon storage?
- How can landscape scale resilience be effectively monitored and evaluated? What are the metrics and indicators that would satisfy the demands of environmental, social and economic resilience for our region?
- How can growers and producers operating at different scales be incorporated effectively into a regional food strategy?
- How can effective collaboration be fostered between different actors within the farming and land management sector in order to deliver regional landscape resilience?

Hydrogen and Industrial Decarbonisation

Published as part of the South Yorkshire Sustainability Centre Consolidated Research Report, March 2026

Case Studies in this section:

194 Hydrogen and Industrial Decarbonisation Recommendations for Regional Policymakers

196 Towards a Resilience Evaluation Framework for Hydrogen Supply Chains

200 Towards a Unified Hydrogen Standard: Benchmarking G20 Nations' Hydrogen Economy Maturity

204 Implications of Steel Decarbonisation for Workers and Communities

210 HySaaS: Securing Social Licence for Hydrogen Storage and Distribution in South Yorkshire

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218 Scoping a Hydrogen Network for the South Yorkshire Region using the Network Optimisation Model AENi

Challenge

South Yorkshire has long stood at the heart of the UK's industrial faculty, with advanced manufacturing, steel, glass and ceramics sectors driving regional growth and job creation for decades. The new South Yorkshire's Growth Plan, published in September 2025, recognises this heritage and sets out a renewed vision to build on this manufacturing legacy, utilising the region's capabilities and expertise in clean energy, innovation and research and development (R&D).

With a population of 1.4 million, South Yorkshire represents a significant regional economy (£39.6 billion gross domestic product (GDP)[1]) transitioning from its industrial heritage toward advanced manufacturing, healthcare and digital services. Manufacturing continues to be the bedrock of the region's economy, accounting for 15.3% of gross value added (GVA), significantly higher than the national average of 9.8%[2], which is now being supercharged by advanced manufacturing and clean energy. Indeed, South Yorkshire now ranks as the UK's third-largest region for employment in clean power and hydrogen[3].

Stretching from Sheffield to Rotherham, Don Valley, home of the University of Sheffield's Advanced Manufacturing Research Centre, is an established innovation district, with global significance. With 30 cutting edge R&D facilities sprawling over four adjacent sites, the internationally recognised translational research facilities set the region apart, supporting over 1,200 businesses with more than 3,500 employees and attracting world-leading advanced manufacturing companies, such as Boeing, Rolls Royce and McLaren Automotive[4].

At the national level, the region's capabilities in both advanced manufacturing and clean energy sectors are recognised in the Modern Industrial Strategy's Clean Energy[5] and Advanced Manufacturing Sector Plans[6]. The government named these and another 6 industries as key for future prosperity and economic growth, both at regional and national levels. The emphasis is placed on transition to low-carbon manufacturing, recognising this as not only a necessity to meet net-zero by 2050 targets, but also a strategic and economic opportunity for regions to sustain jobs, attract investment and lead in the manufacturing economy of the future.

However, key challenges for the region remain. At the end of 2025, the employment rate for South Yorkshire was 73.3%, 2 percentage points below national average. Both unemployment (4.7%) and economic inactivity (23%) rates exceed England's average (with 3.7% and 21.4% respectively) and the proportion of workers in severe job insecurity ranks second highest amongst all combined local authorities at 21.7%[7]. Furthermore, the advanced manufacturing together with other strategic sectors prioritised for growth, such as healthcare and digital skills, are all the fields with projected skill shortages in the region for 2026[8].

Whilst skill shortages might stagnate growth, some of the cornerstone companies are struggling to stay in operation. The recent Defence Growth Deal

1 ONS (2025) Regional economic activity by gross domestic product, UK: 1998 to 2023. Regional gross domestic product: all ITL regions. 2023 data.
2 Pratap Executive (2025) South Yorkshire Growth.
3 SYMCA (2025) South Yorkshire's Growth Plan.
4 Ibid.
5 UK Government (2025) The UK's Modern Industrial Strategy. Clean Energy Industries Sector Plan.
6 UK Government (2025) The UK's Modern Industrial Strategy. Advanced Manufacturing Sector Plan.
7 Yotru (2026) South Yorkshire Labour Market Data 2026: Employment, Wages + Apprenticeships.
8 Ibid.

identified South Yorkshire as one of five leading places in the UK in the defence industrial economy; the region provides specialist steel for use in the defence sector through Forgemasters, BAE Systems and Special Melted Products[9]. However, Speciality Steels UK, crucial to national defence, aerospace and energy industries due to their highly specialist, world-leading steel production capabilities[10], was placed in receivership in 2025 and is now under UK government control. This came after several years of financial uncertainty, during which most of the company's workers were placed on indefinite furlough, not only affecting multiple jobs, but also entire communities in Stocksbridge. Stocksbridge retains a strong sense of identity, rooted in its steelmaking heritage with British Steel and its predecessors historically being central to both the economic and social life of the town, providing welfare and community functions.

This issue is not limited to Stocksbridge. The steel industry in South Yorkshire has undergone significant change over the last 40-50 years. In 1971, 140,000 people were employed in the steel industry in Sheffield alone. This accounted for half of all the city's jobs. In just over a decade this fell by more than half to 57,000 in 1987[11]. This decline in employment numbers continued in the 1990s and 2000s. By 2024 metals production and manufacturing industries were estimated to employ around 15,000 people across South Yorkshire[12].

9 SYMCA (2025) South Yorkshire's Growth Plan.
10 Community Trade Union. (2025) Statement - Liberty Steel.
11 Hudson, R and Sadler, D (1989) The international steel industry: restructuring, state policies and localities. Routledge, Abingdon.
12 Office for National Statistics (2025) Business Register and Employment Survey.

With a population of **1.4 million**, South Yorkshire represents a significant regional economy of **£39.6 bn GDP**

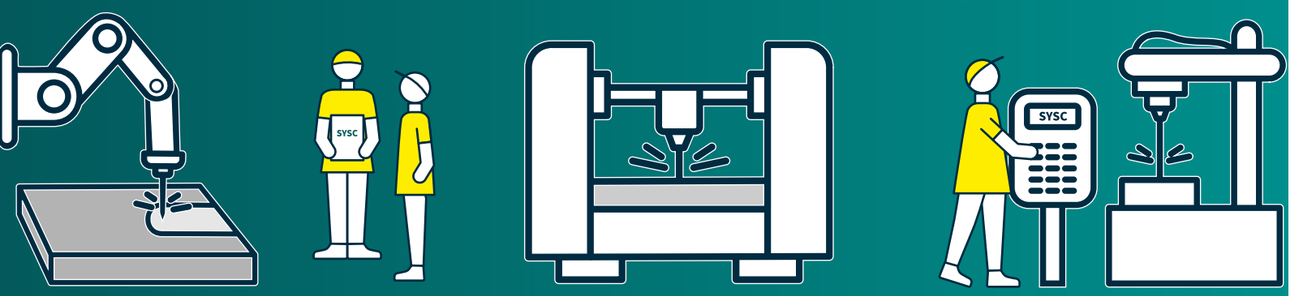
Its history of heavy industry is transitioning toward advanced manufacturing, healthcare and digital services

Manufacturing continues to be the bedrock of the region's economy

Manufacturing accounts for

15.3% GVA
South Yorkshire

9.8% GVA
national average



Additionally, steel and other energy intensive manufacturing industries within the region such as glass and bricks, require significant investment to decarbonise, or risk production moving elsewhere or ceasing entirely. These sectors are not only energy intensive, but also are defined by their hard-to-abate emissions profiles, due to the high temperatures needed. Electrification is not always possible to meet these challenges and decarbonisation via hydrogen potentially requires significant changes to production processes.

If done right, transitioning to low carbon manufacturing could ensure a prosperous future for the region and its residents, with green growth and clean energy supporting manufacturing and innovation hubs that are rooted in the region's history and heritage.

Research Response

Industry and manufacturing decarbonisation, especially of heat-intensive industries such as steel, ceramics and glass making, presents a substantial challenge that requires collaboration between local authorities, industry and academia to overcome. With this goal in mind, South Yorkshire Sustainability Centre (SYSC)' convened key stakeholders and partners across the region - including South Yorkshire Mayoral Combined Authority (SYMCA)', Forgemasters, Marcegaglia, Ardagh Glass, Aggregate Industries, Chesterfield Special Cylinders, E.On, Cadent to name but a few - to hold open discussions through the Industry Decarbonisation Roundtables series. During these discussions, some of the key challenges and barriers to decarbonisation were identified, including: the lack of clear, long term policy steer from the national government, high risk, high operational and capital costs of hydrogen, hydrogen supply uncertainties, readily available volumes of hydrogen in the region and further large scale feasibility studies required.

SYSC's research has sought to ascertain hydrogen economy readiness, benchmarking hydrogen economy maturity of the UK (in terms of investment, legislation, and strategy) against other G20 nations. The study found the UK to be one of the frontrunners, together with the US and China in hydrogen economy maturity. For the UK, and particularly regions such as South Yorkshire seeking to embed themselves in the hydrogen economy, this benchmarking provides insight into the country's competitive positioning relative to other G20 members.

This supports SYSC's State of Hydrogen in South

The steel industry in South Yorkshire has undergone significant change over the last 40-50 years

1971

140,000
employed in the steel industry in Sheffield alone

1987

in just over a decade this figure fell by more than half to
57,000

2024

15,000
employed in metals production across South Yorkshire

Yorkshire report findings. The report aimed to provide readily actionable recommendations for South Yorkshire's Investment Zone and consists of analyses of national and regional policy landscapes, regional manufacturing and innovation capabilities, supply chain maturity, and production capacity and demand. The report also assessed the opportunities and challenges to grow the sector in South Yorkshire. With hydrogen expected to account for 20-35% of UK energy consumption by 2035[13], the report found that South Yorkshire has the potential to be a national and even global leader in hydrogen and the way it is used safely, but quick and decisive action by regional policymakers is needed.

Although South Yorkshire is not within a hydrogen cluster at the moment, it is well connected to two large emerging hydrogen clusters, at Tees Valley and Humberside, whilst also holding 0.37 GW (enough to produce ~1,944 GWh annually) hydrogen production capacity (albeit currently restricted by grid headroom availability). Still, the report identified that the real strengths of the region and its leadership potential lies in hydrogen research, hydrogen use demonstrators and manufacturing for the hydrogen supply chain. The State of Hydrogen in South Yorkshire report was also presented to the SYMCA's South Yorkshire Energy Board, where it received positive feedback from Mayor Oliver Coppard and the Chair of the Board, David Bond. It was also featured at the UK Clean Energy Summit, hosted by the University of Sheffield, and in one of the Sheffield City Chambers of Commerce newsletters.

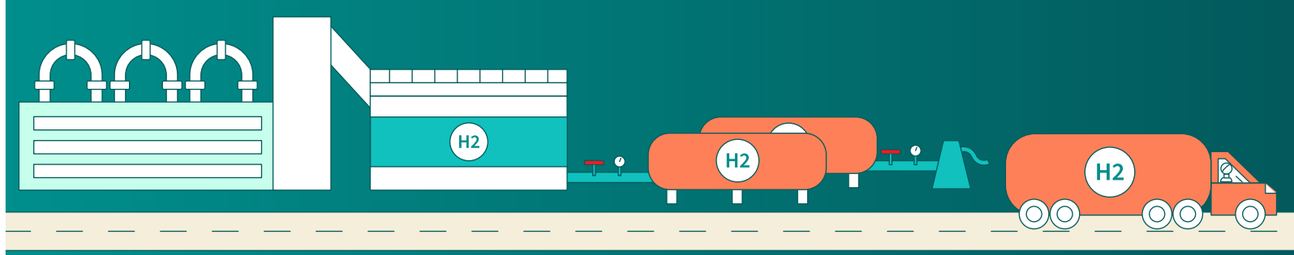
Another SYSC project further investigated how resilience could be built into hydrogen supply chains. The project identified the main challenges within the hydrogen supply chain to be raw material dependencies, weather risks, integration challenges, and sensitivity to stakeholder perceptions. In South Yorkshire, this means that resilience planning should be integrated with environmental regulation, energy market design, and community engagement. Supporting renewable energy communities and decentralised production would enhance both technical resilience and social equity, requiring cross-disciplinary collaboration. The project identified supply network integration as another driver of resilience. Building partnerships across transport, manufacturing, logistics, and heavy industry can foster collective resilience, reduce vulnerabilities, and create high-value jobs, supporting a just transition.

Another study utilised the regional optimisation model AENi to understand where hydrogen clusters could be established to achieve a cost optimal scale-up of hydrogen supply in South Yorkshire. The study considered 21 energy, heat and emission intense manufacturing companies of variable size in South Yorkshire. The AENi software, developed as a spin-out from the Brown group at University of Sheffield, was used to find a cost optimal network linking these sites to the grid supply point at Thurcroft. Although this was just an initial modelling exercise and further in-depth collaboration is needed to develop a more accurate model, including economic analysis to predict the most favourable roadmap for roll out, the current project findings show that a hydrogen network for industrial sites is likely feasible using existing electrical grid connections.

It is important to note that successful hydrogen deployment depends not only on technical feasibility, but on societal and institutional readiness. Hydrogen storage and road-based distribution systems will operate within industrial estates, logistics corridors and alongside residential communities. The existing evidence base is heavily weighted toward techno-economic modelling and carbon intensity analysis, with comparatively limited research examining multi-stakeholder social acceptance, particularly for storage and transport infrastructure. The Hydrogen Storage as a Service (HySaaS): Securing Social Licence for Hydrogen Storage and Distribution

Hydrogen is expected to account for
20-35% of the UK's energy consumption by 2035

South Yorkshire holds **0.37 GW hydrogen production capacity** - enough to produce ~1944 GWh annually



13 Illustrative demand based on analysis for the Hydrogen Transport and Storage Networks pathway (2023), as referenced in GOV.UK (2024) Hydrogen investment roadmap: Leading the way to net zero.

in South Yorkshire project aimed to address this gap by providing a structured, multi-stakeholder assessment of social acceptance focused specifically on hydrogen storage and distribution, the parts of the value chain most visible to communities and emergency responders.

The research found that acceptance of hydrogen storage and distribution is broadly positive but strongly conditioned by perceptions of safety and risk. Across all stakeholder groups, safety emerged as the dominant determinant of acceptance. Crucially, all groups responded positively to enhanced monitoring and transparency. More than 80% of public respondents indicated that additional monitoring systems would increase their comfort with hydrogen storage and distribution. This suggests that visible, data-driven safety mechanisms can materially improve acceptance.

The findings suggest that hydrogen storage and distribution can secure social licence if deployment is treated as a governance and trust challenge as much as a technical one. To improve social acceptance and reduce perceived risk, hydrogen demonstrator projects in South Yorkshire should aim to combine monitored assets, responder training and community engagement, thus strengthening the commercial case for hydrogen investment.

Beyond Industrial Decarbonisation

Lastly, it is important to note that hydrogen is relevant not only for industrial decarbonisation, but also essential for Sustainable Aviation Fuel (SAF) production. The UK's SAF Mandate, which came into effect in 2025, requires 2% of total UK jet fuel demand to be supplied as SAF, rising to 10% in 2030 and 22% in 2040[14]. This policy, designed to reduce aviation emissions, forces fuel suppliers to meet these targets or buy certificates, similar to Renewable Energy Guarantees of Origin (REGOs) certificates issued by Ofgem to certify electricity generation from eligible renewable sources - used as a mechanism for companies to prove renewable energy sourcing.

As SAFs require no engine modifications and because they can be produced from waste products, they are seen as an interim solution for emissions from aviation.

There are several certified routes for preparing SAF that differ in feedstock and/or processing methods to obtain synthetic paraffinic kerosene (SPK), which is then blended with conventional fuels, with the exact blend proportions variable and dependent on the pathway. All of these routes, apart from one, require hydrogen for their processing.

However, several key challenges remain in advancing SAF development and deployment, such as a lack of lifecycle data, limited evidence on the resilience of SAF supply chains under different feedstock, technology, and trade scenarios; and a persistent uncertainty over which SAF pathways should be prioritised, as each involves trade-offs among economic cost and scalability, environmental performance, technological maturity, and broader social and political acceptance.

SYSC research aimed to address these gaps through a comparative analysis of all certified waste-derived feedstock SAF life cycle assessments, supply chain resilience analysis and a stakeholder engagement study, which aimed to gauge perspectives across the SAF value chain and translate them into structured evaluations of competing pathways. One of the key findings from this research is that SAF deployment targets are likely to outpace the sustainable supply of biogenic waste feedstocks, creating potential bottlenecks and competition with other sectors. This highlights the need for diversified feedstock sourcing and resilient, internationally coordinated supply chains, integrating both biofuels and synthetic (power-to-liquid) fuels to achieve the necessary scale-up. For policymakers, the research highlights the need for stronger and more targeted incentives. SAF mandates, subsidies, and funding mechanisms should be designed to only favour pathways with the strongest evidence base for environmental sustainability and supply chain resilience.

Safety emerged as the dominant determinant of hydrogen storage and distribution acceptance **across all stakeholder groups**

Crucially, all groups responded positively to enhanced monitoring and transparency

More than **80%** of **public respondents** indicated that additional monitoring systems would **increase their comfort** with hydrogen storage and distribution

This suggests that visible, data-driven safety mechanisms can materially improve acceptance

14 DfT (2025) Sustainable Aviation Fuel (SAF) Mandate.

Hydrogen and Industrial Decarbonisation Recommendations for Regional Policymakers

1. Local policymakers should commit ongoing resources to support the continuation of the existing **Industrial Decarbonisation Roundtables so that there is a permanent, robust forum in which policymakers, regional industry leaders and academia can collaborate** to a) to identify, scope and deliver regional demonstrators and b) co-design regional policies that directly address policy gaps, barriers to growth and the operational requirements of the sector.

2. To support Local Growth Plan ambitions, policymakers, industry and academia should convene a **working group to determine how South Yorkshire can capitalise on its existing strengths to emerge as a national leader in the technologies and components that underpin hydrogen production, storage and transportation**, such as catalysts, storage tanks and pipeline materials. This offers significant potential for long term economic growth and national leadership.

3. In continued partnership with industry and The University of Sheffield, **local policymakers should identify and create defined hydrogen production and user site clusters** in South Yorkshire, and **take responsibility for attracting, directing and scaling business activity** in existing and emerging clusters.

    i. Scoping a Hydrogen Network for the South Yorkshire Region using the Network Optimisation Model AENi.

4. To promote regional readiness and support the region's Local Growth Plan, l**ocal policymakers should work with South Yorkshire's hydrogen projects**, such as ITM Power, GeoPura, Lhyfe, and Clean Power Hydrogen group **to ensure that they meet or are working to meet international certification requirements**, ensuring competitiveness in global supply chains.

    i. Towards a Unified Hydrogen Standard: Benchmarking G20 Nations' Hydrogen Economy Maturity.

5. **Produce an 'inclusive industrial transition' strategy** which centres on how large investments in industrial decarbonisation can capture value for the region as a whole, provide pathways to good and inclusive work, and benefit the region's SME base. This can build from current on-going work between SYSC and SYMCA on principles for an inclusive industrial transition.

    i. Implications of Steel Decarbonisation for Workers and Communities.

6. **Support industrial workers to become active participants in green industrial future realisation.** This includes access to skills provision and job support where retraining is required, but more broadly to provide open communication and engagement around opportunities and challenges of green industrial futures. Trade Unions can play an important role within this, alongside businesses and policy organisations.

    i. Implications of Steel Decarbonisation for Workers and Communities.

Further Research Opportunities

Hydrogen sector: More research needed to understand the optimal balance between policy support and long-term independence, particularly the extent to which subsidies enable growth but may reduce adaptability and innovation.

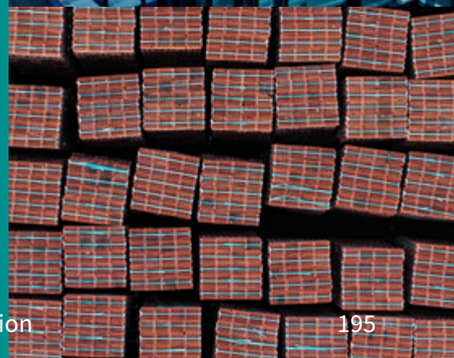
Scoping a SY hydrogen network:

- Carry out further partner engagement to understand which decarbonisation option is preferable/intended.
- Develop a methodology for analysing the economics of sub-sections of the network to predict the most favourable roadmap for rollout.
- Collaborate with partners in areas where the network cost is lowest in order to develop a more accurate model, and gauge willingness to pay.

Jobs and work: Research could support the development of a community-rooted taskforce in Stocksbridge to lead community and infrastructural renewal.

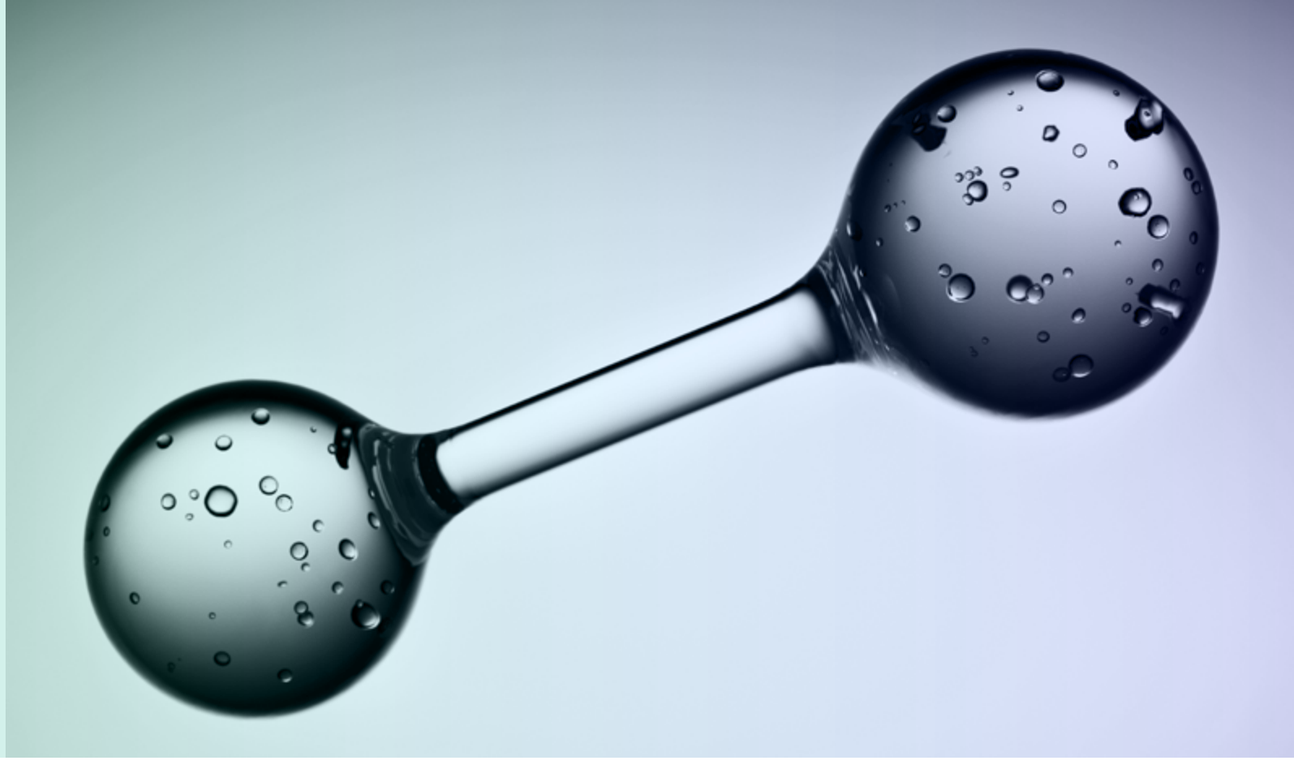
Inclusive industrial decarbonisation: There is ongoing research underway with SYMCA to develop a broader approach to 'inclusive industrial decarbonisation' that seeks to set out a framework for delivering sustainable industrial futures that also addresses key social, economic and cultural challenges.

Public acceptance: Further research should track how public attitudes evolve as hydrogen infrastructure becomes more visible and explore how monitoring data can be translated into meaningful public-facing safety indicators.



Towards a Resilience Evaluation Framework for Hydrogen Supply Chains

Project team:
University of Sheffield: Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood, Liang Kong



Challenge Statement

The case study responds to urgent challenges exposed by current geopolitical tensions, such as instability in the Middle East and the Russia-Ukraine war, where global disruptions have highlighted the limits of traditional resilience practices such as contingency planning. These reactive approaches have proved inadequate for the scale and complexity of modern supply chain shocks[1]. In today's volatile environment, organisations require proactive mechanisms that enable not only recovery but also adaptation and evolution. This is particularly vital for hydrogen supply chains (HSCs), which face raw material dependencies, weather risks, integration challenges, and sensitivity to stakeholder perceptions. Yet no framework currently guides firms in progressively building resilience, leaving a clear gap this study seeks to address. Current evidence supports this view[2]. Existing maturity models remain fragmented and function-specific, with few pathways, limited empirical evidence, and especially scarce hydrogen-specific insights despite the sector's importance to net-zero.

For South Yorkshire, these challenges are immediate. Hydrogen is central to the UK's industrial strategy, but its success depends on supply chains that are robust, adaptable, and sustainable. Funded by Research England, this research develops a conceptual maturity model for hydrogen resilience, providing a tool to strengthen supply chains and support a competitive, fair, and sustainable hydrogen economy.

Research Response

Research contributes to tackling resilience challenges in HSCs by offering structured approaches that reflect the sector's unique vulnerabilities. This study develops a resilience capability maturity model (RCMM) that provides a phased framework for assessing resilience across maturity levels, tailored to hydrogen's regulatory, market, and technological contexts. Drawing on complex adaptive systems (CAS) theory, the model explains how firms adapt and self-organise under disruption. Unlike existing maturity models, which are either sector-specific or largely conceptual, this framework addresses hydrogen's challenges such as hazard management, sustainability demands, and market volatility. It enables benchmarking, identifies capability gaps, and provides actionable insights, while laying the groundwork for broader empirical validation.

Where hydrogen is central to energy and net-zero strategies, the challenge lies not only in scaling technologies but in ensuring the value chains remain resilient and adaptable. Heavy reliance on subsidies risks dependency and reduced adaptability. The RCMM helps address this by equipping firms with tools to benchmark resilience, identify weaknesses, and pursue continuous improvement. Emphasising technical independence, organisational learnability, and ecological resilience, the model supports firms in anticipating risks, building adaptive capacity, and sustaining competitiveness in volatile markets.

The project's goal was to create a sector-specific model for HSCs, operationalising resilience management through defined maturity levels, from reactive recovery to ecological resilience. Tested through exploratory case studies, it offers a roadmap for organisational progression, supports benchmarking, and provides a basis for validation across sectors and regions.

Evidence and Outputs

Existing maturity models in supply chain management are either sector-specific or largely conceptual, making them insufficient for addressing the resilience needs of HSCs. To address this gap, a conceptual RCMM tailored to hydrogen was developed. The model demonstrates a progressive pathway: early stages focus on manufacturing resilience through reactive responses and recovery capabilities, while higher stages emphasise ecological resilience, characterised by proactive adaptation, external network integration, and long-term sustainability. Exploratory case studies of seven companies across three continents showed that the RCMM can identify capability levels, highlight gaps, and provide companies with a roadmap for advancing resilience maturity. The research indicated that firm size and age matter, with larger and older firms generally better positioned to recover and adapt due to accumulated resources and experience. The research also highlights trade-offs. Hydrogen technologies are resource-intensive, with high energy and leakage risks. At the same time, policy dependency, particularly on subsidies, was found to risk undermining long-

1 Koh, S. C. L., Suresh, K., Ralph, P., & Saccone, M. (2024) Quantifying organisational resilience: An integrated resource efficiency view. International Journal of Production Research, 62(16), 5737–5756.
2 Kong, L., Koh, S. C. L., Sena, V., Robinson, D., & Wood, M. (2025) Towards a resilience evaluation framework for hydrogen supply chains: A systematic literature review and future research agenda. International Journal of Hydrogen Energy, 99, 589-606.

Resilience Capability Maturity Model

	Manufacturing Perspectives		Ecosystem Perspectives		
Maturation Path	Level 1: Initial	Level 2: Commercialisation	Level 3: Scale-up	Level 4: Industrialisation	Level 5: Business Ecosystem
		Improved technical ability	Declining costs	Developed supply network	Affordable and new technologies emerge
Themes	Focus on technical infrastructure readiness, organisational structure, resource accumulation for operations and reactive response capabilities	Focus on integrating internal capabilities, developing key supply chain structures and extending proactive resilience capabilities	Adopt a proactive attitude, strengthen internal resilience practices and collaborate with supply chain partners on risk management	A comprehensive and systematic approach to implementing resilience practices, internally and across the supply chain, requires collaboration with partners and stakeholders to build a robust business ecosystem	Resilience practices are embedded across corporate and supply network processes, with strong partner synchronisation driving value creation, business model innovation and a sustainable ecosystem
Stakeholders	Departments of the focal enterprises, the focal enterprises, key component and infrastructure suppliers, power supply companies, governments, academic institutions	Departments of the focal enterprises, the focal enterprises, key component and infrastructure suppliers, power supply companies, customers	Key component and infrastructure suppliers, power supply companies, the focal enterprises, customers	Renewable energy enterprises, the focal enterprises, customers, regional and national governments, international industry associations, academic institutions	Renewable energy enterprises, the focal enterprises, customers, regional and national governments, international organisations, academic institutions

Technical Resilience: considering from manufacturing technique, process, equipment and R&D perspectives

Sub Levels	Level 1: Technical Readiness	Level 2: Commercialisation	Level 3: Scale-up	Level 4: Industrialisation	Level 5: Business Ecosystem
	Objective: Ensure the technical readiness of the system	Objective: Supply and demand coordination	Objective: Improve the scale, stability and efficiency of the manufacturing process	Objective: Regional risk control	Objective: Ensure the technical readiness of the system

Sub Criteria: Foundation of a system coordinated development (Vulnerability Control), reliability, maintainability, independence of critical infrastructures, resources to build up resilience and to response (Monitoring and Landscape)

Operational Resilience: considering from cash, information, material flow and relationship management perspectives

Sub Levels	Level 1: Responsiveness	Level 2: Commercialisation	Level 3: Integration	Level 4: Collaboration	Level 5: Sustainability
	Objective: Develop operations management capabilities	Objective: Production efficiency	Objective: Supply network extension	Objective: A mutually cooperative win-win approach	Objective: Sustainable development capability achieved

Sub Criteria: Operational management capabilities (Cost-down Abilities, Efficient Manufacturing/Optimality), Information sharing (Visibility and Transparency), Adaptability (Flexibility, Optimisation and Recovery Capabilities)

Organisational Resilience: considering from organisational structure, culture and administration process perspectives

Sub Levels	Level 1: Structure Constuction	Level 2: Functional Integration	Level 3: Organisational Process Integration	Level 4: External Stakeholder Integration	Level 5: Dynamic Alliance
	Objective: Appointment of resilience management specialists and establishment of cross-department teams	Objective: Optimisation of organisational structure and establishment of a resilience management system	Objective: Foresight	Objective: Ecosystem building	Objective: Possess high resilience and flexibility, be manageable and continuously improved

Sub Criteria: Organisational structure (Robustness and Agility), Objectives, values and culture (Clarity of Vision and Mission and Learnability)

term resilience, indicating the need for strategies that balance short-term support with sustainable independence.

The main output is a conceptual maturity model (the RCMM) that functions as both a descriptive and comparative tool, enabling firms to assess their resilience maturity, benchmark against peers, and develop strategies for improvement. Incorporating five levels across technical, organisational, and operational dimensions, and grounded in CAS theory, the model offers guidance for companies and policymakers. While designed for HSCs, it has potential transferability to other sustainability-focused industries, though further empirical testing to confirm its generalisability.

Interim access to the framework can be provided upon request through the research team. Please email liang.kong@sheffield.ac.uk for access.

This research has also been published and the research paper can be viewed here.

What does this mean for the region?

For South Yorkshire, where energy affordability is a regional concern, resilience planning should be integrated with environmental regulation, energy market design, and community engagement. Supporting renewable energy communities and decentralised production would enhance both technical resilience and social equity, requiring cross-disciplinary collaboration. The RCMM identifies supply network integration as another driver of resilience. Building partnerships across transport, manufacturing, logistics, and heavy industry can foster collective resilience, reduce vulnerabilities, and create high-value jobs, supporting a just transition.

South Yorkshire can apply the RCMM in regional clusters such as hydrogen transport hubs and decarbonised steel, while also positioning itself as a national and international leader in resilience-focused hydrogen development. By exporting governance frameworks alongside technologies, the region can attract investment and strengthen its reputation.

For the UK and globally, this research informs and highlights the critical need to evaluate maturity and resilience of HSCs, as part of the hydrogen, energy and net-zero policies to maximise sustainability and security.

Next Steps

To maximise the impact of this work, the next step is to apply the maturity model more widely across different firms, sectors, and regions. The model could be embedded into hydrogen clusters such as transport hubs, industrial decarbonisation projects, and renewable energy communities. Doing so would provide benchmarking data, guide targeted interventions, and demonstrate the model's value as a regional policy tool. Embedding the framework into industrial strategies and net-zero roadmaps would also ensure that resilience is systematically assessed alongside growth and sustainability goals.

The research also highlights new questions that warrant further exploration. One important area is how firm characteristics, such as size, age, and resources, shape progression through resilience maturity levels. Another concerns the balance between policy support and long-term independence, particularly the extent to which subsidies enable growth but may reduce adaptability and innovation (Kong et al., 2025). There is also scope to adapt the model to environmental challenges such as energy demand, water use, and hydrogen leakage, linking resilience more closely with environmental governance.

Collaboration is key to advancing this agenda. Partnerships between academia, industry, and regional policymakers could establish pilot projects where firms apply the model and share data to build comparative insights. Cross-regional and international collaborations could further position South Yorkshire as a leader in both hydrogen technology and resilience governance. By pursuing these opportunities, the region can strengthen its evidence base, attract investment, and accelerate progress toward a just and sustainable hydrogen economy.

Figure 1 (left): Proposed RCMM Abstract, credited by Liang Kong, Prof. Lenny Koh, Prof. Vania Sena, Prof. Darren Robinson, Dr Matthew Wood

Towards a Unified Hydrogen Standard: Benchmarking G20 Nations' Hydrogen Economy Maturity

Project team:
University of Sheffield: Prof. Lenny Koh, Dr Moein Shamoushaki, Eleanor Borrill

Challenge Statement

Hydrogen is widely regarded as a cornerstone of the global net-zero transition. However, its development and deployment face significant obstacles due to regulatory fragmentation and policy inconsistency across G20 nations.

One of the key challenges is the lack of a universally accepted hydrogen standard. Different definitions – such as the varying use of the "green hydrogen" label – undermine perceptions of quality and create barriers to trade compatibility. A second challenge stems from policy misalignment, with inconsistent national approaches generating uncertainty for investors, complicating infrastructure planning, and impeding the integration of international markets. Finally, uneven levels of national maturity further exacerbate the issue: while some G20 members have developed strong legislation, strategies, and investment programmes, others remain without clear plans or regulatory frameworks.

Research Response

Contribution of Research

This study represents the first comprehensive review of hydrogen standards, financial commitments, national strategies, and future plans across the G20. Using a Weighted Scoring Model (WSM), the analysis rates each nation on a scale from 1 (lowest maturity) to 10 (highest maturity) across these dimensions. This enables direct cross-country comparison, identification of maturity gaps, and the development of a structured basis for international policy alignment.

Regional Relevance

For the UK – and particularly regions such as South Yorkshire seeking to embed themselves in the hydrogen economy – this benchmarking provides insight into the country's competitive positioning relative to other G20 members. It also identifies opportunities for strategic investment and informs policy design that reflects and aligns with emerging global standards.

Evidence and Outputs

Research Findings

The study highlights the US, China, and the UK as frontrunners in hydrogen economy maturity. These countries already combine standards, strategy, and investment, giving them significant influence over global market rules and trade. Their leadership sets the direction for others, and they are well-positioned to drive international standard harmonisation, scale manufacturing, and provide technical and financial support for emerging markets.

Other advanced economies such as Germany, France, Italy, and Australia show strong progress in policy and investment but need to focus on moving from ambitious strategies to binding regulations and large-scale deployment. Japan demonstrates strong planning but underinvestment, while Brazil, South Africa, Argentina, and India face uneven progress across criteria. These countries would benefit from closing gaps between strategy and financing, building institutional capacity for certification and safety, and deploying pilot projects that match local resources.

At the lowest maturity, Mexico and Russia lack clear hydrogen strategies or standards, which risks their exclusion from future global markets. For these countries, the priority is to establish basic national roadmaps and regulatory frameworks, while leveraging multilateral and bilateral support to develop pilot projects and build institutional capability.

Overall, the results show that the frontrunners must take responsibility for shaping international standards and financing mechanisms, while lagging countries urgently need targeted support to build the foundations of hydrogen economies. Without this alignment, fragmented approaches and investment gaps will slow progress toward a global hydrogen market and delay the role of hydrogen in achieving net-zero goals.

Published academic papers on this research project can be found here[1].

Scalability and Commercialisation

The findings offer clear pathways for scaling hydrogen deployment. In South Yorkshire, maturity benchmarks can help target investment towards production, storage, and distribution projects that comply with international certification criteria. More broadly, the maturity scoring model can be applied to other regional clusters or international groupings to assess and benchmark progress.

Nuances and Trade-Offs

Some trade-offs must be considered in the pursuit of hydrogen market development. While global standardisation could slow short-term deployment due to the negotiation and alignment process, it is essential for ensuring long-term interoperability and stable market conditions. Furthermore,

1 Shamoushaki, M., Koh, S.C. Lenny, Novel maturity scoring for hydrogen standards and economy in G20, Renewable and Sustainable Energy Reviews, 212, (2025).

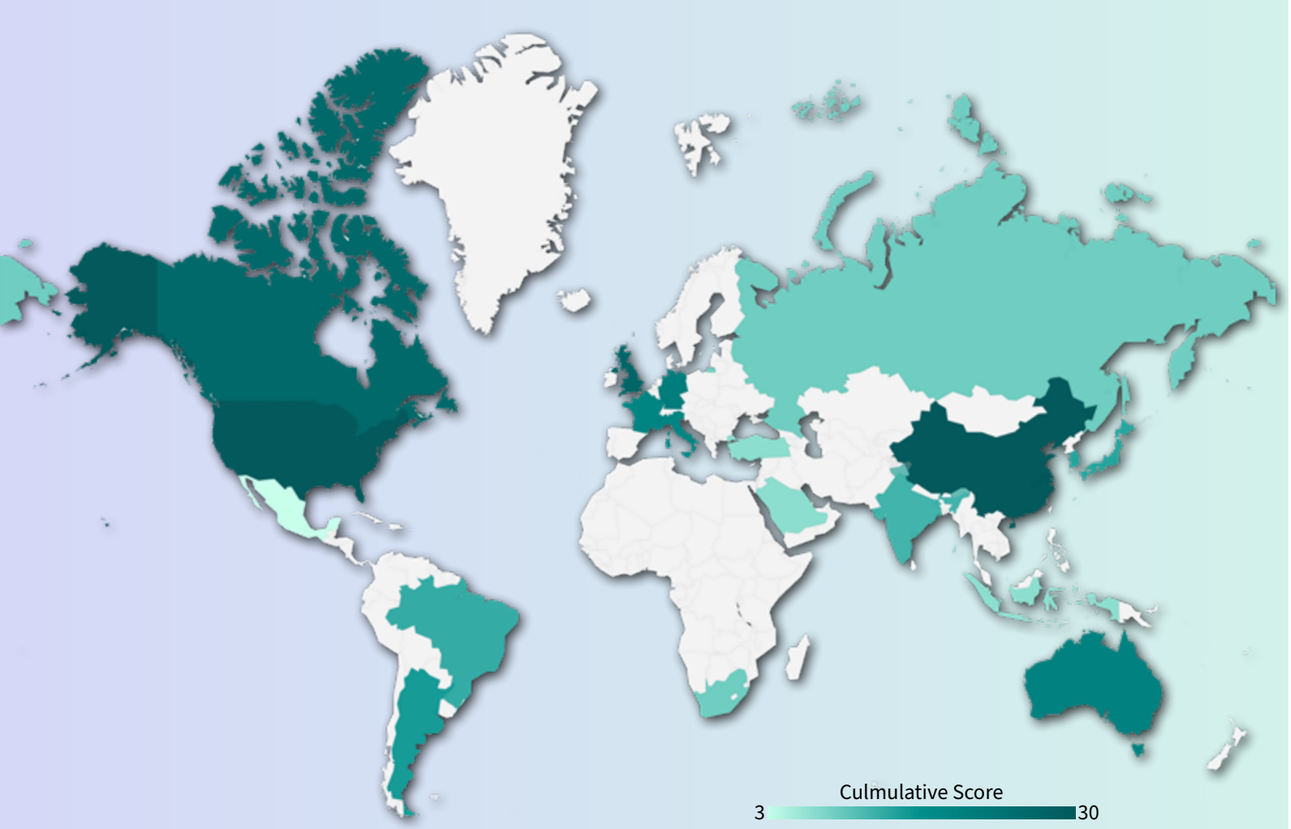


Figure 1: Maturity of hydrogen standards in G20 Countries demonstrated on a world map

regions must carefully balance the pursuit of unique strategic advantages with the need to remain aligned to global frameworks, avoiding potential isolation from emerging international markets.

Policy Insights

While the findings of this research hold global importance as it compares the hydrogen economy in all G20 countries, actionable recommendations can be drawn for South Yorkshire. The following section sets out key policy insights, building on the conclusions and recommendations drawn from the selected publications.

1. Continue to leverage first-mover advantage

   - The UK Low Carbon Hydrogen Standard provides a benchmark for emissions that can be used in international comparison, as well as the UK Low Carbon Hydrogen Certification Scheme – Consultation & Response, and the UK's Hydrogen Strategy which has sections on trade and exports, and explicitly states the importance of keeping "standards and certification for low carbon hydrogen consistent with international standards and schemes where appropriate."

   - As one of the few countries with a formal hydrogen standard, the UK can influence global certification frameworks and international trade agreements.

2. Continue to close strategy–investment gaps

   - In the 2022 UK public sector hydrogen research and innovation document, the government includes "international initiatives" among its focus areas, as well as within UK's Hydrogen Net-Zero Investment Roadmap, there is mention of developing business models for hydrogen transport & storage, export opportunities, and supporting alignment via certification work.

   - Further initiatives are required to ensure the UK's hydrogen strategy is backed by proportionate investment to maintain credibility and leadership, avoiding the "policy–investment mismatch" observed in other G20 nations.

Regional

1. Align with global standards

   - Promote regional readiness by positioning South Yorkshire's hydrogen projects, such as ITM Power, GeoPura, Lhyfe, and Clean Power Hydrogen group, to meet international certification requirements, ensuring competitiveness in global supply chains.

2. Strategic investment has been targeted

   - South Yorkshire Mayoral Combined Authority's (SYMCA's) partnership with Schroders Capital includes infrastructure investment focus via hydrogen generation and storage among other clean energy infrastructure, bringing in external capital.

   - It is recommended to use the Hydrogen Economy Maturity Index to prioritise local investment in hydrogen production, storage, and distribution.

3. Build capacity and skills

   - Work with Sheffield's universities, colleges, Advanced Manufacturing Research Centre (AMRC) training centre, and industry to create specialist training (e.g. accredited courses/ apprenticeships) in hydrogen technologies, ensuring a skilled workforce for scaling.

Next Steps

The research identifies several immediate and longer-term actions. At the international level, the UK should lead diplomatic and technical initiatives aimed at finalising a global hydrogen standard. The Hydrogen Economy Maturity Index should be updated regularly to reflect new standards, financial commitments, and national strategies. In parallel, hydrogen standards should be integrated into trade agreements to ensure that policy frameworks align with market access and competitiveness.

Further research is required to apply the maturity scoring model at sub-national scales and within industry sectors. In addition, economic analyses should be conducted to assess how the adoption of global hydrogen standards will influence trade flows and national competitiveness.

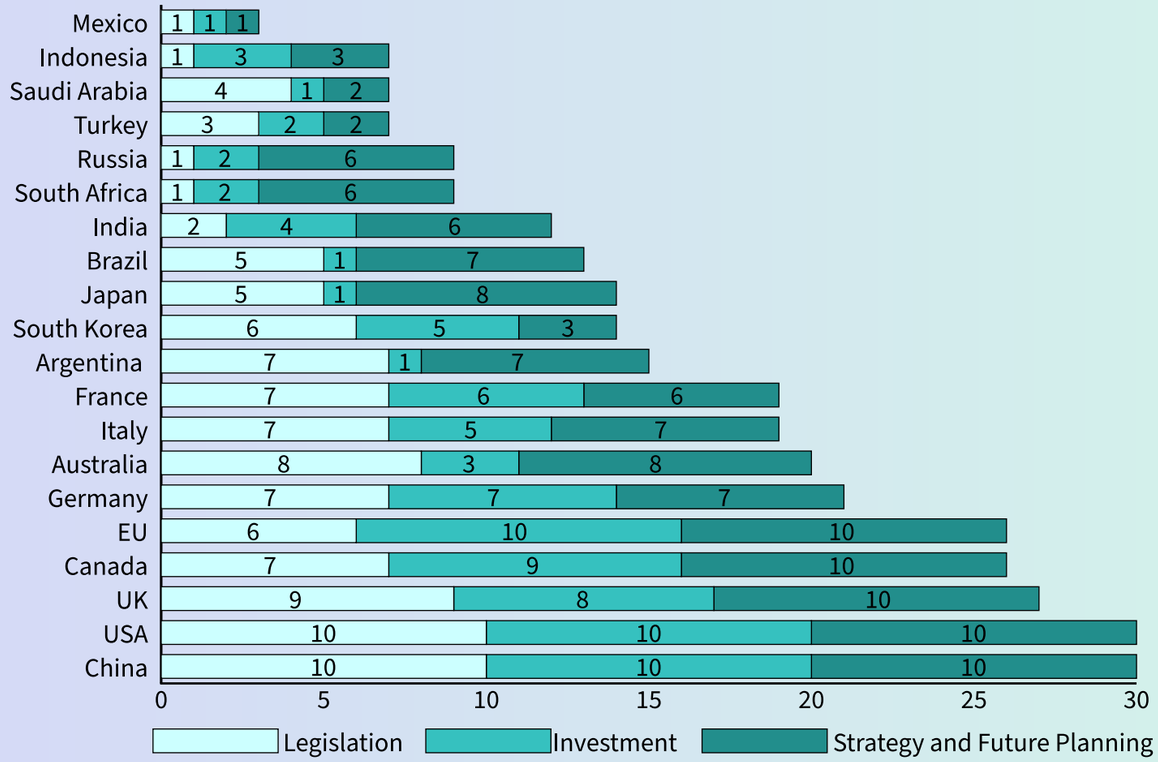


Figure 2: Maturity of hydrogen standards in G20 Countries

Implications of Steel Decarbonisation for Workers and Communities

Project team:
Sheffield Hallam University: Prof. Will Eadson, Dawn Witherley, Dr Rachel Macrorie

Project partners:
Dr Bregje van Veelen (Lund University), Dr Stefan Backius (Karlstad University), Dr Åsa Melin (Karlstad University), Dr Davor Mujezinovic (Karlstad University)

Challenge Statement

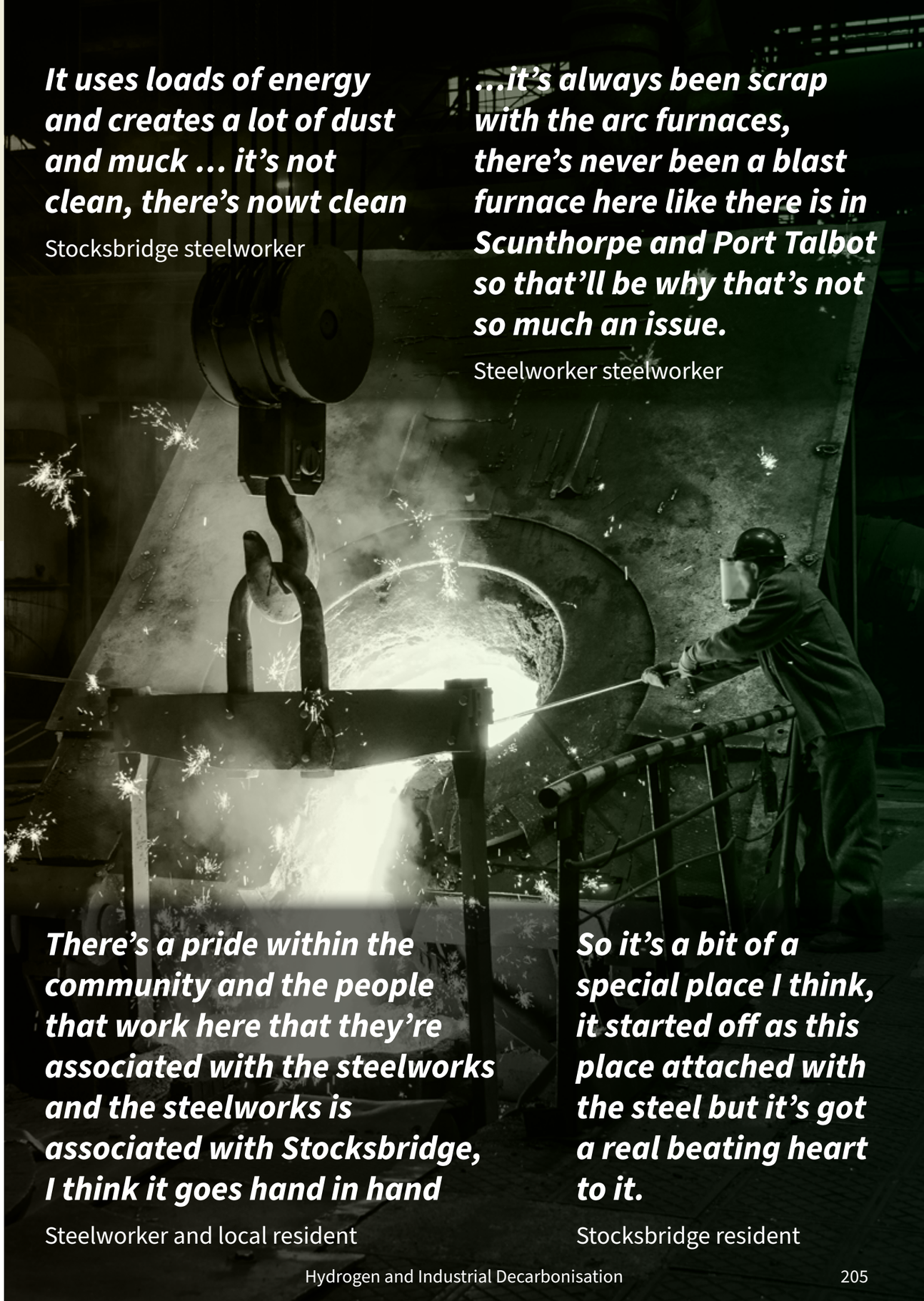
Steel is essential to everyday life. It is used in everything from house-building to surgical tools, from defence to energy systems, and as such is a strategically important industry for the UK. It is also an emission and energy-intensive industry, responsible for 8% of the world's carbon emissions[1] (2.4% of all UK emissions[2]). However, it is also a 'hard-to-abate' industry as decarbonisation potentially requires significant changes to production processes.

Steel decarbonisation can be seen as a phase of restructuring for the industry, in the context of previous phases of industrial change (Figure 1), which also has impacts for workers and communities where steel firms are located.

The development of the steel industry over the late 19th and early 20th centuries led to large concentrations of employment in some places, including communities across South Yorkshire. Those places grew around the industry and the industry often provided social and welfare services to communities. Significant changes to the steel industry since the 1970s have changed its geography, resulting in a relative decline of steel production across Europe and North America. In 1970, 28.3 million tonnes of crude steel were produced in the UK. This declined to 17.8 million tonnes by 1990 and 9.7 million tonnes in 2010[3]. By 2022 production had fallen to 6 million tonnes, almost one-fifth of its 1970 peak[4].

South Yorkshire, an historic heartland of steel production, was particularly hard hit. It is known worldwide for its cutlery production, and more recently specialist steel and advanced metals manufacturing. This is woven through the identity of the region: Sheffield is still known as the 'steel city'; its major sports teams carry this through nicknames 'The Blades' (football) and 'Steelers' (ice hockey). But the steel industry in South Yorkshire has undergone significant change over the last 40-50 years. In 1971, 140,000 people were employed in the steel industry in Sheffield alone. This accounted for half of all the city's jobs. In just over a decade this fell by more than half to 57,000

1 IEA (2023) Tracking Steel.
2 Knight, L and Walker, A (2022) Green Steel. UK Parliament POST Research Briefing Number 672
3 Rhodes, C (2017) UK Steel: Decades of Decline. UK House of Commons Library
4 World Steel (2023) World Steel in Figures.



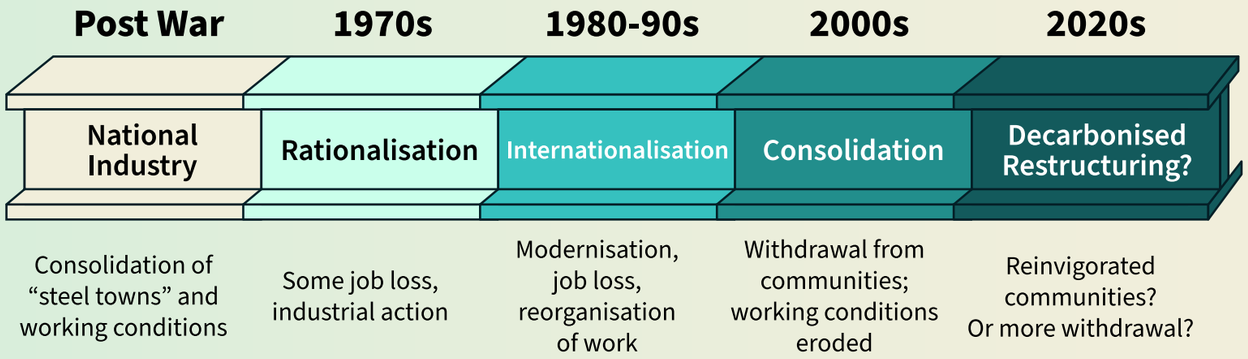


Figure 1: Phases of steel restructuring 1945-2020s

in 1987[5]. This decline in employment numbers continued in the 1990s and 2000s. By 2024 metals production and manufacturing industries were estimated to employ around 15,000 people across South Yorkshire[6]. Despite the decline in the size of the South Yorkshire steel industry, it remains important to the local economy and to national strategic interests. As well as a wide range of metals supply chain and manufacturing businesses, South Yorkshire retains several steel production sites.

Each of these sites are energy intensive and require investment to decarbonise, or risk – in time – production moving elsewhere or ceasing entirely. Decarbonisation also potentially brings opportunities to firms and places that can adapt sooner. As such the low carbon transition brings risks and opportunities for local employment and communities.

To date there has been very little research on how decarbonisation will affect where steel is produced and what the implications of changes to steel production will have on workers and steel communities, despite understanding that previous rounds of industrial change had deep and long-lasting impacts. This was the focus of our research.

Research Response

Our research in South Yorkshire was conducted in collaboration with an international project investigating how steel decarbonisation is beginning to impact on where steel is produced and the implications of these changes for workers and communities[7]. The project included detailed case studies of steel communities in Sweden and the UK. In South Yorkshire we conducted research in Stocksbridge. This research provides detailed understanding of resident and worker experiences of change and perceptions about green steel futures. We sought to understand how present-day experiences and expectations are shaped by historic processes of change. As such our research delved into personal and place-based histories through using oral history techniques and archival analysis. In Stocksbridge we interviewed workers, residents, trade union representatives and other local stakeholders. We also analysed local policy documents, like the Stocksbridge Towns Fund strategy.

The study involved the following methods:

- Document review (company and industry websites, academic and grey literature on the history of UK, Sheffield and Stocksbridge steel)
- Two tours of the Stocksbridge steelworks (October 2023 and February 2024)
- Visit to Stocksbridge history society archives
- Archival research
- Six focus groups with **20 workers** in total (16 'shop floor'; 4 'management'; all men), and two interviews with senior managers (both men)
- Qualitative oral history interviews with **20 residents** (12 men; 8 women)

Interviews were recorded, professionally transcribed and manually coded using NVivo qualitative data analysis software. Resident interviews lasted approximately 1 hour; focus groups lasted approximately 1-1.5 hours.

Evidence and Outputs

Stocksbridge hosts a Liberty Steel site that has faced continual upheaval since the 1980s. Steel remains central to the town's identity, though employment has fallen from 8–10,000 in the early 1980s to about 650 in 2023[8]. Liberty promotes a "Greensteel" strategy, branding South Yorkshire operations as green due to their reliance on Electric Arc Furnaces (EAFs). However, producing specialist steels at Stocksbridge remains highly energy-intensive, and decarbonisation options remain unsettled. This uncertainty is compounded by wider challenges, including high energy costs and competitiveness concerns for UK steel. Following several years of financial uncertainty, during which most of the company's workers were placed on indefinite furlough, in 2025 Liberty Speciality Steels UK was placed in receivership, under UK government control.

Despite green branding, Stocksbridge's processes—remelting, rolling, and alloying—remain energy and carbon intensive. Decarbonising EAFs might involve renewable energy supplied locally or – more likely given site constraints – via grid-based Power Purchase Agreements. Another challenge is replacing natural gas in reheating furnaces. There are plans to use hydrogen, seen as less capital-intensive than electrification and requiring less reskilling. However, this depends on reliable hydrogen supply, which remains uncertain given that there is no clear timescale for development of 'at scale' hydrogen infrastructure locally.

Worker perspectives[9]

Implications of green steel restructuring were unclear to employees, as no concrete plans existed. Managers were broadly aware of options, but 'shop floor' workers less so. Some referenced job losses at blast furnace sites in Scunthorpe and Port Talbot, although some others believed Liberty's use of electric arc furnaces insulated them from similar challenges. There was also uncertainty about what 'green steel' meant, with some cynicism about whether steel could ever truly be green.

Despite this, and wider challenges for the business, confidence in existing markets for the business remained strong. Participants highlighted demand from renewable energy sectors, such as wind turbines, alongside high-carbon industries like oil and gas and aerospace. This belief, coupled with perceptions that Stocksbridge either already produced green steel or that fully green steel was impossible fostered a belief that jobs would not be significantly affected.

For most research participants, green transition was not a pressing concern. Some managers noted potential challenges, such as reaccreditation for specialist aerospace products. However, ongoing financial uncertainty surrounding Liberty's parent company overshadowed low-carbon transition issues. A few participants linked energy policy and carbon costs to this precariousness, while others cited cashflow problems as barriers to green investment. Moves toward electric steel production elsewhere were associated with job losses, reducing the industry's appeal to new entrants.

Overall, workers viewed Stocksbridge's future in the context of a long trajectory of economic change and job decline over decades. Yet, there was an underlying belief that the steelworks would endure, reflecting a sense of resilience despite uncertainty.

5 Hudson, R and Sadler, D (1989) The international steel industry: restructuring, state policies and localities. Routledge, Abingdon.
6 Office for National Statistics (2025) Business Register and Employment Survey.
7 For more information see here

8 All the information and findings in this and subsequent sections are based on our underpinning empirical research. A summary of the Stocksbridge study can be found here.
9 Worker perspectives from Swedish case studies can be found here: Eadson, W., Mukezinovic, D., van Veelen, B., Malmberg, S., Backius, S. (2025) Worker experiences of green steel transitions. Lund University Centre for Sustainability Studies.

I'm not against new development or new ideas at all but I want it to be right for the community and who will be the people who'll work in the offices, are they the kids on the Stubbin estate who would have normally worked in the steelworks?

Stocksbridge resident

Community perspectives[10]

Stocksbridge retains a strong sense of identity, rooted in its steelmaking heritage. Residents described a close-knit community that persists today, with long-standing social connections particularly among those with historic or family ties to the steelworks. Historically, British Steel and its predecessors were central to both economic and social life of the town, providing welfare and community functions. Since the 1990s, this role has diminished, and respondents reflected on the steelworks' decline with mixed feelings. Some mourned its loss, while others highlighted regeneration and Stocksbridge's growing role as a commuter hub.

This shift is not wholly negative. Earlier eras of production reinforced strict gender roles, shaping social life around male workers. Today, reduced engagement by the steelworks and state welfare retrenchment has spurred community mobilisation, supported by strong local ties and the Town Council. These connections, forged through generations, underpin resilience and hope for the future.

Visions for a thriving Stocksbridge varied. Some residents expressed fatalism, while others focused on practical improvements such as housing retrofit, sustainable transport, better amenities, and restored rail links. A recurring theme was the desire for foundational services, connectivity and a future shaped by solidarity. Respondents saw community capacity to organise as vital, rooted in place identity and industrial history. Narratives of independence contrasted with feelings of entanglement in external forces, limiting local control.

Recent developments include the fight to save the town's leisure centre, leading to community management, and a £20m Towns Fund grant in 2023. Official plans emphasise heritage, high street redevelopment, and mixed-use spaces, sparking debate over priorities. While diversification and commuter-town dynamics loom large, respondents stressed that one-off grants and activism cannot replace long-term coordinated efforts. Stocksbridge's future will depend on sustaining its spirit of solidarity amid ongoing economic and political challenges.

What does this mean for the region?

This research highlights a number of key challenges to achieve just transition for the region's foundational industries like steel:

- **Activities to bring about green industrial futures must be sensitive to the fact that industry is tied to worker and community identities**, and that change triggers emotions rooted in lived experiences of previous change. This is especially important when local industrial survival is also seen to be precarious.
- **Local institutions need to reconnect with citizens**. Residents and workers saw local government (Sheffield City Council; South Yorkshire Mayoral Combined Authority (SYMCA)) as distanced from the needs of Stocksbridge.
- **Local and regional stakeholders need to support industrial workers to become active stakeholders in achieving green industrial futures**. This includes access to skills provision and job support where retraining is required, while more broadly providing open communication and engagement around the opportunities and challenges of green industrial futures. Trade Unions can play an important role within this, alongside businesses and policy organisations.
- **Green industrial futures need to encompass community renewal** to overcome fatalism and exacerbating potential 'green backlash'. In Stocksbridge, local community action is strong compared to many similar places but as we know from other research, community action also has its limits and can create challenges/ contestations too; it is not always inherently more 'just', and cannot alone fill the gaps of state and private sector retrenchment.
- **Steel communities' futures are entwined** (especially those directly connected to Liberty Steel at Aldwarke, Brinsworth and Stocksbridge). Changes to operations in Rotherham impact on Stocksbridge and vice-versa. As such it is important that policy solutions recognise these interconnections through a green deal for South Yorkshire steel. This should be at the heart of plans for regional inclusive economic futures.
- **Central government coordination will be critical to low carbon infrastructure provision and regulation**; some of our participants also argued that as a critical industry, steel should be state-owned to provide a just transition and protect the industry. Tata and British Steel have received large subsidies and state intervention to support the conversion to EAFs but at the moment there is no similar offer to support specialist steel producers. The region's leaders need to press for investment in a 'green deal for South Yorkshire steel' or risk further decline and loss.

Next Steps:

We are now working with SYMCA to develop a broader approach to 'inclusive industrial decarbonisation' that seeks to set out a framework for delivering sustainable industrial futures across the region that also addresses key social, economic and cultural challenges. This builds from our work in Stocksbridge along with research on 'green and just' industrial decarbonisation in the UK and internationally[11, 12, 13].

In Stocksbridge, we see opportunity in the current situation of uncertainty for a new community-rooted taskforce to lead community and infrastructural renewal rooted in the town's heritage while working towards a sustainable future. Our research can support development of this. For Liberty Steel, we see an opportunity to work with key stakeholders to support planning for a sustainable steel future working in partnership with workers and communities.

10 Community perspectives from our Swedish case studies can be found here: van Veelen, B., Eadson, W., Melin, Å., Backius, S., Malmberg, S., and Mujezinovic, D (2025) Green steel transitions: impacts on people and places. Lund University Centre for Sustainability Studies

11 Eadson, W and De Leeew, G (2025) Path development politics: contesting regional hydrogen econoimes in Northern Europe. Geoforum 167

12 Dawley, S., Mackinnon, D., Steen, M and Eadson, W. (2025) State-orchestrated green path development? Industrial decarbonisation in Teesside and the Humber.

13 Eadson, W., Northall, P., Copeman, V. and Ahmad, Z (2023) Humber Industrial Cluster Plan: Societal and Cultural Challenges and Social Innovation Study

HySaaS: Securing Social Licence for Hydrogen Storage and Distribution in South Yorkshire

Project team:
University of Sheffield: Dr Alex J.K. Newman and Prof. Rachael Rothman

Project partners:
Hive Hydrogen, Advanced Manufacturing Research Centre, Chesterfield Special Cylinders, Element2

Challenge Statement

South Yorkshire is emerging as a key region in the UK's hydrogen economy, supported by investment across the wider Yorkshire and Humber industrial cluster in production. While hydrogen is widely recognised as essential to industrial decarbonisation, its successful deployment depends not only on technical feasibility and cost reduction, but on societal and institutional readiness. Hydrogen storage and road-based distribution systems will operate within industrial estates, logistics corridors and alongside residential communities. This makes public confidence, emergency preparedness and regulatory clarity critical to delivery. However, the existing evidence base is heavily weighted toward techno-economic modelling and carbon intensity analysis, with comparatively limited research examining multi-stakeholder social acceptance, particularly for storage and transport infrastructure. Existing studies often focus solely on general public opinion and overlook the perspectives of industry actors and emergency responders. This creates a regional evidence gap at a time when South Yorkshire must ensure hydrogen deployment proceeds in a way that maintains trust, supports a just transition and avoids infrastructure resistance that could delay investment.

Research Response

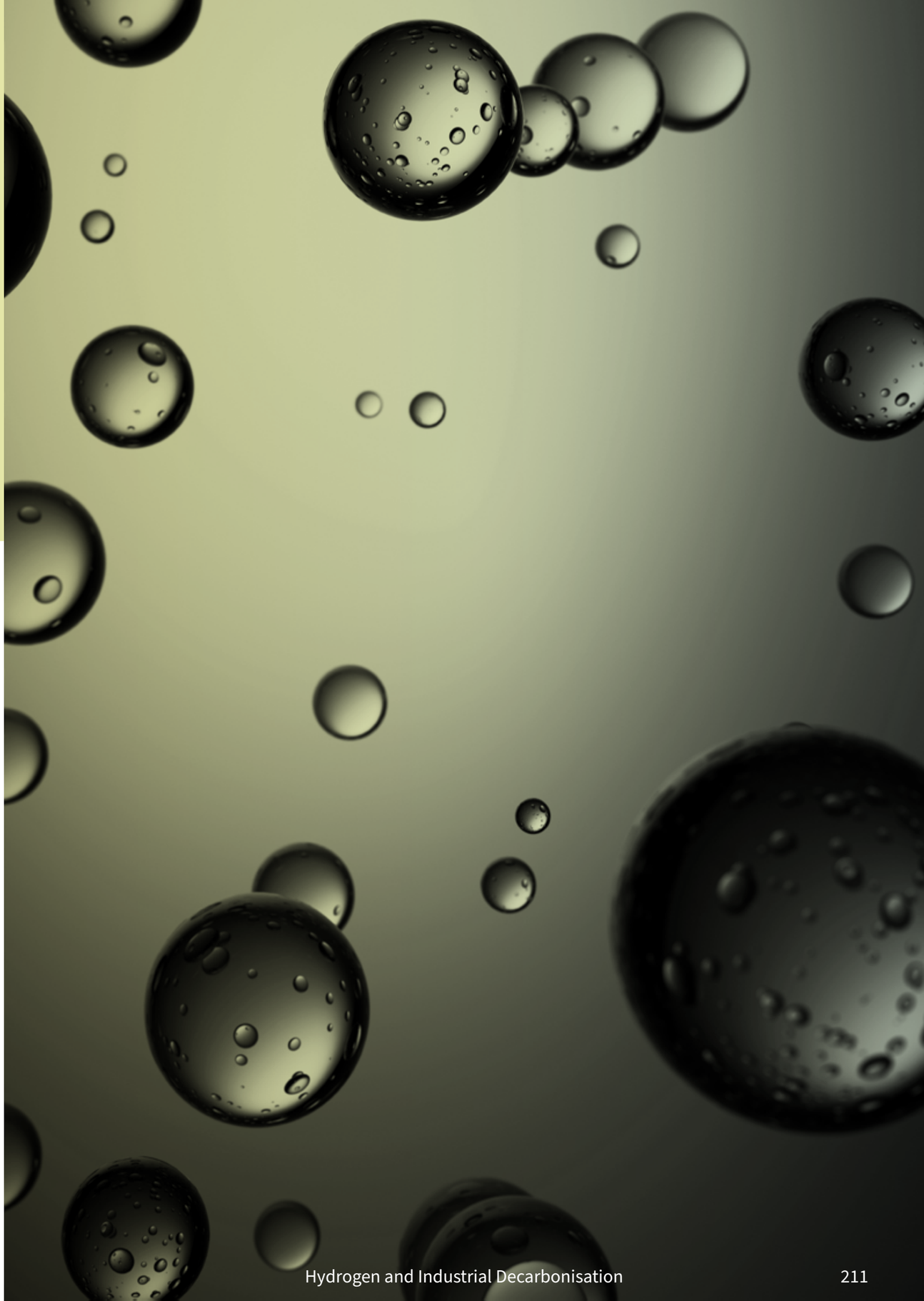
This project responded directly to the regional challenge by providing a structured, multi-stakeholder assessment of social acceptance focused specifically on hydrogen storage and distribution, the parts of the value chain most visible to communities and emergency responders.

Using a mixed-method approach, the research engaged:

- Industry value chain actors
- A nationally representative public sample
- The fire service

The aims were to:

- Assess industry appetite for service-based hydrogen storage models
- Evaluate public attitudes, including the effect of local proximity
- Understand emergency responder



preparedness and information needs

- Generate evidence-based recommendations to support safe and scalable hydrogen deployment in South Yorkshire

Evidence and Outputs

The research found that acceptance of hydrogen storage and distribution is broadly positive but strongly conditioned by perceptions of safety and risk. Across all stakeholder groups, safety emerged as the dominant determinant of acceptance. Industry stakeholders emphasised clear responsibility boundaries between service providers and asset users, regulatory compliance and predictive monitoring systems. Public respondents frequently associated hydrogen with “flammable” and “explosive,” demonstrating that perceived technological risk remains influential despite recognition of hydrogen’s environmental benefits. Fire service representatives highlighted operational challenges including invisible flames and high-pressure systems.

Crucially, all groups responded positively to enhanced monitoring and transparency. More than 80% of public respondents indicated that additional monitoring systems would increase their comfort with hydrogen storage and distribution. This suggests that visible, data-driven safety mechanisms can materially improve acceptance.

Standardisation and clarity also emerged as cross-cutting themes. Industry participants noted that inconsistent design specifications create integration challenges and administrative burden. The fire service emphasised the importance of real-time system data during incident response. Greater standardisation was viewed as enabling smoother deployment and improved safety management.

Important divergences were also identified. Industry actors and emergency responders expressed confidence in regulatory frameworks, whereas public respondents demonstrated persistent technological risk concerns. Support was strongest at national level but declined when infrastructure was framed locally, highlighting proximity-based hesitation. Visual design of transport trailers also influenced public comfort levels.

Key outputs include the Hydrogen Storage as as Service (HySaaS) WP6 Social Acceptance Report, a structured multi-stakeholder engagement framework informed by social life cycle assessment (S-LCA)’principles, and a nationally representative survey dataset.

What does this mean for the region?

The findings suggest that hydrogen storage and distribution can secure social licence if deployment is treated as a governance and trust challenge as much as a technical one.

For South Yorkshire, policymakers should:

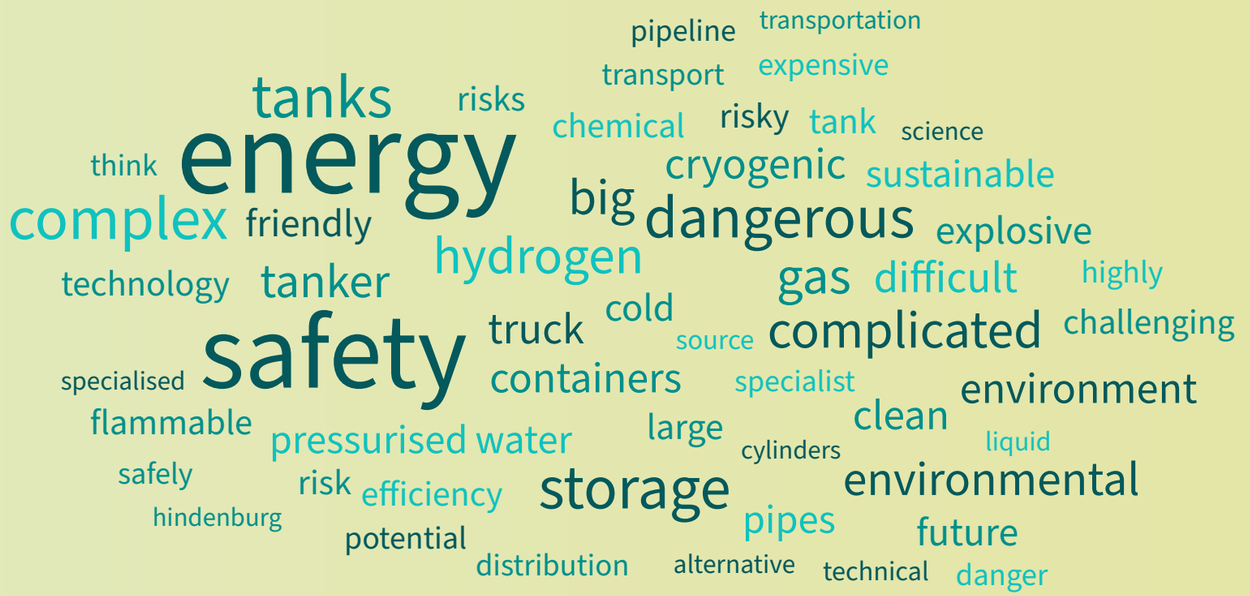
- Prioritise visible and transparent safety mechanisms, including real-time monitoring and clear reporting
- Embed early collaboration with fire and rescue services, including hydrogen-specific training
- Adopt proactive, place-based engagement strategies to address proximity concerns
- Promote standardisation across storage systems and operating procedures
- Ensure clarity in responsibility-sharing within service-based models

South Yorkshire can scale these recommendations through hydrogen deployment demonstrators that combine monitored assets, responder training and community engagement. This approach reduces perceived risk, improves insurability and strengthens the commercial case for hydrogen investment. Lessons learned can be scaled out to other UK regions pursuing industrial decarbonisation.

Next Steps:

Further research should track how public attitudes evolve as hydrogen infrastructure becomes more visible and explore how monitoring data can be translated into meaningful public-facing safety indicators. Collaboration opportunities have emerged across emergency services, insurers, planners and infrastructure developers to support an interdisciplinary, durable hydrogen transition.

Word cloud showing the most common responses to the question: What is the first word/image that now comes to mind when you hear the term ‘hydrogen storage and distribution’?



Towards Net-Zero Aviation: Life Cycle, Resilience, and Decision-Making Evidence for Waste-Derived Sustainable Aviation Fuels

Project team:
University of Sheffield: Prof. Lenny Koh, Eleanor Borrill

Challenge Statement

The UK's Jet Zero Strategy commits to achieving net-zero aviation by 2050, with an interim mandate requiring that 2% of jet fuel demand is met by sustainable aviation fuels (SAF) by 2025. SAFs are a near-term solution for decarbonising aviation because they are drop-in fuels requiring no engine modifications and can be produced from waste resources, supporting both emissions reduction and a circular economy.

Several key challenges remain in advancing SAF development and deployment. Firstly, there is not only a lack of lifecycle data, but also an absence of a comprehensive, comparative evidence base that evaluates all SAF production pathways using waste-derived biogenic feedstocks across key producing countries and energy-mix scenarios. Secondly, evidence on the resilience of SAF supply chains under different feedstock, technology, and trade scenarios is limited. Significant uncertainty exists around the scalability of waste-derived feedstock supplies, potential competition with alternative sectors, and the impacts of geopolitical or logistical disruptions on international trade flows. Thirdly, uncertainty persists over which SAF pathways should be prioritised, as each involves trade-offs among economic cost and scalability, environmental performance across impact categories, technological maturity and conversion efficiency, logistical feasibility of feedstock supply and transport, and broader social and political acceptance.

These challenges have important implications. Without a robust comparative evidence base, policymakers lack the data needed to design effective sustainability standards and carbon reduction policies, while industry faces uncertainty about which pathways deliver the greatest environmental benefits with the fewest trade-offs. Limited understanding of supply-chain resilience constrains long-term investment planning and hinders the design of strategies that ensure both security of supply and progress toward net-zero aviation targets. Moreover, the absence of structured, cross-cutting comparisons between pathways, feedstocks, and national contexts makes it difficult to weigh trade-offs and prioritise sustainable technology-feedstock-country combinations. Addressing these gaps is essential for guiding sustainable SAF investments, improving supply-chain resilience, and informing coherent policy design.

Research Response

Contribution of Research

This project addresses key evidence gaps through three integrated studies. The life cycle assessment (LCA) study provides the first comprehensive, comparative analysis of all SAF technologies certified by the American Society for Testing and Materials that are capable of utilising waste-derived feedstocks[1], measuring environmental impacts across multiple countries and energy-mix scenarios. The supply chain resilience study examines the scalability and stability of SAF production by forecasting feedstock availability, technology adoption, and trade dynamics under various scenarios. The stakeholder engagement and multi-criteria decision analysis (MCDA) study captures stakeholder perspectives across the SAF value chain and translates them into structured evaluations of competing pathways. Together, these approaches generate a holistic evidence base that combines stakeholder priorities, environmental performance, and supply chain feasibility to guide policy and industry decisions.

Evidence and Outputs

Research Findings

A comprehensive assessment of SAF pathways based on waste-derived feedstocks brings together environmental, supply-chain, and stakeholder perspectives to identify the most viable routes toward net-zero aviation. Comparative LCA across key producing countries reveals that environmental performance varies significantly with feedstock type, conversion technology, energy mix, and trade flows. These variations underscore the importance of tailoring SAF pathways to national contexts to maximise greenhouse gas reductions and minimise other environmental impacts.

Building on these insights, scenario modelling links environmental outcomes to supply-chain dynamics, assessing how feedstock availability, technology adoption, and international trade may interact under different future conditions. The results indicate that SAF deployment targets are likely to outpace the sustainable supply of biogenic waste feedstocks, creating potential bottlenecks

1 Borrill, E., Koh, L. and Yuan, R. (2024). Review of technological developments and LCA applications on biobased SAF conversion processes. Frontiers in Fuels, 2.

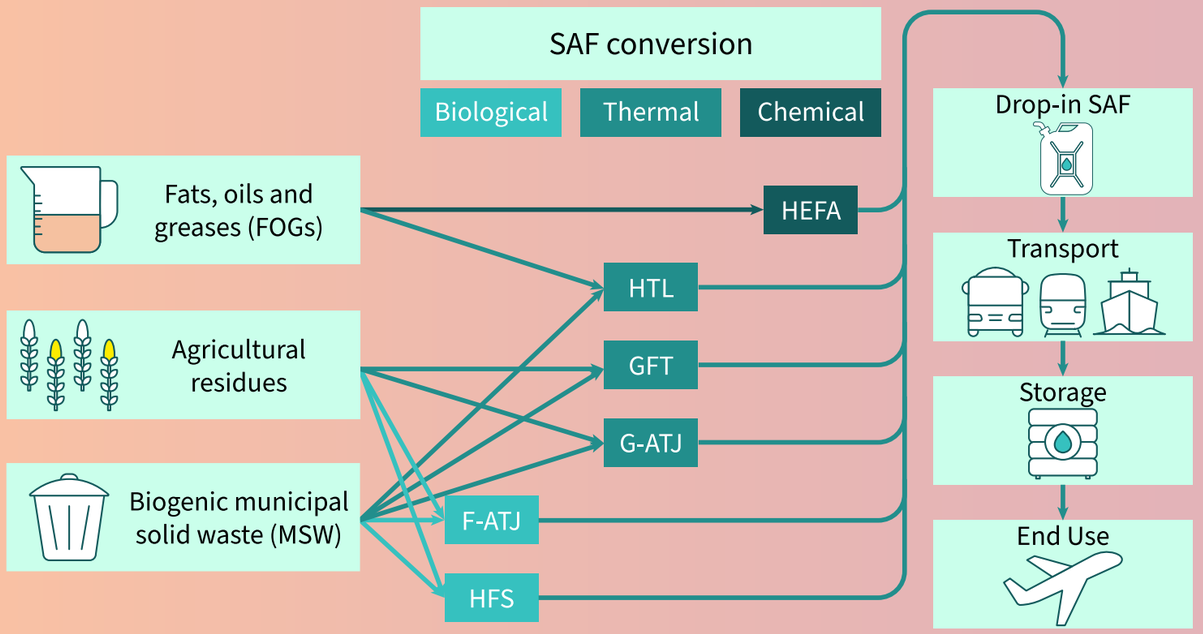


Figure 1: SAF production methods; Hydroprocessed Esters and Fatty Acids (HEFA), Hydrothermal liquefaction (HTL), Gasification with Fischer – Tropsch (GFT), Alcohol-to-Jet (ATJ), Hydroprocessed Fermented Sugars (HFS)

and competition with other sectors. This highlights the need for diversified feedstock sourcing and resilient, internationally coordinated supply chains, integrating both biofuels and synthetic (power-to-liquid) fuels to achieve the necessary scale-up.

To complement these quantitative analyses, stakeholder engagement and MCDA provide an integrated perspective on how different stakeholders, such as feedstock suppliers, fuel producers, airlines, and policymakers, evaluate and prioritise competing criteria such as economic feasibility, environmental sustainability, technical readiness, logistical practicality, and political acceptability. By combining stakeholder preferences with environmental and supply-chain performance data, the MCDA enables a transparent comparison of SAF pathways, identifying which technology-feedstock combinations are perceived as most viable overall and where perspectives diverge.

Together, these integrated analyses provide a robust, evidence-based framework for comparing SAF pathways across environmental, resilience, and socio-political dimensions, supporting more informed decision-making and investment strategies aligned with sustainable, net-zero aviation goals.

Scalability and Commercialisation

For the UK, and South Yorkshire in particular, SAF offers opportunities to integrate local waste resources, advanced manufacturing capacity, and logistics infrastructure into a new green growth sector. South Yorkshire's position as a region with both industrial heritage and research expertise makes it well-placed to participate in SAF supply chains, from feedstock collection to technology development and production.

The proposed re-opening of Doncaster-Sheffield Airport (DSA) further increases the regional significance of SAF. As aviation activity grows, ensuring that operations are aligned with the UK's Jet Zero strategy will be critical. Positioning DSA as an early adopter and distribution hub for SAF could strengthen South Yorkshire's role in sustainable aviation, attract investment, and support the creation of skilled green jobs while demonstrating regional leadership in the transition to net-zero aviation.

Evidence from the LCA and resilience assessments supports targeted scaling of SAF production providing that waste feedstocks and clean energy mixes align, reducing environmental impacts while maximising output potential.

However the below nuances and trade offs should be noted:

- Feedstock competition: Waste-derived feedstocks are also in demand from other bio-based industries (e.g., biogas, chemicals), creating potential conflicts that must be managed through policy.
- Geographical variation: Environmental performance is highly dependent on national energy mixes; countries with fossil-heavy grids may undermine the sustainability of SAF production.
- Technology maturity vs. sustainability: Some pathways with strong emissions reductions face technical or cost barriers, while more mature technologies may offer weaker environmental performance.
- Resilience vs. reliance: Over-reliance on a single feedstock or trade route increases vulnerability to shocks, highlighting the need for diversification.
- Circular economy benefits: SAF from wastes can reduce landfill use and support circularity, but logistics and collection systems must be designed to avoid offsetting emissions gains.

Nuances and Trade-Offs

Recommendations for Industry

For industry, the immediate priority is to use the evidence generated from the MCDA and LCA to determine which SAF pathways present the strongest balance of environmental performance, scalability, and commercial viability. This will enable airlines, fuel producers, and investors to align their resources with the most promising feedstock-technology combinations. At the same time, industry should focus on developing resilient supply chains by building partnerships across feedstock suppliers, technology developers, and end users. Such collaboration can help secure access to consistent waste streams, reduce dependence on imports, and strengthen resilience to feedstock shocks or market fluctuations.

A critical next step for industry is to scale demonstration projects. Pilot and pre-commercial SAF plants should be established both in the UK and internationally, especially for waste-derived pathways that show strong sustainability potential and stakeholder acceptance. Industry actors can also collaborate with local authorities, agriculture, and waste management sectors to embed SAF within circular economy models, turning municipal solid waste, agricultural residues, and other biogenic streams into reliable fuel inputs. Finally, advancing innovation will be essential, in order to improve conversion yields, reduce process energy demand, and accelerate the commercialisation of less mature but environmentally promising SAF pathways.

Recommendation for Policymakers

For policymakers, the research highlights the need for stronger and more targeted incentives. SAF mandates, subsidies, and funding mechanisms should be designed to only favour pathways with the strongest evidence base for environmental sustainability and supply chain resilience. Policymakers should also ensure that SAF is embedded within broader waste and circular economy policies, enabling scalable use of municipal solid waste, agricultural residues, and other feedstocks that can contribute to aviation decarbonisation. Alongside this, national frameworks and international agreements are needed to manage competition for waste-based feedstocks across aviation, energy, and chemicals sectors, reducing risks of scarcity or unsustainable resource allocation.

Policymakers should also support the development of resilient SAF infrastructure, particularly at regional hubs such as the proposed re-opening of Doncaster-Sheffield Airport. Investment in storage, blending, and distribution systems will be vital to enable SAF adoption at scale. On the international stage, the UK should champion harmonised SAF sustainability standards and certification frameworks within International Civil Aviation Organization (ICAO) and related bodies, ensuring market interoperability and building investor confidence in SAF markets. Finally, investment in workforce development is essential. Expanding training and education in SAF technologies, logistics, and circular economy supply chains will ensure that both industry and regions like South Yorkshire have the skilled workforce required to support the transition to sustainable aviation.

Scoping a Hydrogen Network for the South Yorkshire Region using the Network Optimisation Model AENi

Project team:
University of Sheffield: Prof. Solomon Brown, Dr Diarmid Roberts, Dr Victoria Brown, Thomas Cowley, Joseph Hammond

Challenge Statement

The South Yorkshire area has a large number of energy intensive industrial sites, producing a range of products including glass, steel and ceramics. Not all of the processes behind these industries can be decarbonised using electricity, hence there is a need to swap out hydrocarbon fuels for hydrogen, or deploy small scale carbon capture plant. Unlike for electricity, there is no national network for transport of hydrogen or CO_2 that individual emitters may currently tap in to.

The UK government has already provided funding to address this issue, but only for specific larger industrial clusters, such as the Humber Industrial Cluster. As such, there is a lack of research on the feasibility of hydrogen/CO_2 networks in other areas. Additionally, the South Yorkshire area has the challenge of having several large emitters located within an urbanised environment, where routing of networks is considerably more complex than on greenfield sites, or those wholly owned by large industrial companies.

This case study represents a first step toward addressing the industrial decarbonisation challenge in South Yorkshire.

Research Response

Developing shared infrastructure is economically complex, as multiple stakeholders with differing needs and motivations must be catered for. Additionally the development of feasible network routes and modelling of their costs and timescales is complicated and data-intensive, which may prevent industry partners from initiating the research individually. The South Yorkshire Sustainability Centre (SYSC) can act as a central coordinator for multiple industries that may not otherwise share their requirements, and give them collaborative access to researchers and modelling tools.

The specific aims of this research project were to:

- Gather data on notable CO_2 emitters in the South Yorkshire region, and estimate equivalent annual hydrogen consumption.
- Research possible locations for a grid connection large enough to site a hydrogen electrolyser.
- Use the network routing tool AENi to determine a preliminary network route as the first step in assessing feasibility.

Figure 1: Graphic representation of relative CO_2 emission scale of the 21 industrial sites considered in this case study.

Figure 2: Least cost hydrogen network for 21 emitters in the South Yorkshire region, found using routing software AENi. The largest dot represents a hydrogen electrolyser plant sited at the Thurcroft Grid Supply Point (400 kV transmission). Credit Joseph Hammond of AENi.

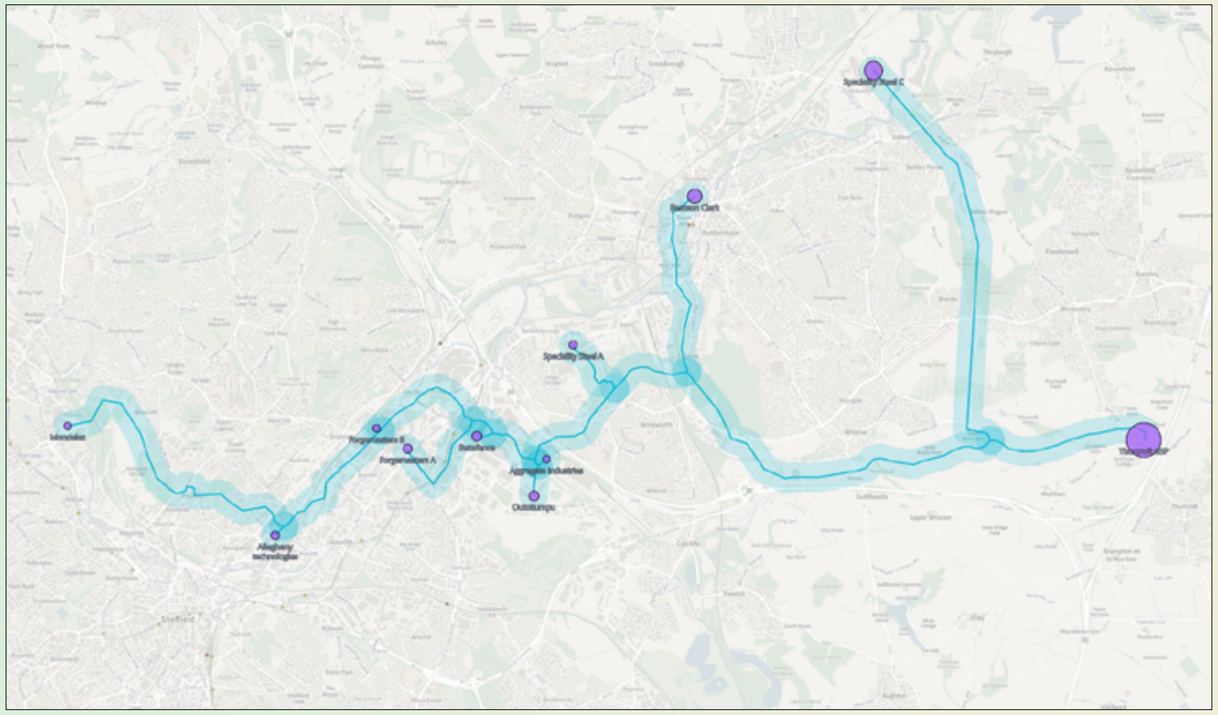


Figure 3: Least cost hydrogen network for 10 emitters in and around the Lower Don Valley area, found using routing software AENi. The largest dot represents a hydrogen electrolyser plant sited at the Thurcroft Grid Supply Point (400 kV transmission). Credit Joseph Hammond of AENi.

Evidence and Outputs

The case study considered 21 large emitters located in South Yorkshire. These ranged greatly in size as shown in Figure 1.

The pipeline routing/sizing software AENi[1] developed as a spin-out from the Brown group at University of Sheffield was used to find a cost optimal network linking these sites to the grid supply point at Thurcroft. The network found is shown in Figure 2. The network shows several notable features, including a tendency to follow existing roads and to take longer detours around built-up areas. The latter is clear to see around Doncaster, at the top right of the image.

A smaller network was then found for a set of 10 emitters in and around the Lower Don Valley (LDV) area[2], as shown in Figure 3.

For the LDV network, the average electricity consumption of the electrolyser was modelled as 70 MW. This is significant, as it is considerably lower than the current headroom of ~200 MW at the Thurcroft grid supply point. The larger South Yorkshire network has an average electrolyser power consumption of 202 MW, which likely cannot be met at Thurcroft. However, the greater challenge for the larger network is the long pipeline distances to parts of the network, particularly to the West.

The representation of the industries in the modelling was crude; it was assumed that all recorded CO_2 emissions were due to burning natural gas, that all of this gas would be replaced by hydrogen, and that hydrogen would be consumed at the same rate throughout the year. These assumptions must be improved upon by further collaboration.

What does this mean for the region?

The findings of the case study are significant in that they provide preliminary evidence that a hydrogen network for industrial sites is likely feasible using existing electrical grid connections. The next step is for policy makers to support more in depth research where partners collaborate more deeply with the researchers to develop network designs that are feasible from an economic and timeline perspective.

The modelling tool used in this case study could easily be applied to other regions with notable industrial activity, such as South Wales.

Next Steps

- Carry out further partner engagement to understand which decarbonisation option they prefer (hydrogen will not be best for all).
- Develop a methodology for analysing the economics of sub-sections of the network to predict the most favourable roadmap for rollout.
- Collaborate with partners in areas where the network cost is lowest in order to develop a more accurate model, and gauge willingness to pay.

1 https://www.runpilot.io/
2 Sheffield City Council (n.d.) Lower Don Valley Master Plan. Part 6 - LDV Districts.

Just Transition

Published as part of the South Yorkshire Sustainability Centre Consolidated Research Report, March 2026

Case Studies in this section:

230 Just Transition Recommendations for Regional Policymakers

232 Ensuring a Just Transition for Small and Medium Enterprises

238 Youth Visions of a Just Transition: Engaging Young People in South Yorkshire to Imagine Sustainable Futures

Challenge

Realising visions for a sustainable South Yorkshire creates challenges and opportunities for fairness and inclusivity. A sustainability transition that does not effectively address concerns over equity and inclusion risks exacerbating recent trends towards 'green backlash', destabilising efforts to move towards an ecologically secure future.

A *just transition* seeks to ensure that addressing the climate and biodiversity emergency does not exacerbate existing inequalities, but seeks to reduce them through embedding inclusivity and equity within sustainability actions. This means supporting marginalised communities, ensuring they share the benefits of the transition to low carbon economies. This includes supporting those who have experienced harm through, or were excluded from, previous economic and energy transitions, and/or those who may be put at a disadvantage by the transition (such as communities tied to high carbon economies, such as steel or oil refining). It also requires the needs of current and future generations to be recognised, for instance, through providing space for youth participation in decision making as they are the key stakeholders in a just transition.

Just transition is multi-faceted, requiring focus on the fair *distribution* of costs and benefits; *recognition* of different identities, cultures and needs; and ensuring inclusive *procedures* for decision-making. While these can be viewed at a regional level it is also necessary to understand differences across different domains of regional life (e.g. at home, work, businesses, leisure, travel). Implications are mediated by *time* (speed of change, historic influences on perceptions and experiences), and will differ between different *places*. The *depth* of change required or desired will also vary in different situations. In some instances, changes to ways of living or working might be relatively slow and incremental, in others more transformative change might occur[1]. More ambitious and proactive attempts to achieve a thriving sustainable future for the region might necessitate more transformative approaches. Developing effective policy and actions for just transition will need to consider each of these facets (summarised in Figure 1).

As well as practical challenges, there are cultural barriers to achieving just transition, such as established ways of life: the daily rhythms and routines built around ways of heating homes, doing business, work, leisure and travel. These norms vary across generations and different households, reflecting complex emotional and behavioural responses towards what feels normal and acceptable for different people. South Yorkshire's residents might need supporting through the emotional process of changing ways of life while providing the means for individual and collective thriving, particularly given the region's post-industrial legacy and enduring social and economic consequences of earlier industrial decline. For policymakers, while a narrow viewing of just transition might be grasped through existing policy ideas like 'inclusive growth', achieving more transformative change will require reconsidering how our existing institutions operate, make decisions and their underpinning objectives. This disrupts established norms and habitual working practices, therefore requiring deep commitment and sustained regional leadership to enact change.

1 Eadson, W., Castano Garcia, A., Butterworth, E. and Parkes, S. (2025) What is an urban just transition? Grappling with an unsettled problem in an industrial region. European Urban and Regional Studies.

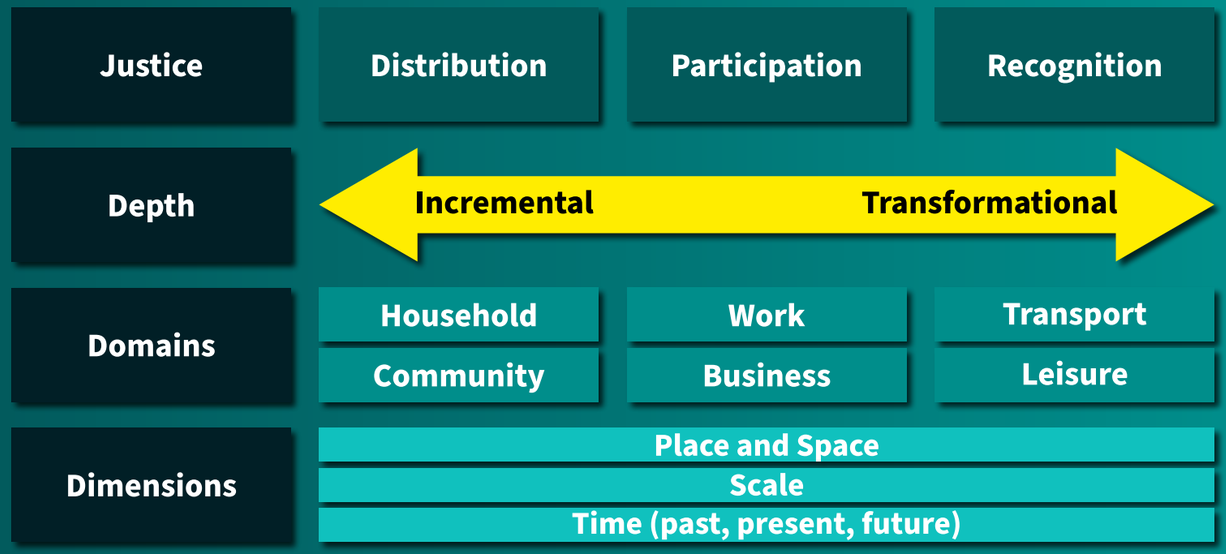


Figure 1: Illustrating justice aspects, domains of activity, depth/ambition, dimensions (time/space)

SYSC Theme	SYSC Just Transition Research
Residential Energy and Transport Systems	JUSTHEAT – lived experiences of home heating transitions
	Retrofit work in the context of modern methods of construction
	Let Zero – governance for equitable retrofit in the private rented sector
Food Systems and Environmental Restoration	Just transition for horticulture SMEs
	Nature recovery farming
Industrial and Commercial Emissions	Implications of green steel futures for workers and communities
	Place-based approaches to SME just transition
	Steel SME just transitions
Cross-Cutting	Youth visions for a sustainable South Yorkshire
	Income inequalities and sustainable futures
	Was the past more sustainable?

Figure 2: Research areas (homes, communities, workers, small businesses, young people)

What does this mean for South Yorkshire?

South Yorkshire has already undergone significant change over the last 40 years. Policymakers, practitioners, business owners, residents and workers who took part in our research all referred to the scarring our region has experienced through previous transitions, especially the industrial change experienced during the 1980s and 90s which harmed many of our communities. Tens of thousands of jobs were lost in mining and manufacturing sectors. Today 20% of local areas in South Yorkshire are in the top 10% most deprived in England[2].

The region's industrial legacy also creates new challenges. Over 22% of workers in Yorkshire and Humber will be affected by climate action[3]. Recent research puts parts of the South Yorkshire among those most vulnerable to the economic implications of transition in the UK[4].

The transition also brings economic opportunities. For instance, clean energy has been identified as a key opportunity area for the region. Effective mechanisms will be required to ensure that the economic benefits created by such opportunities can be harnessed by those that most need them, and that the value created for the region is used to invest in collective goods and services.

But just transition must not be viewed solely within the narrow frame of 'gross value added', jobs and skills. Just transition also concerns people that are not always thought of when it comes to decarbonisation, such as those vulnerable to fuel poverty and in cold and damp homes. Levels of fuel poverty are well above average in the region - ranging from 14% (Rotherham, Sheffield) to 16% (Doncaster, Barnsley), compared to an average of 11.4% for England - and many were excluded from the previous transition from coal to gas[5].

To be truly transformative, a just transition must build from understanding the lived experiences and perceptions of those affected. This has not been well-covered in previous research so our activities in South Yorkshire set out to address this gap.

2 Office for National Statistics (2025) English Index of Multiple Deprivation.
3 Robins et al (2019) Financing inclusive climate action in the UK. An investor roadmap for the just transition. The Grantham Institute.
4 Cantellow, T., Atkins, E., Fox, S and Robinson, C (2026) A net-zero vulnerability index for Great Britain. Regional Studies Regional Science.
5 KADA (2023)South Yorkshire Skills and Employment Evidence Base. A report for for the South Yorkshire Mayoral Combined Authority. 11a.i Appendix A.

Research Response

The South Yorkshire Sustainability Centre just transition programme set out to understand just transition challenges and opportunities for diverse, less-well-heard groups, through exploring their own histories, experiences and perceptions of a sustainable future. It cut across the different SYSC themes, including research on industrial decarbonisation, home heating, housing retrofit and food systems. We aimed to cover a range of different situations to explore the breadth of the challenge and provide solutions across different pieces within the just transition 'jigsaw'. These are outlined in Figure 1.

Each study was a discrete project with research questions and methodologies tailored to the area of focus, but with a shared concern for lived experiences and expectations, over time, and rooted in places. Transition is, by definition, a process of change, an emotional and culturally embedded activity which requires deep understanding of individual and collective perceptions and experiences. Summaries of the different projects can be found in our case study reports. Here we outline some of the key findings and cross-cutting lessons.

Industrial communities

South Yorkshire's industrial communities have experienced significant change over the last 40-50 years. The effects of the decline in coal and steel production were felt in communities across the region. Our research in the steel town of Stocksbridge sought to understand **lived experiences of industrial change** over time, and how this has shaped perceptions of decarbonisation[6]. Changes to the steelworks over time has reduced the role it has played in the economic, social and cultural life of the town, but it has remained central to local identity and to perceptions of what prosperity and community cohesion can look like. Our research found that a 'green' future was not often perceived as a source of renewed prosperity for the steelworks or the town itself, but could be envisioned as a means of preserving the continuation or survival of the town's steel heritage. The town has endured repeated cycles of uncertainty, unsettlement, change and loss since the 1980s. They were ambivalent about whether the green transition

6 This research was co-funded by SYSC and Swedish research councils, as part of an international study of green steel transformations. For more information on the study see here.

would be any different to the past harms they had experienced. The declining steelworks exposes a sense of vulnerability and a disconnect between national level policy priorities and local lived realities. The research highlighted the importance of supporting communities to collectively build their own understanding of what change has meant for them in the past, and how this can be used to shape what a sustainable future might look like. Common to much of our research, we found that support for successful industrial transitions is fostered through understanding cultural and emotional perceptions and experiences of change over time.

Workers

Our work in Stocksbridge also revealed **workers' perceptions of green industrial futures**. This was also viewed in the context of repeated moments of crisis and change within the steel industry. At the time of the research the works was in a period of deep uncertainty over its future, shortly before Liberty Speciality Steels UK was taken under government control. Workers had mixed views on what a green steel future looked like and what it would mean for them. Some were cynical about possibilities of achieving 'green' steel; others thought it would involve little change to their current operations. Sustainability transition was not seen by these workers as a particular opportunity for the business or workers, and this was partly reinforced by concern that high energy costs would continue to make business conditions difficult for steel producers. More broadly, there was a need to support workers to engage positively in the possibilities and challenges for green steel futures, as active stakeholders in change.

Jobs created and altered through a green transition also have the potential for creating decent and fair work which has good pay; is intrinsically rewarding; has good terms of employment; is healthy and safe; has work–life balance; and includes worker representation. However, it should not be assumed that all green jobs are good jobs. Our **research on housing retrofit** has demonstrated this, showing the importance to worker experience of how retrofit is delivered. For instance, modern methods of construction (MMC) can create more inclusive workplace cultures, with safe and consistent working conditions. However, MMC can also be repetitive and lower-skilled, replacing the varied work that currently exists in some parts of the construction sector. While retrofit can be a stimulus for creating green jobs[7] for a just transition, these jobs must be high quality[8]. This highlights the need to work with new and changing industries to develop a well-rounded approach to ensuring a just transition for workers – not just focused on skills supply, but on promoting inclusive business practices and pathways into work. Future green jobs are not necessarily inherently better or worse

7 Brown, D. et al. (2020), A Green Stimulus for Housing: The macroeconomic impacts of a UK whole house retrofit programme. New Economics Foundation, p. 35.
8 See SYSC Case 'What do modern methods of construction mean for housing retrofit jobs and working conditions?' in a Housing retrofit chapter for more information on this study

than previous types of employment and needs to be actively shaped through partnership between policy organisations, relevant voluntary sector organisations, skills providers, trade unions and business.

Home heating

Staying on the topic of housing decarbonisation, the **JUSTHEAT** project focused on home heating across different countries in Europe, and included South Yorkshire as an important case study. The project worked with 14 communities leading, resisting or excluded from the clean heat transition, revealing that expectations and attachments around heating are far more complex than current policy assumes. Drawing on 286 detailed oral histories about keeping warm and feeling cold at home, alongside archival research, art methods, and historic and contemporary policy analysis, we developed new understanding about how to achieve public support for a successful heating transition[9]. The research reveals diverse social, cultural, relational, emotional and financial outcomes that vary by place, household, and social group, underlining the long-lasting consequences of decisions about how homes are heated[10].

Key insights challenge mainstream approaches to clean heat and include:

- **Bricolage:** Households value feeling resilient, which for them means having multiple ways to heat their home. Yet clean-heat narratives often imply a "clean sweep" that reduces options and increases dependence on electricity networks.
- **Thermal delight:** Participants stressed that modern heating systems overlook the sensory pleasure of warmth. People desire more than basic comfort; they seek "thermal delight," often linked to radiant heat and shared, sociable experiences. Many romanticised solid-fuel fires, whether remembered or still used.
- **Anachronism:** Home heating is not experienced on a single timeline. Different European communities inhabit different historical moments, from Romanian wood-burning households living much as they have for centuries to Sweden's advanced, equitable heating systems. Individuals also move backward or forward in time when they change homes, showing that progress is not linear.
- **Emotional baggage:** Heating choices are rarely rational. They are shaped by deep emotional ties, formative memories and personal histories that strongly influence how people respond to the clean heat transition.

All of these cross cutting findings resonate in our South Yorkshire case studies. The study concluded that heating transitions should be led locally, prioritise communities left behind by previous transitions, and focus on what new systems can offer—especially comfort and thermal delight—rather than what they might be perceived to take

9 More information about JUSTHEAT can be found here: https://www.shu.ac.uk/centre-regional-economic-social-research/projects/all-projects/looking-back-to-move-forward-justheat
10 Ambrose, A., Davies, K., McCarthy, L., Shaw, B., & Shahzad, S. (2025). Low carbon heating transitions and Actor Network Theory: Entanglements with the fireside. Energy Research and Social Science, 126.

away (i.e. energy efficiency is sometimes perceived as synonymous with reduced comfort and flexibility)[11].

Small businesses

Small and medium enterprises (SMEs) are essential to achieving net-zero and collectively make up approximately 99% of South Yorkshire's businesses[12]. Yet, despite their aggregate economic and employment significance, SMEs are underrepresented in policy and just transitions debates[13]. Our UK-wide research, which included South Yorkshire as a key case study, shows that SME decarbonisation is shaped by diverse relationships – such as landlords, supply chains and intermediaries – and that businesses face highly varied challenges depending on sector, size and organisational characteristics[14]. Some SMEs, particularly those serving or comprised of vulnerable or marginalised communities, lack access to existing support and risk being left behind. To address this, we developed an operational framework that enables policymakers to diagnose different types of vulnerability, identify intervention points, and tailor support to specific groups of SMEs rather than relying on generic, one-size-fits-all programmes[15].

For South Yorkshire, these insights highlight both the scale of the challenge and opportunities for regional leadership. The region's manufacturing base increases the urgency for coordinated action, but existing support remains dispersed and limited in reach. Policy recommendations focus on building a coherent, place-based strategy[16]; establishing a regional SME decarbonisation steering group; using the just transition framework to identify and engage under-represented businesses; and working through diverse intermediaries - from accountants to community organisations - to reach vulnerable firms. Strengthening regional capacity could include creating a one-stop-shop to link SMEs with local solution providers, coordinating sector-specific support, and investing in climate literacy and skills provision across the further and higher education sectors. Policymakers should also recognise SMEs' wider roles as enablers and influencers of climate action, for example through programmes that support SMEs as climate citizens.

11 Ambrose, A., Shaw, B., Palm, J., Pelsmakers, S., Aho, H., Castano Rosa, R., ... Vornicu, A. (2025). Looking back to move forwards: a social and cultural history of heating in Europe - A summary of key findings across the UK, Romania, Sweden, Finland. Centre for Regional Economic and Social Research, Sheffield Hallam University.

12 Office for National Statistics (2025) UK business: activity, size and location.

13 Hampton, S., Blundel, R., Eadson, W., Northall, P. and Sugar, K. (2023) Crisis and opportunity: transforming SME governance for net zero. Global Environmental Change.

14 See 'Ensuring a just transition for Small and Medium Enterprises (SMEs) case study within this chapter for more information about this research

15 Eadson, W., Hampton, S., Blundel, R., Apostolopoulou, E., Latter, B., Witherley, D., Hardy-Jones, B., and Sugar, K. (2026) Just business? Rethinking SME climate action through a just transition lens. Energy Research and Social Science.

16 Eadson, W., Hampton, S., Blundel, R et al. (2024) Seven principles of place-based net zero policy for SMEs. UK Energy Research Centre.

Young people

Just transition needs to consider the roles of different existing and future generations. **Young people** are a particularly important population group. They have a long-term stake in the planning of sustainable futures, yet are generally excluded from participatory decision-making and research. Our Youth Visioning project addressed this by piloting an approach to understand how young people envision a just transition[17]. Our research found that students have strong environmental values; for example, they prioritise fairness and equality, safety and protection for everyone. Their illustrations and discussions during the research workshops included specific examples of shared green space, renewable energy, and community food growing, whilst protecting privacy and valuing their wellbeing. However, access to tools and knowledge to turn these values into action were limited. Most youth engagement is either consultative or extra-curricular, and not fully integrated into government strategies[18]). The Youth Visioning project demonstrated that young people recognise, and can imagine what a sustainable future looks like, drawing from values formed through early moral development in childhood and reinforced through social learning in family and school settings. It is important that children and young people are provided with a framework for attaching these values to later life career decisions.

Bringing it together: finding our place in history

A shared theme across our research was an emphasis on how change is experienced unevenly and heavily influenced by emotional, social and cultural factors. Much of our research focused on places and communities but with a recognition that looking to the past as well as future possibilities is essential to understanding how to develop actions for just transition in South Yorkshire. One project that exemplifies this is **"Was the Past More Sustainable?"**. This research explored which elements of past ways of life should be preserved and what we should never return to. This involved historical analysis across key domains of everyday life such as heating, transport, waste and air quality. The project has clear relevance for debates about a just transition by highlighting that environmental change is always socially and culturally shaped and unevenly experienced. The project asked not only whether past systems were more sustainable, but also who benefited from them and who bore the costs. By grounding sustainability debates in lived historical experience, the project challenges narratives that frame climate action as an inevitable loss of comfort and lowered living standards. It shows that societies have undergone major transitions before, often with improvements to health and wellbeing, such as cleaner air following the decline of coal. This reframing can help reduce resistance to climate policy and support fairer transitions by making change feel more familiar and legitimate.

17 See Case Study Youth Visioning in this chapter for more detail on this study.

18 Parsons, M., Godden, N. J., Henrique, K. P., Tschakert, P., Gonda, N., Atkins, E., Steen, K., & Crease, R. P. (2025) Participatory approaches to climate adaptation, resilience, and mitigation: A systematic review.

Just Transition Recommendations for Regional Policymakers

1. Recognising that economic gains can only create tangible benefit if felt by all the region's residents, local policy makers should **embed just transition principles and actions within key economic development programmes** such as the South Yorkshire Investment Zone and Local Innovation Partnership Funding, working with key partners, including academic institutions.

2. **Establish a regional just transition commission** to develop a just transition delivery framework. This should include representation from workers, community organisations, SMEs, young people, anchor institutions and sector bodies.

3. **Create a South Yorkshire 'Living Transitions' Programme.** Building from our findings which highlight the importance of emotional and cultural insights for just transition, we recommend that major decarbonisation initiatives are accompanied by programmes of activities, such as community storytelling, oral history and visioning, to both support the design of successful decarbonisation programmes and to enable their acceptance. This could be accompanied by transition hubs in priority neighbourhoods utilising trusted local spaces where residents co-create visions for change, access support and build shared narratives of a sustainable future.

4. **Embed youth voice and intergenerational justice in policy making.** This can include rolling out the model of climate engagement trialled through SYSC alongside further work to embed climate literacy into SY schools' curricula.

5. **Produce an 'inclusive industrial transition' strategy** which centres on how large investments in industrial decarbonisation can capture value for the region as a whole, provide pathways to good and inclusive work, and benefit the region's SME base. This can build from current on-going work between SYSC and SYMCA on principles for an inclusive industrial transition.

6. **Support industrial workers to become active participants in green industrial future realisation.** This includes access to skills provision and job support where retraining is required, but more broadly to provide open communication and engagement around opportunities and challenges of green industrial futures. Trade Unions can play an important role within this, alongside businesses and policy organisations.

7. **Establish a programme for regional decision-makers to share learning about different models of policy-making and economic development.** This will support development of policy and practice towards a genuinely transformational transition to a thriving sustainable future in South Yorkshire, which requires openness to exploring different ways of thinking, doing and understanding what 'success' looks like for South Yorkshire.

Ensuring a Just Transition for Small and Medium Enterprises

Project team:
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Projects Partners:
Dr Sam Hampton (University of Oxford), Prof. Richard Blundel (Open University)

Challenge Statement

Small and Medium Enterprises (SMEs) are critical to achieving climate action goals. They account for 13% of global carbon emissions; consuming 50% of commercial and industrial energy[1]. However, they face a range of challenges in comparison to larger businesses.

SMEs are neglected in policy decision-making, including for sustainability and climate action. They tend to lack the knowledge and resources required to act on climate and sustainability goals. They also tend to be considered as a homogeneous group when they are extremely heterogeneous. This is problematic for both deciding who gets included in decision making (e.g. prioritising particular sectors; not making sufficient effort to ensure diverse business owners are included), as well as for what policy looks like (e.g. basing policy on the needs of well-represented sectors, like the manufacturing sector).

These multiple policy shortcomings not only fail to adequately address an important source of carbon emissions, but also create potential inequalities for SMEs: for instance lack of access to energy rebate schemes available to large consumers, even for SMEs whose operations are energy-intensive. There is also a risk that this lack of attention to small businesses contributes to green backlash.

Regionally, SME climate action and sustainability initiatives have been trialled over at least the last decade. Targeted programmes have been funded through European Structural Funds and the UK Shared Prosperity Fund. The region's colleges and universities have also provided initiatives to support innovation and skills development, and several business sustainability networks have sought to harness possibilities for peer support between businesses. However, provision has been fragmented, and has only reached a very small proportion of the 45,000 South Yorkshire SME population.

While there is not yet a regionally coordinated approach to addressing this challenge, businesses and policy stakeholders in the region recognise the need to act. For example, Sheffield City Council is currently developing its Business Decarbonisation Routemap to address the gap in joined up strategy for SME climate action. Developing policy-relevant solutions for SME climate action, using a just transition lens, therefore addresses an important regional need.

Research Response

Our research sought to address these regional and global challenges by providing a new framework for understanding SME climate action, and to support the development of solutions to support SME transitions.

The research involved stakeholder interviews in five places (South Yorkshire, Belfast, Edinburgh, Oxfordshire, Swansea Bay) and case studies of five sectors: steel supply chains, construction trades, horticulture, hairdressing, and restaurants. These sectors were chosen to explore diverse types of industry facing different climate action pressures. In total we conducted 167 interviews, alongside a detailed policy review.

Evidence and Outputs

Through our research we gathered detailed insights of how a wide range of SMEs in different sectors are facing the climate action challenge. The key findings are summarised below.

- **SME decarbonisation is a 'relational' concern.** That is, we need to understand the diverse sets of relationships SMEs are engaged in – from landlords of their premises to customers to accountants - to provide effective SME decarbonisation policy. Each of these relationships creates different pressures, challenges and opportunities for SME climate action[2].
- **SMEs and the decarbonisation challenges and opportunities they experience are extremely diverse.** Our findings underscored the huge variety of challenges that different SMEs face, which needs to be better reflected in policy solutions. For instance, a medium-sized steel firm has very different needs to a hairdresser with 1-2 employees, but both will need to decarbonise their operations to achieve UK climate goals. It also means acknowledging that different organisations and different levels of operation (e.g. local, regional, national, international) will need

1 Hampton, S., Blundel, R., Eadson, W., Northall, P. and Sugar, K. (2023) Crisis and opportunity: transforming SME governance for net zero. Global Environmental Change

2 Eadson, W., Hampton, S., Blundel, R., Apostolopoulou, E., Latter, B., Witherley, D., Hardy-Jones, B., and Sugar, K. (2026) Just business? Rethinking the role of SME climate action through a just transition lens. Energy Research and Social Science

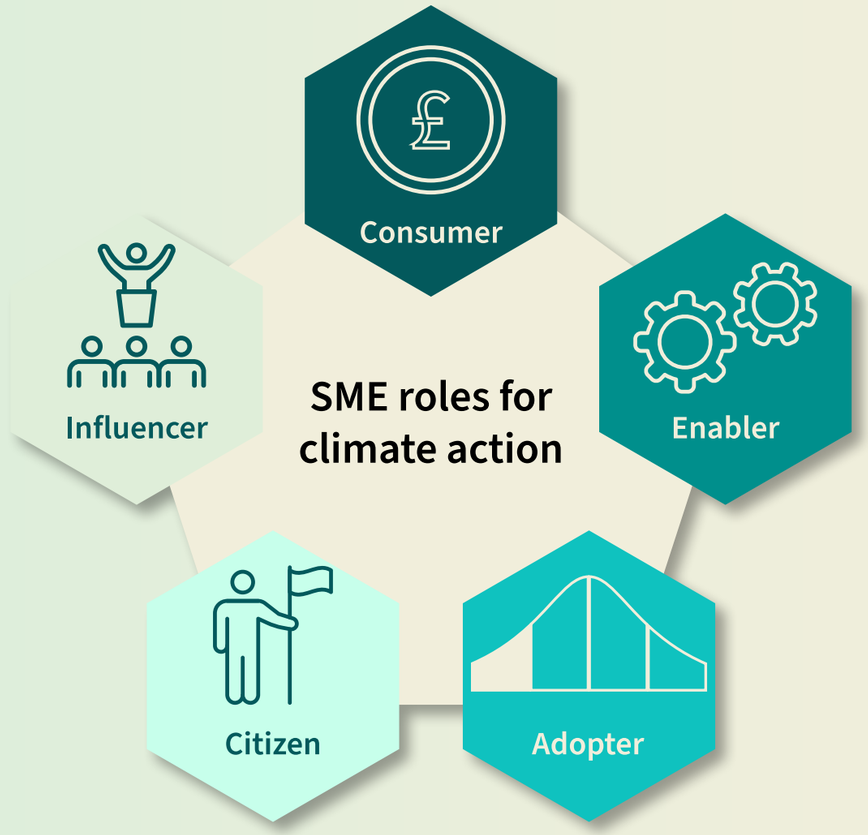

Figure 1: SME roles for climate action. Source: Hampton, S. Eadson, W., Blundel, R et al. (2024) Where Next for SMEs and Net Zero? London: UK Energy Research Centre (UKERC). Available at: https://doi.org/10.5286/UKERC.EDC.000976

to coordinate to effectively support business decarbonisation. This includes coordination between sector bodies, place-based providers and other support organisations[3].

- **Businesses play a variety of roles in climate action.** While local, regional and national policy tends to focus on SMEs as consumers of energy, they also enable transition through the provision of goods and services, support adoption of new technologies and practices, act as climate citizens to support others to act, and influence the actions of others (see Figure 1). Effective SME decarbonisation policy will recognise and target actions focused on each of these roles[4].
- **SME decarbonisation is a question of just transition.** We need to account for SMEs' different levels of vulnerability, capabilities and characteristics. Vulnerable and marginalised SMEs (e.g. based in or led by people from marginalised communities) are not well served by SME support and policy[5].
- **New approaches to SME engagement are needed.** Sophisticated, tailored and comprehensive approaches to engaging with different SMEs is critical to meeting the SME climate challenge. It is especially important to develop strategies to engage with vulnerable and marginalised SMEs[6].
- **Going deeper, broader and faster.** It is essential that policy solutions focus on rapidly deploying decarbonisation technologies and solutions, expanding support tools beyond advice and grants to reach a greater range of SMEs, and move towards support that focuses on comprehensive review of business models and practices rather than technology investments only[7].
- **The role of government and public sector intervention is changing.** There is a growing array of private sector support platforms and businesses. This means reflecting on the best role for local, regional and national intervention. Our research suggests now is the time to expand emerging roles that create the conditions to scale-up markets for SME decarbonisation, such as setting standards, coordinating efforts, procurement requirements, and tightening net-zero regulation for SMEs; and to start to design policies that will steer these markets as they mature, such as consumer protection, compliance and evaluation[8].

3 Ibid
4 Hampton, S., Byfuglien, A., Eadson, W., Latter, B., Hardy-Jones, B., Sugar, K., & Blundel, R (2025) Multiple roles for business action. iScience 28(12)
5 Eadson, W., Hampton, S., Blundel, R., Apostolopoulou, E., Latter, B., Witherley, D., Hardy-Jones, B., and Sugar, K. (2026) Just business? Rethinking the role of SME climate action through a just transition lens. Energy Research and Social Science
6 Eadson, W., Hampton, S., Blundel, R et al. (2024) Seven principles of place-based net zero policy for SMEs. UK Energy Research Centre.
7 Hampton, S. Eadson, W., Blundel, R et al. (2024) Where Next for SMEs and Net Zero? London: UK Energy Research Centre (UKERC).
8 Hampton, S. Blundel, R., Eadson, W., et al. (2023) 'Crisis and opportunity: Transforming climate governance for SMEs', Global Environmental Change, 82, p. 102707.

In response to these findings we have produced two frameworks for policy action.

We developed a new operational framework which allows us to pinpoint how businesses experience different challenges in relation to decarbonisation (Figure 2). Each section of the framework includes a range of sub-fields which can be used as a diagnostic tool at the individual business level as well as to identify broad SME population groups.

The framework can be used by policymakers and support providers to:

- Identify, reach and support the most vulnerable businesses by triangulating dimensional, sectoral and organisational challenges.
- Identify intervention points within individual sectors, places or groups of businesses with shared organisational characteristics through using the framework as a diagnostic tool.

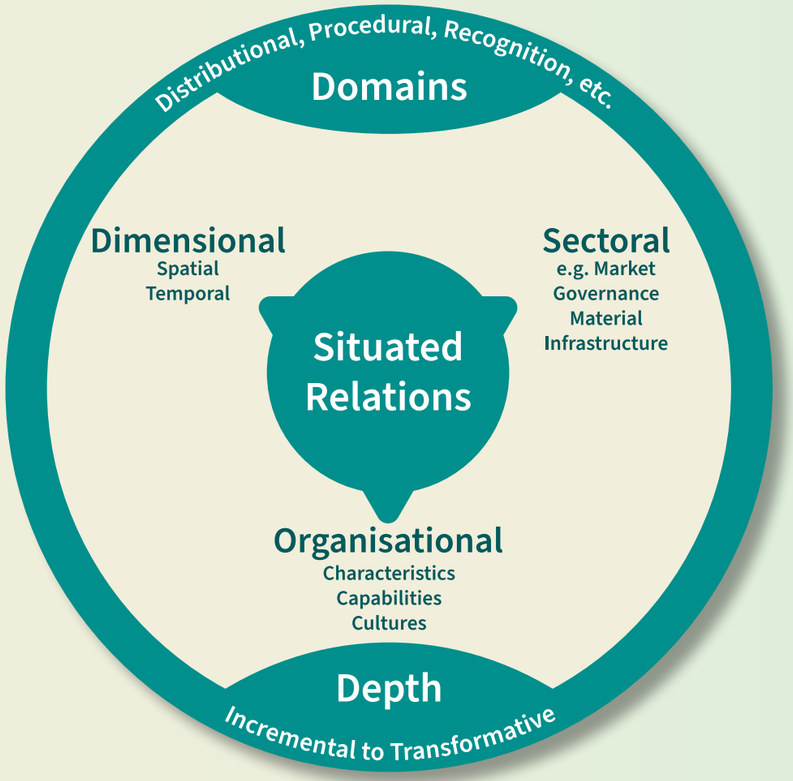

Figure 2: Just Transition Operational Framework. Source: Eadson et al (in review) Just business? Rethinking the role of SME climate action through a just transition lens. Energy Research and Social Science

- Recognise and make use of the different roles SMEs play (e.g. as employers, or as climate citizens) by considering their roles in relation to other businesses, organisations and communities.

Addressing the challenge of developing coordinated local and regional approaches to local and regional SME climate action, the research also involved identifying seven principles for developing more effective place-based support and interventions to catalyse decarbonisation (Figure 2). These were designed to be addressed by local authorities and Combined Authorities in partnership with other local stakeholders (e.g. universities and colleges, private sector support providers, community organisations).

What does this mean for the region?

South Yorkshire faces specific challenges to achieving coordinated and effective climate action. Although there is movement towards developing new approaches to SME decarbonisation, the regional support landscape remains fragmented and – for example compared to Edinburgh and Oxfordshire in our study – is less well developed. SMEs in South Yorkshire face particular challenges: there is a large energy-intensive manufacturing base, which means that the overall SME decarbonisation challenge is greater than many other regions. It also means that its business environment is more fragile than many other regions because of the effects of industrial change over the last 40 years.

However, our research shows ways that the region can become a leader in SME decarbonisation action. The research provides operational tools and actionable policy recommendations to act as a framework for delivering a coherent strategy for SME climate action across South Yorkshire. This includes the following recommendations for regional and local government:

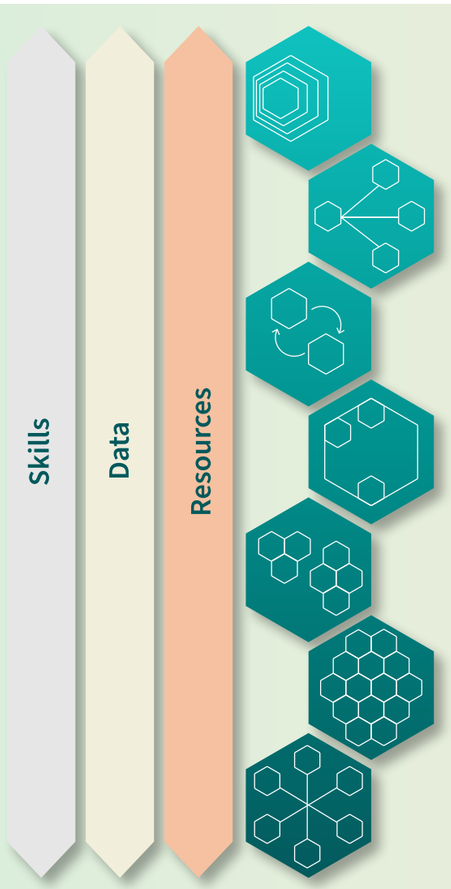

Figure 3: Principles of place-based net-zero policy for SMEs. Source: Eadson et al (2024) Seven principles of place-based net-zero policy for SMEs. SYSC & UKERC https://doi.org/10.5286/UKERC.EDC.000975

Develop a coordinated and consistent place-based approach which recognises the specific benefits of place-based action and where other approaches are better placed (e.g. working through sectors). This will require setting up and resourcing a regional strategic group for SME decarbonisation/ sustainability delivery.

Use the SME just transition framework to develop deeper understanding of different points of vulnerability across the SME base, and – specifically - to develop **strategy to engage less-well-reached vulnerable SMEs.** Utilising different business intermediaries – ranging from accountants to places of worship – will be essential to reaching these businesses.

Working with existing coalitions like the SY Net Zero forum alongside community-based organisations, **develop a programme of SME climate citizens,** recognising the different roles SMEs can play.

Consider a **one-stop-shop** style approach to connecting businesses with local solution providers to drive local supply chain growth and capture the benefits of investment in decarbonisation within the region.

Incorporate a regional SME decarbonisation steering group which ensures a diverse cross-section of SMEs have a voice in regional decision-making on net-zero. This means ensuring that different sectors and communities are represented.

Tailor support programmes to different stages of the decarbonisation (and different roles that businesses can play), prioritising any capital funding for harder-to-treat challenges. That does not necessarily mean focusing on ‘innovation’ – many businesses we spoke to said that the focus on innovation for capital funding was a key barrier to accessing support. The nature of these challenges will vary between firms and sectors so it will be important to engage with sector-bodies and expertise to help identify these.

Utilise place-based strengths in skills delivery (universities and further education sector) to develop a regional programme of SME climate literacy and skills development (including targeted sector based approaches).

Recognise where place-based approaches are less effective. Be clear on the added-value of place-based action, and where – for example – sector-based organisations might be better placed to support and provide guidance.

More detail can be found in our reports which provide further action points for local and regional policy makers and stakeholders.

Next Steps

Our work on understanding challenges for effective SME climate action policy in the region can be the starting point for a programme of further activity, working in partnership with regional stakeholders.

There is a need to operationalise the frameworks into actionable SME climate action policy and practice for the region. The research has also opened up a range of further questions to address through further research and partnership-working. These include developing a deeper understanding of how policy and support organisations can better engage with vulnerable and marginalised SME population groups, and how to operationalise learnings into practice; work with SMEs to develop just transition plans, considering business models and support to workers; and further work to develop activity that supports SMEs’ role as ‘climate citizens’.

One piece of on-going research concerns the metals recycling sector, where SMEs face pressure to decarbonise, but also face challenges and opportunities caused by decarbonisation of steel production in the UK[9]. This has implications for SMEs and for their workers. In collaboration with sector reps and regional businesses, there is an opportunity to further this work to develop a future metals recycling sector action plan for the region, and beyond.

9 Eadson, W., Woodhouse, D., Leather, D. and Witherley, D. (2025) Assessing the impact of potential restrictions on UK recycled metals exports. Centre for Regional Economic and Social Research

Youth Visions of a Just Transition:
Engaging Young People in South Yorkshire to Imagine Sustainable Futures

Project team:
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Project partners:
Rosie Carnall: Creative Facilitator: Philosophy for Communities - thinking more together; Clive Belgeonne: DECSY | Development Education Centre South Yorkshire

Challenge Statement

Young people have a long-term stake in the planning of sustainable futures and in policy responses to climate change. Youth participation fosters not only inclusion, but innovation and long-term thinking in environmental governance[1]. Young people are considered essential stakeholders in shaping resilient, future-focused policy frameworks to achieve the UN's Sustainable Development Goals[2].

However, due to the complexities of engaging children and young people in research and policymaking, this population group is often overlooked. There remains a persistent evidence gap for effectively embedding youth participation to shape future-oriented sustainability and climate policy[3,4]. This gap is especially acute in relation to marginalised communities, where it is widely acknowledged that the poorest in society stand to be the most negatively impacted by the changing climate[5]. These groups not only bear disproportionate impacts but are also frequently left out of participatory processes, which subsequently reinforces cycles of structural inequality.

New demands are placed on existing education systems to equip young people not only with knowledge, but also the skills and practical experience to imagine and navigate uncertain futures. The Department for Education's Sustainability and Climate Change Strategy[6] and the Curriculum and Assessment Review: Interim Report[7], both acknowledge that education must evolve to reflect these realities, and ambitions have been set for the UK education sector to become world-leading in sustainability and climate change by 2030. In response to these national policy ambitions, the South Yorkshire Mayoral Combined Authority (SYMCA) has committed to forming a Youth Climate Assembly in its Corporate Plan 2025-2028[8].

Despite nationally recognised tools and guidance for schools to develop climate action plans, actual models of youth led visioning or co-produced decision making remain in their infancy. Most engagement is either consultative or extra-curricular, and not fully integrated into government strategy[9].

Research Response

Our research responds to this challenge through the design and implementation of two interactive visioning workshops. The two participating schools both have above average levels of Free School Meal (FSM) eligibility, thereby foregrounding youth voices from communities that are often socioeconomically disadvantaged and structurally marginalised in policy and decision-making processes.

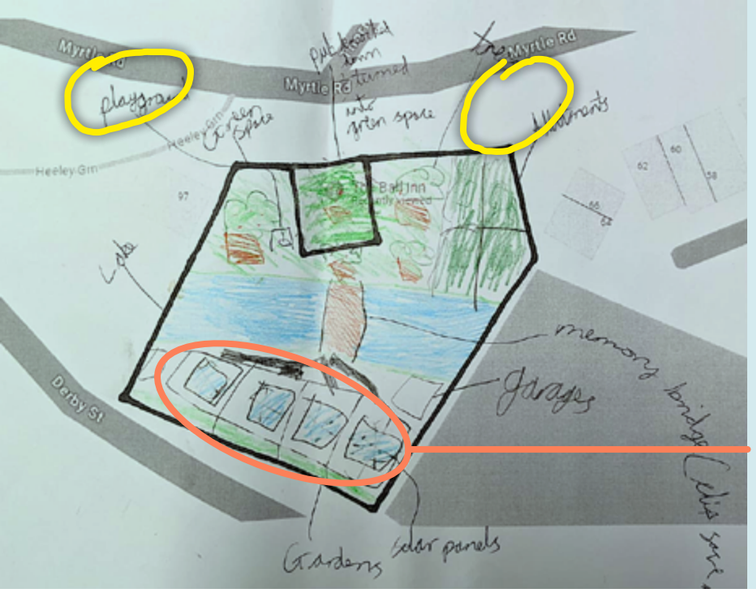
We designed a range of workshop activities, allowing children to explore their understanding and ideas about sustainable transitions in relation to homes, energy, transport, and food. We conducted one workshop with younger children aged 7-11 and another with older children aged 14-17.

We used the Philosophy for Children (P4C) model – an approach to engaging young people in complex philosophical subjects like climate change and decarbonisation, encouraging them to imagine and discuss ideas for a just and fair sustainable future. The workshops were run by facilitators with expertise in P4C and in partnership with the charity Development Education Centre South Yorkshire (DECSY).

Evidence and Outputs

Our research findings revealed a gap in sustainability knowledge for envisaging sustainable futures. Children and young people are not fully equipped with the information and language they need to navigate the challenges of their generation and to attach their future visioning to.

1 Percy-Smith, B., & Burns, D. (2013). Exploring the role of children and young people as agents of change in sustainable community development. Local Environment, 18(3), 323–339.
2 Borojević, T., Petrović, N., Radaković, J. A., Glomazić, H., Radojičić, M., Milenković, N., Maletič, D., & Maletič, M. (2023). Youth participation for sustainable value creation: The role and prioritization of SDGs. Sustainability, 15(23), 16456.
3 Davies, A. R., & Hügel, S. (2021). Just adapt: Engaging disadvantaged young people in planning for climate adaptation. Politics and Governance, 9(2), 100–111.
4 PPercy-Smith, B., & Burns, D. (2013). Exploring the role of children and young people as agents of change in sustainable community development. Local Environment, 18(3), 323–339.
5 Davies, A. R., & Hügel, S. (2021). Just adapt: Engaging disadvantaged young people in planning for climate adaptation. Politics and Governance, 9(2), 100–111.
6 Department for Education (2022). Sustainability and climate change: A strategy for the education and children's services systems. GOV.UK.
7 Department for Education (2025). Curriculum and Assessment Review: Interim report [Independent report].
8 South Yorkshire Mayoral Combined Authority. (2025) Corporate plan 2025–2028.
9 Parsons, M., Godden, N. J., Henrique, K. P., Tschakert, P., Gonda, N., Atkins, E., Steen, K., & Crease, R. P. (2025) Participatory approaches to climate adaptation, resilience, and mitigation: A systematic review.



In thieir designs, all groups included individual house plots with both private and shared gardens, and used the land available to maximise the number of families living in the space. Many included energy or food production as well as recreation space.

Every group created housing units that were equal sizes to promote fairness and reduce conflict between neighbours

Green and Blue spaces were popular design elements

The young people could identify how jobs might change in planning and construction. For example, using eco-friendly materials. When asked to imagine what jobs they would like and dislike, they valued creative roles:

"If you are a plumber you are going into people's home and dealing with dirty pipes. Architects and painters get to create something"

Specifically, our findings reveal that children and young people consistently demonstrate high levels of environmental awareness, with fairness and equality and safety and protection emerging as strong shared values in young people's imagined sustainable futures. Health and well-being are considered a priority, and they imagine a world where communal benefits are shared, and privacy is protected.

However, across all age groups, there was a lack of clarity about how their social values could translate impactfully into real-world future roles or careers, with some misconceptions emerging about what certain jobs involve. Few students had the scaffolding or practical insights to anchor their creative ideas to. They responded positively to the lesson stimuli (interactive activities), demonstrating value in feeling reliably informed and engaged.

The P4C approach supported meaningful dialogue, enabling students to change their minds and reach consensus. Overall, the workshops reveal a deep appetite for climate learning that is practical, empowering, creative, and relatable to their own lives and futures.

What does this mean for the region?

Our research immersed school pupils in climate futures thinking using a child-led pedagogical model (P4C). It provides pilot evidence for schools and trusts to activate SYMCA's commitment to giving young people a chance to shape a just climate transition.

This pilot project made it abundantly clear that improving environmental education is fundamental for the current generation of children and all future generations to follow.

We found out that there is a critical gap between the development of young people's pro-environmental values and the educational structure needed to support and activate meaningful action (aka the value-action gap).

Based on our research findings, we propose the following recommendations for regional policymakers and education leaders:

- **Practical school-based action:** there is scope for regional innovation through actors who already operate in the regional educational environment, embedding climate futures thinking through, for example: school enrichment activities, partnerships with local climate initiatives, youth-led demonstrations and other whole school approaches.
- **Enrichment activity planning:** prioritise practical action-based learning tied to real-world sustainability scenarios and challenges.
- **Careers advice:** increase information on green career pathways and skills development.
- **Embedding the youth voice into regional climate strategies:** through the use of age-appropriate, guided learning approaches and aligning outputs with national DfE sustainability commitments.
- **Co-production workshops and initiatives:** running co-production activities with the youth sector could be prioritised to encourage system-level change. Developmentally, children possess an openness that sees possibility rather than limitation, a quality that can be celebrated and actively harnessed, as demonstrated through pedagogical models such as P4C.
- **Scaling up across South Yorkshire:** the pilot workshop model used in this research could be rolled out across South Yorkshire.

Next Steps

Building on the success of this pilot, there is clear potential for the model to be scaled and adapted across regions, by embedding well facilitated, child-led spaces within broader sustainability and education policy design for just transitions. Sustaining momentum and embedding practices beyond individual pilots involves:

- **Regional connectedness:** bringing together regional actors, including schools, multi-academy trusts, local authorities, youth sector organisations and SYMCA to explore mechanisms for systematically integrating climate strategies and school-level Climate Action Plans.
- **Building and sustaining momentum:** embedding the youth voice into visioning for a sustainable future - moving regional climate planning beyond tokenistic consultation and into sustained active participation.
- **Co-production:** support schools in co-producing their climate strategies with their young stakeholders – remember that futures thinking is a developmental necessity for children and young people.
- **Further research:** produce further empirical insights into what mechanisms can work regionally to include the youth voice in meaningful translation of values to action; or explore longitudinally the impact of child agency in sustainability transitions.
- **Interdisciplinary research collaborations:** sociology (futures thinking), psychology (developmental and cognitive), geography (urban and regional), environmental (science and policy), brought together to maximise impact.
- **Continuity:** secure funding to repeat or extend workshops, embedding P4C methods into teacher CPD or to co-design toolkits for schools.

By continuing to explore through an interdisciplinary lens, research can illuminate the power of curious young minds, to shape a shared and just vision for a sustainable South Yorkshire.

What Young People Imagined for a Sustainable Future

Themes emerging from primary and secondary school workshops

Safe, Protective and Future Ready Spaces

Childeren prioritised feeling safe and protected, and their building designs incorporated practical solutions for future climate resiliece.

"In Pakistan there are lots of floods, so if you have a flat roof you can go to it when there's a flood!"

"In Nigeria, there are flat roofs and when it is hot my grandmother sleeps on the roof."

Some children didn't realise roofs could be flat and worried about falling off. This led to a funny discussion about how not to fall off your roof! New ideas and concepts were shared.

Fairness and Equality

When designing space use, strong values were expressed around fairness and equality.

When presenting their designs for the old pub site, one group said they want their homes to look and feel the same with red brick of equal sizes:

"We don't was new houses to stand out"

The group explained that this is to promote fairness and reduce conflict and jealousy between neighbours, they are concerned about getting burgled and it's important to them that the houses look and feel like a normal house, not a futuristic eco house.

Mixed-Use Community Benefits and Protected Privacy

Young people imagine a world that balances shared communal benefits, healthy lifestyle and protects privacy.

Recurring features in the children's designs include:

- **Green and blue spaces (gardens, allotments for healthy food, eco-ponds)**
- **Renewable energy generation (solar panels and wind turbines)**
- **Private homes alongside shared gardens (blending individual plots and communal areas)**
- **Relaxation and wellbeing spaces (chairs, TVs and books - the most common rooftop suggestion)**

Spaces were framed as multi-purpose, fun and productive, reflecting an intuitive sense of fairness while ensuring personal space, and demonstrating a clear level of eco-literacy.

Collaborative Problem Solving and Consensus Building

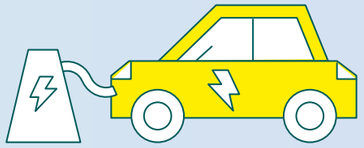
Discussions demonstrated strong skills in collective decision-making and practical problem solving, negotiating design choices thoughtfully:

Recurring features in the children's designs include:

- Checking for consensus: ***"so, do we all agree?"*** and questioning decisions ***"I think we should retrofit that"*** - ***"Why, what have you got against rebuild?".***
- Debating the role of private and communal gardens, linking spaces to wellbeing: ***"it's a mindful thing to have your own space".***
- Assessing materials and sustainability, proposing practical, recyclable solutions: ***"How do we keep costs down?"*** - ***"we could buy our curtains off eBay".***

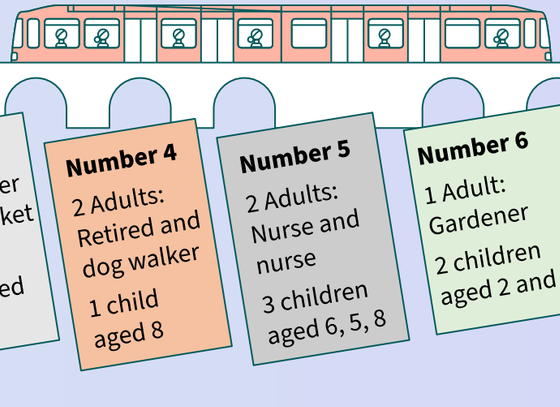
Example Exercise - Who needs the car?

6 households live on Green Street.
On Green Street, everyone can have a free bike to get around locally.
They can also travel free on buses and trains!



There's one electric car for Green Street.

Who do you think most needs to use it and why?



Number 1
2 Adults: Ambulance driver and office worker
4 children aged 8, 7, 4 and 8

Number 2
7 Adults: Office worker, teacher, artist, cook and 3 retired
4 children aged 5, 1, 7 and 8

Number 3
2 Adults: Builder and supermarket worker
3 children aged 13, 4 and 10

Number 4
2 Adults: Retired and dog walker
1 child aged 8

Number 5
2 Adults: Nurse and nurse
3 children aged 6, 5, 8

Number 6
1 Adult: Gardener
2 children aged 2 and 6

What we heard:

I think number 2. They are a big family and would take a lot of space. Also there are a lot of old people there who need support.

6 because she is a single mum and needs it for her kids

No one because they can all use the busses and trains for free

2 because they have a big family and one is disabled

1 Because one of the adults is an ambulance driver.

5 because the hospital worker for example could use the car for an emergency (a surgery or something) and the other people could use the busses, bikes and trains

4 because the 3 cannot drive since they're old or are a kid. They can't take busses or trains because it'll take forever to get to their destination

I think number 1 needs the car because one of them is an ambulance worker and if there's an emergency she needs to get there straightaway

4 because the old people can not walk very well so a car could help them get to places quicker.

2 or 6 because 2 is a big family with many children and 6 is a single mother with young children

4 because they can't walk fast and they are very old but the other people can go on buses, ride trains and ride on free bikes and the old people need to take their child and drop them off at school

6 because they don't have a high paying job

4 needs it because middle aged people can ride a bike

Sheffield Hallam University

South Yorkshire Sustainability Centre Consolidated Research Report

SOUTH YORKSHIRE SUSTAINABILITY CENTRE

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