Quantifying Energy Use and Greenhouse Gas Emissions in UK Food and Drink Manufacturing Facilities

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Quantifying energy use and greenhouse gas emissions in UK food and drink manufacturing facilities

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ABSTRACT

Despite the food and drink manufacturing sector being one of the United Kingdom's (UK) largest manufacturing industries and a significant consumer of industrial energy, there remains limited facility-level evidence on energy use and greenhouse gas (GHG) emissions, particularly among small and medium-sized enterprises (SMEs). This study assesses energy use and GHG emissions across 12 food and drink manufacturing companies in South Yorkshire, UK, a region with a large manufacturing cluster. Data was collected from companies through surveys and informal interviews, with energy use determined from utility bills or calculated from equipment power over operating hours. Scope 1 and 2 GHG emissions were estimated based on the energy equivalent of annual electricity, natural gas, and petroleum-based heating fuels, which is provided by the UK government. The analysis revealed that the average energy mix for participating food and drink manufacturers in South Yorkshire relied approximately 20 percentage points higher on natural gas than the national industry average. Cumulative energy use totaled 34.64 GWh, with corresponding GHG emissions of 7152 t CO_2e. One ready meal company had a disproportionately high share of energy use and emissions due to its much larger size. However, the significance of SMEs was also shown when aggregated. By quantifying energy use and GHG emissions, this study provides baseline data to support measurable sustainability targets, identifies opportunities for decarbonisation intervention, and informs both corporate decision-making and policy development in the food and drink manufacturing sector.

1. Introduction

The global food system faces increasing pressure to deliver 60 percent more food by 2050 while meeting the social and environmental demands of the twenty-first century (Ladha-Sabur et al., 2019). Achieving the global decarbonisation mandate outlined in both the Paris Agreement and Sustainable Development Goals cannot be accomplished without accelerated action to transition food systems (Food and Agriculture Organization of the United Nations, 2025). Particular attention must be directed toward mitigating greenhouse gas (GHG) emissions and reducing energy consumption, as the food supply chain is responsible for 32 percent of global GHG emissions and 30 percent of energy use (Food and Agriculture Organization of the United Nations, 2025).

The United Kingdom's (UK) food system mirrors global emissions patterns, responsible for 30 percent of national GHG emissions, producing 129.5 Mt CO2e annually (WRAP, 2024). Energy use contributes significantly to sector emissions, especially within the food and drink manufacturing stage, which requires 30.31 TWh of energy annually, approximately double the energy requirement of primary agriculture (Department for Environment, Food and Rural Affairs, 2025a). The significant energy demands of the food and drink manufacturing industry have created both financial and environmental challenges (Henning et al., 2021). In 2026, the Food and Drink Federation reported that “many of our companies are facing 400-500% rises in their energy bills,” highlighting the continuing importance of energy reduction measures for businesses (The Food and Drink Federation, 2026). There has been an effort directed towards reducing energy consumption through fuel switching and investment in energy-efficient equipment, resulting in a 2.02 TWh decrease in energy use since 2016 (Chowdhury et al., 2018; Ladha-Sabur et al., 2019). Although considerable, the UK has legally mandated net-zero emissions by 2050, which will be unattainable without accelerating decarbonisation transitions in food and drink manufacturing (Stewart et al., 2025).

There are existing government reports aimed at assessing energy use and carbon emissions within their respective jurisdictions. The Energy

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Efficiency & Conservation Authority contracted research to determine energy use in the New Zealand food and drink manufacturing industry. Major findings included that most energy was sourced from fossil fuels, boilers were the largest user of energy, and only 35 percent of companies measured their GHG emissions (Krishnan et al., 2022). Meanwhile, the UK government only releases semi-regular aggregated data on total energy use and energy type for the sector (Department for Environment, Food and Rural Affairs, 2025a). While national-level statistics provide important insights, there remains limited facility and cluster-level analysis of energy demand and GHG emissions within UK food and drink manufacturing.

Most academic studies focused on evaluating energy consumption and associated GHG emissions in food and drink manufacturing typically research one product type. For instance, research on the energy consumption of bread products has been undertaken by Therkelsen et al. (2014), Carlsson-Kanyama (2000), El-Adly et al., 2015, Jalilian et al. (2020), and Kheiralipour and Sheikhi (2021). Meanwhile, Schmidt Rivera & Azapagic (2019) and Ramírez et al. (2006) evaluated energy use in the ready-meal category. Although these studies offer useful insights into energy consumption, understanding energy use in the food sector requires looking beyond individual product types and examining entire manufacturing clusters. These clusters are geographic areas with a high concentration of food and drink processors, suppliers, services, and shared infrastructure. Measuring and analysing energy use at this level enables a more accurate assessment of regional environmental impacts and supports meaningful comparisons across subsectors.

The present study contributes to the fields of energy management, sustainable development, and industrial research. The primary objective is to quantify energy consumption and associated GHG emissions across a sample of food and drink manufacturing facilities within the South Yorkshire industrial cluster. By doing so, it seeks to deepen understanding of the environmental impact of food and drink manufacturing in Northern England, a region that has received limited research attention. This is due to sustainability research in the food manufacturing industry being in its infancy, with data gaps resulting in the sector being named the 'missing middle' of the supply chain (Marshall et al., 2021; Veldhuizen et al., 2020). There has been limited research focused on energy consumption within regional manufacturing clusters that encompass various subsectors and small and medium enterprises (SMEs). Examining energy consumption on this scale offers a comprehensive insight into the distribution of energy demand within a local industrial ecosystem and underscores the aggregate environmental impact of SMEs in the food and drink manufacturing sector.

By mapping cluster energy demand and GHG emissions, this study provides evidence to support measurable sustainability targets, identifies opportunities for decarbonisation intervention, and informs both corporate decision-making and policy development in the food and drink manufacturing sector.

2. Methodology

2.1. Case study

The companies studied for this paper are based in South Yorkshire, England. The food and drink manufacturing sector is a critical industry in England, with the industry being the UK's largest manufacturing sector, employing nearly 500,000 people and contributing £130 billion in domestic sales (The Food and Drink Federation, 2025). The South Yorkshire region is one of the prominent food and drink manufacturing clusters in England, generating £434 million in economic output annually while providing 9000 jobs across 170 businesses (Sheffield Hallam University, 2025). It covers about 1552 square kilometers and includes Sheffield, Rotherham, Barnsley, and Doncaster (South Yorkshire Mayoral Combined Authority, 2025).

2.2. Research design

A mixed methods approach was applied, relying on surveys, interviews, site visits, and energy auditing. Ethics approval was provided by Sheffield Hallam University to collect original data through the University Research Ethics Committee. Participants provided consent to participate and for their anonymized data to be used for publication. This cross-sectional research evaluated 12 food and drink manufacturing companies operating in South Yorkshire in 2025.

2.2.1. Data collection

To gather data on energy consumption and operational practices, a structured survey was developed. The survey comprised 12 question topics: feedstock supply, products, utility, human resources, logistics, equipment, packaging, detergent, waste and management, water consumption, energy consumption and carbon emissions. Food and drink manufacturing companies were initially contacted for participation via phone and email, using convenience sampling with publicly available contact information. Corporate contact information was found using local government data, trade association websites, and business directories available online. Overall, over 200 companies were contacted in the South Yorkshire region to participate in this study. Of the 200, the response rate was low, with many companies not replying to emails, phone calls, or voice mails. Challenges associated with this recruitment method included companies being incorrectly listed as food and drink manufacturers, outdated contact information, the inclusion of businesses no longer operating, and businesses located outside the South Yorkshire region.

Of those that did answer, larger businesses were more willing to initially engage, requesting questionnaires. However, many of the firms never followed up afterwards. Small businesses were quicker to reject participation from the get-go. Reasons for rejection included time, staffing, resource constraints, and lack of trust in academic or government institutions. Based on 12 positive responses, the research team conducted site visits to distribute and explain the data collection process. Companies were then given time to complete and return the survey independently. In most cases, the submitted questionnaires contained substantial gaps, requiring follow-up visits by the research team. During these visits, a research engineer manually collected missing technical data, including equipment types, model specifications and power ratings. Additional information that was unavailable through company records was obtained through informal interviews with company representatives.

2.2.2. Participants

Sample size was anticipated to be a challenge given historical trends of low participation in previous food and drink academic research. Other sustainability-related studies, including Ahmad and Wong (2019) sampled 1 firm, Frau et al. (2022) sampled 6 firms, and Gimenez-Escalante et al. (2020) sampled 4 firms. Across these studies, low sample size was attributed to high levels of non-response rates, specific inclusion criteria, and the inability to find contact information for widespread participation.

Food and drink manufacturing facilities agreed to participate in this research if they were able to remain anonymous. For this reason, each company is labelled by the main product of which they produce. Participants represent different subsectors in the region, such as baking, dairy, brewing, confectionary, and ready-meal production, enabling analysis across diverse manufacturing activities within the South Yorkshire cluster.

This sample size represents approximately 7.1 percent of the registered food and drink manufacturing companies in South Yorkshire and, therefore, cannot be considered statistically representative of the region. As a result, the findings should be interpreted as indicative rather than definitive. While they cannot be generalised for the region, they provide valuable insights into the trends, challenges and opportunities experienced by participating businesses and offer a useful foundation for future research. The participating companies also exhibited substantial variation in annual energy consumption, reflecting differences in company size, production capacity and manufacturing processes. Therefore, caution should be exercised when extrapolating the results.

The participants of this study are predominantly SMEs, which is reflective of the composition of the food and drink manufacturing sector in South Yorkshire. Small manufacturers are defined as having less than 50 employees with no more than £10 million in annual turnover, while medium manufacturers have less than 250 employees with no more than £57 million. Most of the food and drink manufacturers in England and South Yorkshire are SMEs, representing 98.6 percent of the industry (Department for Environment, Food and Rural Affairs, 2025b).

Even among the 12 participating companies, full data collection often required 2-3 emails, phone calls, and site visits. Data collection took over 1 year to complete, mainly due to very low response rates and incomplete data. This low response rate reflects the practical challenges often encountered when collecting operational data from manufacturing companies (see Table 1).

2.3. Energy use calculation

Energy data for this study were collected using company energy bills, reflecting wider industry practices, as it is estimated that only 36 percent of UK manufacturing firms monitor energy use, and 85 percent of those that do rely on energy bills for tracking consumption (Department for Energy Security & Net Zero, 2023). Energy bill usage is a well-known strategy of calculating energy consumption, either through monthly or quarterly bills (Henning et al., 2021; Jagtap et al., 2022). Smart meters are also a common form of collecting detailed energy consumption data, including from different sources like electricity and natural gas (Henning et al., 2021). Separate sub-metering of individual equipment was not available in the participating companies. Therefore, the energy calculations were mainly based on facility-level utility bills and other operational information provided by the companies. For 10 of the 12 participating companies, annual energy consumption was obtained directly from utility bills. For the remaining two companies, annual energy consumption was calculated from equipment power and reported operating hours because annual consumption records were not available. Table 2 provides the energy and GHG inventory for this research.

For companies missing bills, annual electricity consumption of each item of equipment was estimated by multiplying the equipment power by its annual operating hours, as shown in Equation (1):

$$E_{i,annual} = P_i \times h_i \quad (1)$$

where $E_{i,\ annual}$ is the estimated annual electricity consumption of equipment i (kWh/year);

P_i is the equipment power used in the calculation (kW);

h_i is the annual operating time of equipment i (hours/year).

Where necessary, the reported operating time was converted to annual operating hours using the operating schedule provided by the company. The estimated annual electricity consumption of all equipment was then summed to calculate the total annual equipment-based electricity consumption for each facility.

The values were collected from the equipment labels during site visits and were not taken from the nameplates of individual electric motors. For some equipment, both nominal power and practical power values were stated on the label. In these cases, the practical power value was used in the calculation as it represented the equipment power during normal operation more closely than the nominal values. This approach assumes that the reported equipment power and operating schedule are representative of normal operating conditions during the year. This method was only applied when measured annual energy consumption data were not available.

For the two companies where this calculation method was used, the calculated energy consumption was checked against the monthly energy costs reported by the companies. The calculated consumption was converted to an expected cost using the electricity and gas tariffs applied by the companies, and the results were consistent with the monthly expenditures reported by both companies. This comparison was used as an additional check on the calculated energy values. However, as these values are calculated instead of directly measured, some difference from actual energy consumption may still happen due to changes in operating conditions and equipment load.

Table 2
Energy and GHG inventory.

Energy Source	GHG Scope Classification	Activity Data	Emissions Factors	Applicability
UK electricity	Scope 2	Utility bills or equipment-based estimates	0.177 kg CO_2e/kWh	10 of 12 companies supplied utility bills while the remaining 2 relied on equipment-based estimates
Natural gas	Scope 1	Utility bills or equipment-based estimates	0.185 kg CO_2e/kWh	9 of 12 companies used natural gas. Of the 9, only 1 was relied on equipment-based estimates
Mineral diesel	Scope 1	n/a	2.66 kg CO_2e/L	No company used mineral diesel
Fuel oil	Scope 1	Fuel purchase	3.175 kg CO_2e/L	1 of 12 companies used fuel oil
Refrigerants	Scope 1	Refrigerant purchase, maintenance or equipment records	Dependent on the refrigerant type	Company-specific activity data were unavailable; therefore, refrigerant emissions were not quantified

*All emissions factors were based on the UK Government GHG Conversion Factors for Company Reporting (Department for Energy Security & Net Zero, 2025).

2.4. Scope 1 & 2 GHG emissions calculation

Annual Scope 1 and Scope 2 GHG emissions released from natural gas, electricity, and petroleum-based consumption was performed manually. For electricity, the conversion factors used in this analysis apply to the electricity supplied to the grid that companies purchase.

Table 1
Food and drink manufacturing participants.

Product	Confectionary	Coffee Roaster	Artisanal Bread 1	Artisanal Bread 2	Rice	Potted Meat	Craft Beer 1	Craft Beer 2	Ice Cream	Dairy	Ready Meals 1	Ready Meals 2
Employees	0-20	0-50	0-10	0-10	0-10	0-50	0-50	0-10	0-10	0-10	+1000	50-100

These factors represent the emissions associated with electricity generation but do not account for emissions from transmission and distribution losses. Similarly, for natural gas, the emission factors applied are based on combustion emissions only, reflecting the direct carbon release within the factory premises. These values exclude upstream emissions, such as those from the extraction, refinement, and transportation of primary fuel. It is important to note that, although energy-related GHG emissions account for most of the Scope 1 and Scope 2 emissions in food and drink manufacturing, non-energy emission sources such as refrigerant leakage and on-site wastewater treatment can also contribute to overall emissions. None of the participating companies operated on-site wastewater treatment.

Information on refrigerant type, charge, recharge, servicing and potential leakage was not available from the participating businesses. Foster et al. (2023) also highlights that limited data are available on refrigeration use and refrigerant leakage within the UK food and drink manufacturing industry. Data from 2010 estimated that direct emissions from the UK food and beverage manufacturing sector were approximately 0.89 $MtCO_2e$, comprising emissions from hydrofluorocarbons and hydrochlorofluorocarbons associated with refrigeration systems, including blast freezers and chillers (Foster et al., 2023). Although this represents a substantial historical estimate, legislation has since phased out all use of hydrochlorofluorocarbons and introduced measures to reduce hydrofluorocarbons through controls on equipment, leak prevention and servicing (United Kingdom Government, 2024). As a result, although refrigerant leakage remains a likely material source of Scope 1 emissions, current emissions may be lower than the historical estimate. As refrigerant emissions could not be quantified for the participating businesses, their exclusion should not be interpreted as evidence that emissions were zero. Instead, refrigerant emissions represent an unquantified source of Scope 1 emissions and a limitation to the completeness of the reported inventory. The potential significance of this source is likely to vary between businesses depending on the size and type of refrigeration systems used, the refrigerant type and associated leakage rates.

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. As a result, the actual carbon footprint is higher when T&D losses and WTT are included, which is often the case in software-based analyses like LCA tools.

The GHG emission factors presented in Table 3 were obtained from the UK Government Greenhouse Gas Reporting Conversion Factors 2025 (Department for Energy Security & Net Zero, 2025). The factors are reported as kilograms of carbon dioxide equivalent (kg CO_2e) per unit of energy or fuel consumed. The values have been presented using an appropriate number of significant figures. The petroleum fuel type was identified from the information provided by each participating company, including the stated fuel name, its use within the facility, and available operational records. Mineral diesel was identified where the fuel was reported for use in diesel generators, while fuel oil was identified where it was reported for heating applications. The reported fuel type was then matched with the corresponding category in the UK Government Greenhouse Gas Reporting Conversion Factors 2025, and the relevant emission factor was applied. To preserve anonymity, the manuscript reports only the fuel category and its application and does not link the fuel information to any named company or identifiable site.

Table 3
UK Government GHG emission factors used in this study.

Resource	Quantity	Unit
Electricity	0.177	kg CO_2e/kWh
Gas	0.185	kg CO_2e/kWh
Mineral Diesel	2.66	kg CO_2e/L
Fuel oil	3.175	kg CO_2e/L

Natural gas consumption data were obtained either directly from company utility bills in kWh or converted from billed gas volume (m^3) to kWh using the standard UK gas billing methodology. In the UK, gas suppliers convert metered gas volume to energy units for billing using the calorific value of the gas (Office of Gas and Electricity Markets, 2014). The UK Government GHG Conversion Factors methodology states that natural gas consumption reported in kWh by UK suppliers is generally calculated on a gross calorific value basis. Therefore, the gross calorific value (GCV) emission factor was used for natural gas calculations, unless the supplier specifically reported the consumption on a net calorific value basis (Department for Energy Security & Net Zero, 2025).

3. Results

3.1. Corporate response

Surveying the 12 companies exposed a substantial knowledge and data gap regarding corporate information. Every participating company was unable to provide information for at least one of the twelve question topics, with most leaving multiple sections incomplete because data had not been collected or was not readily accessible. For example, several companies were unable to identify the power ratings or model specifications of key pieces of equipment, requiring researchers to conduct on-site inspections to collect the necessary information. Furthermore, only two participating companies had an existing estimate of their GHG emissions, demonstrating that carbon accounting remains uncommon among the SMEs included in this study. This lack of baseline data limits companies' ability to understand their current resource use and environmental performance. This was directly evidenced by companies' limited understanding of their own energy hotspots and the associated opportunities for improving energy efficiency.

Where essential data was missing from surveys responses, the researchers conducted informal interviews and site visits to develop a more comprehensive understanding of the companies' equipment, operations and environmental performance. These interactions revealed that many manufacturers had limited awareness of energy efficiency opportunities within their own facilities. Most participants were unable to identify their principal energy hotspots or areas where operational improvements could reduce energy consumption and associated emissions. However, after receiving individualised audit results and recommendations, several companies contacted the research team to learn more about the identified energy-saving opportunities and to seek advice on potential next steps. This response suggests that the primary barrier was not a lack of willingness to improve, but rather a lack of access to the information, technical expertise and resources needed to identify and implement energy efficiency measures.

3.2. Energy mix

The makeup of energy sources that contribute to energy use is known as the energy mix, which provides insights into national energy security and differing emissions. Fig. 1 compares the energy mix of research participants of this study with the energy mix of the entire UK food and drink manufacturing industry in 2023 (Department for Environment, Food and Rural Affairs, 2025).

The energy mix of the participating companies shows a similar overall pattern to the UK food and drink manufacturing sector, with natural gas being the largest energy source. However, natural gas accounted for approximately 77.6 percent of energy use in the study sample compared with 57.9 percent in the UK food and drink manufacturing sector in 2023, a difference of approximately 20 percentage points. This comparison relates to the participating companies and should not be considered representative of the whole South Yorkshire food and drink manufacturing sector. High natural gas consumption has important implications, including higher GHG emissions

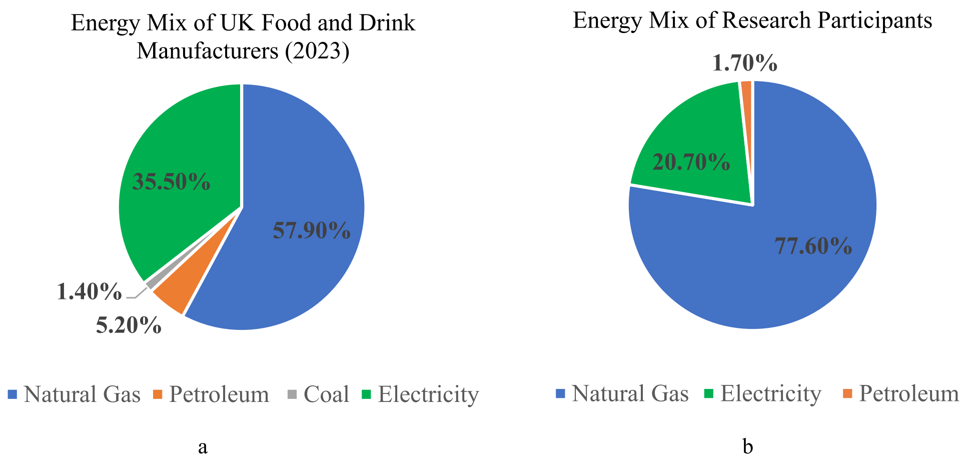

Fig. 1. Fig. 1a demonstrates the energy mix of the entire UK food and drink manufacturing industry in 2023, as provided by Department for Environment, Food and Rural Affairs (2025a). Fig. 1b provides the energy mix of the 12-research participants of this study.

relative to electrified systems, continued reliance on lower-cost fossil fuels, and the ongoing use of older, less energy-efficient machinery.

3.3. Total energy consumption

Fig. 2 demonstrates annual energy consumption by the research participants. Logarithmic scaling is used on the y-axis in all figures due to the wide spread of values across sites. For clearer presentation, numerical values are not displayed on the figure. The exact annual energy consumption and corresponding GHG emission values for each participating company are presented in Table 4.

The aggregate annual energy consumption for the 12 manufacturers is 34.64 GWh, which shows that a considerable amount of industrial energy demand is present in the food and drink cluster in South Yorkshire. One large manufacturer contributes 32.51 GWh due to their size and industrial intensity, whereas the remaining contribution comes from a diverse group of SME manufacturers with less yet remarkable energy needs. For this reason, Ready Meals 1 was interpreted separately in some parts of the discussion.

3.4. Scope 1 & 2 GHG emissions

As this research focused on Scope 1 and 2 emissions resulting from energy consumption, annual GHG emission trends reflect energy use. Fig. 3 compares annual GHG emissions across the participating companies. A logarithmic scale is used on the y-axis due to the wide range of GHG emissions across the companies, while the exact values are provided in Table 4. In total, 7152 t CO_2e in annual emissions are emitted from Scope 1 and 2 for these 12 companies. Ready Meals 1 is responsible for 6708 t CO_2e of these emissions. Fig. 3 demonstrates corporate Scope 1 and 2 GHG emissions while Table 4 shows the annual energy consumption and GHG emissions for participating companies.

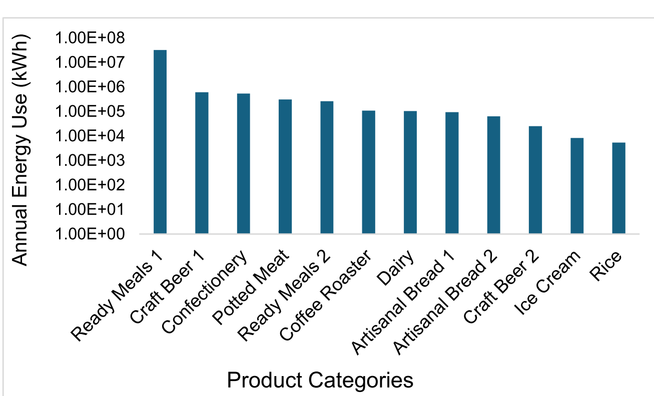

Fig. 2. Total annual energy use from 12 food and beverage manufacturing firms.

Table 4
Annual energy consumption and GHG emissions of the participating food and drink manufacturing companies.

Product category	Annual energy use (kWh)	Annual GHG emissions (kg CO_2e)
Ready Meals 1	32,506,814	6,708,000
Craft Beer 1	613,560	168,530
Confectionery	537,724	99,331
Potted Meat	308,557	55,143
Ready Meals 2	264,285	47,149
Coffee Roaster	108,388	19,858
Dairy	103,992	18,406
Artisanal Bread 1	93,355	16,973
Artisanal Bread 2	63,814	11,682
Craft Beer 2	25,191	4459
Ice Cream	8340	1476
Rice	5425	960

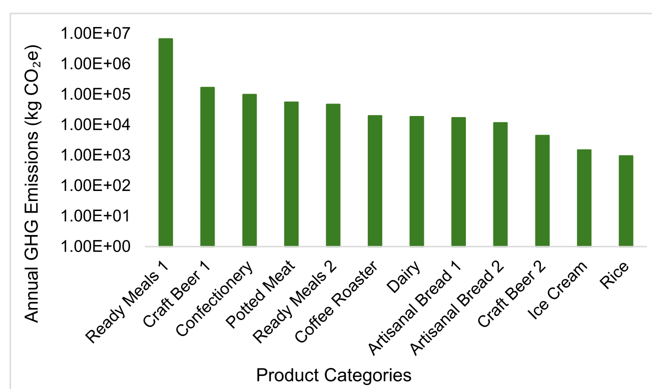

Fig. 3. The annual GHG emissions for 12 food and drink manufacturers from electricity and fuel use (Scope 1–2 only).

Since these 12 firms represent 7.1 percent of the registered food and drink manufacturers in South Yorkshire, the reality is that the sector's total contribution to regional emissions is much higher, which requires focused support for decarbonisation. If Ready Meals 1 is removed as an outlier, the average GHG emissions from energy consumption for this group of businesses is approximately 40, 360 kg CO_2e annually. These findings are significant, as they demonstrate both the disproportionate environmental impact of large manufacturers and the substantial aggregate contribution of large clusters of SMEs. This highlights the importance of tailoring decarbonisation strategies to address all sizes of food and drink manufacturing.

4. Discussion

4.1. Contextualising the findings

This study contributes to the existing literature in two important ways. First, it provides one of the few facility-level cross-sectional assessments of energy use, GHG emissions and resource efficiency in food and drink manufacturing, generating primary quantitative data within a sector where such evidence remains limited. Facility-level data are particularly valuable, as it provides evidence of corporate environmental impact which enables the identification of practical opportunities for improving resource efficiency and reducing emissions. Although previous research has examined sustainability within food and drink manufacturing, relatively few studies have collected primary operational data directly from various manufacturing facilities and subsectors. For example, Gowreesunker et al. (2018) modelled energy use across UK food and drink subsectors using national statistics to identify cost-optimal pathways for achieving industry decarbonisation. Altenburg et al. (2021) conducted mass and energy balance modelling to determine energy intensive processes in the sector while O'Shea et al. (2022) used Multi-Criteria Decision Analysis to evaluate alternative decarbonisation pathways for food and drink manufacturing facilities. Although important contributions, these studies rely on conceptualising with secondary data, which does not capture the operational complexity of individual manufacturing facilities.

Second, among the existing literature that collects quantitative operational data within the food and drink manufacturing sector, most studies focus on individual product categories rather than the sector as a whole. For instance, research on the energy consumption of bread products has been undertaken by Therkelsen et al. (2014), Carlsson-Kanyama (2000), El-Adly et al., 2015. Meanwhile, Schmidt Rivera & Azapagic (2019), and Ramírez et al. (2006) evaluated energy use in the ready-meal category. This research extends existing literature through adopting a cross-sectoral approach, encompassing a diverse range of food and drink manufacturers. This broader perspective enables comparisons across subsectors, identifies common barriers and opportunities for decarbonisation, and provides a stronger evidence base to inform regional policy and industry support programmes.

4.2. Energy efficiency

Energy efficiency is one of the most critical strategies for decarbonising the manufacturing sector in the UK. Energy efficiency measures fall into two categories: general efficiency improvements and energy-efficient technologies. General efficiency includes improved energy management and maintenance practices, such as reducing idle equipment, optimizing production scheduling, and appropriately sizing controls and motors, while energy-efficient technologies involve adopting new equipment and installing advanced insulation on machinery and piping (Sovacool et al., 2021).

This research found that most participants were not aware of energy efficiency options available for their businesses based on information gathered during interviews and site visits conducted with participating companies. In addition, none of the participating businesses had submetering within their facilities. During the recruitment process, many manufacturers expressed that they did not see the benefits of energy auditing or research. A key challenge identified during site visits and informal interviews was the limited technical and financial capacity available within SMEs to evaluate energy performance and decarbonisation opportunities. Many smaller businesses lacked dedicated sustainability personnel, formal energy management systems, or the financial flexibility required for investment in new technologies. As a result, operational decisions were often driven by immediate production requirements and short-term economic pressures rather than long-term energy optimization strategies.

Across the 12 companies included in this study, heating equipment, particularly ovens and boilers, were identified as a major energy-intensive hotspot. Boilers represent a significant challenge for the sector, as facilities that rely on them may attribute up to 70 percent of total energy consumption and associated GHG emissions to steam generation. Industrial boilers currently depend primarily on natural gas or diesel, presenting important potential for decarbonisation through electrification. However, the emissions reduction potential depends on the source of electricity. Where electricity is generated from fossil fuels, electrification may offer little or no reduction in GHG emissions compared to direct natural gas and diesel use. In contrast, where electricity is supplied directly from renewable sources, such as on-site solar power or a decarbonised electricity grid, the electrification of boilers could reduce emissions to near net-zero. Regardless, further technological innovation is required, as large-scale electric boiler systems suitable for industrial food and drink manufacturing are not yet widely commercially available. An alternative option to waiting for innovation advancements is implementing heat recovery systems. Recovered heat can be used for preheating air, products, or generating hot water, especially when switching to electric equipment is not feasible. Additional research is therefore needed to better understand the technical and economic feasibility of electrifying heating equipment within the food and drink manufacturing sector.

The lack of knowledge by SMEs on their energy use and efficiency opportunities suggests that a regional or national energy auditing program would provide the opportunity for decarbonisation in the sector. A funded audit programme would close the gap between knowing and doing, enabling SMEs to identify initial, practical decarbonisation actions, and would strengthen both the regional and subsectoral evidence base. As SMEs frequently encounter a last-mile barrier even when the opportunity is clearly identified, such a program should combine audits with implementation support (e.g., vendor-neutral guidance, template specifications, and shortlists of accredited installers) to maximize uptake. While acknowledging that process constraints (temperature requirements, hygiene, and throughput) will determine feasibility, audits could, when appropriate, screen sites for fuel-switching readiness (e.g., potential for low-temperature heat pumps, electrification of process heat, or hybrid solutions).

4.3. Fuel switching

The results indicate that food and drink manufacturing facilities in South Yorkshire broadly follow the national energy-use pattern, with natural gas being the dominant energy source. The participating companies relied less on coal and petroleum products on average, which presents some decarbonisation benefits. However, the proportion of natural gas consumption among the 12 participating facilities in South Yorkshire is higher than the UK sector average, indicating a greater reliance on gas-based energy within the study sample. However, this finding relates to the study sample and should not be generalised to the wider South Yorkshire sector.

The results of this research found that participants heavily rely on natural gas for heating processes, but it is also related to 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.

Although electrification is frequently proposed as a major pathway toward industrial decarbonisation, implementation within food and drink manufacturing remains technically challenging. Many manufacturing processes require continuous operation, high-temperature heat, and strict hygiene control, which can limit the immediate feasibility of replacing gas-fired systems with electric alternatives. Furthermore, older industrial facilities may require substantial infrastructure upgrades before electrification can be practically implemented. Consequently, transitional approaches such as hybrid systems, waste heat recovery, and gradual fuel switching may currently represent more realistic pathways for many SMEs.

4.4. Implications for industrial decarbonisation policy

Despite its economic importance and substantial energy demand, the UK food and drink manufacturing sector has received comparatively less strategic attention within national industrial decarbonisation policy than traditional energy-intensive industries. For example, the *Industrial Decarbonisation Strategy* (2021) and the *Modern Industrial Strategy* (2025) primarily focus on sectors such as steel, cement, chemicals and refining, where emissions are concentrated within very large industrial clusters. By contrast, food and drink manufacturing is characterized as a dispersed industry, comprising geographically distributed production facilities that are not reliant on centralized industrial infrastructure (United Kingdom Government, 2021). Although these types of sites account for 54 percent of UK industrial carbon emissions, national decarbonisation policy has prioritised more centralised sectors where emission reductions are viewed as being quicker (United Kingdom Government, 2021). However, with food and drink manufacturing requiring over 30 TWh of energy annually, national decarbonisation targets cannot be achieved without its systematic inclusion and accelerated action (Department for Environment, Food and Rural Affairs, 2025a).

A further challenge is that the sector is mainly composed of SMEs, many of which fall outside the scope of existing decarbonisation policies and regulatory requirements. For example, although Climate Change Agreements provide relief on the Climate Change Levy in return for meeting energy efficiency or carbon reduction targets, participation is generally only economically beneficial for businesses with high energy costs. It has been estimated that annual energy costs of approximately £100,000 are required before participation becomes feasible, disqualifying most SMEs (The Manufacturers' Organisation, 2026). Similarly, the Energy Savings Opportunity Scheme, which mandates energy assessments, only applies to large businesses, exempting most of the food and drink manufacturing sector. Consequently, many food and drink SMEs lack both the regulatory incentive and the technical support to systematically monitor energy consumption, quantify GHG emissions and identify cost-effective decarbonisation opportunities. This policy gap is reflected in the findings of the present study, where many participating businesses had limited baseline environmental data and were unable to identify their principal energy-consuming processes prior to the facility assessments.

This research demonstrates that these policy gaps have important consequences, as the food and drink manufacturing sector represents a significant source of industrial GHG emissions. Across just 12 participating companies in South Yorkshire, annual operational emissions totaled 7152 tCO_2e, illustrating that even relatively small groups of manufacturers can have a substantial environmental footprint. When considered alongside the approximately 25,000 food and drink manufacturing businesses operating across the UK, the cumulative emissions from the sector are considerable. Furthermore, the predominance of natural gas as the primary energy source among participating businesses highlights the significant potential for emissions reductions through energy efficiency improvements and fuel switching. These findings suggest that greater policy support for SME food and drink manufacturers is necessary if the UK is to achieve its industrial decarbonisation and net zero objectives.

4.5. Study limitations

This research aimed to quantify annual energy use and associated GHG emissions from food and drink manufacturing companies in South Yorkshire. The facility-level focus was deliberate, enabling a detailed assessment of operations energy use and decarbonisation opportunities, but it also presents several limitations. First, this study did not include Scope 3 emissions, meaning that the reported emissions underestimate the total environmental impact of food and drink manufacturing. In food systems, upstream and downstream supply chain activities including farming, ingredient sourcing, packaging, and shipping often account for a large part of the total lifecycle emissions. Consequently, the operational emissions reported in this study represent only a small part of the sector's overall carbon footprint.

Second, the study surveyed and interviewed only 12 companies across South Yorkshire, representing approximately 7 percent of the population. As such, the sample cannot be considered statistically representative of South Yorkshire or the UK food and drink manufacturing sector. The limited sample impacts the generalisability of the findings, meaning the findings should be interpreted as indicative rather than representative, and any extrapolation to the wider population should be undertaken with caution.

Third, companies provided varying levels of operational detail during data collection. While some participants supplied detailed utility bills and production information, all companies provided some partial operational records or equipment specifications. In such cases, annual energy consumption was estimated using equipment power ratings, operational hours, or utility expenditure data. For the two companies without annual energy consumption records, calculated energy values were used instead of directly measured consumption. Although these values were checked against the reported monthly energy costs, some uncertainty may remain due to variations in equipment load and operating conditions.

Fourth, refrigerant data was not available from the participating companies. As discussed, refrigerant leakage may represent a material, although potentially limited, source of Scope 1 emissions. Consequently, the Scope 1 emissions reported in this study may be underestimated, resulting in an incomplete Scope 1 and 2 GHG inventory. Future research should focus on documenting and quantifying refrigerant type, charge, recharge, servicing and leakage.

Finally, the applicability of the findings to other regions or manufacturing sectors should be considered, but with caution. South Yorkshire represents a unique regional context within the UK, with the companies examined in this study reporting natural gas consumption high above the industry average. The region also has a high concentration of businesses and ageing infrastructure, which may have influenced the results. However, many of the challenges identified in this work, including limited access to environmental data, low awareness of energy efficiency opportunities, financial and technical barriers are common among SMEs and widely reported in broader manufacturing literature. Consequently, while the quantitative results should not be directly generalised beyond this study, they can provide a useful point of comparison with other regions. In addition, the methodological approach and operational insights are likely to be transferable to other SME-dominated food and drink manufacturing clusters, which can inform business and regional decarbonisation initiatives.

5. Conclusion and future research

This research shows that the environmental impact among the participating food and drink manufacturing companies through energy use and carbon emissions is noteworthy. Across the 12 participating companies, total annual energy use was 34.64 GWh, with corresponding GHG emissions of 7152 tCO_2e. Although the sample is not statistically representative of the wider South Yorkshire sector, these findings indicate the potential importance of food and drink manufacturing within industrial decarbonisation policy. While this study examines a regional manufacturing cluster in South Yorkshire, the results show the energy-intensive nature of food and drink manufacturing processes, underscoring the sector's potential significance in broader industrial decarbonisation initiatives. By quantifying energy use and GHG emissions, this study provides baseline data to support measurable sustainability targets, identifies opportunities for decarbonisation intervention, and informs both corporate decision-making and policy development in the food and drink manufacturing sector. The findings also showed that although one large manufacturer contributed much higher energy use and carbon emissions compared to the other companies, the combined environmental impact of the SMEs is still important when considered together.

Future research should explore the technical and financial feasibility of transitioning existing manufacturing equipment to electrified versions. This is particularly relevant given the strong reliance on natural gas observed among the participating companies, especially for heating-related processes. In doing so, it would create a better understanding of what transitions are currently practical while providing a business case for clean production. This could help support corporate decision-making and policy development. Future studies should also investigate the use of smart meters and digital monitoring systems to help companies better understand and manage their energy consumption. In addition, determining energy use per product should also be explored, as it can provide a more comprehensive comparison across firms and highlight energy inefficient products. Using indicators such as kWh/kg product or kg CO_2e/kg product could also improve benchmarking between companies operating at different production scales.

CRediT authorship contribution statement

Cassandra Hayward: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Aida Daei:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Data curation. **Hongwei Zhang:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Ethics statement

Ethics approval was provided by Sheffield Hallam University to collect original data. Ethical approval for this study was obtained from the University Research Ethics Committee (Ethics review number: ER70658916). Verbal or written informed consent was obtained from all participants prior to their inclusion in the study. Participants provided consent to participate and consent for their anonymized data to be used for publication. No participants were under the age of 18.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors do not have permission to share data.

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