Waste Heat Mapping: A UK Study

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Abstract

The following study considers the spatial distribution, grade and seasonal variation of waste heat from UK industry in 2018 and examines opportunities to offset the emissions caused by heat generation by the use of waste heat recovery schemes. The findings of this study are presented as a UK Waste Heat Map. Data containing information on the natural gas consumption of different industries are used as a proxy for waste heat. Opportunities have been identified within each industry to reclaim and utilise waste heat. This report finds that the approximated waste heat is concentrated around densely populated areas and areas with a traditionally strong industrial base, making a large amount of the waste heat suitable for heat reuse, such as in a district heating scheme. The total estimated waste heat from UK industry and electricity generation is nearly 350,000 GWh. The information is represented in the UK Waste Heat Map as point location data and by waste heat per Local Authority.

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Introduction

In 2018, total non-domestic natural gas (methane) consumption accounted for 571,464 GWh of total UK gas consumption [1]. This is approximately 65% of total gas consumption in the UK in that year. All this gas was burnt to produce heat. Some heat was used to drive industrial processes and some heat was converted to electricity by the power generation industry. However, most of the heat was not used but emitted as waste. The purpose of this work was to identify the quantity and distribution of waste heat from non-domestic sources in the UK and determine how the waste heat could be used. As 2050 approaches, it is of paramount importance that the UK is able to reach its target to become carbon neutral [2]. Furthermore, if the United Nations Sustainable Development Goals are to be met by 2030, in particular Goal 17: Affordable and Clean Energy, better use must be made of available resources [3]. The way in which the current resource of heat is wasted must be curtailed, thus possible uses for the waste heat were considered.

Waste heat has various uses, governed mainly by the location of the waste heat, grade of the waste heat and whether the heat emission varies with season. Here we used natural gas consumption as a proxy for waste heat generation. Gas consumption data and estimated efficiencies of the facilities were used to derive waste heat figures for industry. Facility efficiency data are from published literature. Industries with a high gas consumption were the focus of this study. Geographic supply of waste heat was compared with geographic demand for heat.

Many industries deploy heat recovery systems, a few engage in larger heat networks that supply domestic sources in district heating schemes [4]. For a district heating scheme to be successful there must be a sufficient supply of heat and a long-term commitment from all parties is necessary. Almost 450,000 UK homes are supplied with heat from approximately 17,000 heat networks in the UK [5]. However, only 3% of the proposals reported in the Heat Network Delivery Unit's 2019 pipeline utilised a 'primary energy source' (heat source) from industrial waste heat [4]. As the literature on waste heat recovery increases and the technology improves, becoming more viable, industry has a decreasing number of reasons not to adopt heat recovery practices. Therefore, this study aims to give an overview of the waste heat available in the UK, in order to increase industrial awareness of the heat recovery resource.

The UK Waste Heat Map, the companion to this report, is hosted on the energy charting site MyGrid [6].

Methodology

Bottom-Up Approach

The initial approach this study took was bottom-up, aiming to extract census level data of all industrial gas usage in the UK and find industrial efficiencies to calculate the waste heat from each site individually. An enquiry or freedom of information request was sent to each facility investigated, requesting information about process thermal efficiencies, gas consumption and waste heat processes already in use. Based on this information, an estimate of waste heat would have been calculated for each facility. Ideally, this would have allowed a high level of resolution on the map, similar to the Scotland Heat Map [7]. The data would have been combined by postcode area as a potential tool for heat network planning.

Top-Down Approach

Due to low enquiry response rate (< 5% of approximately 400 companies), a different approach was taken. A top-down approach was used and based on gas consumption data from the Digest of UK Energy Statistics (DUKES). The resolution is Local Authority area, with supplementary point maps detailing the location of facilities for the industries researched. For all industries excluding electricity generation, natural gas consumption was selected as a proxy for heat that is eventually wasted. The most commonly burned fuel for heating is natural gas, making this an appropriate assumption. For electricity generation, half hourly energy balance data from Elexon were used to create an estimate of waste heat. Gas data were taken from DUKES Table 4.1, part of its annual report on energy usage in the UK [1]. Electricity consumption shows similar industrial consumption trends to those of gas (excluding power transformation) and so electricity is not included in the waste heat estimate.

Where process efficiency figures are not available, a representative efficiency of 30% is used to calculate waste heat. This is the case for every industry excluding electricity generation. Despite the potentially low level of accuracy, this arbitrary figure is necessary as the primary function of the map is to provide spatial information rather than quantitative data. This efficiency figure is applied to the DUKES gas consumption statistics to produce the approximate waste heat figures. This assumes that all appreciable energy waste is lost as heat.

The UK Waste Heat Map contains data from the electricity generation sector based on Elexon half-hourly settlement periods and data from five of the eight largest gas consuming industries; ‘chemical’, ‘food and beverage’, ‘mineral’, ‘vehicle’, and ‘iron and steel’ based on gas consumption statistics from DUKES [8,1]. Although consumption figures for ‘mechanical engineering’, ‘paper and textiles’ and ‘other industries’ are included in the DUKES data set, they are not included in the following analysis as no comprehensive list of the industrial sites was found and their gas consumption is relatively small in comparison with Electricity Generation and the Chemical industry.

The locations of major industrial facilities were investigated and mapped at postcode area resolution. The data were then collated into Local Authority areas. The number of instances of each industry in a Local Authority area acts as a weighting for the proportion of waste heat from that industry. Then, the total industrial gas consumption data provided by DUKES were split evenly across Local Authority areas dependent on the weighting. This provided an estimate of the waste heat available in each Local Authority area based on the industry in that area. Together with the mapped data, this provides an overview of the waste heat available across the UK. All units of energy are GWh. Domestic gas consumption was not the focus of this study.

Although the necessary individual energy consumption data are not available, a small review of data centres is included because the industry is rapidly growing and is likely to play a long-term part in both the world’s economy and electricity consumption for years to come. Large quantities of energy are required to run the servers, producing a potentially large resource of waste heat, potentially suitable for use in district heating schemes.

The top-down approach utilised provides the map with comprehensive, albeit low resolution, information about the scale of waste heat in the UK. Exact methodologies for each industry are discussed below.

Electricity Generation SIC 35

Half hourly energy balance data from Elexon were used to create an estimate of waste heat. A parsed and cleaned data set prepared by the Energy Data Analytics Group at the University of Birmingham has been used [9]. The power generation at each half hourly interval was converted into energy generated. Using efficiency figures from DUKES Table 5.10 and other sources, the waste energy has been back calculated to provide an estimate of total waste heat for each generating fuel type [10]. Using the installed capacity figures from DUKES Table 5.11, the total waste heat from each power station was approximated. The total waste heat per Local Authority area has been represented on the map. Data for the point map are also taken from Table 5.11 [11].

Chemical SIC 20 & 21

Approximated sector waste heat is divided across Local Authority areas identified as the four main clusters of chemical production in the UK [12], namely Hull, Teesside, Runcorn and Grangemouth. Facilities outside of these areas are disregarded as the waste heat in these areas is too small to have a noticeable effect on the distribution presented. A point map of large chemical plants and petrol refineries is included in the map for industrial representation. Chemical manufacturing facilities are selected from the Chemical Industries Association membership list and other industry research [13]. Oil refineries, although considered a separate industry (SIC 19), are included under the title of 'Chemical' as they are featured in the Carbon Trust 2012 report on energy efficiency [14].

Food and Beverage SIC 10, 11 & 12

Disregarding energy for transportation, the largest source of waste heat in the food and beverage industry is assumed to come from heating, pasteurisation and refrigeration. A comprehensive map of all farms, abattoirs and food production sites was beyond the time constraints of the project, as the list of UK dairies alone numbers almost 9,000 [15]. Thus, a waste heat map layer was created using data from large commercial breweries (SIC 11.05) and large dairy treatment centres (SIC 10.5), as both use pasteurisation and refrigeration processes. Only the fourteen largest brewing companies were included in this study. A map of small, independent brewers has been compiled by an independent group, which could be useful in further industrial analysis into heat recovery in small independent breweries[16]. The three largest dairy producers in the UK were contacted with a single response offering a tour, but no quantitative data. All sites have been added to a point map. The approximated waste heat has been weighted between the industrial sites in each Local Authority area.

Mineral SIC 08 & 23

The focus of analysis of the mineral sector is on the production of ceramics and cement. Facilities included are those listed as a member of the British Ceramics Confederation and cement plants listed under the Mineral Products Association [17]. Each of the facilities belonging to the members of these associations are included in the point map.

Vehicles SIC 29 & 30

Data from the Society of Motor Manufacturers & Traders (SMMT) annual industrial report were used to inform the vehicle data with active UK manufacturing sites (SIC 29) [18]. Active train manufacturing companies (SIC 30.2) were researched and have been included. No responses were received from any automotive or train manufacturing company contacted and so the decision was taken not to contact any aircraft or ship manufacturers (SIC 30 exc. 30.2) as they are mainly contracted to the Ministry of Defence and deemed unlikely to disclose any information.

Iron and Steel SIC 24

Iron and steel manufacturers were identified based on industry research. There are very few iron or steel works still operating in the UK, so this was done on a case by case basis.

Data Centres SIC 63

A point map of data centres is included as a representation of waste heat resources and demonstration of links to domestic housing. As no qualitative data on efficiencies or exact grade of waste heat could be collected, no heat map is provided. A small industrial analysis is instead included in this report.

Carbon Dioxide Emissions

As carbon dioxide is released with the combustion of organic fuel, it can be used to provide an alternate method of approximating waste heat in Local Authority areas [19]. There are many potential sources of carbon dioxide that cannot be linked to waste heat. Therefore, only carbon dioxide emissions from non-domestic sources were considered in this study. The amount and distribution of carbon dioxide emissions in the UK are collected from the European Pollutant Release and Transfer Register [20]. These data provide the quantity and source of carbon dioxide emissions, allowing the sources that would not be suitable for waste heat reuse to be removed from the dataset.

Waste heat distribution and recovery potential

The total estimated waste heat resource in the UK is 391,000 GWh. This is an estimated figure and the findings have shown that although much of this heat can be recovered, some is either irreclaimable (such as heat produced by the welding of car bodies) or already being reclaimed (such as in the calcination preheating in cement production facilities). Findings are discussed in detail below.

Total waste heat, 391,000 GWh

Total approximated waste heat from industry is around 46,000 GWh and waste heat from electricity generation is approximated to be 345,000 GWh. Distribution of total waste heat is focussed mainly in the centre of the UK, in the Midlands and the North East (Figure 1).

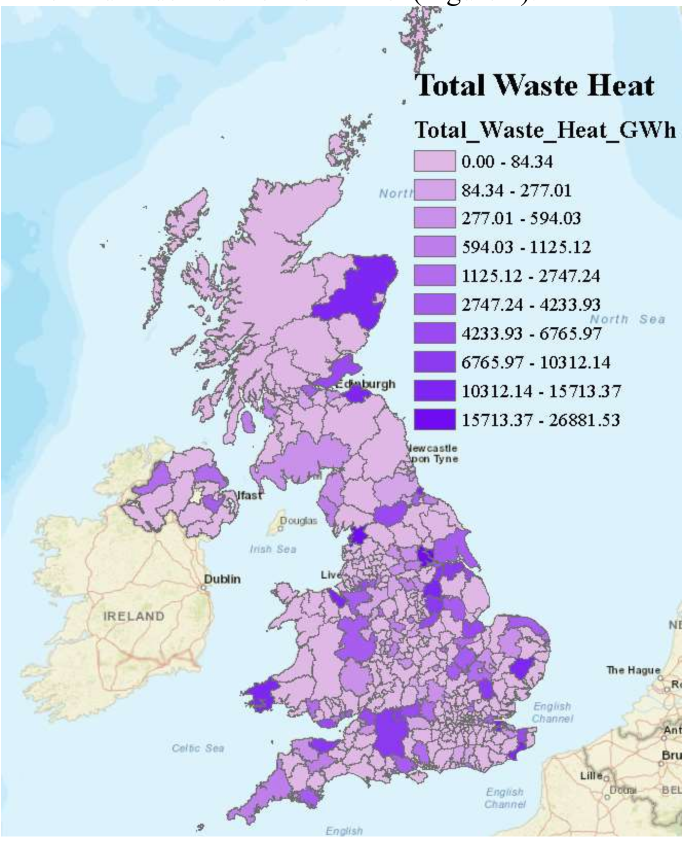

Figure 1: Distribution of estimated total waste heat in the UK.

The majority of waste heat is produced by the electricity generation sector, with the food and beverage, chemical and mineral sectors all contributing large amounts, metal processing and vehicle manufacture contributing less (Figure 2).

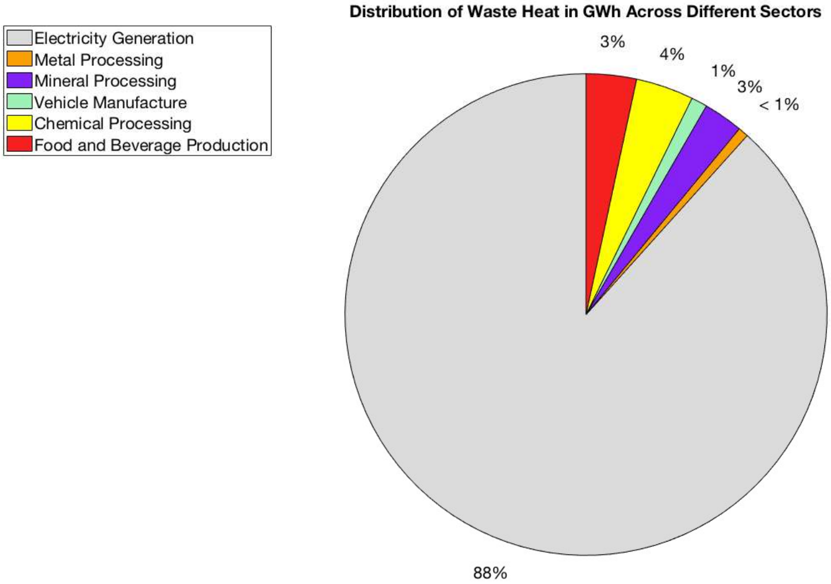

Figure 2: Distribution of estimated total waste heat.

Electricity Generation, 345,000 GWh

The majority of waste heat in the UK is located centrally in Yorkshire and the Midlands with other localised high regions in other areas of the country (Figure 3a). Areas of high waste heat occur where there is a high concentration of power stations, especially those that are operating continuously (with a high load factor) (Figure 3b).

There are multiple factors that may affect the location of a power station, such as access to fuel and a suitable heat sink. Historically, the building of a power station would result in an increase in population density in that area, as workers would live in close proximity to the power station. This may explain the rough correlation between population density and waste heat from electricity generation, seen in Figures 3a and 3b. However, the location of different types of power stations will be dependent on different factors. For example, natural gas power stations are found on the coast, close to gas pipelines, which may explain the high waste heat approximations in Aberdeenshire and South Wales. Detailed analysis of the location of each type of power station is beyond the time constraints of this report. The findings from sector research into each type of electricity generation and the waste heat involved are discussed.

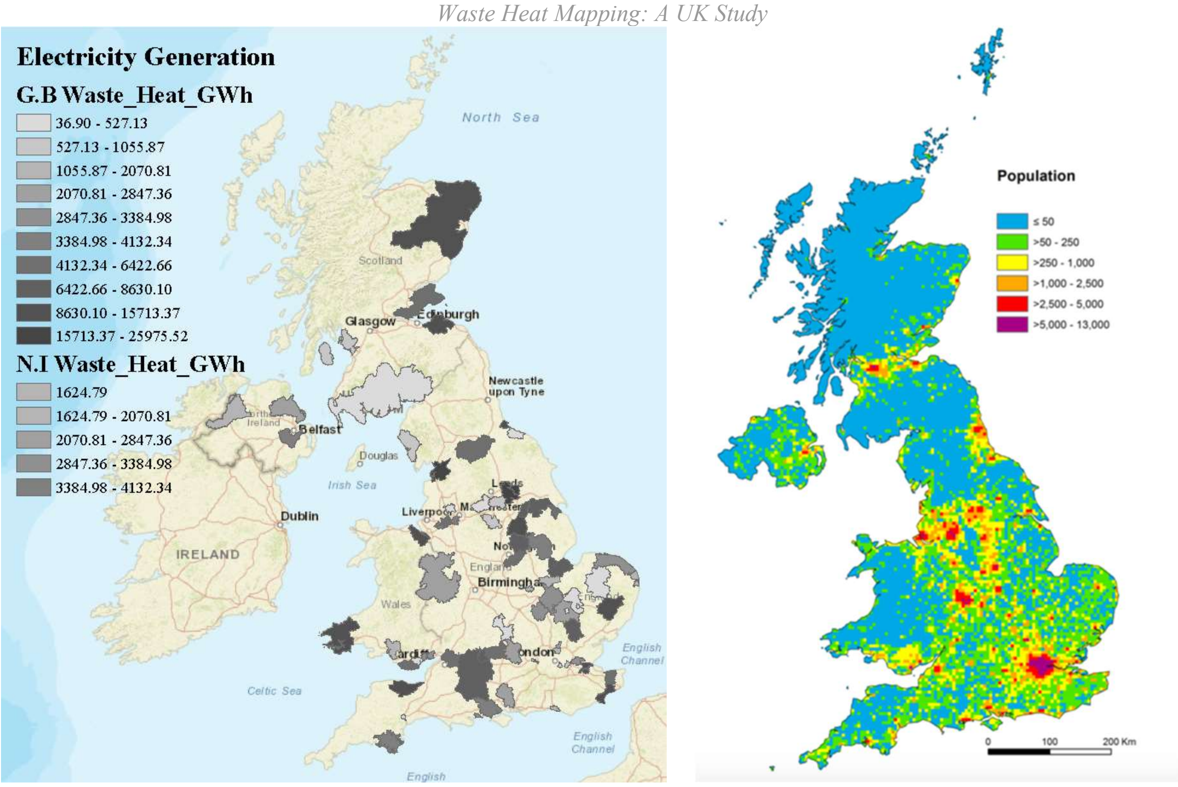

Figure 3: (a) distribution of estimated waste heat from electricity generation in the UK, (b) population density in the UK [21].

Natural Gas

As of summer 2019, there were 61 natural gas power stations in the UK. This includes the categories Gas, Gas Oil, Gas Oil/Kerosene and CCGT. CCGT power stations make up 38 of these power stations and have an efficiency of 49%, with an installed capacity ranging from 50 to 2,199 MW [11]. CCGT power stations have a power load factor of 42.7%, indicating that they are operating a large percentage of the time when compared with other power stations, where all except nuclear have lower load factors. Therefore, they create a large contribution to total heat waste, approximately 120,000 GWh (Table 1). For the purpose of this study, all natural gas power stations are assumed to have the same efficiency and load factor.

Nuclear Power

All except one nuclear power station in the UK are Advanced Gas-Cooled Reactors (AGR). The AGR has an efficiency of approximately 40% and a power load factor of 72.3% [11], indicating that there is a large resource of waste, as they are operating the majority of the time. The UK will remain dependent on nuclear energy for part of the energy supply as the transition to renewables is made. Although the current nuclear fleet is to be decommissioned, these facilities will be replaced by small modular reactors. Therefore, nuclear power stations can be depended on to provide relatively consistent waste heat to waste heat reuse schemes. However, as nuclear power stations are not strictly renewable, this may not be the case. More industry research is required.

Coal

There were seven coal-fired power stations still in use in the UK as of summer 2019. An approximate thermal efficiency for a coal plant is 34% and their load factor is 14.2% in 2018 [11]. Due to their inefficiency and high installed capacity, coal fired power stations produce a large amount of waste heat when in use. However, a low load factor means the power stations are only operating a small fraction of the time. There is also a continuous push to remove coal from the energy network in the UK, planned to have occurred by 2025, therefore using waste heat from coal fired power stations is not a sustainable option.

Solar

There are 18 solar power stations in the UK recorded by BEIS, with an average installed capacity of 36.9 MW and approximate efficiency of 15% [22]. Due to their dependence on the weather, solar power stations have a low load factor of 11.3%. This limits the potential of solar waste heat, especially as solar waste heat availability will be lowest in the winter, when it is required most. Combining a photovoltaic cell with a metal absorber can create a photovoltaic thermal (PVT) collector [23]. These hybrid collectors could be utilised to increase the efficiency of solar panels by collecting heat simultaneously. However, the UK has a very small PVT market and the 10-100 systems installed each year are for domestic use [22]. Therefore, it is unlikely that PVT technology will be utilised in UK solar power stations in the near future, although the technology is available.

Biomass

Biomass power stations are approximately 36% efficient [24], but this can depend on the type of fuel, its energy content and the method of generation selected. In biomass pyrolysis, thermal decomposition starts at 350-550°C and rises to 700-800°C in the absence of oxygen [25]. Therefore, it can be seen that there is a large reserve of waste heat available from biomass power stations, although the amount of waste heat is difficult to quantify on a large scale because of the variation in types of biofuel and methods of energy extraction from them. There are ten biomass power stations identified in this report, with an average installed capacity of around 210 MW. This suggests that there is a large reserve of waste heat available from biomass power stations.

Energy From Waste

Pre-treated non-recyclable waste is burned at high temperatures under controlled conditions [26]. Incineration plants are designed to ensure that flue gases reach a minimum temperature of 850°C for 2 seconds [27]. Therefore, the minimum temperature reached in this process is 850°C. This creates a resource of high grade heat. According to DEFRA, EFW power stations reach efficiencies of 15 – 27%, but that most modern facilities have an approximate efficiency of 25% [28]. A load factor of 21.8% suggests that EFW facilities are only used when necessary, however as they are more sustainable than fossil-fuel powered facilities they are more likely to be able to supply waste heat, if not continuously, for a long period of time.

Oil

Power stations dependent on oil are OCGT and diesel. They are grouped and assumed to have the same efficiency and load factor as natural gas-powered power stations, as both depend on fossil fuel. The 8 diesel power stations are situated on Scottish islands, where without a small local diesel generator there would be blackouts. They are small and produce very little waste heat.

Assumptions

Information provided by DUKES categorises power stations under the titles given in the first column of Table 1. For the purpose of this study, power station types are grouped together to simplify calculation. Coal and coal/oil are given the same efficiency and load factor as coal power stations. Gas, gas oil, gas oil/kerosene and CCGT are grouped and given the same efficiency. OCGT and diesel are grouped as OCGT power stations. Load factors are taken from DUKES, Plant loads, demand and efficiency, Table 5.10 [10].

Power Station Type	Number	Average Installed Capacity (MW)	Efficiency (%)	Load Factor (%)	Estimated Waste Heat (GWh)
Coal	6	1,932.00	34.1	14.2	30,000
Coal/Oil	1	560.00	34.1	14.2	
Gas	8	102.69	48.9	21.8	120,000
Gas Oil	14	73.43	48.9	21.8	
Gas Oil / Kerosene	1	140.00	48.9	21.8	
CCGT	38	793.18	48.9	42.7	
OCGT	1	32.30	48.9	21.8	20
Diesel	8	17.61	48.9	21.8	
Biomass	11	211.03	36.0 [23]	21.8	29,000
Waste	11	35.86	25.0 [27]	21.8	
Nuclear	8	1170.13	39.8	72.3	91,000
Solar	17	36.09	15 [21]	11.3	76,000

Table 1: Electricity generation waste heat. Data is taken from [11] unless otherwise stated.

An example calculation: Electricity generation from coal.

In 2018 Elexon reported an average power consumption from all coal power stations of 1,756 MW. Therefore, the total electricity generated over the 8,760 hours in the year was 15,385 GWh. Using the BEIS average coal power station efficiency figure, 34.1%, the total energy of coal consumed to produce this electricity was 45,251 GWh. Therefore, the heat wasted from coal power stations in the UK was 29,866 GWh.

This energy was then distributed between the coal power stations weighted by their installed capacity as reported by DUKES in Table 5.11. For example, the Fiddler's Ferry power station in Cheshire has an installed capacity of 1,961 MW and therefore has a weighting of 1,961 MW / 11,592 MW, where 11,592 MW is the sum of the total installed capacities of all coal power stations in the UK. Therefore, Fiddler's Ferry is estimated to produce 29,866 GWh * (1,961 MW / 11,592 MW) = 5,052 GWh of waste heat.

Chemical 15,200 GWh

The chemicals industry is the second largest waste heat resource in the UK (Figure 4). Chemical facilities tend to be based near ports, facilitating easy imports and exports, and steeped in a historical industrial presence. As they are often based in large clusters away from domestic settlements, use for district heating networks could be limited. However, internal use within companies or around industrial sites could have some potential. No indication of seasonal variation has been found in the chemicals sector.

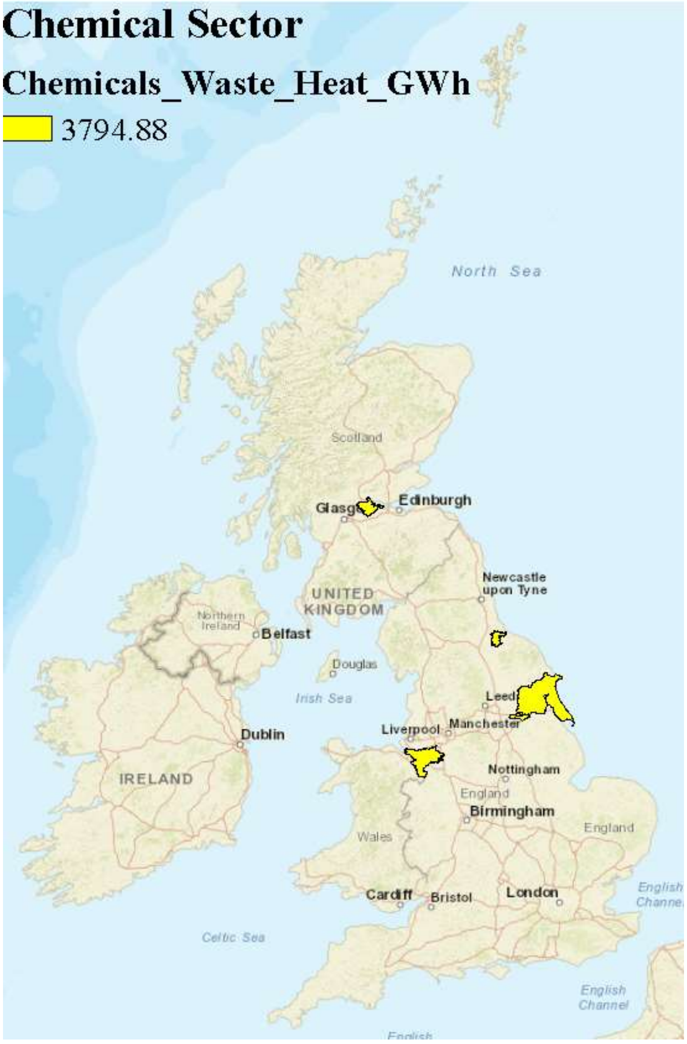

Figure 4: Distribution of estimated waste heat from the chemical industry.

The manufacture of chemicals is an exceptionally broad ranging industry with heating required for a distillation, curing, boiling, drying, cooling, transportation and cold storage [14]. Sterilisation and pasteurisation are also widely employed for products that are used and consumed by humans. The heating and cooling processes used by each company and heat recovery methods currently employed could not be found due to commercial confidentiality.

The 2012 Carbon Trust report on the chemicals sector includes simple energy saving initiatives such as keeping doors closed and insulating warehouses, tanks and pipes. This implies that energy efficiency considerations were still in their infancy in the sector. However, anecdotal information suggests that the industry is making improvements in heat retention and recovery [29].

The chemical industry is a prime candidate for Refrigeration Heat Recovery (RHR) systems. Products with a high volume of liquids and solids use up to 85% of the total process energy consumption in the refrigeration of the product [30]. Thus, a large proportion of the products manufactured by the industry would have large potential energy savings if RHR technologies were employed.

Food and Beverage, 14,700 GWh

A total waste heat reserve of 14,700 GWh is identified from food and beverage processing facilities. The heat distribution is displayed in Figure 5. Breweries and dairies are analysed in detail.

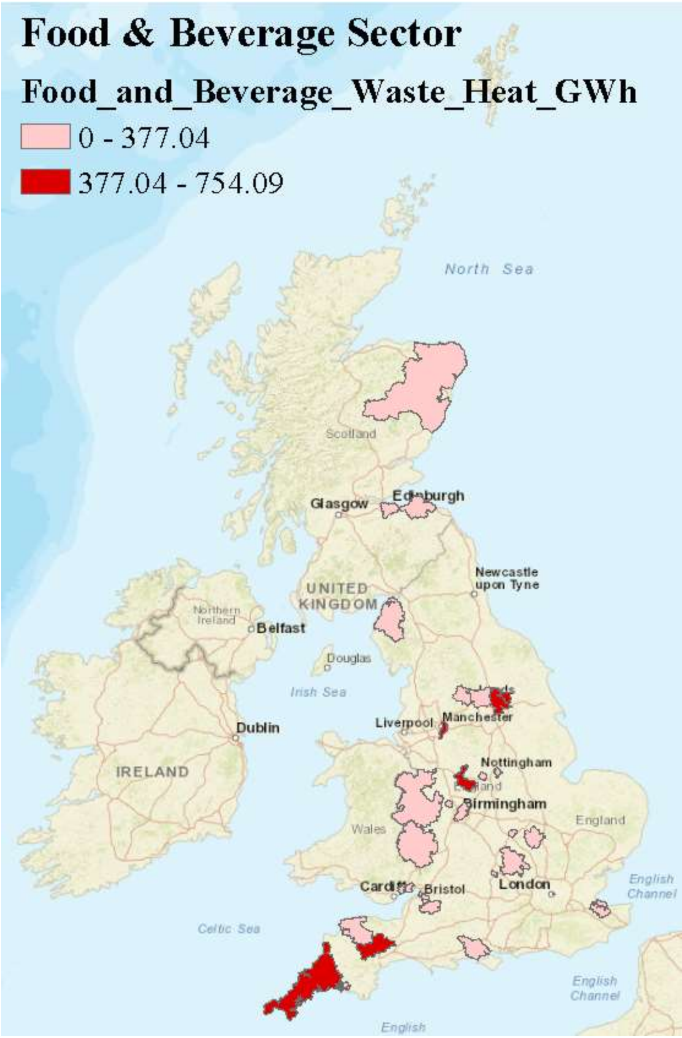

Figure 5: Distribution of estimated waste heat from the UK Food & Beverage sector.

Breweries

A non-automated response rate of 14% to enquiries of commercial breweries about quantitative energy consumption and current heat recovery techniques gave the useful insight that heat recovery from refrigeration or cooling plants is never used in the responding companies [31]. Independent breweries show a fairly even but patchy distribution across the country. These breweries are often attached to a public house. Thus, there is potential for waste heat recovery and use within the brewery-pub site. Due to the grade of heat produced there is limited potential outside this setting. Large commercial breweries are located in cities or suburban communities.

With the current boom in the number of small, independent breweries and the progression of many to large commercial businesses, the application of heat recovery and Refrigeration Heat Recovery (RHR) systems in the brewing industry would appear to be ideal for waste heat capture.

Brewing consists of four main stages before pasteurisation. Mashing involves grains and water heated to 67°C for 2 hours to produce the wort for boiling and fermenting [32]. Just before the wort is removed from the vessel it is heated to 75°C to deactivate the enzymes and stop the mashing process. The wort is then boiled at 100°C for an hour with hops to infuse flavours into the beer. The beer is then cooled in a heat exchanger to 6-25°C for fermentation which lasts 5-6 days. The beer is then aged between -1-10°C for a week before it is pasteurised at 75°C for 30s during ‘flash sterilisation’ and sent to market. Measures such as heat recovery from the heat exchanger for wort pre-heating and other heat integration techniques could save 25% of the energy required for the brewing process [33]. By considering the spent grain discarded at the end of the brewing process or employing methods such as UV pasteurisation further energy reductions can be achieved [34].

Dairies

The UK produced 14,713 million litres of milk in 2017/18, almost all of which are subjected to pasteurisation and refrigeration [35]. There are different methods of pasteurisation utilised at different sites, the most common being high temperature short time pasteurisation, which occurs at 71°C for 15 seconds, and low temperature long time pasteurisation, which occurs at 63°C for 30 minutes. Both produce significant waste heat which can be captured through thin plate heat exchangers as the milk is processed. Milk is refrigerated at 3°C [36].

Use of RHR in pasteurisation was first found to be economically viable and attractive in a study from New Zealand conducted in 1987 [37]. Research and the commercial responses in this report have given little indication that refrigeration waste heat is used for anything other than defrosting the circuitry of the refrigeration unit. Dairies are making steps towards environmentalism, as seen with the biomass CHP plant at Arla’s Aylesbury plant. Heat exchangers and dairies are often located rurally, away from densely populated areas. This makes the use of waste heat for district heating schemes questionable, however use within farming and other industry is plausible.

Mineral, 10,400 GWh

Waste heat is distributed across the middle of the UK, mainly in the Midlands, the North East and parts of the South (Figure 6). This is appropriate, because the transportation of cement is an expensive process because of its density. Having cement works in central locations reduces transportation costs. Historically, ceramics works are based in Stoke on Trent, therefore it stands to reason that there would be a high concentration of waste heat in this area.

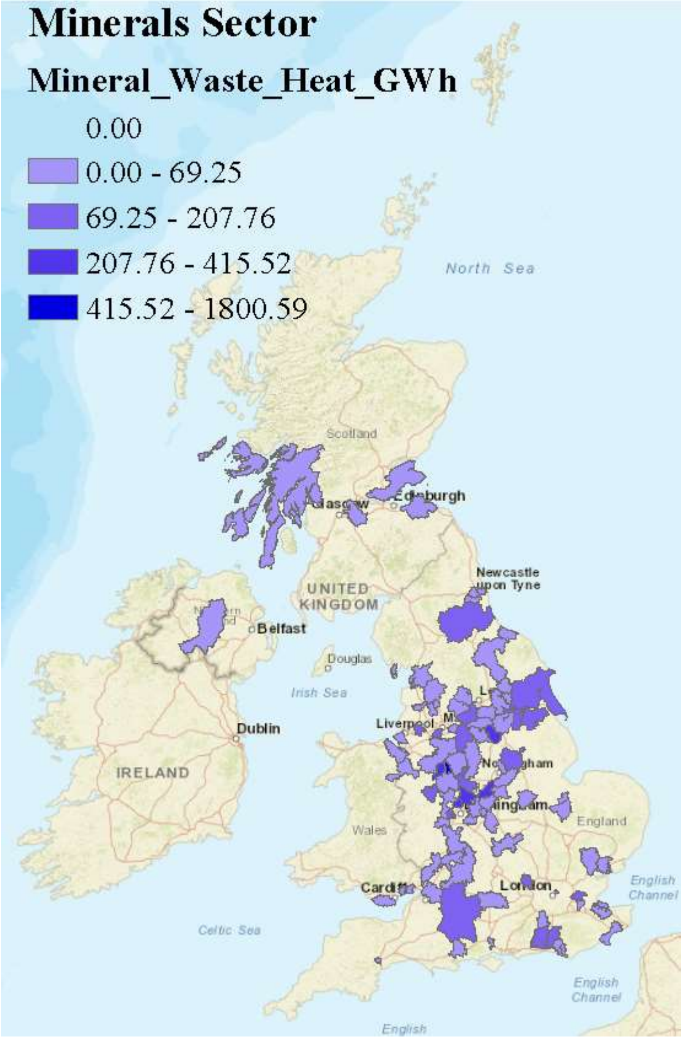

Figure 6: Distribution of estimated waste heat from the UK Minerals sector.

Cement

Responses to enquiries from industry members help to create a picture of the reuse of waste heat in a cement production facility. Cement is the basic ingredient of concrete and is a binder used in construction, where it is often lime or calcium silicate based [38]. A large amount of the cement used in the UK is also manufactured in the UK, as it is expensive to import because of its density and high demand. In the case of Portland cement, there are twelve manufacturing and two grinding and blending plants in the UK that produce around ten million tonnes of Portland cement each year, about 90% of the cement sold in the UK [39]. The temperature reached in the cement kiln can be up to 1450°C [40]. In order to minimise energy waste from the cement manufacturing process, the waste heat from the cement kiln is fed back into an earlier stage through a preheating system. An example is given by Hanson Cement, where waste heat is recycled into the beginning of the process, where it is used in the calcination of the limestone [41]. On exit from the cement kiln, cement clinker is placed over a cooling grate and the high-grade waste heat is recycled into the coal mill to dry incoming coal. The majority of heat is lost in the kiln through the flue gases. The clinker exiting the kiln can be cooled in a grate cooler with cool air. The hot air is then used as a secondary air entering the furnace, reducing the energy losses.

Based on the few replies received from members of this sector, it can be assumed that there are many heat reuse technologies already in use during cement making, although more research is required. Therefore, there may not be much room for development in this sector, particularly in terms of district heating schemes as there may not be enough waste heat to justify investment. Heat is likely to be of a high grade but available for a short period of time.

Ceramics

The ceramics industry includes the manufacture of brick, aggregates and pottery. The response rate was greater here than in other areas of enquiry at 9%. Some companies provided technical information of the temperatures involved in their manufacturing processes. Both Saint-Gobain Abrasive and Furlong Mills gave information on their gas and electricity usage but did not detail heat reuse processes that may already be in use. Although the responses were helpful, the low response rate means that the information provided is of little use, as it is anecdotal and therefore cannot be used to create a picture of the industry as a whole. During the manufacture of bricks, temperatures differ according to whether the bricks are made from clay or shale, but final drying takes place at around 200°C, dehydration at around 150 - 1000°C, oxidation from 500 - 1000°C and vitrification from 850 - 1300°C [42]. Therefore, further research needs to be done on ceramics manufacture in the UK to assess its potential for use in heat reuse schemes. The location of ceramics manufactures focuses on areas in the Midlands, such as Stoke-on-Trent, that are typically co-located near areas of high population density.

Vehicles, 4,200 GWh

Automotive manufacture occurs in the historic manufacturing centres of the country. Birmingham, Warwick and the North-East all have high densities of vehicle manufacture facilities (Figure 7). As with the majority of UK industry, the domestic production of vehicles is gradually decreasing. This, in conjunction with the extreme difficulty of extracting sufficient quantity and grade of heat from industrial processes leads to a sparse prospect regarding heat reclamation from vehicle plants in the UK. The primary energy demand for the manufacture of a medium-sized passenger car is estimated to be 69 GJ (including mining and transport) [43]. 50% of the energy demand of assembly is in the painting process which requires the paint to be heated before it can be sprayed onto the vehicle body. The temperatures required for commercial spray painting are difficult to find if not redacted completely. However, there is theoretically some potential for waste heat recovery. An estimated 288 MJ is required in the welding of each car. There is little available research or outlook for heat recovery from welding processes.

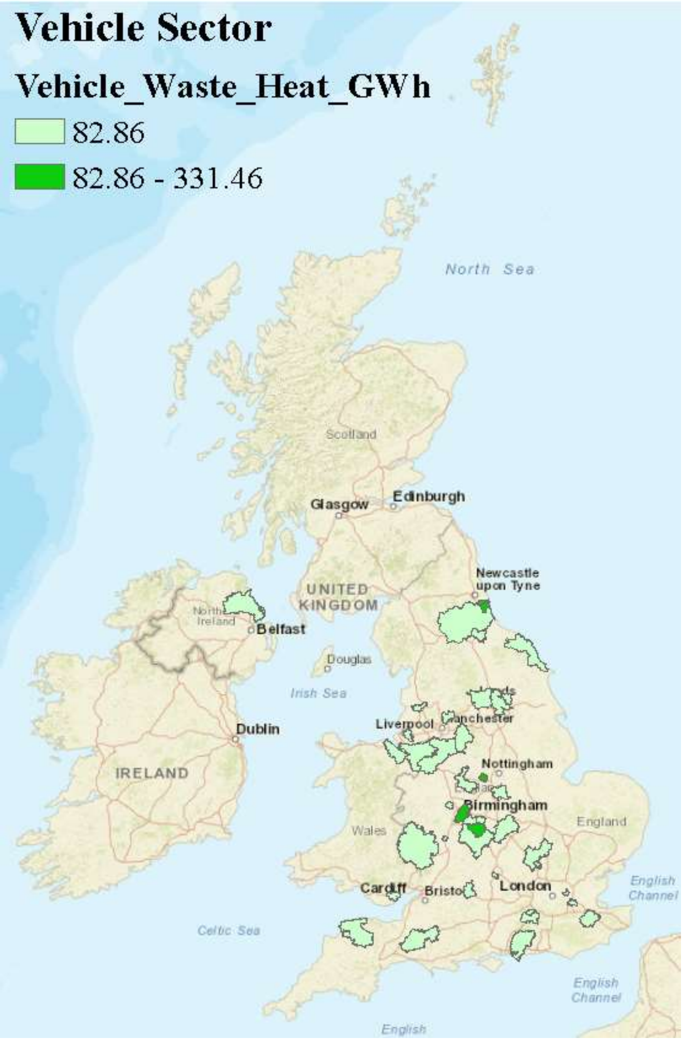

Figure 7: Distribution of estimated waste heat from the UK vehicle sector.

Iron and Steel, 2,800 GWh

Iron and steel manufacturing processes require a large amount of energy because a blast furnace is required. There are few large-medium sized iron and steel works operating in the UK, the majority are in densely populated areas, such as South Wales and North East England (Figure 8). The hot blast temperature of the blast furnace can vary from 900-1300°C but can reach temperatures of 2300°C depending on the design and condition of the stove [44]. It is possible for waste heat to be extracted from the flue gases of the blast furnace and because of the high temperatures utilised, the waste heat is likely to be of a high grade. Molten slag is exhausted with a high temperature of about 1450-1550°C and therefore is also a potential energy resource. More investigation is required to assess whether the heat extracted from an iron or steel manufacturing facility could be of a grade and quantity high enough to use in a district heating scheme. This is likely the case, however due to the declining nature of the iron and steel industry in the UK, it is unlikely it will be of use in future district heating schemes.

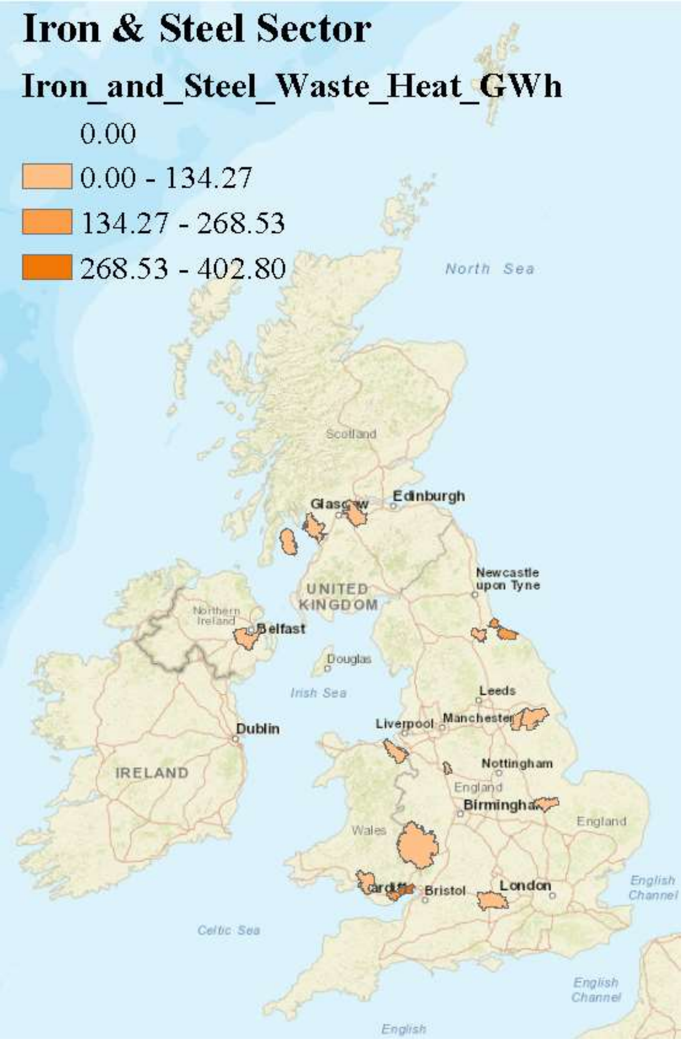

Figure 8: Distribution of estimated waste heat from the UK Iron & Steel sector.

Data Centres

As data centres run, the computers which host the servers reject electricity as heat. To prevent the circuit electronics from overheating and becoming damaged, cooling systems are integrated into data centres. The circuits are commonly cooled to 25°C with the waste heat from the coolant exhausted into the atmosphere [45]. Waste heat can typically be recaptured from the coolant at 25-35°C for air-cooled systems and 50-60°C for liquid submersion-cooled cooling systems [46]. Data centres are located near cities, commonly in industrial estates. The main UK concentration is based around London, with other hubs in Manchester, Reading and Birmingham. The 4% response rate to surveying provided little useful data. Companies were unwilling to share exact power consumption figures and only returned Power Usage Efficiency values with no quantitative figures on heat grade or coolant volumetric flow rate.

Carbon Dioxide Emissions

This study has found that the majority of carbon dioxide emissions arise from the energy sector, essentially as a by-product of the combustion of organic fuel. Other industries that are main emitters of carbon dioxide are chemical processing, waste and waste water management, mineral processing, paper and wood production, food and beverage processing and production and processing of metals. The weighting of carbon dioxide emissions is similar to the weighting of waste heat distribution estimate across industry (Figure 9).

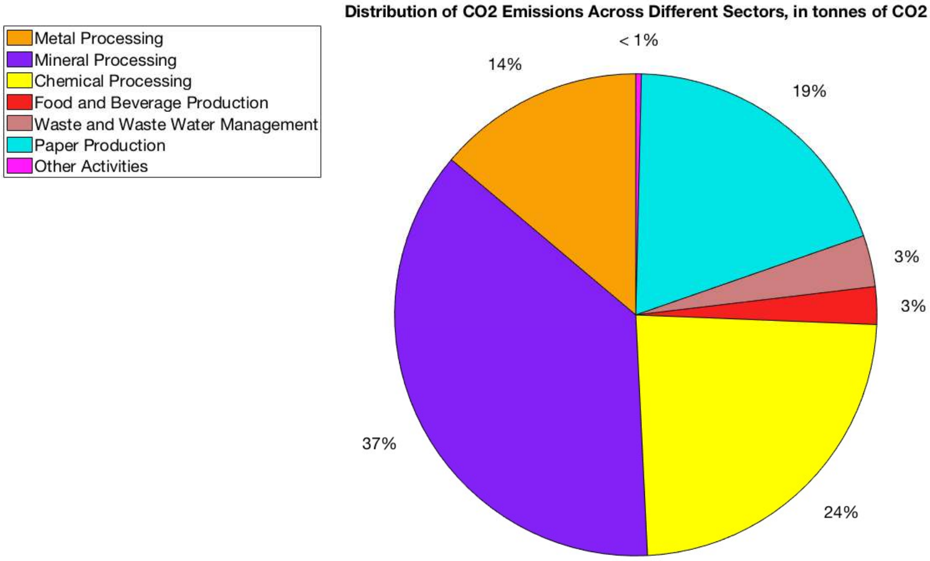

Figure 9: Distribution of UK Carbon Dioxide emissions across industrial sectors.

The level of carbon dioxide emissions is greatest in the North East, the Midlands, South Eastern Scotland and Northern Ireland (Figure 10). The areas displaying the lowest emissions are Cornwall, Devon, Dorset, East Anglia and the Highlands. As expected, the areas with the greatest emissions are areas with a higher density of industry. Rural areas, such as Dorset, Somerset and the Highlands, have either no or very low emissions data from industry. When used to approximate waste heat distribution, the distribution of carbon dioxide emissions suggests that areas in the Midlands, the North East and South East Wales would be most appropriate for the implementation of district heating schemes. This is a similar distribution to that seen in Figure 3a. By layering the location data for industry, it can be seen that there are higher carbon dioxide emissions in the areas where there is a greater connection to industry.

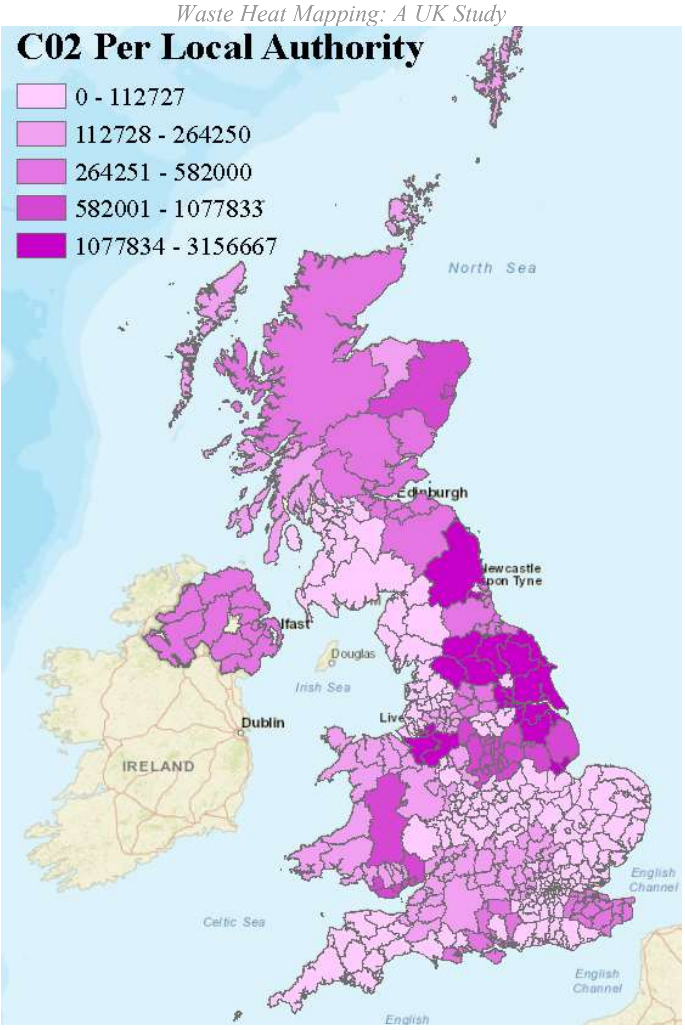

Figure 10: Distribution of carbon dioxide emissions in the UK.

Heat networks & Government Policy

The government established the Heat Networks Delivery Unit (HNDU) in 2013 as part of the then Department for Energy and Climate Change. BEIS now manages the unit and is currently accepting applications for its 10th round of funding. It has previously granted funding to heat networks in 162 Local Authorities, totalling at least £22,488,700. HNDU provides support to Local Authorities in Britain in progressing the developmental stages. HNDU funding can provide up to 67% of costs for development studies contracted to third parties from Local Authorities. In Britain, heat networks encompass a broad range of source and scale. Biomass, waste, sewerage, CHP, geothermal and other heat pumps are all utilised for water heating. The scale of these projects ranges from small projects (<10MW) to larger projects (>50MW).

In March 2020 Scotland became the first country in the UK to legislate on the development of heat networks, creating regulations on the supply of thermal energy by a heat network and the construction and operation of the heat network [47]. Currently there are over 830 heat networks operating in Scotland and the government has set a target of 1.5 TWh of heat to be delivered by 2020 [48]. Scotland operates the District Heating Loan Fund to address the financial and technical barriers to district heating projects to circumvent difficulties obtaining commercial borrowing. Scotland utilises a range of technologies in their heat networks including biomass boilers, ground heat pumps and combined heat and power (CHP) [49]

What is clear however, is that there is a great push from the UK government to decarbonise heating across the UK, which gives clear support to implementation of district heating schemes and other heat reuse technologies that may reduce the emissions caused by heating.

Natural Gas Demand

If households are to become more dependent on district heating schemes for their domestic heating, a correlation between demand and supply of waste heat is necessary. Annual variation in gas demand from different sectors is given by Figure 11. There is a large variation in domestic gas demand between summer and winter time and that this correlates with smaller variations in industrial gas demand and demand from the electricity generation sector over the same timescale. Therefore, increasing the dependency of households on waste heat from both the industrial and electricity generation sectors is a viable option because an increase in demand for heat correlates with an increase in supply. However, while domestic heating demand is mainly dependent on the weather, industrial and electricity generation demand will depend on a variety of factors. For example, the effect of the Coronavirus pandemic is likely to have a negative effect on industry and a reduction in industrial gas demand, and therefore industrial waste heat, is expected. The demand for domestic heating is higher than the combined demand for industry and electricity generation, therefore waste heat cannot be solely relied upon for domestic heating and other low carbon options need to be explored.

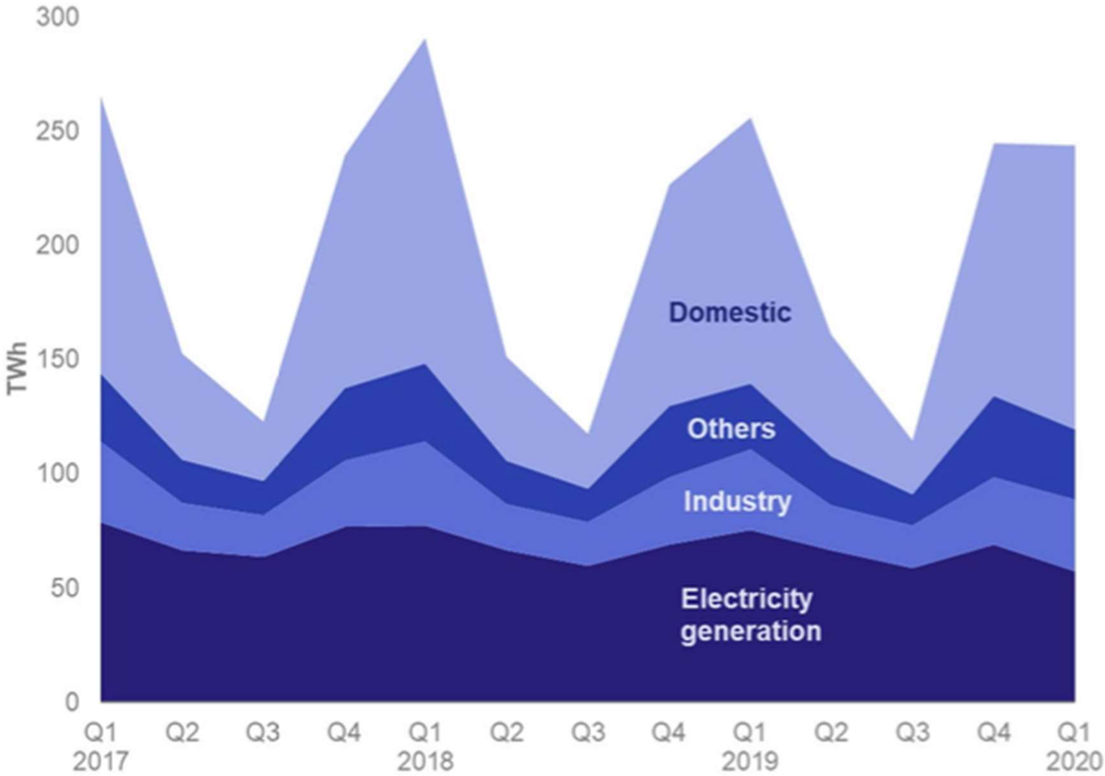

Figure 11: UK demand for natural gas [51].

Heat Grade

The grade of waste heat is dependent on its temperature, with higher temperature equalling higher grade [52]. In general, the higher the grade of waste heat the more useful it can be. Recovered heat of 70-80°C is useful in district heating schemes, as domestic and non-domestic buildings require a flow in this temperature range so that no material changes to building fabric are required. Waste heat in the range of 40-70°C is more suitable to modern buildings with suitable insulation and underfloor heating. For waste heat of this grade to be supplied to customers without these building modifications, the heat must be elevated to a higher temperature using a gas/biomass boiler or a heat pump. This added cost often prevents this use of waste heat. Low grade heat of 30°C or less is most useful in the winter and when its supply is constant, however a heat pump is needed.

Discussion

Data for this study have been taken directly from BEIS and ELEXON and both deal with granular data taken from individual energy transactions. These data are taken to be accurate and complete. The assumptions made for each industry have been formulated from available data and studies concerned with each industry and are outlined below.

- Electricity generation: ELEXON data gives energy transfer data accurate to half hourly periods for each power station type. The efficiencies have come, where possible from BEIS, or other reputable sources.

- Chemicals industry: The Carbon Trust report details that half of the chemical industry is concentrated in four discrete areas (those represented on the map) and the rest is widely dispersed around the UK. Therefore, there will be a greater potential for waste heat recovery than outlined in this report.
- Food & Beverage: As mentioned above the number of individual abattoirs, bakeries, vintners and food processing plants is colossal. The decision was taken to prioritise the grade of available waste heat over the quantity of sites. The spatial representation displayed on the map is thought to give a fair estimation to the overall distribution, as food processing plants are likely to be located near to regions with a higher intensity of agriculture or to ports.
- Minerals: all sites listed under the British Ceramics Confederation and cement plants listed under the Mineral Products Association are investigated. Sites not included in these listings are not included in this study and were not investigated due to time constraints.
- Vehicles: the points represented from the vehicle industry are believed to be comprehensive. However, this resource is likely to deplete over time as the UK ceases vehicle production.
- Iron and Steel: no comprehensive list of operational iron and steel works could be found and therefore they were selected based on broad industry research.

Assumptions had to be made due to time constraints.

The above analysis demonstrates that there is a large, well-distributed resource of waste heat from non-domestic sources in the UK that has the potential to be utilised in heat recovery schemes, such as in district heating. Findings also reveal the lack of nation or region wide coordination on waste heat reuse, due to the extremely low response rate from industry to requests for information. It is clear that much of the waste heat identified in this study could be reused. The location of industry is approximately correlated with population density, which is expected as settlements are usually built in areas with good natural resources. We find that seasonal variation in waste heat is correlated with the seasonal variation in demand for heat. Furthermore, making use of this resource would reduce carbon dioxide emissions, aiding in reaching the UK's target to be carbon neutral by 2050.

Total waste heat is focused in areas with a traditionally strong presence from industry and high population density, such as Yorkshire and the Humber (Figure 12). These areas are well connected to power stations and close to roads for transportation. Proximity to facilities with large quantities of heat waste makes these areas appropriate for district heating schemes. They are often already well connected to industry, in particular the electricity generation, mineral and chemical production sectors. The electricity generation sector accounts for the majority of waste heat and therefore should be the focus of any waste heat recapture scheme. By analysing the point map (Figure 13), we see that the local authority areas containing one or more power stations are often those with higher waste heat. In particular, CCGT and nuclear power stations would be appropriate because of their high load factor. However, neither CCGT nor nuclear power are renewable technologies and consideration needs to be taken to assess whether long term investment into heat reuse technology for these types of power stations is appropriate. Although nuclear power itself does not release carbon dioxide, it is an extremely resource intensive technology and much carbon dioxide is released in the building and upkeep of a nuclear power station and the containment of nuclear waste. Research into waste heat capture from renewable technologies may be more appropriate and other, more permanent industries, such as the mineral and chemical sectors may be investigated, although they offer a lower quantity of waste heat.

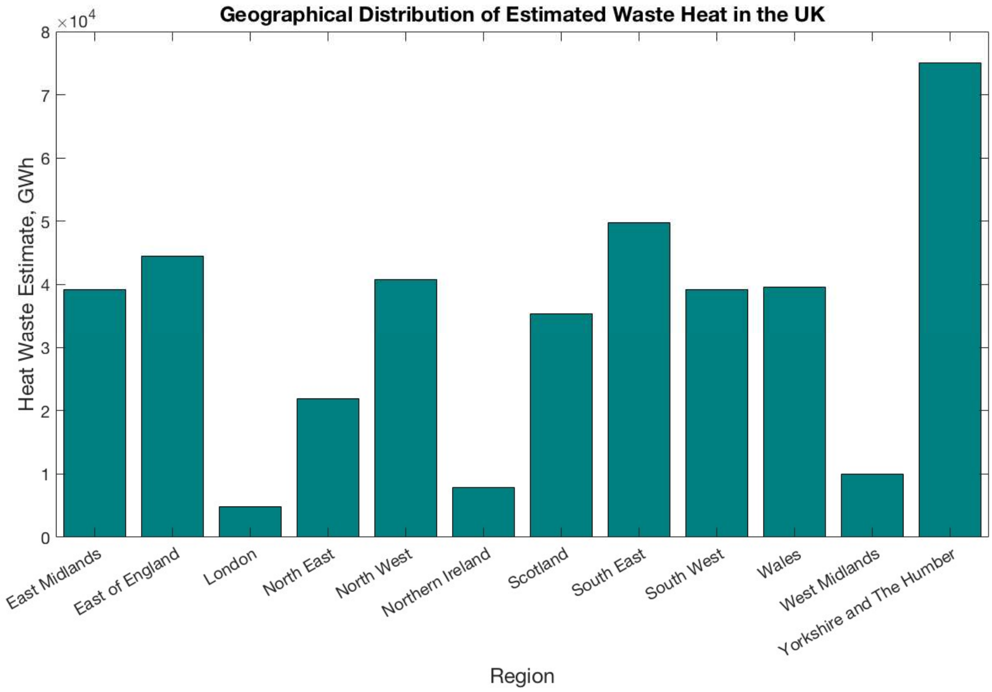

Figure 12: Total estimated waste heat per region.

Figure 14 details approximate population density across each region of the UK. It can be seen that on average the areas with high population density are those with high proportions of waste heat and high CO2 emissions.

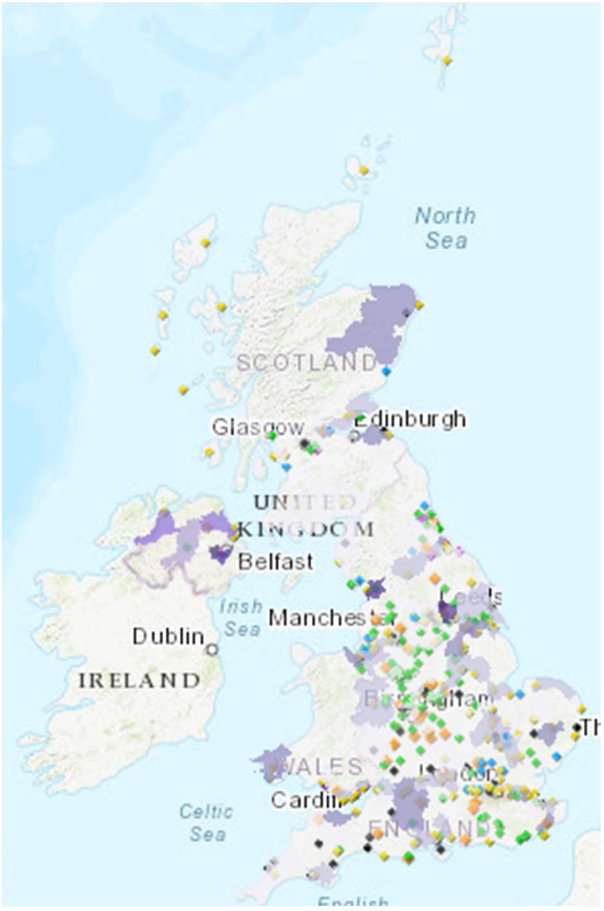

Figure 13: Point map data for UK industry and electricity generation sectors.

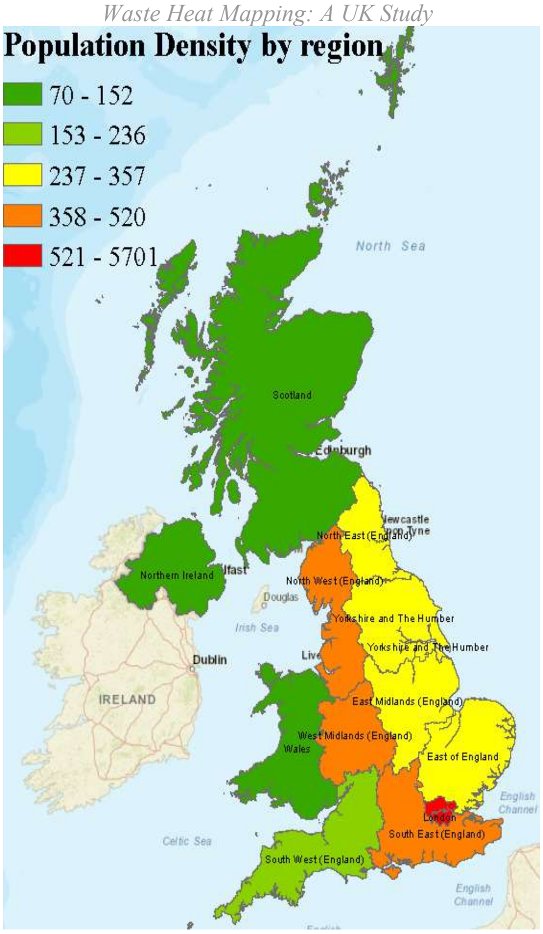

Figure 14: Average population density per region in the UK.

The distribution of carbon dioxide emissions provides some information about the distribution of waste heat, although its distribution is not perfectly matched to that of estimated waste heat (Figure 15). A large proportion of carbon dioxide emissions come from Yorkshire and The Humber, the East Midlands and the South East. Similar to patterns seen in the distribution of estimated waste heat, these areas have a large amount of industry and high population densities. Regions such as Wales, the South West and the North West produce a small amount of carbon dioxide, but account for a larger proportion of the estimated waste heat.

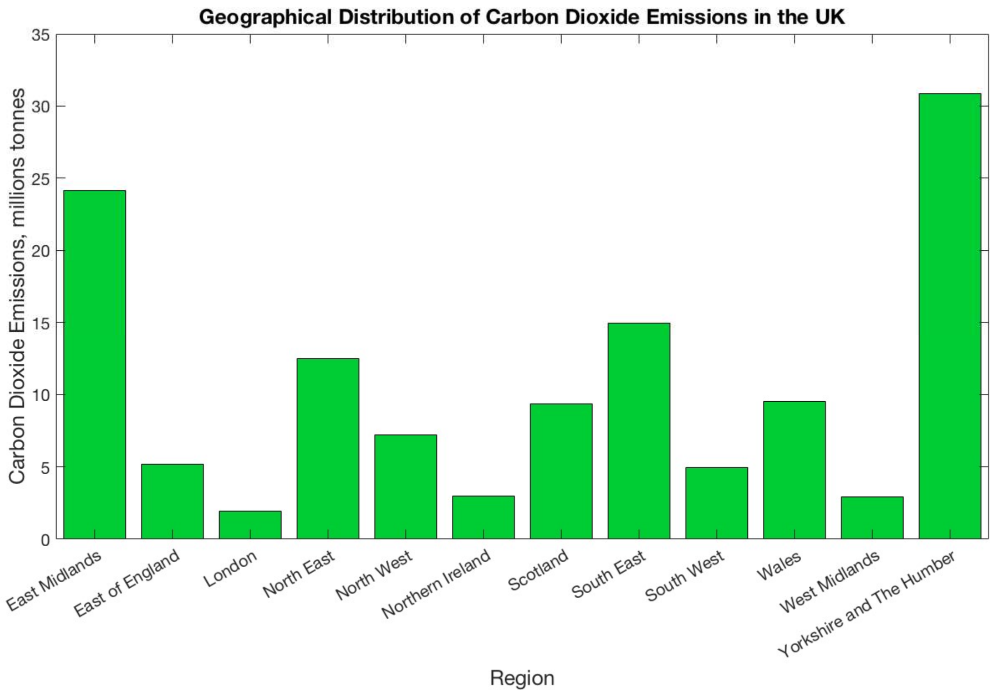

Figure 15: CO2 emissions per region.

Discrepancies could be accounted for by approximations and assumptions made when estimating waste heat per Local Authority area. Many approximations were made when performing the top-down analysis. Carbon dioxide emissions data were provided by the European Pollutant Release and Transfer Register (E-PRTR), which utilises a bottom-up approach [53], and so has the potential for a greater degree of accuracy. The bottom-up approach is as such: the E-PRTR include data from qualifying European facilities that each report their individual data to their respective authority. These data are then provided to the European Commission and the European Environmental Agency, who compile the data and supply it to the E-PRTR. The combination of maps of estimated heat waste, carbon dioxide emissions and point map facility location data can be used to provide a detailed picture of potential waste heat distribution in the UK. CO2 distribution data are similar to waste heat distribution data, qualifying that despite the assumptions made the waste heat distribution is relatively accurate.

There is a large degree of uncertainty surrounding the effects of COVID 19 and there will be impacts on the energy market. Based on the effect of the 2008 financial crash, certain assumptions about the effect of COVID 19 on energy in the UK can be made. Between 2003 and 2015 there was a decline in energy consumption, despite occasional growth in industrial activity [54]. The impact of the financial crisis varied across different industries and the majority of industries were negatively impacted. It is also clear that the negative impacts continued for many years after the recession, for example in 2014 the percentage decrease in total energy consumption since 2007 was approximated to be 17% [55]. Although effects are only discussed here very briefly, it is clear that there will likely be a large decrease in industrial energy consumption in the aftermath of COVID 19. This will have a negative effect on the viability of district heating schemes. However, as more people are working from home, there has been an increase in demand for domestic heating supply [56]. As the government pushes for a new greener economy in the wake of COVID 19, it is important that green technologies are utilised to meet this new demand.

The main issue this study faced was the extremely low response rate to enquiry from industry. This was disappointing, as it changed the scope of the project and has limited the accuracy of much of the information provided by the UK Heat Map. A much better picture of waste heat potential could have been provided had this information been available. However, what has been demonstrated is the reluctance from industry to divulge what it perceives to be commercially sensitive information, despite the clear need for clarity on this subject for there to be progress. The nature of ventures such as district heating schemes depend on the collaboration of different industrial sites to provide the necessary amount of waste heat. Without sharing even basic information on available waste heat, heat reuse schemes cannot hope to be implemented. While it is assumed, and confirmed in a few cases, that there are many heat reuse technologies currently employed by companies at specific facilities, it is not known whether these are the most economic or sustainable options available and there will inevitably be room for improvement. Therefore, if real progress is to be made in this area, it is paramount that the government encourage the sharing of information and expertise in order to create the most suitable heat reuse scheme in each case. Although there are many heat networks already operating in the UK, as a nation we are still massively dependent on natural gas for domestic heating. Heat networks will play a large role in reducing and eventually eliminating this dependence, but for this to happen, more collaboration across industry is needed. If the aim is to reduce carbon dioxide emissions and create a greener future for energy and heating in the UK, then this is a necessity.

Conclusions

As of 2019, only 450,000 homes, out of about 25 million, are heated from district heating networks. Many of these networks are fuelled by energy from waste or combined heat and power systems. This report has found that there is significant overlap between the spatial distribution of waste heat in the UK and the population demand for domestic heating. Certain regions, such as Yorkshire and The Humber and the East of England, show particularly high waste heat potential, mainly due to the large, high capacity power stations in these areas. These are also areas with high population densities and therefore there is a great potential for heat reuse. The greatest potential for waste heat recovery has been found to be from CCGT and nuclear power stations, which could provide a near constant supply of heat due to the consistency in their operating profile as seen by their load factors. The potential for waste heat recovery from industry is smaller and less certain because usage patterns are less predictable and industry is largely concerned with profit. Financial incentives may be required to encourage the entrance into waste heat reuse schemes. Certain industries, such as ceramic and mineral production, show a high availability of waste heat.

Poor response rate from industrial questionnaires has limited the accuracy and scope of this work and large assumptions were made. These assumptions introduce uncertainties about the quantity and grade of heat available. However, analysis of carbon dioxide distribution confirms the distribution of waste heat at a basic level. Significant change is necessary to lower carbon dioxide emissions in the UK, and industry is required to change its practises to reduce their emissions and consumption. This report has found a serious reluctancy from industry to be involved in this study, reflecting on the attitudes of industry towards collaborative heat reuse schemes. If progress is to be made, UK industry must collaborate with studies such as this one to allow an increase in understanding of the problems faced and solutions available. However, this report finds that the industries and electricity producers that provide the greatest availability of waste heat are also some of the less environmentally friendly industries in the UK and are all highly dependent on natural gas. We must ask: as the supply of energy to industry is mainly natural gas or gas-derived electricity, does the long-term sustainability of waste heat reuse technologies truly aid the move to a greener economy?

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