National Heat Study

District heating and cooling: Spatial analysis of infrastructure costs and potential in Ireland

Appendix C – Assessment of the potential of waste heat in Ireland

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Contents

I. Introduction

The National Heat Study aims to provide a rigorous and comprehensive analysis of the options to reduce CO_2 emissions associated with heating in Ireland. The Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the study. The project was carried out in close collaboration with the Department of the Environment, Climate and Communications.

As well as contributing to national policy, the findings also supported Ireland's second submission to the EU of a National Comprehensive Assessment of the Potential for Efficient Heating and Cooling, as required by Article 14 of the Energy Efficiency Directive. The data, assumptions and outcomes of the National Heat Study are detailed in eight technical reports. The concluding report is *Net Zero by 2050*, which outlines the study's key insights across scenarios that achieve net-zero emissions from heating and cooling.

The present slide deck is an appendix to the *District Heating and Cooling: Spatial analysis of Infrastructure Costs and Potential in Ireland* report.

Official Journal of the European Union, 2012. Directive 2012/27/EU of the European Parliament and of the council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

I. Introduction

The purpose of this work was to identify and assess potential waste heat and cooling sources within Ireland, as requested by Commission Recommendation (EU) 2019/1659. This was divided into six distinct components:

I. Thermal power generation installations that can supply or can be retrofitted to supply waste heat with a total thermal input exceeding 50 MWth;

II. Heat and power cogeneration installations using technologies referred to in Part II of Annex I of the Energy Efficiency Directive (EED) with a total thermal input exceeding 20 MWth;

III. Waste incineration plants;

IV. Renewable energy installations with a total thermal input exceeding 20 MWth other than the installations specified under the first and second bullet points above generating heating or cooling using the energy from renewable sources;

V. Industrial installations with a total thermal input exceeding 20 MWth which can provide waste heat, such as alumina, ceramic, cement sites etc.;

VI. Other low temperature waste heat sources, such as cooling towers serving space and other cooling systems, where the waste heat can be captured and upgraded where necessary using high efficiency heat technologies to meet heat demands elsewhere.

Furthermore, opportunities for waste cold recovery were to be evaluated.

I. Introduction

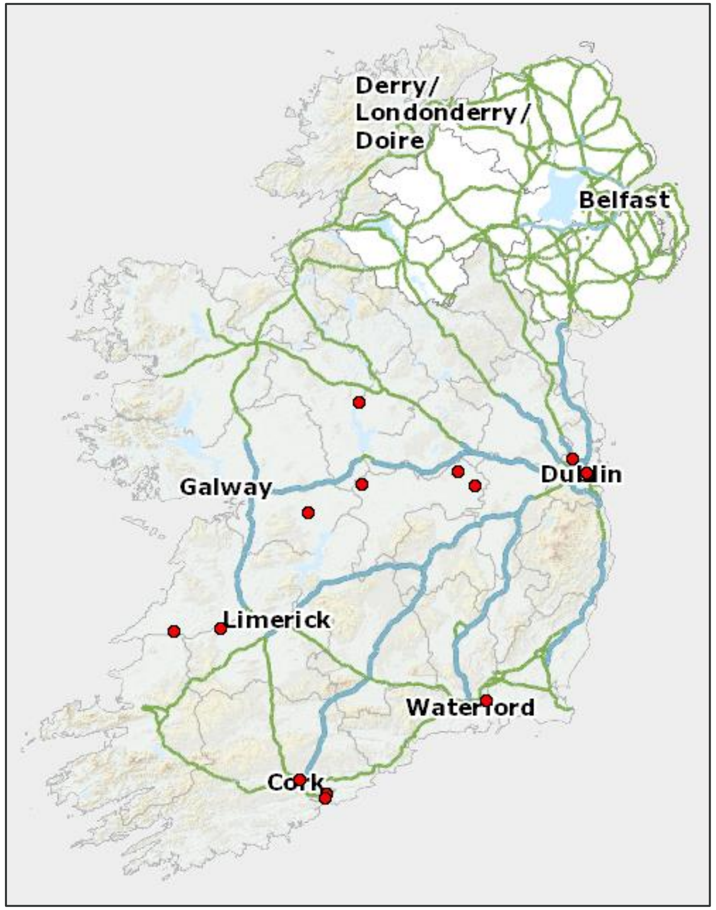

Figure 1: Power stations

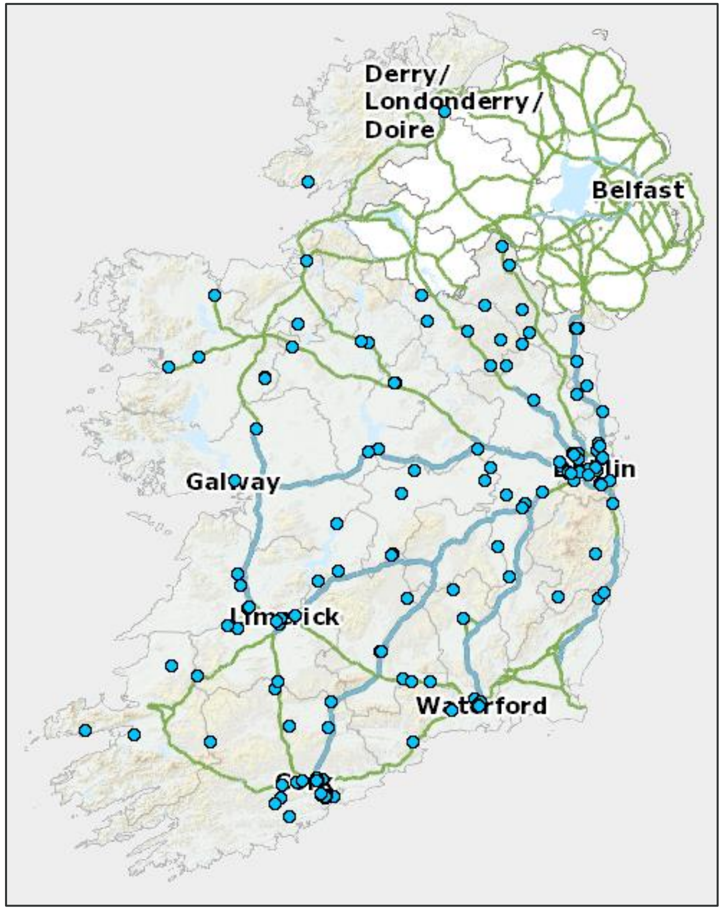

Figure 2: Large industrial sites

Power stations consume large quantities of fuel, not all this energy is converted to electricity, and hence there is often considerable potential for waste heat recovery. The location of power stations throughout Ireland is shown in Figure 1.

Whilst power stations typically consume more fuel than industrial sites, sectors such as alumina, ceramic and cement require high process temperatures. This thermal energy is obtained via the combustion fuels onsite, thus there is the potential for waste heat recovery. Figure 2 shows members of the SEAI Large Industry Energy Network group, these account for some of the largest industrial fuel consumers in Ireland.

Sustainable Energy Authority of Ireland (SEAI). Heat demand map. Available at: Map Of Heat Demand In Ireland | SEAI GIS Maps | SEAI. (Accessed: 29/12/2020)

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I. Introduction

Out of an initial 67 sites across Ireland, Table 1 below shows the number of sites that met the fuel input threshold defined by the EED. The review of these sites and reasons for site exclusion are discussed throughout this slide deck and in the *District Heating and Cooling* report. .

Table 1. Sites evaluated

Sector	No. Sites Reviewed	No. Sites that met the Fuel Input Threshold	Comment on heat extraction from power plants / waste heat from industrial sites
Power Station	16	16*	Power plants and incinerators aim to maximise power generation with heat exiting the process at around 30 ^{o}C. In converting the power station to a CHP mode, low grade heat (60-80 ^{o}C for 4th generation heat networks) suitable for DH can be recovered. Peaking plants and plants expected to cease operation by 2023 have been excluded from this assessment.
Waste Incineration	2	2	
Alumina	1	1**	
Cement	4	4	For industrial sites, where there was a waste heat recovery opportunity, we assumed that the grade of heat is based on the process itself and the grade of heat that is available. For some sites such as food & drink, the heat available is low grade (40-250 ^{o}C) while for other sites such as cement it may be medium (250-500 ^{o}C). Due to lack of data on waste heat available from industrial sites in Ireland, we estimated waste heat based on UK data, utilising benchmarks from well-established previous work in the UK. These benchmarks were then applied to Irish data to estimate the waste heat available from various industrial sectors.
Lime/Magnesia	3	1	
Refinery	1	1	
Chemicals	4	0	
Ceramics	1	0	
Food & beverage	28	10	
Pharmaceutical	7	1	
Total	**67**	**36**	

***** 10 power stations are later excluded due to closure etc.
****** Whilst the alumina site did meet the threshold, it was later excluded because the site already operates a CHP.

II. Thermal power generation installations

Initial Data

The fundamental data used to assess the potential of each Irish power stations came from a dataset produced by the ECA (Economic Consulting Associates). In this Plexos dataset technical generator information was collected for the Irish sites in question.

Method

In order to evaluate the potential waste heat recovery from these sites further data was needed, and so the following calculations were performed.

- Heat rate* data from the Plexos dataset was used to calculate the electrical efficiency for each data point along the heat rate curve. The highest of these efficiencies was dedicated the maximum electrical efficiency. This was done for each site.
- Open cycle gas turbines (OCGTs) were assumed to have a maximum total efficiency (electrical & heat) of 75%, whilst steam turbines and CCGTs were set at 80%.
- For OCGT prime movers the heat efficiency was determined simply by subtracting the electrical efficiency from the maximum.
- However, for combined cycle gas turbines (CCGTs), steam turbines and gas turbines, a z ratio** also had to be used to calculate the heat efficiency. z was assumed to be equal to 8 for every site:

$$Heat\ Efficiency = \frac{Total\ Efficiency\ - Condensing\ Electrical\ Efficiency}{1 - \frac{1}{z}}$$

Where the condensing electrical efficiency is the electrical efficiency of the system if zero heat is extracted.

- Following this, the heat capacity (MW) was determined using each sites maximum electrical capacity (from the Plexos dataset), as well as its calculated electrical and heat efficiencies.
- The load factor of 65% was derived based on EirGrid data from *All-Island Generation Capacity Statement 2019-2028*. This was applied to all power stations.
- Finally, the total heat potential per year was assessed (GWh/year).
- The fuel input for each site (MW) was estimated by dividing the electrical capacity by the maximum electrical efficiency.

* The heat rate refers to how much fuel energy (MJ) is required for each unit of electricity generated (MWh).

** The Z ratio is a term applicable to pass-out (condensing) steam turbines and is defined as the ratio of heat output (MW) to the reduction in electricity output due the extraction of steam

Economic Consulting Associates, 2020. Generator technical data (confidential)
EirGrid, 2019. All-island generation capacity statement 2019-2028. Available at: All-Island GCS 2019 (eirgridgroup.com)
BEIS, 2021. Guidance note 28 – Determination of Z ratio. Available at: Combined heat and power quality assurance (CHPQA) guidance notes - GOV.UK (www.gov.uk)

II. Thermal power generation installations

Results

A number of the power stations have closed, or are closing in the coming years, and thus were excluded.

Table 2 shows the calculated heat potentials for the remaining 6 Irish power stations. As previously stated, in order to be considered power stations must have a fuel input exceeding 50 MW.

Table 2. Waste heat potential from power stations

Installation Name*	Type	Operation	Fuel Input [MW]	Heat Potential [MWth]	Heat Potential [GWh/year]
PS-1	Power Station	Operational	810	267	1519
PS-2	Power Station	Operational	810	210	1199
PS-3	Power Station	Operational	1270	377	2148
PS-4	Power Station	Operational	1623	342	1951
PS-5	Power Station	Operational	754	187	1063
PS-6	Power Station	Operational	763	189	1075

*In the interest of confidentiality, site names have been removed.

EirGrid, 2019. All-island generation capacity statement 2019-2028. Available at: All-Island GCS 2019 (eirgridgroup.com)

III. Heat and power cogeneration installations

Analysis

In Ireland there are 315 CHP installations, most of which consume natural gas. Services, such as airports and hospitals, make up 262 of these, whilst industry has 53. Of all these systems, there is only one substantial producer of energy (non-ferrous metals), see Table 3.

Once again, the ECA dataset was used to investigate heat recovery from heat and power cogeneration sites. Of all the power stations listed in this data, only one is a CHP plant, which uses large quantities of process heat. Whilst the ECA data could be used to assess heat recovery, it was reasoned that the site is most likely already optimised to recover as much energy as realistically possible. It was therefore assumed that no further waste heat could be extracted.

Table 3. CHP in Ireland

	No. of Units	Operational Capacity MWe
Airport	3	6.7
Communal Heating	34	0.2
Education	12	4.2
Hospital	30	4.9
Hotel	67	8.7
Leisure	46	3.6
Nursing Home	14	0.3
Office	12	1.8
Public sector	19	6.0
Retail	10	1.3
Services Other	15	1.3
	No. of Units	**Operational Capacity MWe**
Food	26	76.7
Manufacturing	6	10.6
Pharmaceutical	14	24.7
Non Ferrous Metals	1	160.0
Other Industry	6	8.0

SEAI, 2019. Combined heat and power in Ireland – 2019 Update.

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IV. Waste incineration plants

Analysis

The ECA dataset identified two energy from waste (EfW) sites in Ireland, EfW 1 and EfW 2. Unfortunately, the technical generator information for these plants was not included, and so an alternative method was required.

As previously stated, in order to be considered EfW sites must have a fuel input exceeding 20MW.

The Irish Heat Atlas was the outcome of a research collaboration between ESB and Europa-Universität Flensburg. In this study several high consuming Irish sites were evaluated to assess the potential for waste heat recovery. It was found that the EfW 1 had a theoretical excess heat of 401 TJ/year. Assuming an annual operation of 8,000 hours, this equates to an average heat potential of 14 MWth.

The Heat Atlas does not provide a theoretical excess heat value for the EfW 2. It was estimated that 35 MWth of heat could be recovered.

Irish District Energy Association. Irish heat atlas. Available at: Heat Atlas (districtenergy.ie) (Accessed: 29/12/2020)

V. Renewable energy installations

Analysis

According to EU ETS data there are several sites in Ireland that consume a mix of renewables and fossil fuels. Sites consuming both renewable and non-renewable fuel have been evaluated in other sections of this work.

Of the 315 CHP installations in Ireland, there are 2 biomass and 20 biogas CHP sites. Together these 22 sites produce a total of 14.7 MWe, and hence they are small installations. Therefore, these renewable CHP sites were excluded from evaluation.

No sites were evaluated that solely used renewables.

VI. Industrial installations

Initial Data

An ETS dataset detailing the fuel consumption of the largest industrial fuel consumers in Ireland was used as the basis for the following calculations. Sites were grouped into the following sectors: cement, ceramics, chemicals, refineries, food & beverage, pharmaceuticals, magnesia and lime production. From the fuel consumption of each site, a means of estimating the potential waste heat recovery was needed.

Whilst the method for assessing heat recovery from power stations is well established, there is no such set of steps for industrial sites. Heat usage varies widely between sectors. Literature regarding waste heat recovery from industrial sites was found to be limited, often focusing on specific sites, rather than any particular sector as a whole.

In 2014 Element Energy modelled the potential for heat recovery at various sites across the UK. In this study the quantity of waste heat available for district heating (MWth) was calculated. Featured sites were from the following sectors: cement, ceramics, chemicals, refineries and food & beverage. ETS data documenting the fuel consumption of these UK sites was also obtained.

Method

This methodology followed the idea that if a relationship between fuel consumption and waste heat recovery could be obtained for the Element Energy sites in the UK, this same relationship could be applied to the Irish sites. The Element Energy UK sites were manually paired with the corresponding ETS fuel data. This data is plotted in Figures 3a & 3b, for which linear lines of best fit have been added.

In the interest of developing a more accurate relationship, UK sites were removed if the fuel consumption was considerably higher than any Irish site, or they yielded a negative relationship.

Element Energy, 2014. The potential for recovering and using surplus heat from industry. Available at: The potential for recovering and using surplus heat from industry - GOV.UK (www.gov.uk)

VI. Industrial Installations

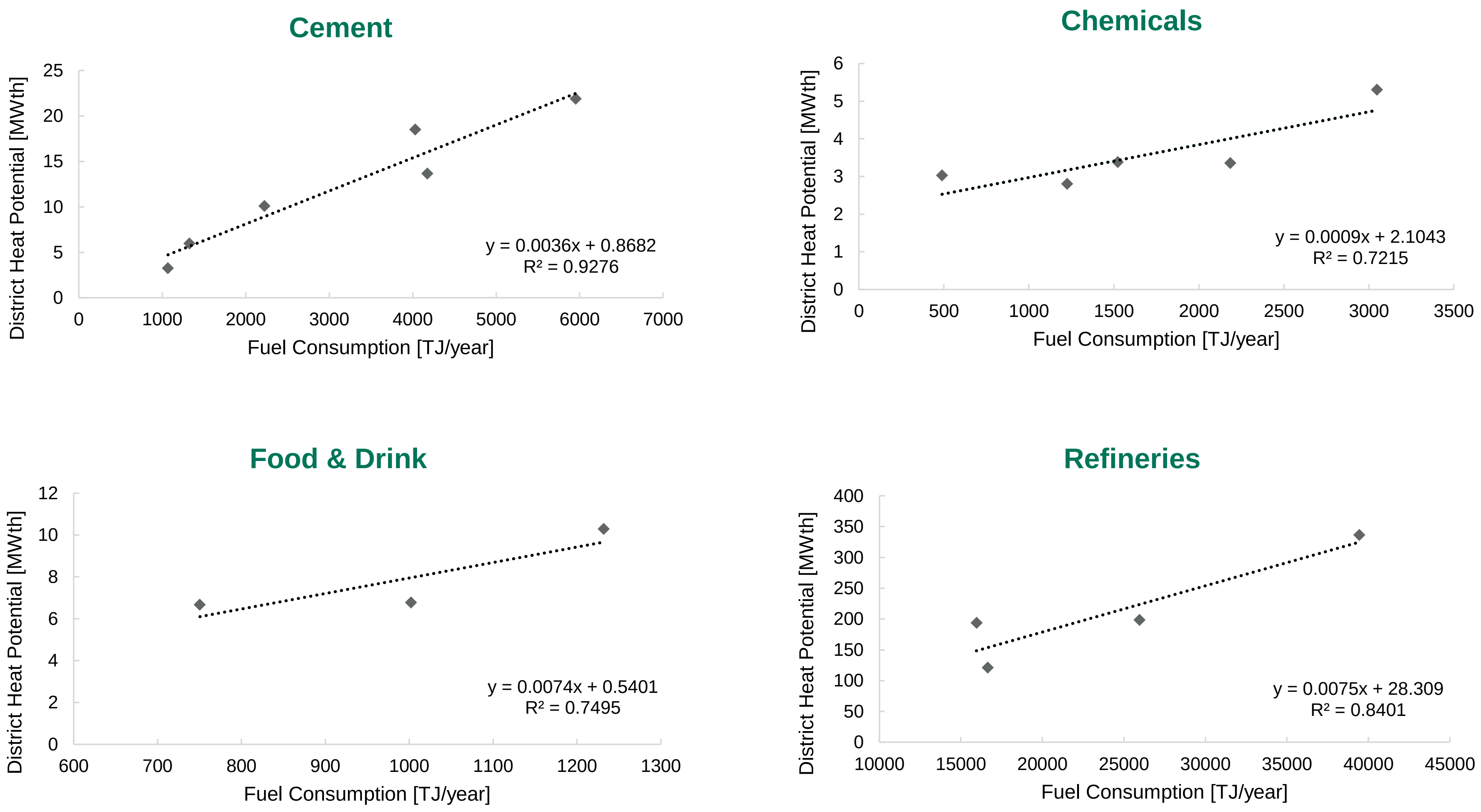

Figure 3a. Relationship between fuel consumption and district heat potential for each sector

VI. Industrial Installations

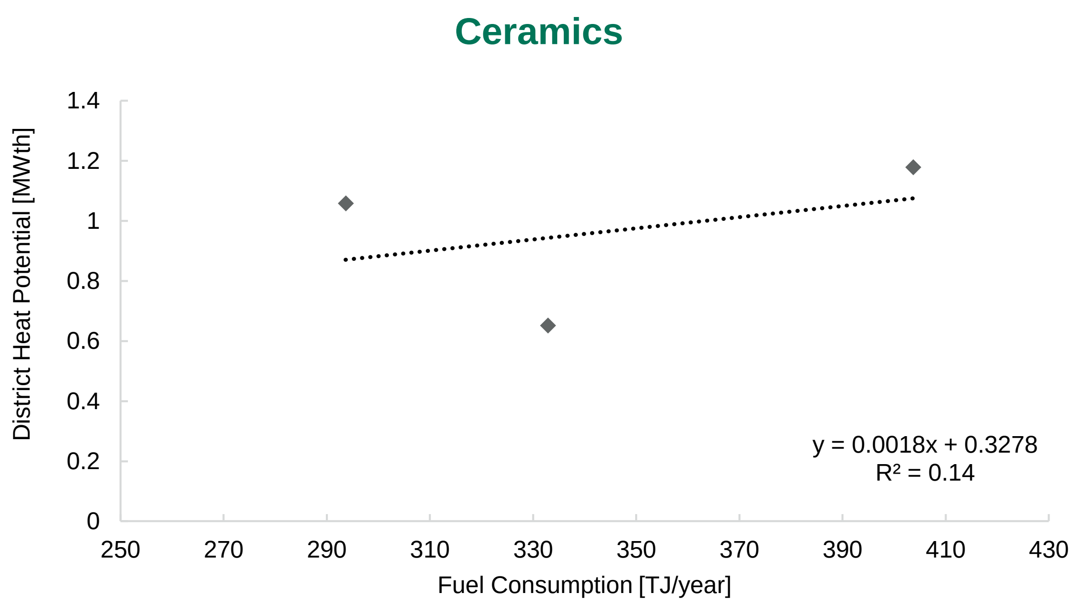

Figure 3b. Relationship between fuel consumption and district heat potential for each sector

VI. Industrial installations

Method Cont'd

These linear lines of best fit were then used, alongside the fuel consumption of the Irish sites producing cement, chemicals, refineries and food & beverage, to estimate heat recovery. For example, if a cement site consumes 1922 TJ of fuel per year, its waste heat can be estimated as follows:

$$Potential\ Waste\ Heat = 0.0036(1922) + 0.8682 = 7\ MWth$$

Additional Steps

The Element Energy study did not include any pharmaceutical sites, and so the relationship for chemicals was also applied to the Irish pharmaceutical sites.

The Element Energy study did not include any lime production sites. As an alternative approach, the waste heat potential for lime sites was evaluated using a specific case study. The UK Steetly Dolomite dolime producer in Thrislington is known to recover waste heat to generate 3,000 MWh of electricity per year. This data, paired with the fuel input for the site, was used to determine the ratio of waste heat recovered to fuel input. This ratio was then applied to the Irish lime production sites. This relationship was also applied to Premier Periclase Ltd, which produces magnesia.

A small selection of Irish industrial sites were excluded, such as plants producing solid fuels, render and wood products.These are niche sites with very little literature regarding waste heat potential. They also have limited potential for heat recovery due to low quantities of fuel input.

As previously stated, in order to be considered industrial installations must have a fuel input exceeding 20 MW. This was estimated from ETS data given the annual operating hours stated below:

- Refinery - 8,400 hours
- Food & Drink - 7,500 hours
- Cement - 8,400 hours
- Lime/Magnesia - 8,400 hours
- Alumina - 8,400 hours
- Ceramics - 8,400 hours
- Chemicals/ Pharmaceuticals - 7,500 hours

Heatcatcher - Waste Heat & Power. UK's first waste heat to power system completed at Thrislington. Available at: https://heatcatcher.com/insights/uks-first-waste-heat-to-power-system-completed-at-thrislington-plant (Accessed: 24/12/2020)

VI. Industrial installations

Results

Of the initial 49 industrial sites considered in Ireland, Table 4 shows the calculated heat potentials for the 17 sites that met the 20MW fuel input threshold.

Table 4. Waste heat potential from industrial sites

Installation Name	Type	Operation	Fuel Input [MW]	Heat Potential [MWth]	Heat Potential [GWh/year]
Ind-1	Refinery	Operational	173	67	567
Ind-2	Food Processing & Beverages	Operational	50	11	79
Ind-3	Food Processing & Beverages	Operational	34	7	55
Ind-4	Food Processing & Beverages	Operational	45	10	71
Ind-5	Food Processing & Beverages	Operational	54	11	85
Ind-6	Food Processing & Beverages	Operational	21	5	35
Ind-7	Food Processing & Beverages	Operational	40	8	63
Ind-8	Food Processing & Beverages	Operational	27	6	44
Ind-9	Food Processing & Beverages	Operational	31	7	50
Ind-10	Food Processing & Beverages	Operational	21	5	36
Ind-11	Food Processing & Beverages	Operational	35	7	56
Ind-12	Pharmaceutical	Operational	22	3	20
Ind-13	Cement	Operational	83	9	76
Ind-14	Cement	Operational	150	16	138
Ind-15	Cement	Operational	64	7	59
Ind-16	Cement	Operational	104	11	96
Ind-17	Magnesia	Operational	36	2	15

VII. Other low temperature waste heat sources

Data Centres

Data centres typically consist of racks of IT equipment arranged in rows. The electrical energy supplied to this IT equipment generates heat, which must be extracted from the system. Should the IT equipment become too hot, the operation and safety of the system is put at risk. Heat is usually extracted from this system using air. The exhaust air is low grade heat, 35-45°C, and hence the heat is often discharged to the atmosphere. However, this heat can be recovered and transferred to a hot water stream using a heat exchanger for use in a district heating network. This stream can be upgraded using a heat pump to obtain water temperatures more suitable for district heating.

Waste heat recovery from data centres is not a well-established practise, and hence literature surrounding the topic is limited. Two important cases studies come from data centres in Stockholm, Bahnhof Thule and Bahnhof Pionen. Both sites extract waste heat from the system using a series of heat exchangers. This heat is then supplied to a local district heating scheme. These systems can recover 1.6 MW_{th} (~14,000 MWh) and 0.6 MW_{th} (~5,300 MWh) of heat respectively.

The Energy Recovery Factor (ERF) is used to quantify the ratio between reused heat and all the energy consumed by the data centre. ERF typically ranges from 25-55%, in the interest of not overestimating the waste heat potential, 25% will be used for the following calculation.

$$\mathrm{ERF} = \frac{Reused\ Heat}{Total\ Energy\ Consumed\ by\ the\ Data\ Centre}$$

The electricity consumption of data centres was assessed; it was found that 2,900 GWh of electricity are consumed each year at data centres in Ireland. Combined with an ERF of 25%, there is the potential to recover a total of 725 GWh (83 MW_{th}) of waste heat from centres in Ireland. At the time the study was undertaken, there were approximately 24 data centres across Ireland, most of which were in Dublin. However, there is a lack of public information regarding the size of each site and hence the total heat potential was evenly distributed across all 24 centres. This method yields a heat potential of 30 GWh/year/site. Out of the 24 centres, 4 did not have publicly disclosed locations, hence they were excluded. The remaining 20 centres were paired with a small area.

Oro, E. et al., 2019. Waste heat recovery from urban air cooled data centres to increase energy efficiency of district heating networks. Sustainable Cities and Society 45. 522-542. https://doi.org/10.1016/j.scs.2018.12.012
Huang, P. et al., 2020. A review of data centers as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating. Applied Energy 258. https://doi.org/10.1016/j.apenergy.2019.114109
Celsius Project, 2020. Excess heat from datacentres: Let your insta-selfies heat your home. Available at: Excess heat from datacentres: Let your Insta-selfies heat your home - (celsiuscity.eu) (Accessed 06/04/2021)

VIII. Overall heat recovery results

Table 5 shows that there are 6 power stations, 2 EfW facilities, and 17 industrial sites that meet the defined fuel input thresholds.

Table 5. Waste heat potential from industrial sites and power stations

Installation Name	Type	Operation	Fuel Input [MW]	Heat Potential [MWth]	Heat Potential [GWh/year]
PS-1	Power Station	Operational	810	267	1519
PS-2	Power Station	Operational	810	210	1199
PS-3	Power Station	Operational	1270	377	2148
PS-4	Power Station	Operational	1623	342	1951
PS-5	Power Station	Operational	754	187	1063
PS-6	Power Station	Operational	763	189	1075
EfW-1	Energy from Waste	Operational	77	14	111
EfW-2	Energy from Waste	Operational	192	35	278
Ind-1	Refinery	Operational	173	67	567
Ind-2	Food Processing & Beverages	Operational	50	11	79
Ind-3	Food Processing & Beverages	Operational	34	7	55
Ind-4	Food Processing & Beverages	Operational	45	10	71
Ind-5	Food Processing & Beverages	Operational	54	11	85
Ind-6	Food Processing & Beverages	Operational	21	5	35
Ind-7	Food Processing & Beverages	Operational	40	8	63
Ind-8	Food Processing & Beverages	Operational	27	6	44
Ind-9	Food Processing & Beverages	Operational	31	7	50
Ind-10	Food Processing & Beverages	Operational	21	5	36
Ind-11	Food Processing & Beverages	Operational	35	7	56
Ind-12	Pharmaceutical	Operational	22	3	20
Ind-13	Cement	Operational	83	9	76
Ind-14	Cement	Operational	150	16	138
Ind-15	Cement	Operational	64	7	59
Ind-16	Cement	Operational	104	11	96
Ind-17	Magnesia	Operational	36	2	15

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VIII. Overall heat recovery results

Table 6 shows the 20 data centres with a known location and the potential heat recovery.

Table 6. Waste heat potential from data centres

Data Centre	City	Waste Heat Potential
DC 1	Dublin	3.5 MWth 30 GWh/year (for all sites)
DC 2	Clonshaugh	
DC 3	Dublin	
DC 4	Dublin	
DC 5	Dublin	
DC 6	Dublin	
DC 7	Dublin	
DC 8	Dublin	
DC 9	Dublin	
DC 10	Dublin	
DC 11	Dublin	
DC 12	Kilcarbery	
DC 13	Dublin	
DC 14	Dublin	
DC 15	Dublin	
DC 16	Dublin	
DC 17	Dublin	
DC 18	Galway	
DC 19	Cork	
DC 20	Dublin	

VIII. Overall heat recovery results

Whilst some promising findings have been presented, it is important to scrutinise the validity of the methodology followed.

The power stations were evaluated using a well established method, which utilised extensive plant data. Therefore, the waste heat potential from these sites can be stated with confidence. This is important because these are also the sites in Ireland that are capable of generating the most heat, and are therefore most likely to be selected for development. It is worth noting that the EfW sites were not evaluated using this method, and so the uncertainty for these sites is greater.

The estimation of waste heat potential from the industrial sites does not follow an established method, and hence these results have a greater uncertainty. This however is not a tremendous problem because the industrial sites show less of a potential for waste heat recovery, and thus are less likely to be selected for development. The same is true for data centres.

Ideally, this kind of analysis would include visiting each individual site to evaluate the system and potential for waste heat recovery. However, this was not possible during the timeline of the project, thus the data available has been utilised in the most accurate way possible.

Since this analysis was performed, Host in Ireland released *Ireland's Data Hosting Industry*, a report in which 70 data centres are stated to be in operation throughout Ireland (65 in Dublin). However, the exact geographical location of these 70 data centres is not stated and hence they could not be incorporated into the modelling work performed. It is expected that the 24 data centres considered in this analysis represent the most sizable data centres that were operational pre-2021. Therefore, whilst future modelling work should aim to locate and utilise all 70 data centres, this work provides a strong first analysis for the heat recovery potential of data centres in Ireland.

Host in Ireland, 2021. Ireland's data hosting industry. An industry of substance. Biannual report. Available at: Biannual Market Report May 2021 | Host in Ireland (Accessed: 17/12/2021)

IX. Waste cold sources

When evaluating the potential for recovery from waste cold sources, analysis was restricted to LNG terminals. However, at the time of writing this report Ireland has no LNG terminals.

Dunne M., 2019. Ireland: Developing LNG terminals In Ireland. Mondaq – Connecting Knowledge & People. Available at: Developing LNG Terminals In Ireland - Energy and Natural Resources - Ireland (mondaq.com) (Accessed: 30/12/2020)
New Fortress Energy. Widespread welcome as new backers come on board Shannon LNG project. Available at: | New Fortress Energy (Accessed: 30/12/2020)