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

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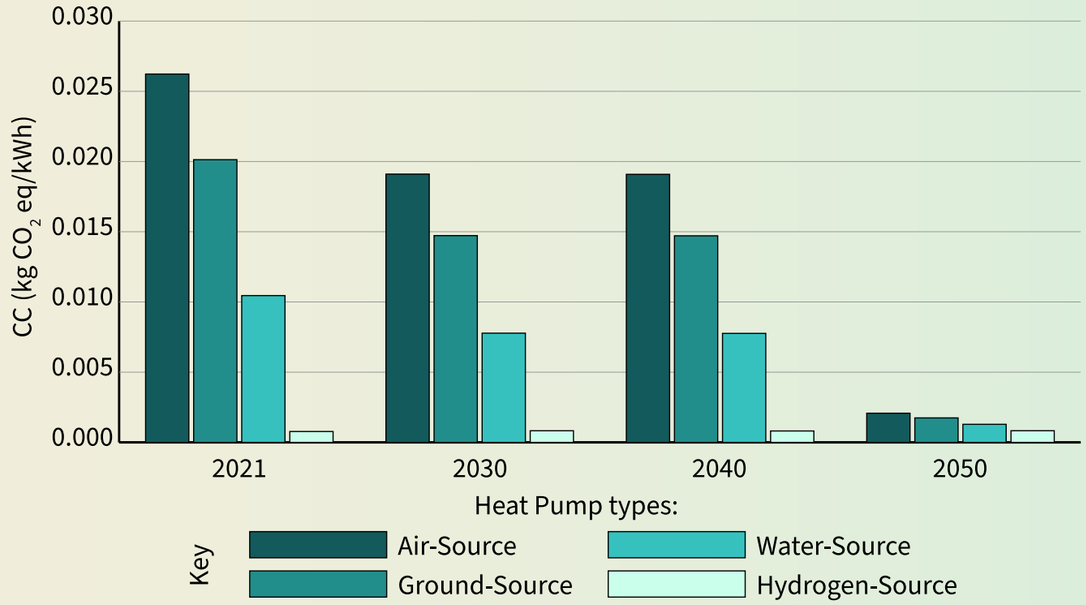

Figure 1: The UK heat pump supply chain climate change impact based on net zero plan forecast.

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.

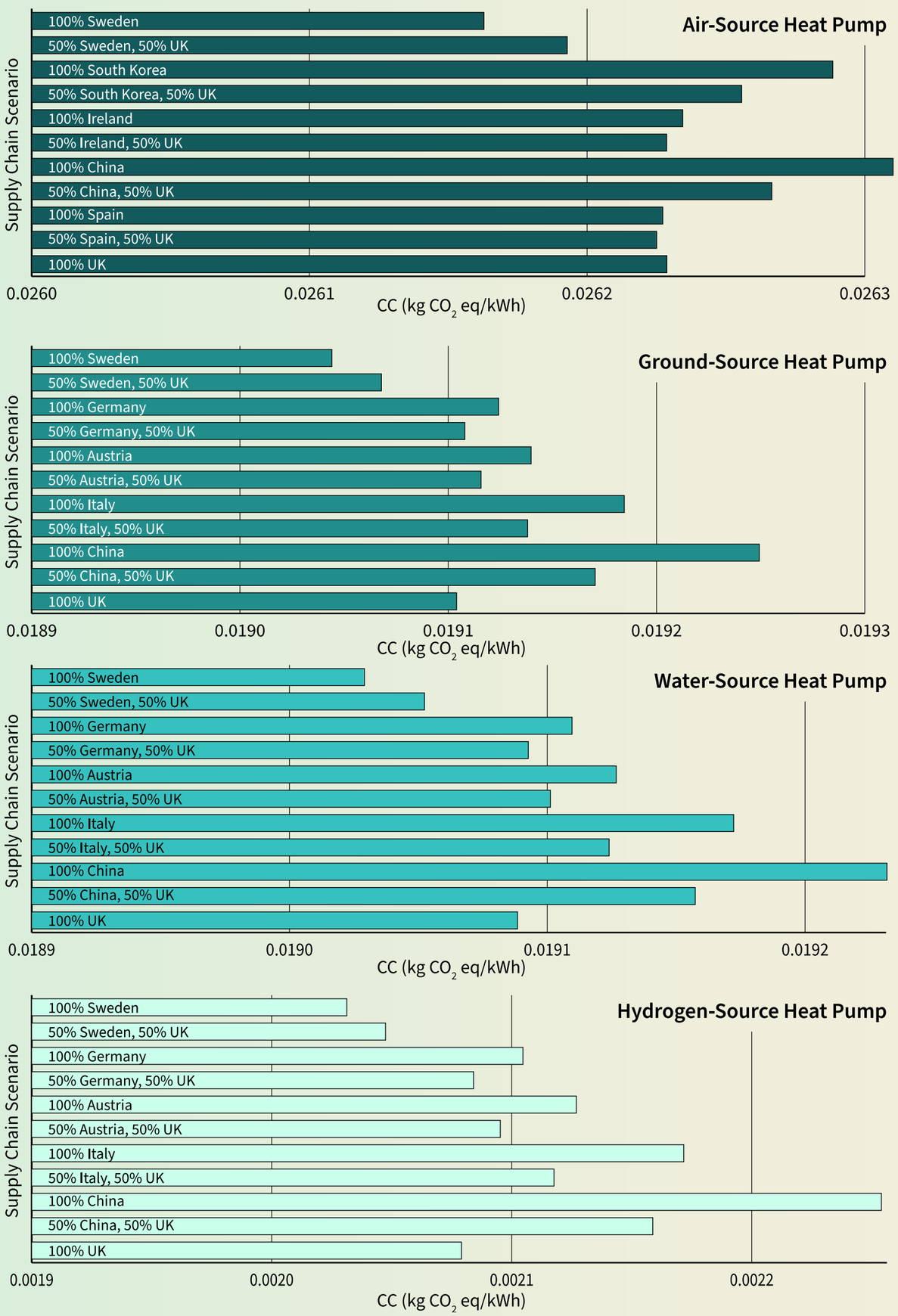

Figure 2: Climate change impact comparison for all supply chain scenarios.

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).