

DECARBONISING DISPERSED INDUSTRIES: A FRAMEWORK FOR UNDERSTANDING RURAL INDUSTRIAL ENERGY TRANSITIONS IN THE UK

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Abstract

The decarbonisation of rural and dispersed industrial sites is a critical but underexplored element of the United Kingdom's net-zero transition. These sites account for more than half of industrial emissions yet face distinct challenges compared to industrial clusters, including severe electricity network constraints, prohibitive connection costs and timelines, and limited access to emerging hydrogen and carbon capture infrastructure. This study presents findings from the Rural Industrial Decarbonisation Energy Solutions (RIDES) project, which conducted 17 in-depth stakeholder interviews to develop an archetype-based framework for understanding rural industrial decarbonisation pathways. Five archetypes were identified, reflecting variations in energy demand, process requirements, and spatial context: remote medium-heat industries, seasonal agro-processing, high-temperature rural manufacturing, rural SME industrial estates, and off-grid anchor sites. Analysis revealed that high electricity prices—up to fourteen times higher in policy costs than gas—constitute a structural barrier to electrification, compounded by fragmented policy support and limited organisational capacity among smaller enterprises. Targeted interventions are proposed, including Energy Service Company (ESCO) delivery models, demand aggregation approaches, electricity pricing reform, and archetype-specific technology packages. The findings highlight the importance of place-based strategies that integrate infrastructure planning, policy reform, and local collaboration. Addressing the needs of dispersed industries is essential for achieving national climate goals, safeguarding rural employment, and enabling these sectors to act as anchors for distributed renewable energy systems.

Keywords: industrial decarbonisation, rural industries, energy transition, net-zero, infrastructure constraints, archetype analysis

Introduction

The United Kingdom's legally binding commitment to achieve net-zero greenhouse gas emissions by 2050 necessitates comprehensive decarbonisation across all sectors of the economy (*The Climate Change Act*, 2008). While considerable attention has focused on decarbonising large industrial clusters such as Grangemouth, Teesside, and Humber, a sizeable portion of UK industrial emissions comes from dispersed sites. Recent analysis by Taylor (2024) quantifies this challenge, finding that dispersed sites account for over 50% of UK industrial emissions—a figure that becomes particularly striking when considered alongside the fact that these sites represent only 23% of industrial installations, indicating their disproportionately high carbon intensity. This emissions concentration outside clusters is distinct from, though related to, patterns of energy demand distribution. As one expert noted in our research, “About 50% of industrial energy demand is outside clusters—a significant challenge for decarbonisation” (Hardy, L., Green Alliance, Interview, March 2025). The alignment between high emissions share and energy demand share suggests that dispersed sites not only consume substantial energy but often rely on carbon-intensive fuel sources, lacking the infrastructure advantages available to clustered facilities. This aligns with Rosenow et al. (2025), who systematically demonstrate that industrial electrification represents a critical decarbonisation pathway across Europe, though policy frameworks remain inadequate, particularly for dispersed sites. Simply extending cluster-focused decarbonisation strategies will not suffice for these locations. This finding is reinforced by Rattle and Taylor (2023), who demonstrate that most cluster initiatives internationally concentrate on deploying carbon capture and hydrogen infrastructure in a few large coastal industrial hubs, creating a “funnelled” investment approach that neglects smaller sites and alternative decarbonisation measures like electrification. Recent analysis by Green Alliance (2025) reinforces this potential, finding that 78% of all industrial energy demand could be electrified with technologies that are already established, rising to 99% with technologies currently under development.

Since the completion of the RIDES research, the UK Government published its Modern Industrial Strategy in June 2025, which whilst identifying clean energy industries as a high-growth sector, provides limited new support for dispersed industrial sites. Notably, the Industrial Energy Transformation Fund will not continue beyond existing commitments, removing a critical capital support mechanism for dispersed sites (DBT, 2025). The strategy does introduce a British Industrial Competitiveness Scheme from 2027 and proposes developing Corporate Power Purchase Agreements (CPPAs), though eligibility criteria remain unclear and may exclude smaller dispersed sites. Whilst plans to accelerate grid connections through a new Connections Accelerator Service are welcome, the strategy's continued focus on energy-intensive industries and specific sectors like aerospace and automotive leaves the majority of rural SMEs without dedicated support mechanisms.

This research responds to the strategic imperative of raising the profile of industrial and commercial decarbonisation beyond clusters, as identified by the Association for Decentralised Energy (ADE) as a critical priority for achieving net-zero. By providing detailed evidence on industrial decarbonisation pathways, their geography, and supply chain

71 implications, this article addresses a significant gap in current policy discourse. Furthermore,
72 the research aligns with broader strategic priorities for reforming electricity pricing to lower
73 the cost of heat across business and industry—a reform that our findings demonstrate is
74 essential for enabling rural industrial transformation.

75 The former Conservative government's Industrial Decarbonisation Strategy (BEIS, 2021)
76 acknowledges the imperative to address emissions from both clustered and dispersed
77 industrial sites. However, the strategy's implementation has thus far prioritised larger facilities
78 with greater emissions intensity, leaving rural industries with fewer tailored support
79 mechanisms despite their structural importance to regional economies and supply chains. A
80 BEIS study on CCUS at Dispersed Sites established that 36 industrial sites across the UK with
81 carbon capture potential are located more than 30km from established industrial clusters,
82 collectively accounting for 20.7 MtCO₂ emissions annually (2020). These "truly dispersed sites"
83 face compound challenges including prohibitive costs for carbon dioxide transport and
84 storage, complex permitting requirements in protected landscapes, and limited local technical
85 expertise in emerging low-carbon technologies. This aligns with findings from ADE (Savoie, J.
86 and Wade, J., 2025), which emphasises that dispersed sites are responsible for approximately
87 half of UK industrial emissions and that 770,000 jobs could be saved by effectively
88 decarbonising these sites.

89 Recent research by Butler et al. (2023) highlights that dispersed sites face unique challenges
90 compared to clustered industrial facilities, noting that,

91 the sometimes-challenging locations, and lack of ability to share new infrastructure with
92 other industrials (e.g., CO₂ or hydrogen pipelines), may make other decarbonisation
93 solutions such as carbon capture or fuel-switching to hydrogen less accessible or less
94 economical. (Butler, T *et al.*, 2023, p. 69)

95 This infrastructure disadvantage is compounded by the current policy framework which has
96 prioritised larger facilities with greater emissions intensity through initiatives such as the CCUS
97 Cluster Sequencing programme (BEIS, 2020).

98 The spatial and social dimensions of industrial decarbonisation add further complexity to this
99 challenge. Sovacool et al. (2024) synthesise lessons from the UK's IDRIC programme, stressing
100 that the geographical distribution of industry introduces a "nuanced layer" to the transition,
101 requiring tailored strategies for different locations. They emphasise that industrial
102 decarbonisation is fundamentally a place-based process in the UK, recognising the diverse
103 challenges of clustered versus dispersed industries. This place-based understanding is crucial,
104 as O'Sullivan et al. (2020) demonstrate through their concept of "energy peripheralisation,"
105 showing how rural areas can be systematically sidelined in low-carbon transitions despite
106 abundant renewable resources, due to lack of political power and infrastructural advantages.

107 This article addresses this critical gap by analysing findings from the Rural Industrial
108 Decarbonisation Energy Solutions (RIDES) project, which conducted comprehensive
109 stakeholder engagement to understand the specific barriers and opportunities facing rural
110 industrial decarbonisation. Through 17 in-depth interviews with representatives across
111 industry, technology providers, network operators, and policy experts, the research developed
112 an innovative archetype-based framework for understanding and addressing the

heterogeneity of rural industrial sites. This typological approach builds on established methodological foundations, as Martínez-Reyes et al. (2025) identify in their systematic review of energy region typologies, which demonstrates how regional characteristics shape transition pathways and notes that peripheral regions face unique challenges requiring social innovation to avoid being left behind.

The contribution of this research is threefold. First, it provides empirical evidence of the specific barriers facing rural industrial sites, distinguishing between challenges that arise from rural location versus those common to all industrial decarbonisation efforts. Second, it develops a novel typological framework that categorises rural industries into five distinct archetypes based on shared characteristics including energy intensity, process requirements, and spatial contexts. Third, it identifies targeted intervention strategies tailored to each archetype's specific constraints and opportunities, moving beyond one-size-fits-all approaches that have proven ineffective for dispersed sites. These contributions directly support the strategic priority of building better evidence on industrial decarbonisation pathways and their geography, whilst highlighting the critical importance of electricity pricing reform for enabling the transition. The barriers identified through this research are systematically compared in Table 2 demonstrating the heterogeneity of challenges across rural industrial contexts.

Methods

Research Design

This study employed a qualitative research approach centred on stakeholder engagement to capture the complexity and heterogeneity of rural industrial decarbonisation challenges. The research was conducted as part of the Strategic Innovation Fund (SIF) 'Discovery Stage' project between February and April 2025, acknowledging the inherent limitations of sample size within this compressed timeframe.

Participant Selection

Participants were strategically selected to ensure diverse representation across the rural industrial decarbonisation landscape. The selection criteria included: (1) sectoral diversity spanning food and drink, chemicals, glass manufacturing, and other energy-intensive industries; (2) geographical distribution across Scotland, East Anglia, South West England, and other regions with significant rural industrial presence; (3) organisational types including industry associations, individual businesses, network operators, technology providers, policy experts, and academic researchers; and (4) value chain positions from energy suppliers to end-users.

Participants were offered the choice between full attribution or anonymisation of their contributions. Seven participants consented to being identified by name and organisation, while ten requested varying degrees of anonymity. To respect these preferences whilst maintaining consistency, Table 1 presents all participants using stakeholder IDs and functional

descriptions. In-text citations identify participants by name where consent was given, or by functional role where anonymity was requested.

The final sample comprised 17 stakeholder organisations whose roles and sectors are detailed in Table 1. This diverse group included Distribution Network Operators (DNOs), trade bodies representing glass, chemical, and food and drink sectors, a distillery company, technology providers, academic experts, LPG suppliers, energy consultants, hydrogen advocates, waste management specialists, and food processors. While this sample cannot claim comprehensive representativeness of all rural industries across Great Britain, it provided meaningful indicative insights appropriate for this discovery phase.

Table 1 presents participants using a standardised format to protect the identity of those requesting anonymity whilst providing sufficient context about the diversity of perspectives represented.

Table 1 Interview Participants

Stakeholder ID	Professional Role	Function
Interview 1	Head of Decarbonisation	Food & Drink Manufacturing Company
Interview 2	Climate Change Executive	Trade Association
Interview 3	CEO	Technology Provider
Interview 4	Head of Corporate & Public Affairs	LPG Provider
Interview 5	Director	Regional Hydrogen Initiative
Interview 6	Head of System Planning	Electricity Distribution Network Operator
	DSO Engineer	
Interview 7	Head of Research	Climate Change Organisation
Interview 8	Sustainability Director	Spirits Production Company
Interview 9	Head of EA	Federation Manager
Interview 10	Energy Consultants	LAEP Consultancy
	Energy Consultant	

Interview 11	Professor of Sustainable Energy Solutions	Academic Institution
Interview 12	Emeritus Profession	Academic Institution
Interview 13	Climate Change Manager	National Supermarket Chain
Interview 14	Deputy Director	Beverage Trade Body
Interview 15	Energy Futures Manager	Gas Distribution Network Operator
	Energy Futures Project Officer	
Interview 16	Head of Climate Change and Energy Policy	Trade Organisation
Interview 17	Head of Decarbonisation Consultancy	Energy Services Company
	Political & Regulatory Advisory	
	Head of Development for Low-Carbon Energy	

Note: Interview dates have been omitted from this table to further protect participant anonymity, particularly for organisations with single representatives in specific roles

Data Collection

Semi-structured interviews lasting approximately 60 minutes were conducted remotely via video conferencing. The interview protocol covered 11 thematic areas: (1) organisational role and responsibilities; (2) diversity and characteristics of rural/remote industrial sites; (3) energy infrastructure and network considerations; (4) policy and regulatory environment; (5) challenges of decarbonisation for rural/remote industries; (6) collaboration and stakeholder engagement; (7) demand-side flexibility and storage; (8) technology and innovation; (9) financial and investment considerations; (10) future pathways and opportunities; and (11) interest in decision-support tools.

All interviews were recorded with participant consent and subsequently transcribed to facilitate detailed analysis. Participants were offered anonymity in reporting.

Data Analysis

Initial familiarisation with the data involved comprehensive review of all transcripts and interview notes. Open coding identified recurring themes, challenges, and potential solutions

across the dataset. These codes were subsequently grouped into coherent themes and sub-themes through an iterative process of review and refinement.

To enhance analytical capacity given the substantial volume of qualitative data, the research team employed large language model (LLM) technology as an analytical assistant for pattern recognition. This computational approach was combined with expert review and validation to ensure identified patterns accurately reflected the realities of rural industrial contexts. The use of LLM technology enabled more comprehensive identification of latent patterns and connections across diverse stakeholder insights while maintaining analytical rigour through human oversight.

Archetype Development

Building on the thematic analysis, the research developed a typological framework categorising rural industrial sites into distinct archetypes. This methodological approach aligns with established practice in energy transition research, as Martínez-Reyes et al. (2025) demonstrate that categorising regions or sites based on shared characteristics is an established method to understand differential transition dynamics. The process involved: (1) compiling key parameters from interview data including energy demand profiles, process temperature requirements, and grid connection status; (2) identifying clusters of sites with similar characteristics and challenges; (3) defining archetype boundaries based on operational and spatial factors; (4) validating archetypes against stakeholder feedback; and (5) refining definitions to ensure clarity and applicability.

The archetype names were deliberately chosen to honour historical industrial pioneers whose work resonates with the characteristics of each category, providing memorable identifiers while acknowledging the UK's industrial heritage.

Results

Infrastructure and Technical Constraints

The research identified severe infrastructure limitations as a fundamental barrier specifically linked to the dispersed nature of rural industrial sites. Unlike their clustered counterparts, rural facilities operate at the grid edge with infrastructure originally designed for agricultural or residential loads rather than industrial demand. This infrastructure penalty aligns with OECD (2022) findings that rural areas systematically face higher per-unit infrastructure costs due to lower population densities, greater distances between demand points, and more challenging terrain—factors that compound when industrial decarbonisation requires substantial infrastructure upgrades.

Grid capacity emerged as the most acute constraint. One food manufacturing representative described how full electrification would require, "100-120 MW to decarbonise [one site] through electrification – about 15-20 times the amount of electricity we can currently import"

(McNaughton, P., British Sugar, Interview, February 2025) This magnitude of upgrade necessitates significant primary infrastructure development beyond simple connection enhancements. These findings align with Gailani and Taylor (2025), who quantify that without significant grid upgrades, 65% of major industrial sites (responsible for ~69% of emissions) could be electrically constrained by 2040, noting that an extra 71+ GW capacity will be needed, especially in central and rural regions of England and Wales.

Connection timelines present additional barriers. A distillery representative reported concrete plans for a 10 MW electric boiler with thermal storage to use surplus local wind power but noted, “the thing that’s blocked that is [the] grid connection’s not available till 2028.” (Baird, C., Edrington, Interview, February 2025). In extreme cases, infrastructure costs become prohibitive: one technology provider shared that “a distillery abandoned electric boilers after receiving a £10 million connection upgrade quote” (Ronde, M., Exergy3, Interview, February 2025), while a major retailer reported, “we have received varying cost quotes from different distribution-network operators for power-upgrade work across our distribution centres in different regions.” (Anonymous retail stakeholder, Interview, 2025).

Network operators confirmed these challenges are systemic. As NGED explained,

Rural networks often supply fewer customers with less interconnection than urban networks. Primary substations can be 15–20 km apart, making some network reinforcement costly and lengthy, especially due to terrain and environmental consents... Network assets generally last 40–50 years and, depending on size, can take years to install, so upgrades need to factor in a long-term view of the future. (Spink, O., NGED, Interview, February 2025)

Geographic isolation from emerging infrastructure networks compounds these challenges. A chemicals industry representative explained that their rural locations were, “relatively unlikely” (Mitchell, D., Chemical Industry Association, Interview, February 2025) to receive networked hydrogen in the near term, with a food manufacturer estimating at least “15–20, maybe longer, [years]” (McNaughton, P., British Sugar, Interview, February 2025) before hydrogen infrastructure might reach their sites. This isolation limits access to infrastructure-dependent decarbonisation solutions being developed for industrial clusters, a challenge that Rattle et al. (2024) identify as particularly acute for the nearly half of UK industrial emissions that come from dispersed sites outside the reach of cluster-centric infrastructure investments.

Economic and Financial Barriers

The economic case for rural industrial decarbonisation faces severe challenges from multiple interconnected factors. The substantial price differential between electricity and gas creates a fundamental disincentive for electrification. An energy technology provider quantified this disparity: “UK policy costs on electricity can reach up to £70/MWh versus only ~£5/MWh on gas” (Ronde, M., Exergy3, Interview, February 2025) representing a 14-fold difference in policy costs alone. Multiple stakeholders confirmed this finding, with Veolia noting that, “all green levies sit on electricity, not gas, which should be reversed” (Bevan, D., Veolia, Interview, April 2025). This finding is corroborated by Green Alliance (2025), which identifies the same 14-fold

disparity as a fundamental barrier to industrial electrification across the UK. Rosenow et al. (2025) confirm this pricing disparity as a Europe-wide phenomenon, demonstrating how policy costs on electricity versus gas systematically disadvantage electrification across all European countries studied.

British Glass provided stark context:

UK Industrial Electricity is the most expensive in developed countries due to early decarbonisation costs and levies... This high cost hinders electrification; a support mechanism for addressing the price disparity between gas and electricity is needed to allow further electrification in the UK glass sector. (Pearcy, P., British Glass, Interview, March 2025)

Capital intensity compounds these operational cost challenges. Stakeholders described how decarbonisation investments must compete against core business priorities, with one noting: "I could spend £10 million on decarbonising the site, or I could use that money to build an entire new production line (Anonymous industry stakeholder, RIDES Project Interview, 2025). This trade-off is particularly acute for rural facilities operating with tight margins and facing higher infrastructure costs due to their location. As O'Sullivan et al. (2020) observe, economic and policy inequalities often mean that benefits of clean energy transitions are unevenly distributed, with remote regions facing higher costs, weaker grid access, and less attention from policymakers.

The perceived "first-mover pays" principle for infrastructure upgrades creates additional disincentives. An energy consultant revealed a practical workaround:

Connection upgrade budget estimates can be misleading; a site with an initially prohibitive connection upgrade cost was later found to have much lower costs upon further DNO engagement and detailed analysis. Collaboration among neighbouring firms and more easily accessible up-front feasibility time with the DNO can reduce costs and open up much more optimal localised electrical infrastructure solutions. Current institutional barriers to information-sharing hamper this (Pyatt, R., CR Plus, Interview, March 2025)

Investment patterns reveal clear prioritisation challenges. British Sugar explained their decision-making:

Investment prioritisation balances regulatory compliance, capital payback, and EBITDA impact, favouring large sites with scale advantages. Environmental permits required an approximately £20 million investment recently, ahead of decarbonisation capital allocations. (McNaughton, P., British Sugar, Interview, February 2025)

Policy and Regulatory Environment

Current policy frameworks demonstrate a disproportionate focus on industrial clusters, leaving dispersed sites underserved. A spirits industry sustainability manager highlighted this imbalance: "There's billions going into hydrogen... lots into biomass... Where's the support for just using electricity?" (Baird, C., Edrington, Interview, February 2025). This cluster-centric approach in programmes like CCUS Cluster Sequencing creates systematic disadvantages for

rural industries, a pattern that Rattle and Taylor (2023) identify across international cluster initiatives, which tend to concentrate on a few large coastal industrial hubs while neglecting other decarbonisation measures and smaller sites.

Green Alliance confirmed that,

Funding is heavily skewed toward clusters, with dispersed sites mainly reliant on the Industrial Energy Transformation Fund. High UK electricity prices stifle electrification while network constraints prevent many from connecting, causing regional disparities. (Hardy, L., Green Alliance, Interview, March 2025)

Multiple stakeholders emphasised the need for policy reform, for example,

Government have indicated they could consider an off-gas-grid renewable-heating obligation similar to the existing road-fuel RTFO to encourage the development of new renewable liquid gases. Government should also reform EPCs to remove unintended consequences that currently discourage energy-efficiency measures and, in some cases, perversely incentivise switching from lower-carbon LPG back to higher-carbon heating oil. (Flogas, Interview, March 2025)

Process-specific regulations present additional barriers in certain sectors. Heritage industries face constraints, with Scottish whisky production legally required to use traditional pot stills, preventing adoption of more energy-efficient continuous distillation methods without losing product designation. As the Scotch Whisky Association explained,

It is important that distillery by-products are classified as non-waste materials recognising the value they have in different established (e.g. animal feed and energy) and emerging value chains (e.g. food supplements and biobased materials). This is key to avoid disproportionate regulation and additional costs which would create a barrier to use, undermining the circular economy, efficiency gains and emissions savings from these value chains. (Scotch Whisky Association, Interview, April 2025)

The Food and Drink Federation highlighted how,

Multiple reporting mechanisms such as with Climate Change Agreements and UK ETS can create pinch points: consolidation would improve data consistency as well as being more efficient. (Piercy, E., Food and Drink Federation, Interview, March 2025)

The complexity extends beyond national policy, with Hydrogen South West noting,

inconsistent government messaging—DfT mandates battery-electric vans while DESNZ acknowledges hydrogen engines—and limitations in hydrogen-production business models that inhibit contracting with third-party risk takers. (Eccles, D., Hydrogen South West, Interview, February 2025)

Planning and permitting complications further delay implementation. Food and drink industry representatives noted that, “since SMEs often face resource constraints, this can limit engagement with this critical group” (Piercy, E., Food and Drink Federation, Interview, March 2025). These processes prove particularly complex in rural areas with landscape designations, conservation areas, or heritage considerations.

These policy gaps have been further entrenched by the Modern Industrial Strategy (DBT, 2025). Whilst the strategy promises to reduce electricity costs through the British Industrial Competitiveness Scheme, eligibility appears limited to 'thousands' of businesses in

manufacturing-intensive sectors. The uplift of the Network Charging Compensation Scheme from 60% to 90% will benefit only around 500 eligible businesses. Most significantly for dispersed sites, the discontinuation of the Industrial Energy Transformation Fund removes the primary capital support mechanism for industrial decarbonisation outside clusters, with no successor programme planned. The strategy's emphasis on Strategic Sites Accelerator and frontier technologies continues the pattern of overlooking the specific needs of dispersed rural industries.

Organisational Capacity and Knowledge Gaps

Resource disparities between large corporations and rural SMEs create significant implementation challenges. A distillery representative observed that medium and smaller companies often, "don't have someone thinking about energy 24/7 - they've maybe just got a procurement person thinking about it one month a year" (Baird, C., Edrington, Interview, February 2025). This capacity constraint reflects Barney's (1991) resource-based view of the firm, where competitive advantage derives from valuable, rare, inimitable, and non-substitutable resources. Rural SMEs lack not just financial capital but the human and organisational capital necessary to navigate complex decarbonisation transitions, creating systematic disadvantages compared to their larger or urban counterparts.

Skills gaps emerge as particularly acute in rural contexts. British Sugar highlighted that, Attracting and retaining skilled engineering and digital technology staff is challenging in rural areas, especially with competition from renewables projects. Future needs include more electrical, control, data-analytics, and AI skills alongside mechanical and scientific roles. (McNaughton, P., British Sugar, Interview, February 2025)

This represents not just a capacity issue but a fundamental shift in required capabilities.

Risk perception further inhibits adoption of new technologies. Policy experts noted a preference for proven approaches: "nobody wants to be the first to install the new electric technology; they want to be the 5th or 6th" (Anonymous academic expert, Interview, February 2025). This caution is magnified in rural areas where technical support services are less accessible and failure recovery more challenging. As one distillery manager explained, "Medium and small distilleries [lack] dedicated energy staff to validate their strategies and explore viable options" (Baird, C., Edrington, Interview, February 2025).

Data limitations compound decision-making difficulties. This absence of granular data makes identifying and prioritising decarbonisation opportunities particularly challenging. The Food and Drink Federation confirmed that, "awareness, internal resources and finance remain major barriers to decarbonisation for SMEs." (Piercy, E., Food and Drink Federation, Interview, March 2025). This digital capacity gap intersects with Roberts et al.'s (2017) analysis of rural resilience in a digital society, where they identify how rural areas face compound disadvantages in accessing and utilising digital technologies that could support transformation processes. The inability to collect and analyse energy data represents a fundamental barrier to informed decision-making about decarbonisation pathways.

Knowledge transfer mechanisms remain underdeveloped. While some positive examples exist, the retail stakeholder we interviewed “run webinars for our suppliers to share our experience and promote their decarbonisation uptake” (Anonymous retail stakeholder, Interview, April 2025). The Scotch Whisky Association described how,

SWA members collaborate on technical and regulatory matters via a network of working groups. These groups engage with regulators, policymakers, and other stakeholders, and provide forums to share best practice and monitor performance against the industry’s voluntary sustainability commitments—always within the bounds of competition law. (Scotch Whisky Association, Interview, April 2025) but noted this requires significant association infrastructure that many rural sectors lack.

Archetype Framework



Figure 1 Rural Industry Archetypes

The analysis identified five distinct archetypes capturing the heterogeneity of rural industrial sites:

1. The **“Watt”** archetype encompasses remote medium-heat industrial sites including distilleries, breweries, and small food processors. Named after James Watt, whose improvements to the steam engine revolutionised industrial heating processes, this archetype reflects facilities dependent on thermal energy for their core operations. These facilities require intermittent heat at 100-150°C and typically rely on liquid fossil fuels due to limited gas network access. As one distillery manager explained, “our

distilleries are mostly rural, using about 80 GWh per year at large sites. They run traditional inefficient pot stills, heavily reliant on gas for heat (~90% of energy)" (Baird, C., Edrington, Interview, February 2025). Key barriers include grid connection delays—"large distillers face lengthy connection timelines (to 2028 and beyond)," (Baird, C., Edrington, Interview, February 2025) and regulatory constraints on process modifications. Promising pathways include partial electrification with thermal storage. Veolia provided a successful example:

At Roseisle Distillery we use by-products to generate biogas; at a Welsh dairy lactose goes to AD to offset LNG tanker deliveries... On Islay five distilleries pool resources and are considering a common anaerobic digestion plant and shared heat, illustrating collaboration benefits. (Bevan, D., Veolia, Interview, April 2025)

2. The **"Bose"** archetype represents seasonal agro-processing facilities such as sugar refineries and vegetable processing plants. Named after Jagadish Chandra Bose, the pioneering Indian physicist who studied plant physiology and seasonal responses, this archetype captures industries intrinsically linked to agricultural cycles. Operating intensively during harvest periods, these sites face severe connection constraints. As British Sugar explained, "Sugar beet processing is seasonal, running mid-September to early March, with year-round demand managed by storage." They would require, "100-120 MW to decarbonise through electrification—about 15-20 times the amount of electricity we can currently import." The seasonal demand profile creates challenging economics: "Wind and solar don't match seasonal heat demand profiles; electricity is expensive; grid capacity is limited. AD and biomethane are four to five times the cost of natural gas" (McNaughton, P., British Sugar, Interview, February 2025).
3. The **"Ayrton"** archetype includes high-temperature rural industries like cement, glass, and ceramics manufacturers requiring temperatures exceeding 500°C. Named after Hertha Ayrton, the British engineer and inventor renowned for her work on electric arcs and high-temperature electrical phenomena, this archetype represents industries requiring extreme heat for their processes. As British Glass explained,
They use about 80% gas and 20% electricity, with container glass in Europe moving to mostly electric or hybrid furnaces but hindered in the UK by high electricity costs and challenging grid connections.

Critical timing challenges exist:

Furnace rebuilds occur every 15-20 years, requiring perfect alignment of price and connection timing. About eleven furnace rebuilds are due in the next five years, representing 30% of the sector that could lock in emissions without affordable electricity and connections.

Current pilots testing hybrid furnace technologies achieve only 30% electrification:

Hybrid furnaces can shunt load between gas and electricity, increasing electricity use overnight if prices are lower. Electric furnaces have limited flexibility and may require more, smaller units (Pearcy, P., British Glass, Interview, March 2025)

4. The **"Arkwright"** archetype covers rural SME industrial estates hosting diverse light industrial activities. Named after Richard Arkwright, who pioneered the factory system and created the template for industrial estates, this archetype embodies the collective industrial model where multiple smaller enterprises share common infrastructure. As described by Bradford Manufacturing Futures:

Bradford has about 1,200 manufacturers with 24-25,000 employees and £1.3-1.5 billion GVA. Five Clean Growth Hubs cover 70% of industrial emissions. (Calder, D., BMF Consultancy, Interview, March 2025)

Fragmented ownership creates coordination challenges, though innovative approaches show promise. Infrastructure cost-sharing opportunities exist but face barriers:

Through our inland industrial cluster project work, we have explored with DNOs a community approach for industrial sites to share infrastructure costs. Generally, DNOs have engaged on these concepts via the industrial clusters but gaining traction at a localised 'Clean Growth Hub' level to develop further is difficult. Creating a safe space for open information-sharing remains a challenge. (Pyatt, R., CR Plus, Interview, March 2025)

5. The **"Faraday"** archetype encompasses off-grid anchor sites in ultra-remote locations, including fish processing in the Northern Isles and remote timber mills. Named after Michael Faraday, whose pioneering work in electricity and electromagnetism laid the foundation for modern electrical systems, this archetype represents sites that must generate their own power solutions in isolation from national infrastructure. As Flogas explained,

LPG is used by off-gas-grid industrial users including, for example, aggregates and asphalt producers, breweries and distilleries, poultry- and livestock-rearing, and grain and cereal drying. Seasonality creates logistics challenges because LPG must be trucked in smaller volumes to dispersed sites rather than flowing through pipes. These industries are often rural/off-gas-grid and/or require direct-heat applications, making delivered LPG - or renewable liquid gases - an ideal solution where installing gas pipelines would be prohibitive and/or where electrification does not meet process needs. (Flogas, Interview, March 2025)

SGN confirmed the existence of,

off-main-grid remote gas networks supplied by LNG or LPG tankers in locations like Wick and Stornoway, serving mostly domestic customers but also small industrial users. (Thomson, C., SGN, Interview, April 2025)

Table 2 systematically compares the barriers facing each rural industrial archetype across four critical dimensions. This comparative analysis reveals how dispersed sites face not merely scaled versions of cluster challenges, but qualitatively different combinations of constraints requiring fundamentally different intervention approaches. The infrastructure and logistics barriers particularly demonstrate how rural location compounds decarbonisation challenges beyond simple distance effects.

Table 2 Comparative Barriers to Rural Industrial Decarbonisation by Archetype

Archetype	Infrastructure & Logistics	Economic & Financial	Technical & Operational	Policy & Regulatory
Watt (Remote medium-heat industrial)	- Expensive grid upgrades with 2028+ timelines - Weak rural networks designed for agriculture - Single-point vulnerabilities (one feeder = total shutdown) - Competition with agriculture for local biomass "£2.3 million connection quote with 6-year timeline"	- Steeper electricity levies vs cheaper gas - High connection costs for individual sites - Limited capital for infrastructure investment - "Could lock in emissions without affordable electricity"	- Intermittent/batch processes complicate electrification - Process regulations (e.g., pot stills for whisky) - Limited local technical support - "Traditional inefficient pot stills" required by law	- Excluded from cluster-focused programmes - Complex planning in protected landscapes - No support for electricity-based solutions - "Where's the support for just using electricity?"
Bose (Seasonal agro-processing)	- Require up to 20x current electrical capacity - Intensive but seasonal demand profile - Remote from emerging H₂ infrastructure - "15-20 years for hydrogen infrastructure"	- Challenging business case for year-round infrastructure used seasonally - Capital competition with core business - "First-mover pays" for grid upgrades - "£20 million on permits ahead of decarbonisation"	- Food-safety constraints hamper technology changes - Continuous process requirements during campaigns - Limited flexibility in process timing - Skills gaps: "need electrical, data analytics, AI skills"	- Mismatch between seasonal operations and policy timeframes - Heritage/origin designations restrict efficiency improvements - "Overlapping CCAs and UK ETS create conflicts"
Ayrton (High-temperature rural)	- No access to CO₂ pipelines or H₂ networks - Transport logistics for CCS prohibitive - Isolated from industrial cluster infrastructure - "10-12-year connection quotes for urban sites"	- "Bet the company" CAPEX levels - Alternative transport for CO₂ extremely costly - Limited access to demonstration funding - "Connection costs often in tens of millions"	- Current electric tech cannot achieve >500°C economically - Only 30% electrification achievable with hybrids - Process-critical temperature requirements - "Furnace rebuilds every 15-20 years"	- Regulatory uncertainty hampering investment - Excluded from CCUS cluster sequencing - Ambiguous long-term policy direction - "Government should consider taking domestic demand off-grid"
Arkwright (Rural SME estates)	- No gas network connectivity - Fragmented infrastructure ownership - Limited grid capacity for collective upgrades - "Initially prohibitive costs found lower on analysis"	- Stringent 2-3-year payback requirements - No anchor tenant to drive investment - Limited access to finance - "Cost of new electric equipment is major hurdle"	- Lack of energy monitoring/data - No dedicated energy management - Diverse processes prevent standardisation	- Fall below thresholds for support programmes - Planning delays for shared infrastructure - No aggregation mechanisms - Need "safe space for information sharing"

			- "Don't have someone thinking about energy 24/7"	
Faraday (Off-grid anchor)	- Complete diesel dependence for heat & power - Days away from spare parts/engineers - No grid connection option - Extreme transport costs for fuel - "LPG must be trucked to dispersed sites"	- Must bear full energy system costs alone - Extreme logistics inflate all costs - No economies of scale - "bioLPG costs about three times more than fossil LPG"	- Skills gaps for advanced technologies - Risk of stranded assets if tech fails - Limited redundancy options - "Certain applications need direct flame"	- Minimal policy recognition - Standard regulations do not account for isolation - No specific support mechanisms - "Government should remain technology neutral"

The differentiated barriers revealed in Table 2 underscore the importance of place-based interventions that leverage local assets and address region-specific constraints. Local energy systems could particularly benefit 'Arkwright' estates through shared infrastructure investment, whilst 'Faraday' sites might anchor off-grid renewable microgrids. The success of Bradford Manufacturing Futures' Clean Growth Hubs demonstrates how local coordination—creating 'mini-clusters'—can partially overcome the disadvantages of dispersion. These local approaches require supportive frameworks that enable peer-to-peer energy trading, simplified grid connection processes for co-located sites, and aggregated participation in flexibility markets.

Discussion

Theoretical Implications

This research contributes to industrial decarbonisation literature by providing empirical evidence of how spatial factors create distinct transition challenges beyond simple scale considerations. The archetype framework extends existing typological approaches (Butler, T et al., 2023) by incorporating operational characteristics, spatial contexts, and infrastructure access into a comprehensive categorisation system tailored to rural contexts. This differentiated approach aligns with Tödtling and Trippl's (2005) argument against "one size fits all" regional innovation policies, demonstrating how place-specific characteristics require tailored intervention strategies. As demonstrated in Table 2, these spatial factors manifest differently across archetypes, with infrastructure barriers particularly acute for 'Faraday' sites facing complete grid isolation, while 'Arkwright' sites struggle more with fragmented decision-making and policy blind spots. This approach aligns with Martínez-Reyes et al.'s (2025) identification of regional typologies as an established method for understanding differential transition dynamics, particularly for peripheral regions that face unique challenges and must leverage social innovation to avoid being left behind.

The findings challenge assumptions in current decarbonisation strategies that treat dispersed sites as scaled-down versions of clustered industries. Geels' (2019) Multi-Level Perspective on socio-technical transitions emphasises how incumbent regimes (in this case, centralised infrastructure systems) create path dependencies that disadvantage niche innovations. Rural industries face not just technical challenges but systemic regime barriers that require coordinated action across multiple levels. This aligns with recent research by Rattle et al. (2024) recognising that approximately 50% of industrial emissions originate outside established clusters, highlighting the importance of targeted strategies for dispersed sites. Rosenow et al. (2025) reinforce this finding through their comprehensive European analysis, demonstrating that the policy gap for industrial electrification is particularly acute for dispersed sites, which face compound disadvantages from both infrastructure limitations and policy frameworks designed primarily for clustered industries. The place-based nature of these challenges

resonates with Sovacool et al.'s (2024) emphasis on industrial decarbonisation as a fundamentally place-based process requiring tailored strategies for different locations. The identified 14-fold disparity in electricity versus gas policy costs represents a structural barrier to electrification that transcends individual site characteristics. This finding supports calls for comprehensive energy pricing reform as a prerequisite for industrial decarbonisation, particularly where alternative infrastructure-dependent solutions remain geographically inaccessible. As Gailani and Taylor (2025) note, planning for network expansion is often overlooked in decarbonisation debates, yet without addressing these infrastructure and pricing disparities, rural industrial transition will remain economically unviable. Real-world collaboration attempts reveal systemic challenges. Ownership changes and strategic misalignment can derail collaborative decarbonisation efforts, challenges amplified when potential partners are geographically dispersed. The failure of such initiatives reflects the difficulties in achieving what Chertow and Ehrenfeld (2012) term "self-organizing" industrial symbiosis systems. While industrial ecology theory suggests that firms should naturally collaborate to exchange resources and reduce waste, our findings demonstrate that rural contexts lack the "kernels" of coordination—anchor tenants, shared infrastructure, or institutional mechanisms—that enable such symbiotic relationships to emerge and persist.

Practical Implications

ESCO models emerge as particularly promising for addressing multiple barriers simultaneously. By transferring technology risk and capital requirements to specialists, ESCOs can overcome the capacity constraints identified across multiple archetypes (see Table 1), while providing necessary technical expertise. ADE (Savoie, J. and Wade, J., 2025) similarly identifies ESCO models as particularly promising for addressing the multiple barriers facing rural industrial sites, especially for 'Watt,' 'Arkwright,' and 'Faraday' archetypes where internal capabilities are most limited.

The research highlights the potential of aggregator-based approaches to achieve collectively what individual rural sites cannot accomplish alone. Demand aggregation for technology procurement, knowledge sharing networks, and flexibility aggregation for market participation all offer mechanisms to overcome scale disadvantages while maintaining business autonomy. Successful examples include the retail stakeholder's approach of running webinars, and Bradford Manufacturing Futures' Clean Growth Hubs—mini-clusters.

The upcoming Regional Energy Strategic Planning (RESP) framework presents crucial opportunities for place-based solutions that recognise the distinct characteristics of rural industrial areas. As SGN emphasised,

Collaboration gaps exist between gas and electricity networks; coordinated planning via NESO and Regional Energy Strategic Planners is vital to align decarbonisation efforts across sectors and regions' (Thomson, C., SGN, Interview, April 2025).

With Distribution Network Operators formally tasked with convening stakeholders, RESPs could facilitate local industrial clusters and microgrids that aggregate demand across dispersed sites, creating viable investment cases for infrastructure upgrades.

This place-based approach could enable co-location strategies where rural industries share not just infrastructure costs but also locally-generated renewable energy. For instance, the 'Arkwright' archetype industrial estates could develop as local energy communities, with shared battery storage and demand response capabilities. Similarly, 'Watt' archetype distilleries could anchor local renewable energy projects, absorbing excess generation whilst providing grid services. As recommended by ADE (Savoie, J. and Wade, J., 2025), RESPs should specifically identify where co-location and microgrid systems represent optimal solutions for dispersed industrial sites, with targeted policy support for the investment required. This local coordination could transform infrastructure disadvantages into opportunities for innovative, community-scale energy systems that benefit both industry and surrounding rural communities.

Technology-specific opportunities emerge from the interviews. Ultra-high-temperature thermal energy storage systems are being developed that can displace fossil fuels in industrial thermal processes through co-firing with gas, enabling gradual emissions reduction whilst managing costs. A pilot installation at a distillery demonstrates the practical application of this approach. Similarly, flexibility potential exists:

Demand-side flexibility is an enormous opportunity in rural Scotland, where renewable generation exceeds network export capacity. Allowing distilleries to absorb surplus electricity could decarbonise heat, reduce curtailment, and avoid costly interconnectors. (Anonymous technology provider, RIDES Project Interview, 2025)

Policy Recommendations

First, energy pricing reform must address the current disincentive for electrification. Multiple stakeholders emphasised this urgency, with recommendations to “remove electricity levies and shift to general taxation” (Hardy, L., Green Alliance, Interview, March 2025) and recognition that “Levies must be reallocated or removed, network upgrades subsidised or socialised, and carbon prices raised to make electrification viable” (Anonymous technology provider, Interview, February 2025). Both Green Alliance (Hardy, L and Herman, K. S, 2025) and ADE (Savoie, J. and Wade, J., 2025) emphasise the urgent need for an Electrification Business Plan that would put electrification on par with hydrogen and CCUS support, addressing the current policy bias that disadvantages dispersed sites.

The urgency of these reforms has been partially acknowledged in the Modern Industrial Strategy's proposals for a British Industrial Competitiveness Scheme and development of CPPAs. However, these measures fall short of the comprehensive reform needed. The scheme's narrow eligibility and the voluntary nature of CPPAs mean most dispersed sites will continue facing prohibitive electricity costs. The discontinuation of the IETF without replacement particularly disadvantages dispersed sites that lack access to cluster-focused funding streams.

The need for comprehensive policy reform extends beyond the UK context. Rosenow et al. (2025) identify significant gaps in European industrial electrification policy, particularly the absence of dedicated support mechanisms for dispersed sites and the over-reliance on cluster-

focused initiatives. Their systematic analysis of policy instruments across ten European countries reveals that most nations lack the integrated policy mix necessary to drive industrial electrification at scale.

Second, dedicated support mechanisms for dispersed sites should complement cluster-focused programmes. The differentiated barriers shown in Table 1 highlight the need for archetype-specific support mechanisms—for instance, aggregation support for ‘Arkwright’ estates versus infrastructure investment for ‘Faraday’ sites. As Green Alliance noted,

No specific funding mechanisms exist to support rural dispersed electrification. Existing schemes are complex and fragmented... Simpler, technology-neutral incentives are needed to provide certainty and attract investment. (Hardy, L., Green Alliance, Interview, March 2025)

Third, demonstration programmes showcasing viable pathways for each archetype could address knowledge gaps and risk perception barriers. Government-supported pilots demonstrating technical and economic viability would provide the precedents that risk-averse rural industries require before committing to transformation. As British Sugar noted, “Best-case scenario: progressive adoption of emerging technologies with calculated risk-taking leads to longer-term payback” (McNaughton, P., British Sugar, Interview, February 2025).

Fourth, regulatory frameworks should be reviewed to identify where heritage and planning restrictions unnecessarily impede efficiency improvements. The Scotch Whisky Association’s advocacy for reclassifying distillery by-products from waste to enable biogas production exemplifies needed regulatory evolution.

Infrastructure investment approaches require fundamental reform. Multiple stakeholders advocated for socialised network upgrade costs and for regulatory reforms to enable anticipatory investment:

Ofgem’s historic opposition to anticipatory investment slows urgent network upgrades. Rapid decarbonisation requires strong regulatory incentives and anticipatory infrastructure investment (Anonymous academic expert, Interview, February 2025)

Finally, implementing a place-based just transition framework, as proposed by Lai et al. (2025), could ensure that rural industrial decarbonisation proceeds with genuine community engagement and local fairness in benefits distribution. This approach emphasises that not only where decarbonisation happens but also how it is implemented—with local buy-in and equity considerations—is key to an effective transition that builds social licence in host communities.

Limitations and Future Research

This research acknowledges several limitations. The sample size of 17 stakeholder organisations, while providing rich qualitative insights, cannot claim statistical representativeness. The three-month timeframe limited the depth of engagement possible with each stakeholder category. Additionally, the research focused primarily on barriers and pathways rather than quantitative assessment of costs and carbon reduction potential.

Future research should expand the sample to include more diverse rural industrial sectors and geographical regions. Quantitative analysis of infrastructure upgrade costs and

decarbonisation potential by archetype would complement these qualitative findings. Longitudinal studies tracking implementation of different decarbonisation pathways would provide valuable evidence on effectiveness. Investigation of international approaches to rural industrial decarbonisation could identify transferable lessons. Countries with different energy pricing structures or infrastructure development models may offer insights into alternative pathways. Comparative analysis of regions successfully supporting dispersed industrial transitions would be particularly valuable.

Conclusions

This research demonstrates that rural industrial decarbonisation faces distinct challenges requiring targeted approaches beyond current cluster-centric policies. The archetype framework provides a foundation for developing interventions tailored to the specific constraints and opportunities of different rural industrial contexts.

The findings reveal that infrastructure limitations, economic barriers, policy misalignments, and capacity constraints combine to create systematic disadvantages for rural industries in the net-zero transition. Concrete examples from our interviews illustrate the scale of these challenges: £2.3-60 million grid connection costs with 5-10-year timelines, a 14-fold electricity price penalty compared to gas, and failed collaboration attempts when ownership structures change. Table 2's systematic comparison of these barriers underscores that no single policy intervention can address the diverse challenges facing rural industries. As Rattle et al. (2024) emphasise, with nearly half of UK industrial emissions coming from dispersed sites, addressing these challenges is not a peripheral concern but central to achieving national decarbonisation goals. The identification of archetype-specific pathways and crosscutting solutions offers routes forward that could enable these vital economic contributors to decarbonise while maintaining their operations.

Achieving the UK's net-zero targets requires recognising that meaningful climate action must extend beyond industrial heartlands to encompass the full diversity of the productive landscape. With 23% of businesses and 3.6 million jobs depending on rural industries (DEFRA, 2022), their successful transition is not merely an environmental imperative but an economic and social necessity. As O'Sullivan et al. (2020) warn, without proactive policy intervention, rural areas risk becoming trapped in a peripheral position despite their potential contributions to the clean energy transition.

The archetype-based approach developed here provides policymakers and industry leaders with a framework for understanding and addressing this diversity. By implementing targeted interventions including ESCO models, pricing reforms, aggregation mechanisms, and demonstration programmes, rural industries can transition from high-carbon operations to become part of the net-zero solution. Crucially, as Lai et al. (2025) argue, this transition must proceed with attention to local justice concerns and community engagement to build the social licence necessary for successful transformation.

The urgency of addressing these challenges is underscored by recent analyses showing that without significant policy intervention, the UK risks losing international competitiveness. As

Green Alliance (Hardy, L and Herman, K. S, 2025) notes, the UK currently has the highest industrial electricity prices across all IEA countries, with prices 46% higher than the IEA median, creating a significant disadvantage for UK industry. This challenge is not unique to the UK; Rosenow et al. (2025) demonstrate that inadequate policy frameworks for industrial electrification persist across Europe, with particular gaps in support for the dispersed sites that our research shows face the most acute barriers.

The path forward requires coordinated action recognising rural industries not as problematic outliers but as integral components of a sustainable industrial future. Their geographic dispersion, while creating challenges, also positions them as potential anchors for distributed renewable energy systems and circular economy approaches. Their integration into local energy systems through microgrids, industrial symbiosis, and community energy projects could catalyse broader rural economic development whilst addressing decarbonisation challenges. This requires a fundamental shift from centralised to distributed energy planning, recognising rural industrial sites not as isolated energy consumers but as potential anchors for local clean energy economies. With appropriate support frameworks that address their unique challenges, rural industries can contribute meaningfully to the UK's net-zero ambitions whilst maintaining their vital economic and social roles in rural communities.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT and Claude in order to assist in outlining the paper. After using these tools, the author(s) reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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