Powering Parks

Unearthing the ground source heat potential from parks and public green spaces across Great Britain

By Louise Waters & Sandy Robinson

Published December 2019.

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Hackney

The London Borough of Hackney has 58 parks and green spaces totalling 282 hectares. Our green spaces range from Hackney Marshes, the largest concentration of football pitches in Europe, to the biodiverse and historic settings of Springfield Park and Abney Park Cemetery. Hackney Council have pledged to reach zero net emissions by 2040.

Supported by

Rethinking Parks

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Contents

The ground beneath the parks, playing fields and public green spaces across Great Britain could supply

30 GW of heat

to keep our buildings warm

saving over

8 million tonnes

of carbon emissions each year

Introduction

Parks are the perfect place to take kids to play, enjoy a quiet stroll or have a kick about. But they cost money to maintain - something councils have less and less of.

Parks are also home to a large amount of ambient heat, stored in the ground below the lawns and playing fields. We can harvest this low carbon thermal energy for our buildings with the help of heat pumps.

A heat pump is a cunning device for collecting the ambient heat all around us - in the air, the ground or bodies of water - concentrating it, and pumping it into spaces we need to warm like schools, leisure centres or housing blocks.

Powering Parks is a project by Possible, Hackney council and Scene. We have been investigating the potential for installing heat pumps in Hackney's parks to provide heat to nearby buildings. If successful, it has the potential to tackle climate change, improve air quality and generate income for councils and park authorities to re-invest locally.

We reviewed the potential for four possible sites in Hackney, and hope to install some heat pumps, prove the model works and share what we've learned so that other local authorities can do the same. If you'd like to know more about our work in Hackney and find out when our replication tool and resources are available, please contact **neil.jones@wearepossible.org**

But what's the potential for Powering Parks across Great Britain?[1] **Just how much of a contribution could ground sourced heat in our parks and publicly accessible green spaces make to the decarbonisation of heat?** We brought together data from Ordnance Survey, the British Geological Society, the European Environment Agency, industry standards and academic papers to generate estimates of the total ground source heat potential in the parks of England, Scotland and Wales. We broke these estimates down to the level of individual local authorities so that we could see which cities, districts and boroughs have the greatest untapped potential.

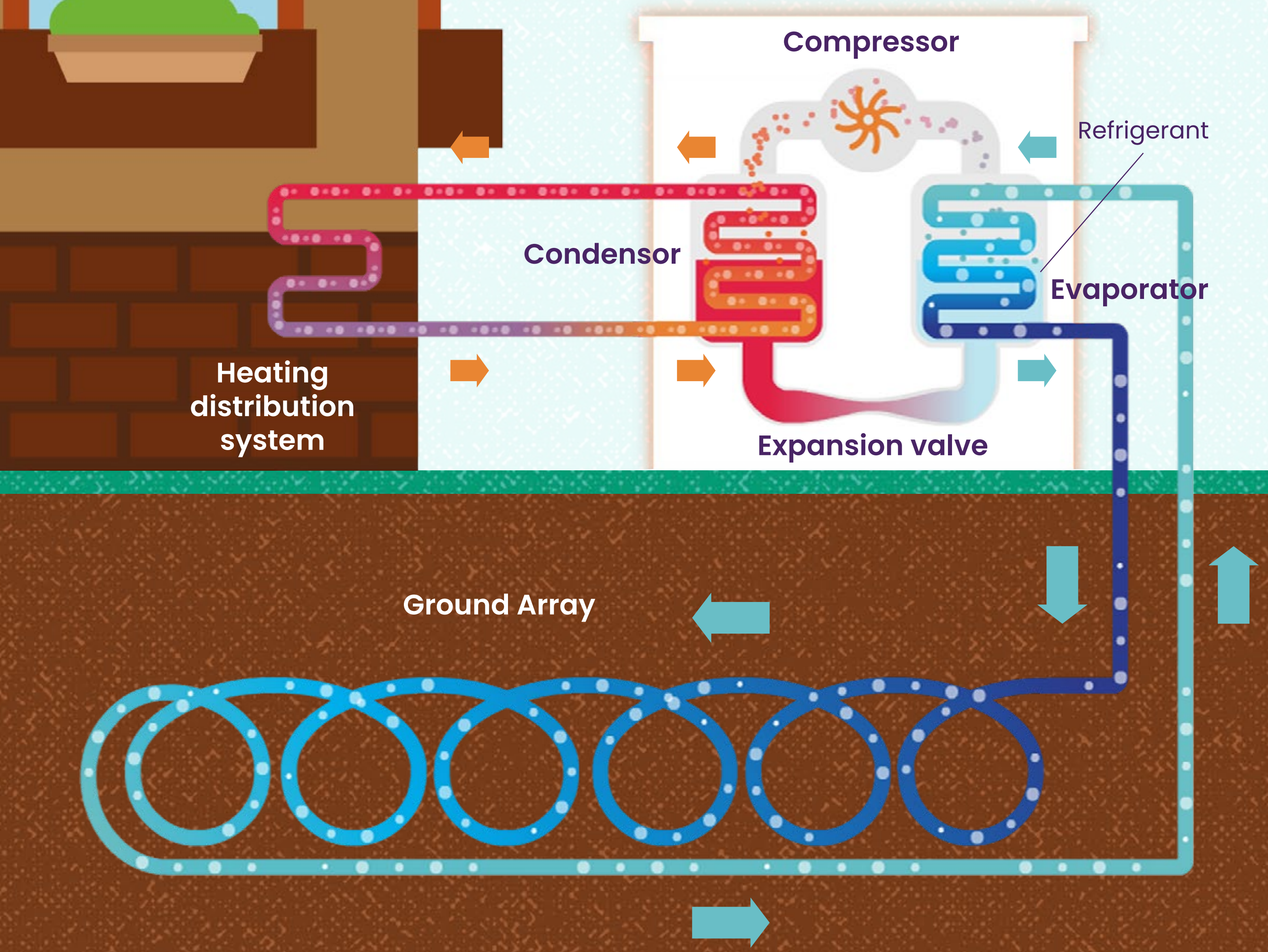
We found that the London Borough of Richmond upon Thames (famous for Richmond Park, Bushy Park and Kew Gardens) was the local authority with the greatest total ground source heat potential from parks. Birmingham City Council came out top when we added other publicly accessible green spaces. Among all the local authorities of Great Britain, Birmingham has the highest population – so it's great that the renewable heat potential of its parks is correspondingly strong. The most populous local authorities in Scotland and Wales – Glasgow and Cardiff respectively – also top the lists of public parks' and other green spaces' potential heat resource in each country.

The amount of heat that could potentially be supplied from parks, playing fields and other green spaces across Great Britain totals around 30 GW - **equivalent to about 10% of the country's total peak heat demand.**[2] More than 20 GW of this would be the heat that

1. We weren't able to carry out this analysis for Northern Ireland, because our principal data source – the Ordnance Survey MasterMap Greenspace Layer – only covers England, Scotland and Wales.

2. Future Insights Series: The Decarbonisation of Heat, Ofgem, 2016. Subtraction made for Northern Ireland heat demand.

is extracted from the ground itself, with the remainder generated by the electricity used to power the pumps. If 100% of this potential was exploited, over 8 million tonnes of carbon emissions could be avoided each year – that's more than 2% of the country's total emissions. It would be possible to increase these totals somewhat if we used more vertical (borehole) installations than has been assumed for this study. Plus widespread energy efficiency retrofit programmes could increase the number of buildings that could be supplied from the ground heat resource. Our analysis finds that while heat pumps in parks can't get us to net-zero alone, they could be one of the most effective and low cost technological solutions for decarbonising heat in urban areas.



What is a heat pump?

There are two ways you can warm up a cold room. One is to create heat, as you would by running a traditional electric heater. The other is to move heat into the room from elsewhere, and the most efficient way to do that is by using a heat pump.

Understanding how a heat pump works means remembering two key things from your school physics lessons. The first thing is that pressure affects the boiling point of a liquid. Lowering the pressure means a fluid will turn into a gas at cooler temperatures, while raising the pressure means the fluid must be hotter before it can boil. That's why it's easier to boil water on top of a mountain, where air pressure is low, than it is at sea level.

The second thing is that a gas turning into a liquid will release heat energy and warm the environment, while a liquid turning into a gas does the opposite - sucking in heat energy and cooling the environment. (This is why sweating cools us down, as the liquid sweat evaporates).

The combination of these two effects means that by controlling the pressure, we can make a liquid turn into a gas, or a gas to a liquid, whenever we want - warming or cooling the environment in the process.

A real-world heat pump is essentially a loop of sealed tube where this process can take place. At different points in the circuit there are interfaces with pipes that deliver energy to the place you want to change the temperature of (ie the place you want to heat up or cool down), and pipes that bring energy from the outside – that's where energy enters and leaves the central loop. The central tube is filled with a refrigerant, which can be any liquid that has the right blend of thermodynamic properties. Those properties will differ depending on the task, but commonly used refrigerants include ammonia, carbon dioxide, isobutane and hydrofluorocarbons.

The refrigerant is circulated around the tube. It enters the compressor in a gaseous state at a lower pressure and temperature. The compressor increases the pressure of the gas. It then goes into the hot side of the tube where, thanks to the high pressure, it turns into a liquid, releasing heat energy. In the example shown here, this released heat goes into the 'heating distribution system' – in other words, the radiators and hot water tanks inside the building.

The refrigerant is then pushed through an expansion valve, which dramatically lowers the pressure. This drop in pressure begins the process of converting the refrigerant back into a gas, which is completed in the cool side of the tube. The energy it needs to do this is pulled out of the surrounding environment, such as the ground beneath a park, the water in a lake or the air. In our example, this heat comes from the 'ground array' of pipes laid beneath the top layer of earth. The cool, low pressure refrigerant then passes back into the compressor, and the cycle starts again.

The cool side can be fairly cool and still contain plenty of 'heat' for the heat pump to transfer. When in liquid form, the refrigerant is so cold that it absorbs heat from the pipework it is in contact with –

even when the fluid in those pipes is below zero degrees! The ground itself, or the water of a lake or river, might itself only be a few degrees above freezing, but still offers a source of energy. By pumping the refrigerant round the system, the not-very-hot heat from the external environment can be converted into usable heat.

There are lots of ways this technology can be used. In a fridge, or air conditioning unit, heat is moved from inside to the outside. In a heating system, the reverse is true and heat energy is moved from outside to inside. It's possible to build a system that's reversible - releasing heat to the outdoors in the summer and capturing it in the winter.

Either way, harvesting heat energy from the external environment, rather than creating it in place, makes heat pumps one of the most efficient forms of heating available. Putting just one unit of electrical energy in will produce up to five units of heat energy. It's basically magic.

Objective of study

The objective of the work was to produce a high-level estimate of the ground source heat potential from the public parks and publicly accessible green space in Great Britain. The estimate is for heating-only schemes without inter-seasonal heat storage. Such schemes represent the vast majority of installations in the UK, and are significantly simpler and cheaper than schemes that incorporate ground source cooling and/or inter-seasonal heat storage. Inter-seasonal storage allows a greater winter heating load to be supplied from a given area, so the inclusion of that type of scheme would increase the overall estimated potential.

In Scotland, the ParkPower programme has been a parallel research project exploring the potential for public greenspaces to support a range of green energy services and associated infrastructure.

ParkPower has been led by greenspace scotland, a charitable social enterprise specialising in pioneering new approaches to managing and resourcing greenspaces. Phase one of the project led to the development of Scotland's first low carbon park, Saughton Park in Edinburgh, where visitors now enjoy buildings and greenhouses heated by ground-source heat pumps and power generated by a micro-hydro scheme. Phase two is soon to report on the potential contribution that a range of green heat and power technologies can make in each of Scotland's 3,500 public parks and playing fields towards national, low carbon energy generation targets. This phase has been funded through the Rethinking Parks programme.

The ParkPower website provides a range of resources, including case studies and exemplar sites. Additional outputs and resources will be added over the coming months and a ParkPower Symposium is planned for early 2020.

Find out more at **www.parkpower.org.uk** and **www.greenspacescotland.org.uk**

greenspace scotland
transforming urban spaces into people places

Discussion of results

In England, aside from Richmond, the other places with the largest ground source heat potential from public parks include districts on the peripheries of Greater London (Windsor and Maidenhead, Redbridge), major cities (Bristol, Manchester, Leeds and Liverpool) and the planned town of Milton Keynes which features a high proportion of parkland and green space. Stoke-on-Trent features perhaps erroneously in the top ten, with much of its "public park" greenspace being contributed by a large area of reclaimed industrial land to the southeast of the city centre that is currently classed as a 'park' in the Ordnance Survey greenspace data. This area, Berryhill, is used for the grazing of horses by tenants who rent paddocks and by the community for walking and other recreational activities. However, it is not owned by the local authority, and is currently earmarked as the largest single site for housing development in the draft Local Plan (against local opposition).

In Wales, Cardiff is joined by the peripheral districts of Caerphilly and Vale of Glamorgan in hosting the greatest park-based ground source heat potential, alongside the country's other two major cities of Swansea and Newport.

After Glasgow, the Central Belt district of North Lanarkshire and the City of Edinburgh have the largest ground source heat potential from public parks in Scotland. Fife contains two large towns and several other medium-sized settlements that are relatively well-endowed with parks. The other district in the top five, North Ayrshire, has a relatively low population but also enjoys a large total park area, concentrated around the new town of Irvine.

Looking at the resource represented by playing fields, the English districts with the greatest potential are dominated by northern cities (Leeds, Kirklees, Sheffield, Bradford, Wakefield, Doncaster and Liverpool), plus Birmingham and the London boroughs of Bromley and

Croydon. In Wales, the playing field resources are concentrated in the populous cities of Cardiff, Swansea and Newport and in the South Wales Valleys (Rhondda Cynon Taf). In Scotland, Fife, Lanarkshire (North and South) and Glasgow have the greatest potential from playing fields.

Comparing the scale of the ground heat resource to the population in each district, we found that the per capita resource was always greatest in England, and dominated by places like Windsor and Maidenhead, Richmond Upon Thames and Milton Keynes. In Scotland, Ayrshire (North and South) and Stirling districts have the greatest per capita resource but are only slightly better than other districts in central and southern Scotland. In Wales, no local authorities have a significantly better than average per capita resource. The per capita resource is an important measure because the commercial viability of a large scale heat pump system is largely determined by the spatial density of the demand for heat that the system is designed to meet. More densely developed areas will be able to harness their ground heat resource more cost effectively than areas where the population is thinly spread across a wide area.

England results summary

Table 1: Public parks - Top ten local authorities in England by magnitude of ground source heat resource.

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential (tCO_2e/year)[3]
Richmond upon Thames	997	225	63,000
Birmingham	965	197	55,000
Windsor and Maidenhead	718	162	45,000
Bristol, City of	674	148	41,000
Milton Keynes	588	126	35,000
Redbridge	493	111	31,000
Stoke-on-Trent[4]	506	105	29,000
Manchester	484	105	29,000
Liverpool	481	103	29,000
Leeds	453	97	27,000
England Total	**33,142**	**7,186**	**2,012,000**

3. Rounded to the nearest 1,000 tonnes of CO2 equivalent. Assuming emissions factors of 0.185 tCO2e per MWh (GCV) for natural gas combustion and 0.200 tCO2e per MWh of grid electricity consumption (a conservative estimate of grid carbon intensity for the early 2020s). Also assumes that the efficiency of heat generation from natural gas is 87%, and the Seasonal Coefficient of Performance of ground source heat systems is 3.5.

4. Affected by the inclusion of hard-to-classify greenspace at Berryhill, so not necessarily comparable to the other local authorities' totals. However, this greenspace does still represent a renewable heat resource.

5. Affected by the inclusion of Blackpool Airport, which makes up the majority of the district's "green space".

Table 2: Playing fields - Top ten local authorities in England by magnitude of ground source heat resource

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential (tCO_2e/year)
Leeds	542	115	32,000
Birmingham	403	82	23,000
Kirklees	349	71	20,000
Sheffield	299	64	18,000
Bradford	296	60	17,000
Wakefield	264	56	16,000
Bromley	224	49	14,000
Croydon	223	49	14,000
Doncaster	233	49	14,000
Liverpool	227	48	14,000
England Total	**24,733**	**5,325**	**1,491,000**

Table 3: Top ten local authorities in England by per capita ground source heat resource.

Public Parks		All Green Space	
Local Authority	Heat supply potential per capita (kW)	Local Authority	Heat supply potential per capita (kW)
Richmond upon Thames	1.1	Windsor and Maidenhead	1.7
Windsor and Maidenhead	1.1	Richmond upon Thames	1.4
Epsom and Ewell	0.5	Milton Keynes	1.3
Milton Keynes	0.5	Corby	1.1
Torridge	0.5	Bromsgrove	1.1
Corby	0.4	Peterborough	1.0
Stoke-on-Trent	0.4	Fylde[5]	1.0
Peterborough	0.4	Halton	0.9
Epping Forest	0.4	Epsom and Ewell	0.9
Bromsgrove	0.4	South Bucks	0.9

Wales results summary

Table 4: Public parks - Top five local authorities in Wales by magnitude of ground source heat resource.

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential ($tCO_2e/year$)
Cardiff	220	47	13,000
Caerphilly	126	24	7,000
Swansea	85	19	5,000
Vale of Glamorgan	77	17	5,000
Newport	69	15	4,000
Wales Total	**1,039**	**215**	**60,000**

Table 5: Playing fields - Top five local authorities in Wales by magnitude of ground source heat resource

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential ($tCO_2e/year$)
Cardiff	163	35	10,000
Swansea	159	35	10,000
Rhondda Cynon Taf	151	29	8,000
Newport	116	25	7,000
Wrexham	104	21	6,000
Wales Total	**1,508**	**313**	**88,000**

Table 6: Top five local authorities in Wales by per capita ground source heat resource

The data suggests that the per-capita heat supply potential from public parks in Wales is very low. However, see the 'Dataset completeness' section in the 'Challenges' chapter for a discussion of the greenspace data's coverage of Wales.

Public Parks	
Local Authority	**Heat supply potential per capita (kW)**
Caerphilly	0.1
Cardiff	0.1
Vale of Glamorgan	0.1
Wrexham	0.1
Merthyr Tydfil	0.1

All Green Space	
Local Authority	**Heat supply potential per capita (kW)**
Blaenau Gwent	0.8
Newport	0.7
Torfaen	0.7
Neath Port Talbot	0.6
Merthyr Tydfil	0.6

Scotland results summary

Table 7: Public parks - Top ten local authorities in Scotland by magnitude of ground source heat resource.

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential ($tCO_2e/year$)
Glasgow City	544	108	30,000
North Lanarkshire	440	81	23,000
City of Edinburgh	366	67	19,000
Fife	363	64	18,000
North Ayrshire	240	47	13,000
Falkirk	222	42	12,000
South Lanarkshire	192	35	10,000
Aberdeen City	168	30	8,000
Dundee City	175	30	8,000
Stirling	138	26	7,000
Scotland Total	**4,237**	**784**	**219,000**

Table 8: Playing fields - Top five local authorities in Scotland by magnitude of ground source heat resource

Local Authority	Suitable Area (hectares)	Heat Supply Potential (MW)	Carbon Saving Potential (tCO_2e/year)
Fife	290	51	14,000
North Lanarkshire	251	46	13,000
Glasgow City	196	37	10,000
South Lanarkshire	194	34	10,000
Dumfries and Galloway	173	33	9,000
Scotland Total	**3,407**	**616**	**172,000**

Table 9: Top ten local authorities in Scotland by per capita ground source heat resource.

Public Parks		All Green Space	
Local Authority	**Heat supply potential per capita (kW)**	**Local Authority**	**Heat supply potential per capita (kW)**
Stirling	0.3	North Ayrshire	0.7
Falkirk	0.3	Na h-Eileanan Siar	0.7[6]
North Lanarkshire	0.2	Stirling	0.6
East Renfrewshire	0.2	Renfrewshire	0.6
Dundee City	0.2	Scottish Borders	0.6
South Ayrshire	0.2	Falkirk	0.5
Glasgow City	0.2	North Lanarkshire	0.5
Fife	0.2	East Ayrshire	0.5
Scottish Borders	0.2	West Lothian	0.5

Implications of results

The heat supply potential figures reported in the previous section and the following table represent the heat that could be supplied to buildings from ground source heat pumps. This is the sum of the heat that is extracted from the ground and the electricity consumed by the heat pump, minus losses.

6. Affected by the inclusion of Stornoway and Benbecula airports, which make up the majority of the district's "green space".

7. Assumes an average peak load COP of 3.1.

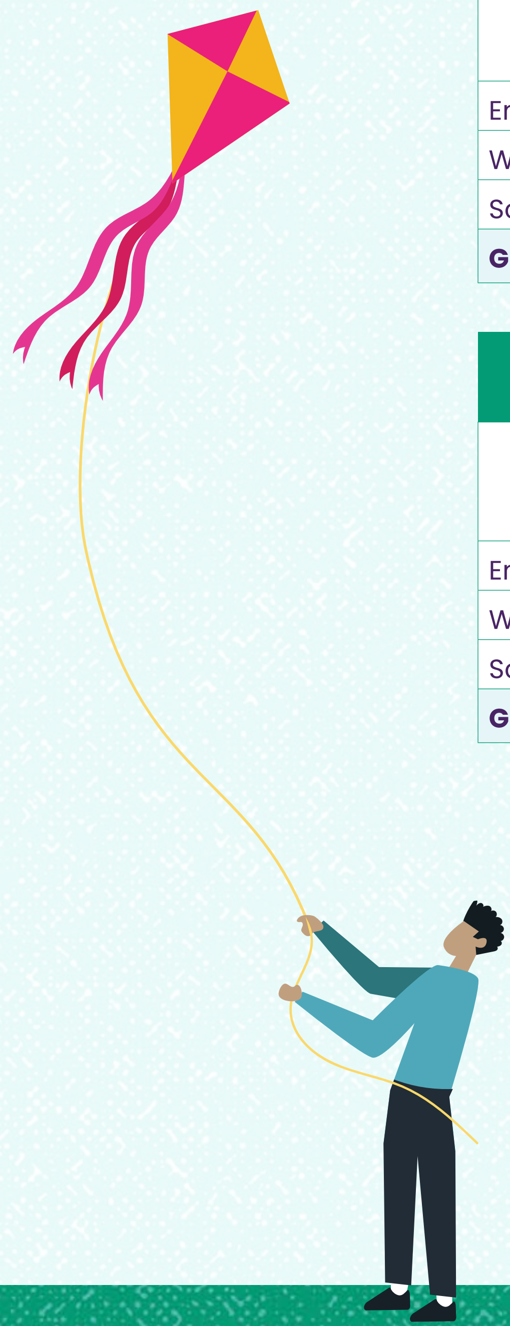
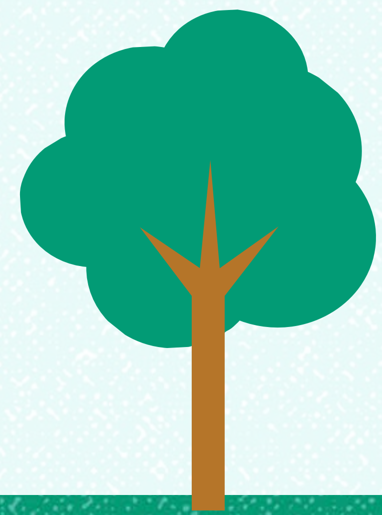


Table 10: Potential peak heat supply, ground heat extraction and corresponding electricity consumption, by country.

Heat Supply Potential (MW)				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	7,186	5,325	12,261	**24,772**
Wales	215	313	836	**1,363**
Scotland	784	616	2,416	**3,816**
GB Total	**8,185**	**6,254**	**15,512**	**29,952**

Ground Heat Extraction Potential (MW)[7]				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	4,868	3,607	8,306	**16,781**
Wales	146	212	566	**924**
Scotland	531	417	1,637	**2,585**
GB Total	**5,545**	**4,236**	**10,508**	**20,290**

Heat Pump Electrical Consumption (if 100% of potential is exploited) (MW_e)				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	2,318	1,718	3,955	**7,991**
Wales	69	101	270	**440**
Scotland	253	199	779	**1,231**
GB Total	**2,640**	**2,017**	**5,004**	**9,662**



The peak domestic (i.e. household) heating demand of GB in a cold year is estimated to be 170GW[8]. This means that, on the coldest days, 18% of domestic heat demand could be supplied from parks, playing fields and other green spaces. In reality, the deployment of ground source heat in parks and green spaces would serve a combination of domestic and non-domestic loads.

It is also useful to consider the proportion of annual demand that could be met across the entire course of a normal year (see Table 11). Our results show that 54 TWh of heat could be supplied from parks, playing fields and other green spaces, against a current GB domestic heating demand of 328 TWh – that's 16%. As a proportion of Great Britain's total (all sectors) current heat demand[9], the same figure is 7%. Widespread energy efficiency drives would somewhat reduce demand, meaning that a larger number of buildings could be connected to systems tapping into the green space heat resource.

Table 11: Potential annual heat supply, ground heat extraction and corresponding electricity consumption, by country.

Annual Heat Supply Potential (TWh)				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	12.9	9.6	22.1	**44.6**
Wales	0.4	0.6	1.5	**2.5**
Scotland	1.4	1.1	4.3	**6.9**
GB Total	**14.7**	**11.3**	**27.9**	**53.9**

Annual Ground Heat Extraction Potential (TWh)[10]				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	9.2	6.8	15.8	**31.9**
Wales	0.3	0.4	1.1	**1.8**
Scotland	1.0	0.8	3.1	**4.9**
GB Total	**10.5**	**8.0**	**19.9**	**38.5**

8. Watson, Lomas and Buswell, Energy Policy 126 (2019) 533-544. Decarbonising domestic heating: What is the peak GB demand?

9. Future Insights Series: The Decarbonisation of Heat, Ofgem, 2016. Subtraction made for Northern Ireland heat demand.

10. Assumes an average Seasonal Coefficient of Performance (SCOP) of 3.5.

11. Digest of UK Energy Statistics (DUKES) 2018, BEIS.

Annual Heat Pump Electrical Consumption (if 100% exploited) (TWh)				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	3.7	2.7	6.3	**12.7**
Wales	0.1	0.2	0.4	**0.7**
Scotland	0.4	0.3	1.2	**2.0**
GB Total	**4.2**	**3.2**	**8.0**	**15.4**

Annual Carbon Savings (if 100% exploited) (tCO_2e)				
	Public parks	**Playing fields**	**Other green space**	**Green space Total**
England	2,012,000	1,491,000	3,432,000	**6,934,000**
Wales	60,000	88,000	234,000	**382,000**
Scotland	219,000	172,000	676,000	**1,068,000**
GB Total	**2,291,000**	**1,750,000**	**4,342,000**	**8,384,000**

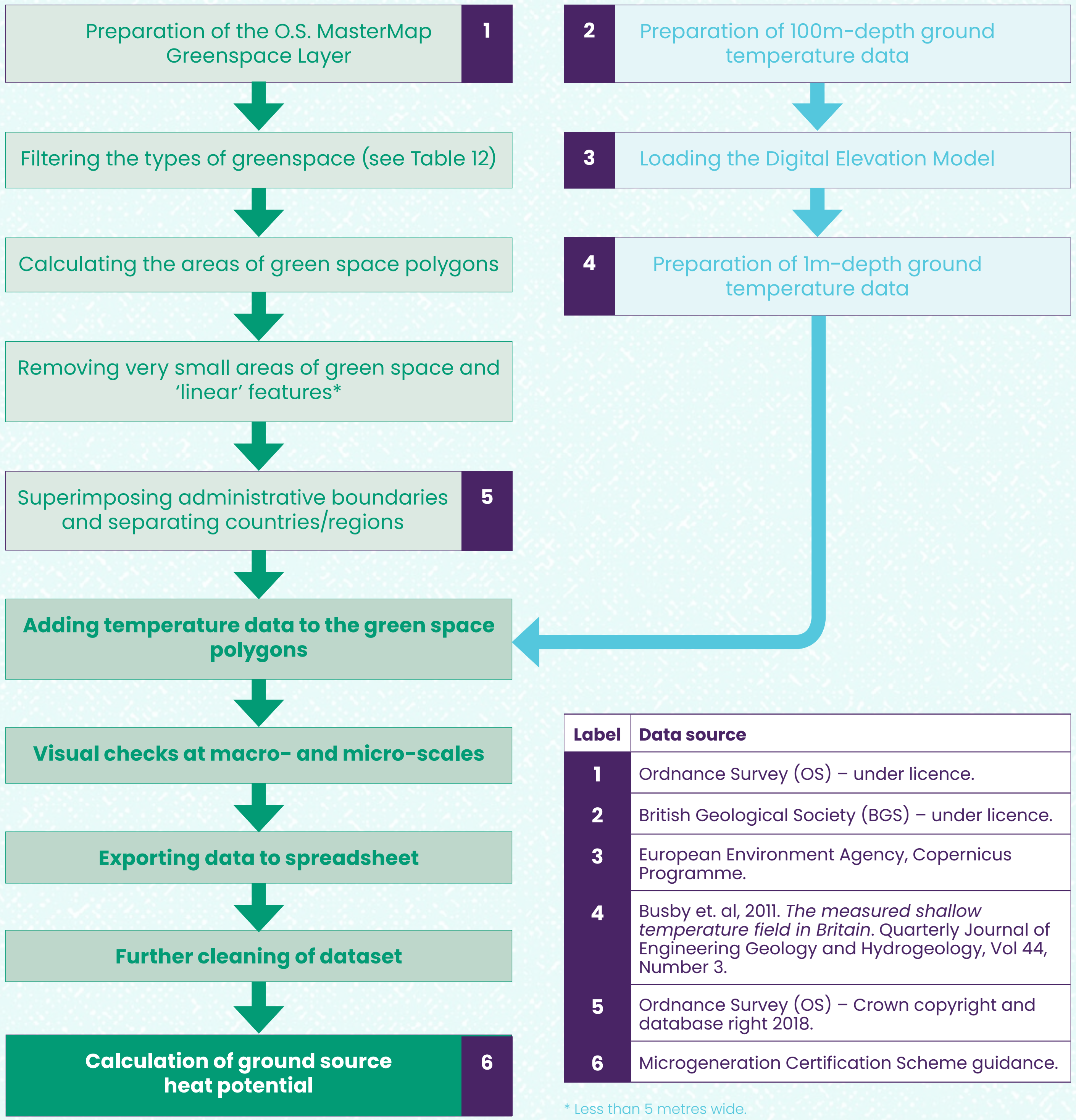
The 'all green space' scenario would add about 5% to GB's current annual electricity demand (final consumption, from all sectors[11]) and about 16% to the peak electricity demand. Adding several GW of electricity demand has real implications in terms of the amount of renewable electricity generation and storage capacity that the country must install. However, this conclusion is consistent with the bigger picture of the heat and transport decarbonisation challenge: for example, the CCC's net zero report envisages significant electrification of heat alongside transport, with a corresponding expansion of renewable electricity generation capacity (for example, offshore wind expanding from 8GW today to at least 75GW by 2050).

It would be possible to exploit the ground heat resource to a greater degree than implied by the previous tables and figures by using more vertical (borehole) installations than has been assumed for this study. Vertical systems take up much less space than horizontal installations, but are significantly more expensive. Our analysis assumed that about half of the installed capacity would be vertical systems and half horizontal, based on 20% of the available area being used for vertical systems and 80% for horizontal. The rationale here is that parks offer the ideal soft-dig conditions for horizontal systems to be installed extremely cost efficiently - optimal conditions that are otherwise lacking in high-density urban environments. If England, Scotland and Wales wanted to increase their use of ground source heat in parks beyond the limits presented in this report, then they would need to install more vertical systems - despite the additional cost of doing so – and devote less of the available area to horizontal systems.

Summary of process

Figure 1 summarises diagrammatically the process that we followed to arrive at the results. This process is laid out in more detail in the methodology report. The GIS program used was QGIS. Later stages of analysis were carried out using Microsoft Excel.

Figure 1: Summary of analysis process.



Label	Data source
1	Ordnance Survey (OS) – under licence.
2	British Geological Society (BGS) – under licence.
3	European Environment Agency, Copernicus Programme.
4	Busby et. al, 2011. *The measured shallow temperature field in Britain.* Quarterly Journal of Engineering Geology and Hydrogeology, Vol 44, Number 3.
5	Ordnance Survey (OS) – Crown copyright and database right 2018.
6	Microgeneration Certification Scheme guidance.

* Less than 5 metres wide.

Picking which types of green space to include and which to leave out was the fundamental step that whittled down all the OS Mastermap green space into our dataset from which ground source heat potential could be estimated. Table 12 lists the different 'functions' that were included or excluded from the analysis, with an explanation for each choice.

Table 12: Greenspace Functions that were included or excluded from the analysis.

Function	Included?	Notes
Allotments or Community Growing Spaces		Most sites unsuitable without major disruption to users.
Amenity - Residential or Business	✓	**Includes lawns or surfaced areas in between residential or commercial buildings, where ground source heat pumps may be highly suitable – but also contains problematic areas.**
Amenity - Transport	✓	**Includes lawns or surfaced areas adjacent to roads or part of transport hubs, where GSHPs may be highly suitable – but also contains problematic areas.**
Bowling Green		Unsuitable due to expense of surface reinstatement (extremely flat surface required for bowling greens).
Camping or Caravan Park		Some potential exists, but areas should not be routinely included in estimates.
Cemetery		Unsuitable.
Golf Course		Some potential exists, but areas should not be routinely included in estimates.
Institutional Grounds		Significant potential exists, but outside the scope of this estimate as many areas are not publicly accessible.
Land Use Changing	✓	**Includes sites undergoing redevelopment where GSHPs may be highly suitable – but also contains problematic areas.**
Natural		Most sites unsuitable due to presence of woodland, areas of high ecological value, open water etc. Water source heat opportunities outside the scope of this estimate.
Other Sports Facility		Most sites unsuitable.
Play Space		Some potential exists (e.g. during redevelopment), but areas should not be routinely included in estimates.
Playing Field	✓	**Includes football, cricket and similar pitches where GSHPs may be highly suitable and can be combined with drainage improvement works.**
Private Garden		Significant potential exists, but outside the scope of this estimate as these areas are not publicly accessible.
Public Park or Garden	✓	**The main focus of the study; includes many areas where GSHPs are highly suitable.**
Religious Grounds		Significant potential exists, but outside the scope of this estimate as many areas are not publicly accessible.
School Grounds		Significant potential exists, but outside the scope of this estimate as many areas are not publicly accessible.
Tennis Court	✓	**GSHPs may be highly suitable when combined with resurfacing work.**

Additionally, areas of land which had been marked as having one of the following 'forms' were excluded: Woodland, Open Semi-Natural, Inland Water, Beach Or Foreshore and Multi Surface. Green space which was classified as having a "Manmade Surface", or which did not have a form classification (including mown grass areas), were included.

Key assumptions

Soil temperatures

We created a country-wide model of the temperature of the soil at 1m depth by plotting geo-located measurements, with corrections to account for the effect of altitude. **We assumed that air (hence soil) temperature decreases by 0.65°C per 100m of altitude gain.**

Ground heat collector types

We suggest that due to cost, practical considerations and landowner decarbonisation ambitions a mixture of horizontal and vertical heat collectors would be installed in different places. However no sufficiently rigorous data was available on what kinds of heat collectors have been installed in the UK so far. Our analysis assumed that **20% of the available area would be used for vertical systems and 80% for horizontal**, meaning that each type would represent about half of the installed capacity.

We have not included open-loop groundwater systems or any systems tapping into old mine workings.

Borehole characteristics

In line with typical designs, we assumed that an **average depth of 150 metres and an average borehole-to-borehole spacing of 12 metres** applies across all types of land and the regions of the country. We assumed that **borehole arrays cover 80% of the suitable land** that is allocated to vertical systems, leaving 20% for land that is unsuitable for reasons such as land shape, buried services like pipes or restricted access.

We did not have access to a dataset or 3D model of below-ground thermal conductivities across GB, so we have assumed a conservatively low **average thermal conductivity of 1.5 W/mK**. This falls within the conductivity ranges for many common rock types.

To convert the average ground temperature and average ground thermal conductivity into a maximum power that can be extracted from a typically-designed borehole, we used look-up tables from the Microgeneration Certification Scheme.[12] We assumed that the average system's **annual 'Full Load Equivalent' (FLEQ) run time is 1800 hours**. Maximum heat extraction per unit length of borehole ranges from **18 W/m at a mean ground temperature of 6°C to 41 W/m at a mean ground temperature of 15°C**.

12. MCS 022: Ground Heat Exchanger Look-Up Tables: Supplementary Material to MIS 3005, Issue 1.0. DECC, 2011.

Horizontal heat collector characteristics

In line with the underlying assumptions for the MCS lookup tables, we assumed that **trench spacing is 3 metres**, and that **spaced trenches cover 60% of the suitable land** that is allocated to horizontal systems.

Soil types and water content are highly varied across Great Britain. In the absence of more precise data, we have assumed a conservatively low **average thermal conductivity of 1.5 W/mK**. This is the lower limit of the range for water-saturated sand, and near the middle of the range for water-saturated clay or silt.

A linear interpolation of data from MCS look-up tables (with annual FLEQ run time equal to 1800 hours) gives maximum heat extraction per unit length of trench varying from **26.5 W/m at a mean ground temperature of 6°C to 60.0 W/m at a mean ground temperature of 12°C**.

Heat pump performance

Heat pumps connected to both vertical and horizontal collectors are assumed to have an **average Seasonal Coefficient of Performance (SCOP) of 3.5**.

Challenges and implications for results

The major challenges we encountered during the analytical process - that have implications for the results - relate to computational issues, dataset completeness and coverage and the inclusion of unsuitable or irrelevant locations.

Computational

The OS MasterMap Greenspace Layer dataset, that covers the whole of Great Britain, contains a lot of data that was hard for our computers to process and analyse at all once. To improve speed and reliability, the data was divided into several packages and we carried out all the processing and calculation steps on each separate file. This approach meant the possibility of systematic errors, so we had to check everything carefully, and meant we couldn't generate graphics showing the potential of ground heat in green spaces across Great Britain.

Because of the limits of our computing power, we also used raster with 10km x 10km resolution for shallow ground temperatures. Because average soil temperature changes substantially with altitude, reducing the resolution of the shallow ground temperature raster meant smoothing out the heights of hills over each 10km x

10km area. For most urban areas, this has only a minor effect on the results. However, a test run on the dataset for Wales found that increasing the resolution of the shallow ground temperature data to 2km x 2km led to changes in the heat resource estimate of up to 4.3% for any one local authority area (and an average of 2.2% overall). This discrepancy always made the main results more conservative, so we accepted the errors.

Dataset completeness

Examination of the GIS and exported spreadsheet data led us to identify discrepancies in the coverage of smaller towns in the OS MasterMap Greenspace Layer. In Scotland, green spaces in and around even fairly small villages (below 1,000 population) seem to be included. In Wales, towns with populations above 15,000 all seem to be included, but below this size there is inconsistency. Several key Welsh towns with populations between 10,000 and 15,000 are missing, while some much smaller settlements do feature. In England, similar inconsistency exists for towns with populations of around 20,000, and again some settlements that are much smaller than this are included.

The discrepancy between Scotland and the rest of GB (and, to a lesser extent, between England and Wales) means that the estimates of greenspace heat potential for each country are not directly comparable. The figures for England and Wales underestimate the ground source potential because many sizeable towns' green spaces have not been taken into account, and it is possible that a bias exists that affects some regions or districts more than others.

Unsuitable or irrelevant locations

Most of the categories of green space that were included in the analysis contain some spaces that appear to have been misclassified, or which do not comfortably fit within the definition of "parks and publicly-accessible green space" intended for this study, or which would not be suitable for ground source heat systems due to their size and shape.

We took steps to eliminate features such as narrow grass verges and paths, and to prevent farmland or new property developments from inflating the results of calculations. On the other hand, we wanted to retain categories of green space other than formal parks which do represent important ground heat resource. For example, the green space recorded as "Amenity – Transport" makes up a large proportion of the area of Milton Keynes. Some of the green space that has ultimately been included is located within the boundaries of airports or seaports that are not publicly accessible. Therefore, the figures relating to the categories of "Amenity – Transport" and "Land Use Changing" should be used with caution.

Public parks: full results

Table 13: Ground source heat potential from public parks in England, by local authority.

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Adur	5	**1**	**294**
Allerdale	22	**4**	**252**
Amber Valley	77	**16**	**142**
Arun	24	**5**	**239**
Ashfield	114	**24**	**102**
Ashford	74	**16**	**144**
Aylesbury Vale	3	**< 1**	**299**
Babergh	49	**11**	**180**
Barking & Dagen...	284	**64**	**18**
Barnet	247	**55**	**26**
Barnsley	149	**32**	**75**
Barrow-in-Furness	22	**5**	**249**
Basildon	93	**21**	**118**
Basingstoke & D...	105	**23**	**110**
Bassetlaw	12	**3**	**276**
Bath & NE Somerset	59	**13**	**169**
Bedford	159	**35**	**64**
Bexley	124	**28**	**90**
Birmingham	965	**197**	**2**
Blaby	2	**< 1**	**305**
Blackburn w. Dar...	68	**13**	**171**
Blackpool	51	**11**	**182**
Bolsover	47	**10**	**189**
Bolton	138	**28**	**88**
Boston	9	**2**	**284**
Bournemouth	66	**15**	**153**
Bracknell Forest	83	**18**	**129**
Bradford	186	**38**	**57**
Braintree	13	**3**	**272**
Breckland	25	**5**	**237**
Brent	205	**46**	**38**
Brentwood	41	**9**	**195**
Brighton and Hove	68	**15**	**148**
Bristol, City of	674	**148**	**4**
Broadland	26	**5**	**238**
Bromley	247	**55**	**28**
Bromsgrove	179	**37**	**59**
Broxbourne	112	**25**	**99**
Broxtowe	36	**8**	**207**
Burnley	37	**7**	**213**
Bury	109	**23**	**109**
Calderdale	78	**16**	**147**
Cambridge	153	**33**	**71**
Camden	195	**44**	**41**
Cannock Chase	64	**13**	**166**
Canterbury	62	**14**	**163**
Carlisle	54	**10**	**185**
Castle Point	46	**10**	**183**
Central Beds.	33	**7**	**218**
Charnwood	77	**16**	**145**
Chelmsford	181	**41**	**48**
Cheltenham	32	**7**	**221**
Cherwell	81	**18**	**134**
Cheshire East	93	**20**	**119**
Cheshire W & Ch...	193	**42**	**47**
Chesterfield	66	**14**	**160**
Chichester	21	**5**	**248**
Chiltern	36	**7**	**210**
Chorley	84	**17**	**139**
Christchurch	5	**1**	**295**
City of London	< 1	**< 1**	**313**

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Colchester	67	15	151
Copeland	< 1	< 1	310
Corby	135	29	86
Cornwall	31	7	215
Cotswold	< 1	< 1	313
County Durham	82	17	140
Coventry	185	39	55
Craven	< 1	< 1	313
Crawley	32	7	225
Croydon	254	55	27
Dacorum	128	27	92
Darlington	72	15	157
Dartford	103	23	108
Daventry	13	3	273
Derby	193	43	43
Derbyshire Dales	14	3	271
Doncaster	87	18	132
Dover	18	4	258
Dudley	110	23	111
Ealing	173	39	54
East Cambridgesh..	1	< 1	308
East Devon	17	4	262
East Dorset	114	25	101
East Hampshire	145	31	78
East Hertfordshire	38	8	203
East Lindsey	5	< 1	296
East Northants.	8	2	287
East Yorkshire	30	6	228
East Staffordshire	8	2	288
Eastbourne	40	9	199
Eastleigh	186	43	44
Eden	3	< 1	300
Elmbridge	54	12	175
Enfield	266	60	22
Epping Forest	220	50	33
Epsom and Ewell	185	42	46
Erewash	17	4	264

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Exeter	48	11	181
Fareham	16	4	267
Fenland	10	2	279
Forest Heath	3	< 1	301
Forest of Dean	< 1	< 1	309
Fylde	39	8	202
Gateshead	195	42	45
Gedling	68	14	159
Gloucester	46	10	190
Gosport	96	22	114
Gravesham	44	10	188
Great Yarmouth	8	2	289
Greenwich	262	59	24
Guildford	186	40	50
Hackney	97	22	115
Halton	124	27	93
Hambleton	< 1	< 1	312
Hammersmith & F...	88	20	122
Harborough	9	2	286
Haringey	137	31	80
Harlow	89	20	120
Harrogate	93	19	126
Harrow	109	24	105
Hart	35	8	205
Hartlepool	34	7	223
Hastings	101	22	112
Havant	73	16	146
Havering	284	64	19
Herefordshire	70	14	158
Hertsmere	97	22	116
High Peak	13	3	275
Hillingdon	263	59	23
Hinckley & Bosw...	12	2	278
Horsham	19	4	256
Hounslow	345	78	13
Huntingdonshire	77	18	135
Hyndburn	33	7	227

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Ipswich	114	26	97
Isle of Wight	32	7	216
Islington	37	8	201
Kensington & Chel...	27	6	229
Kettering	33	7	212
King's Lynn & W.N.	20	4	251
Kingston upon Hull	64	13	165
Kingston u. Thames	29	7	224
Kirklees	191	40	52
Knowsley	160	34	65
Lambeth	200	45	39
Lancaster	68	14	162
Leeds	453	97	10
Leicester	335	70	16
Lewes	10	2	281
Lewisham	193	43	42
Lichfield	102	21	117
Lincoln	85	18	131
Liverpool	481	103	9
Luton	169	35	63
Maidstone	163	35	62
Maldon	31	7	217
Malvern Hills	89	19	128
Manchester	484	105	8
Mansfield	53	11	179
Medway	122	27	94
Melton	40	8	200
Mendip	2	< 1	303
Merton	226	51	31
Mid Devon	9	2	283
Mid Suffolk	3	< 1	302
Mid Sussex	41	9	197
Middlesbrough	84	17	137
Milton Keynes	588	126	5
Mole Valley	17	4	265
New Forest	43	10	191

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Newark & Sherw...	27	6	232
Newcastle u. Tyne	400	86	11
Newcastle-u-Lyme	123	26	98
Newham	140	31	77
North Devon	12	3	277
NE Derbyshire	47	10	187
NE Lincolnshire	38	8	204
North Hertfordshire	48	10	186
North Kesteven	3	< 1	298
North Lincolnshire	58	13	174
North Somerset	161	36	61
North Tyneside	256	53	29
North Warwickshire	19	4	257
NW Leicestershire	23	5	247
Northampton	105	24	106
Northumberland	144	31	81
Norwich	66	14	164
Nottingham	190	40	51
Nuneaton & Bedw...	37	7	209
Oadby and Wigston	17	3	269
Oldham	89	18	130
Oxford	106	24	104
Pendle	26	5	244
Peterborough	353	80	12
Plymouth	130	30	85
Poole	53	12	176
Portsmouth	89	20	121
Preston	162	33	70
Purbeck	< 1	< 1	313
Reading	58	13	168
Redbridge	493	111	6
Redcar & Cleveland	95	20	123
Redditch	126	26	95
Reigate & Banstead	65	14	161
Ribble Valley	< 1	< 1	313

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Richmond u. Tha…	997	225	1
Richmondshire	14	3	274
Rochdale	130	27	91
Rochford	20	5	250
Rossendale	23	4	255
Rother	10	2	280
Rotherham	324	70	15
Rugby	20	4	253
Runnymede	75	17	141
Rushcliffe	83	18	133
Rushmoor	17	4	266
Rutland	< 1	< 1	313
Ryedale	< 1	< 1	311
Salford	152	33	68
Sandwell	220	45	40
Scarborough	29	6	230
Sedgemoor	9	2	282
Sefton	189	41	49
Selby	6	1	293
Sevenoaks	156	32	73
Sheffield	316	69	17
Shepway	29	7	226
Shropshire	24	5	245
Slough	108	24	103
Solihull	107	22	113
South Bucks	112	25	100
S. Cambridgeshire	31	7	222
South Derbyshire	65	15	156
S. Gloucestershire	149	34	66
South Hams	< 1	< 1	313
South Holland	2	< 1	307
South Kesteven	21	4	254
South Lakeland	8	2	290
South Norfolk	9	2	285
South Northants…	< 1	< 1	313
South Oxfordshire	47	10	184
South Ribble	65	13	167

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
South Somerset	25	6	235
South Staffordshire	34	7	219
South Tyneside	243	52	30
Southampton	124	28	89
Southend-on-Sea	86	19	124
Southwark	145	33	72
Spelthorne	51	12	177
St Albans	172	38	56
St Edmundsbury	67	15	152
St. Helens	229	49	35
Stafford	34	7	214
Staffordshire Mo…	53	11	178
Stevenage	71	15	155
Stockport	337	73	14
Stockton-on-Tees	180	38	58
Stoke-on-Trent	506	105	7
Stratford-on-Avon	18	4	261
Stroud	90	19	127
Suffolk Coastal	18	4	260
Sunderland	242	51	32
Surrey Heath	31	7	220
Sutton	175	39	53
Swale	42	9	193
Swindon	148	32	76
Tameside	158	33	67
Tamworth	44	9	194
Tandridge	28	6	234
Taunton Deane	6	1	292
Teignbridge	17	4	259
Telford and Wrekin	147	30	84
Tendring	25	6	236
Test Valley	13	3	270
Tewkesbury	2	< 1	304
Thanet	33	7	211
Three Rivers	22	5	246
Thurrock	104	23	107
Tonbridge & Malli…	27	6	231

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Torbay	115	26	96
Torridge	137	31	79
Tower Hamlets	133	30	82
Trafford	69	15	150
Tunbridge Wells	36	8	206
Uttlesford	< 1	< 1	313
Vale of White Horse	17	4	263
Wakefield	172	37	60
Walsall	226	46	37
Waltham Forest	57	13	172
Wandsworth	252	57	25
Warrington	228	49	34
Warwick	162	33	69
Watford	75	16	143
Waveney	23	5	243
Waverley	149	32	74
Wealden	7	2	291
Wellingborough	56	13	173
Welwyn Hatfield	57	13	170
West Berkshire	81	17	138
West Dorset	4	< 1	297

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
West Lancashire	147	30	83
West Lindsey	2	< 1	306
West Oxfordshire	23	5	241
Westminster	213	48	36
Weymouth & Port…	22	5	240
Wigan	306	63	20
Wiltshire	135	29	87
Winchester	42	10	192
Windsor & Maide…	718	162	3
Wirral	284	61	21
Woking	16	4	268
Wokingham	86	19	125
Wolverhampton	73	15	154
Worcester	35	8	208
Worthing	22	5	242
Wychavon	26	6	233
Wycombe	72	15	149
Wyre	43	9	198
Wyre Forest	44	9	196
York	87	18	136

Truncated or abbreviated English district names: Barking and Dagenham, Basingstoke and Deane, Blackburn with Darwen, Central Bedfordshire, Cheshire West and Chester, East Cambridgeshire, East Northamptonshire, East Riding of Yorkshire, Hammersmith and Fulham, Hinckley and Bosworth, Kensington and Chelsea, King's Lynn and West Norfolk, Kingston upon Thames, Newark and Sherwood, Newcastle upon Tyne, Newcastle-under-Lyme, North East Derbyshire, North East Lincolnshire, North West Leicestershire, Nuneaton and Bedworth, Richmond upon Thames, South Cambridgeshire, South Gloucestershire, South Northamptonshire, Staffordshire Moorlands, Tonbridge and Malling, Weymouth and Portland, Windsor and Maidenhead.

Conversion factor (based on the assumptions laid out elsewhere in this report) for potential heat supply [MW] to potential carbon savings [tCO2e/yr]: 280 tCO2e/yr/MW[13].

13. For example: Aberdeen City potential heat supply is 30 MW. Potential carbon savings are: 30 MW × 280 tCO2e/yr/MW = 8,400 tCO2e/yr.

Table 14: Ground source heat potential from public parks in Wales, by Local Authority.

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Blaenau Gwent	37	**7**	**13**
Bridgend	27	**5**	**15**
Caerphilly	126	**24**	**2**
Cardiff	220	**47**	**1**
Carmarthenshire	33	**7**	**10**
Ceredigion	2	**< 1**	**20**
Conwy	20	**4**	**16**
Denbighshire	15	**3**	**17**
Flintshire	35	**8**	**9**
Gwynedd	11	**2**	**18**
Isle of Anglesey	6	**1**	**19**
Merthyr Tydfil	32	**6**	**14**
Monmouthshire	< 1	**< 1**	**22**
Neath Port Talbot	31	**7**	**12**
Newport	69	**15**	**5**
Pembrokeshire	< 1	**< 1**	**21**
Powys	45	**9**	**8**
Rhondda Cynon Taf	62	**12**	**7**
Swansea	85	**19**	**3**
Torfaen	36	**7**	**11**
Vale of Glamorgan	77	**17**	**4**
Wrexham	71	**15**	**6**

Table 15: Ground source heat potential from public parks in Scotland, by local authority.

District	Potentially suitable area [ha.]	Potential heat supply [MW]	Rank
Aberdeen City	168	30	8
Aberdeenshire	82	14	20
Angus	81	15	17
Argyll and Bute	20	4	29
City of Edinburgh	366	67	3
Clackmannanshire	27	5	28
Dumfries & Gallo...	47	9	24
Dundee City	175	30	9
East Ayrshire	108	20	13
E. Dunbartonshire	44	8	25
East Lothian	79	14	19
East Renfrewshire	97	19	14
Falkirk	222	42	6
Fife	363	64	4
Glasgow City	544	108	1
Highland	65	11	23
Inverclyde	36	7	27
Midlothian	72	13	22
Moray	46	8	26
Na h-Eileanan Siar	4	< 1	30
North Ayrshire	240	47	5
North Lanarkshire	440	81	2
Orkney Islands	3	< 1	32
Perth and Kinross	81	14	18
Renfrewshire	94	19	16
Scottish Borders	106	19	15
Shetland Islands	3	< 1	31
South Ayrshire	102	21	11
South Lanarkshire	192	35	7
Stirling	138	26	10
W. Dunbartonshire	72	14	21
West Lothian	120	20	12

Truncated or abbreviated Scottish district names: Dumfries and Galloway, East Dunbartonshire, West Dunbartonshire.

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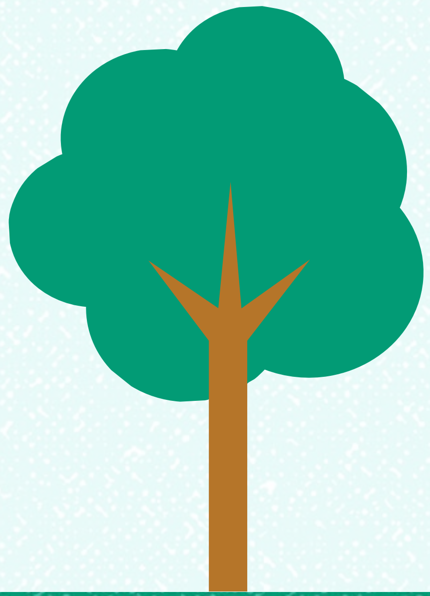

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