Spatial Analysis of Heating Demand in Ireland to Identify Candidate Areas for District Heating

Directorate of Research and Policy Insight

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1. Introduction

This report details an initial, modelled analysis of heating demand in Ireland to identify *Candidate Areas* for district heating. The analysis uses the best spatial data for heating demand currently available to SEAI. District heating candidacy through this analysis is largely based on *heat demand density* and does not consider the detailed local, technical or stakeholder aspects of project opportunities within Candidate Areas. Further detailed assessments will be essential in understanding if projects within these areas could provide heat to properties at a cost that is competitive against alternative options. It is emphasised that the Candidate Areas identified, as well as the summaries of their key characteristics, should be considered in this context.

2. Methodology

2.1 Datasets

All heating demand data used in this analysis has been aggregated at the level of *Census Small Area.* Census Small Areas are the smallest official geographic division of Ireland (18,919 as of 2022) and their size is determined by their population (between 80-120 households on average). Note that to avoid ambiguous use of the term "area" in this report, Census Small Areas will hereafter be referred to as *Census Divisions*.

2.1.1 Modelled Heat Demand at the Census Small Area Level

As part of the 2022 National Heat Study (1), SEAI produced a modelled spatial disaggregation of Ireland's national heating demand at the level of *Census Division*. This dataset was prepared through an archetype-based analysis of building stocks in each Census Division. It contains:

- An estimated total annual heating demand within each Census Division for each sector i.e. residential, commercial, public sector and industrial heat demand.
- An estimation of annual *suitable* demand for district heating within each Census Division, for each sector. For this analysis, the industrial sector is not considered suitable for district heating as the heating demands for industry are far higher than those in the commercial, public and residential sectors. For the commercial, public and residential sectors, any building archetype where the primary heating source is electricity is deemed unsuitable to switch to district heating.

The full details of the dataset and the methodology behind the archetype-based modelling can be found in SEAI's *Heating and Cooling in Ireland Today* (1) report. A visualisation of spatial heat demand data for Portlaoise can also be seen in Figure 1.

2.1.2 Public Sector Significant Energy Users (SEUs)

Since the publication of the National Heat Study, SEAI has determined that while the archetype-based modelling of heat demand described in 2.1.1 provides a good generalisation of heat demand at the level of Census Division, it nevertheless under-represents the demand of certain large energy users, particularly those in the public sector such as hospitals, universities, leisure centres etc. This presents a limitation for two reasons – firstly, the establishment of district heating networks largely depends on these *Significant Energy Users (SEUs)* to act as *anchor loads*, and secondly, it is anticipated that district heating in Ireland will initially be a public-led initiative. SEAI is therefore

working with several public sector bodies such as the Health Service Executive (HSE) and Office of Public Works (OPW) to collect data on SEUs that should be considered as potential anchor loads for district heating. These SEUs have been selected as they account for a disproportionately large share of public sector heating demand. To date, SEAI has collected data on approximately 400 SEUs across the country, and this is made up primarily of:

- Hospitals (HSE)
- Universities
- Prisons
- Local authority-owned leisure Centres
- Miscellaneous OPW buildings

For each SEU building, the annual heating demand data has been collected (and provided) by either the public sector body associated with the building, or by SEAI themselves through the Public Sector Monitoring and Reporting (PSMR) database. **Together, these 400 buildings account for approximately 25% of national public sector heating demand.**

All demand data related to SEUs has been mapped and aggregated at Census Small Area level – this is subsequently used to amend the 2022 heat study dataset by appropriately re-distributing the national sum of public sector demand among all Census Divisions. An example of the locations of Portlaoise-based SEUs can be seen in Figure 1.

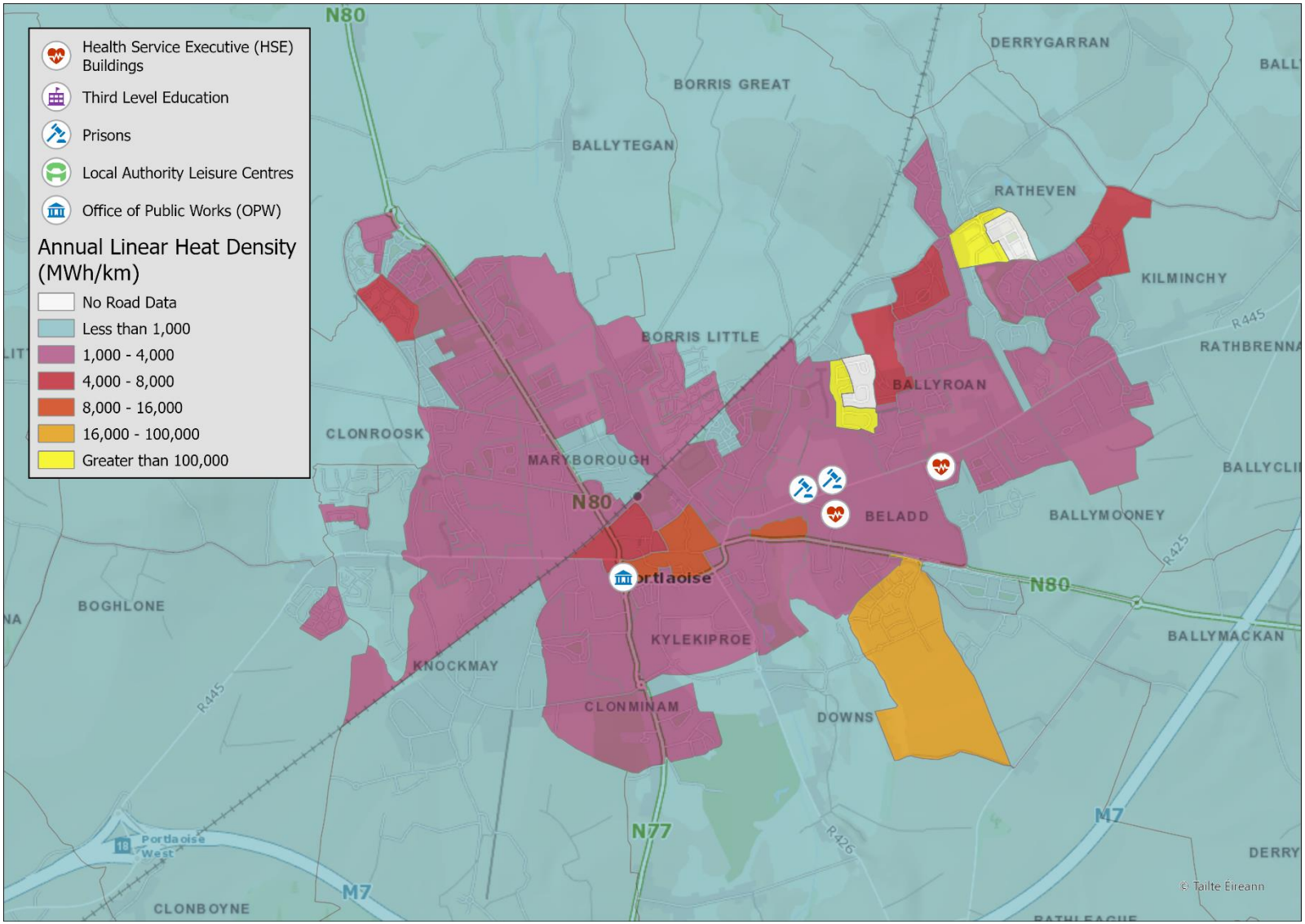

Figure 1: Spatial Heat Demand and Public Sector Significant Energy Users in Portlaoise

2.2 Technical Overview

2.2.1 Kernel Density of Heat Density

A typical heuristic of district heating suitability for an area is its density of heat demand, often in the form of *area heat density* (total demand/total size) or *linear heat density* (total demand/total road length). Both of these metrics are a proxy for the amount of piping required to supply the given heat demand, thus providing an indication of the economic viability of district heating for that area. Using these metrics alone, however, makes it difficult to establish which Census Divisions are ideal starting-points for Candidate Areas, as no consideration is given to a Census Division's geographical context. When creating Candidate Areas, a geographic cluster of economically viable Census Divisions is a more attractive option than a single economically viable Census Division that is geographically isolated. To address this limitation, this analysis uses a *kernel density estimation* (KDE) (2) of suitable heat demand as the metric for district heating potential.

KDE in this context is a calculation which weights the suitable heat demand of a Census Division with the suitable heat demand of its neighbours, whilst simultaneously factoring in the distances between neighbours. The calculation effectively dissolves the boundaries between neighbouring Census Divisions and considers Ireland as a *terrain of heat demand*, allowing for the identification of geographic peaks of suitable heat demand.

A visualisation of KDE can be seen in Figures 2 – 3: conceptually, a smoothed curved surface is fitted over the centre-point, or *centroid*, of each Census Division. The peak surface value occurs at the centroid and diminishes with increasing distance from that point, reaching zero at a given radius or *bandwidth.* The total volume beneath the surface is equal to the suitable heat demand of the Census Division and the density value for any point on the surface is determined by the height of the surface at that point. (Figure 2). In the case where the surfaces of two or more Census Divisions overlap spatially, the volume of the overlapping surfaces are summed.

For the purposes of calculating the KDE of suitable heat demand in this analysis, **the bandwidth is set to a radius of approximately 322m.** This value represents the median distance between all Census Division centroids and ensures that the KDE calculation for 50% of Census Divisions will be weighted by at least one neighbour, whilst simultaneously avoiding large heating demands indicating district heating potential over unrealistic distances.

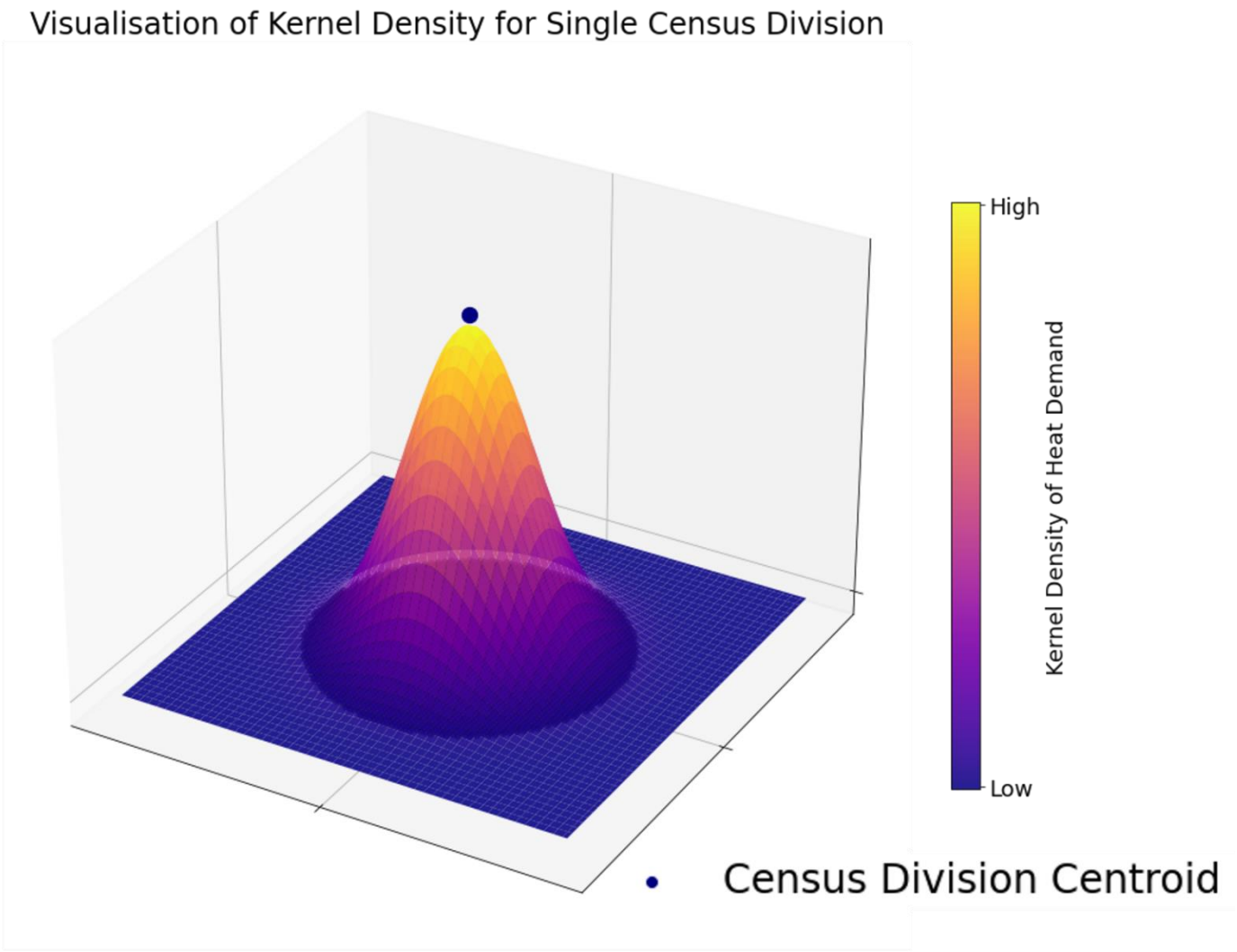

Figure 2: Visualisation of kernel density estimation for a single Census Division. The centroid for the Census Division has an associated value for heat demand, and the volume under the surface is equal to that demand value. The density value is highest at the centroid and diminishes to zero at a 322m radius.

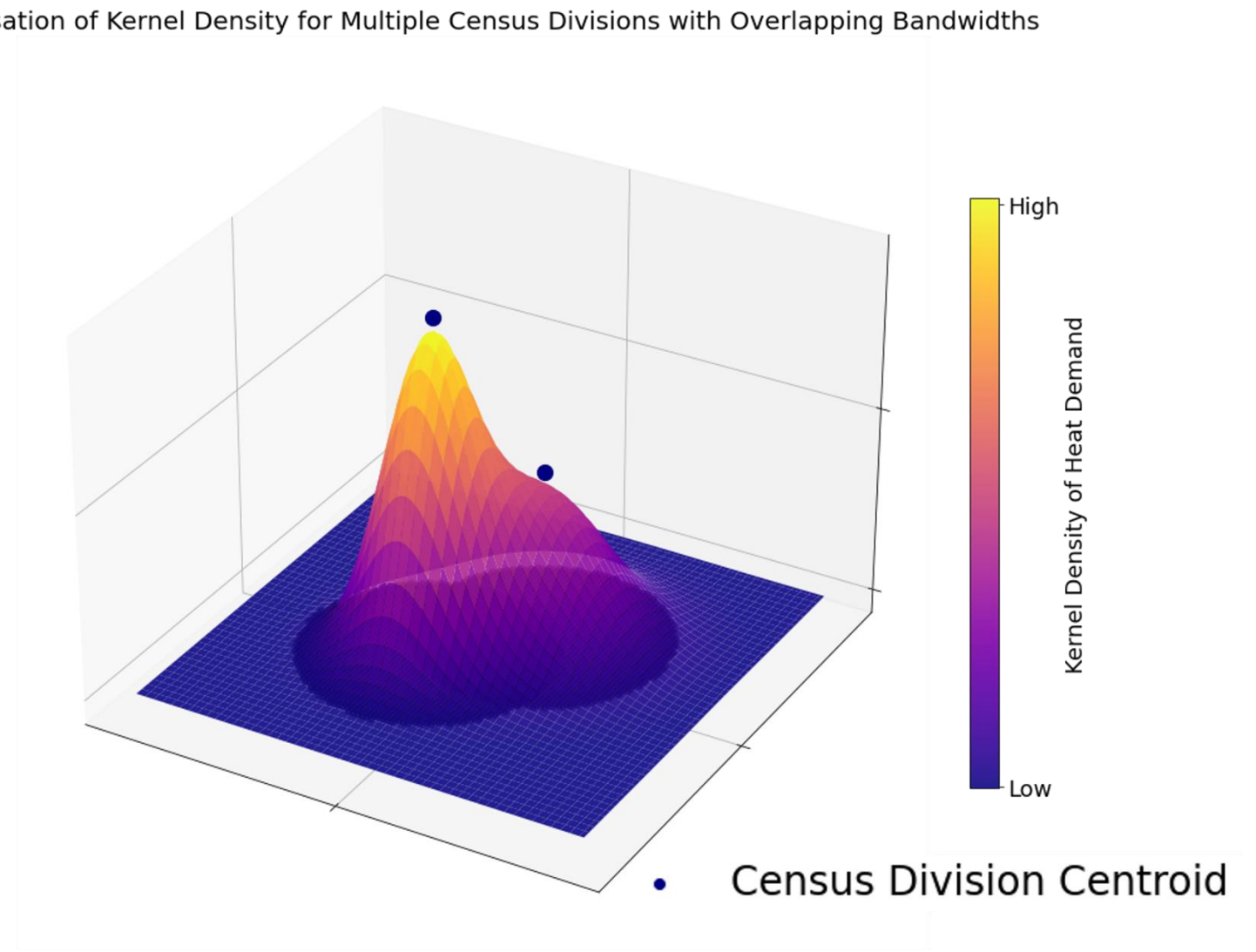

Figure 3: Visualisation of kernel density estimation for two neighbouring Census Divisions with different heat demands. Since the 322m bandwidths of the two divisions overlap, the density values of each surface in the overlapping regions are summed to create the single peak and shoulder shown.

2.2.2 Spatial Model

2.2.2.1 Model Phase 1 – Commercial/Public Nodes

The Candidate Areas for district heating are created by a spatial model which first calculates the mean KDE value of **suitable commercial and public sector heat demand** within each Census Division (note that this value includes actual data on SEUs in the public sector). This calculation allows the model to identify Census Divisions that correspond to geographic peaks of commercial or public sector demand. Demand in these sectors can be thought of as a reliable and stable source of heat demand, thus they are ideal for district heating networks and used as the starting points, or *nodes,* for the model to create Candidate Areas. A visualisation of the KDE for commercial and public sector demand for Waterford City and the subsequent identification of nodes can be seen in Figures 4 – 7.

2.2.2.1 Model Phase 2 – Aggregation of Census Divisions

The model subsequently aggregates Census Divisions around the previously identified nodes. Census Divisions are continuously added to Candidate Areas until the sum of the suitable heat demand in all aggregated Census Divisions meets a specified annual target for district heating supply. For the purposes of this report, the model has been run with three separate targets:

- **2.7 TWh/year:** the 2030 Climate Action Plan (CAP) target for district heating. (4)
- **5.1 TWh/year**: the supply of renewable heat by district heating by 2030 under the Rapid Progress Scenario of the National Heat Study. (5)
- **8.1 TWh/year:** the supply of renewable heat by district heating by 2050 under the Rapid Progress Scenario of the National Heat Study.

The aggregation of Census Divisions into Candidate Areas requires the calculation of the mean KDE value of **total suitable heat demand** within each Census Divisions i.e. suitable residential, commercial and public sector demand. The model then processes each Census Division in order of decreasing KDE value and evaluates its neighbourhood to determine if it can either be used to create a new Candidate Area, or be added to an existing Candidate Area. The possible scenarios and outcomes are as follows:

- The Census Division has no neighbours that form part of an existing Candidate Area but it has previously been identified as a node – the Census Division creates a new Candidate Area.
- The Census Division has an immediate neighbour that forms part of an existing Candidate Area – the Census Division is added to that Candidate Area.
- The Census Division results in the joining of two or more existing Candidate Areas – the first of these Candidate Areas to be created assimilates the other(s) and the Census Division is added to that Candidate Area.
- The Census Division has no neighbours that form part of an existing Candidate Area and it has not previously been identified as a node – the Census Division is not added to any Candidate Area, however it is continuously reassessed with every subsequent addition of any Census Division to a Candidate Area.

Note that the model is not necessarily required to use all of the previously identified nodes to meet the specified district heating target. Nodes are identified based on commercial and public sector demand alone and are simply points where the model can create a new Candidate Area in the second phase if needed. The processing steps involved in the second phase of the model are illustrated in Figure 8 – 12.

For reference, an additional stepwise illustration of the creation of a Candidate Area from Census Divisions can be found in the Appendix Figures 1 – 14.

2.3 Non-Technical Summary

Candidate Areas are created by aggregating clusters of Census Divisions with a high density of suitable heat demand. This is achieved by a model that operates in two phases: firstly, it identifies Census Divisions that correspond to localised peaks of suitable commercial and public sector heat demand. These peaks, or *nodes*, are the geographic points from which the model can start a new, distinct Candidate Area and they are representative of the need for a high, stable and reliable demand for heat within each Candidate Area. Once the nodes have been identified the model begins aggregating neighbouring Census Divisions to create Candidate Areas. Census Divisions are processed in order of highest to lowest density of heat demand, and aggregation continues until the sum of the suitable heat demand within each aggregated Census Division meets a specified national target for district heating supply. For the purposes of this report, the results for the model corresponding to three targets are presented:

- **2.7 TWh/year:** the 2030 Climate Action Plan (CAP) target for district heating.
- **5.1 TWh/year**: the supply of renewable heat by district heating by 2030 under the Rapid Progress Scenario of the National Heat Study.
- **8.1 TWh/year:** the supply of renewable heat by district heating by 2050 under the Rapid Progress Scenario of the National Heat Study.

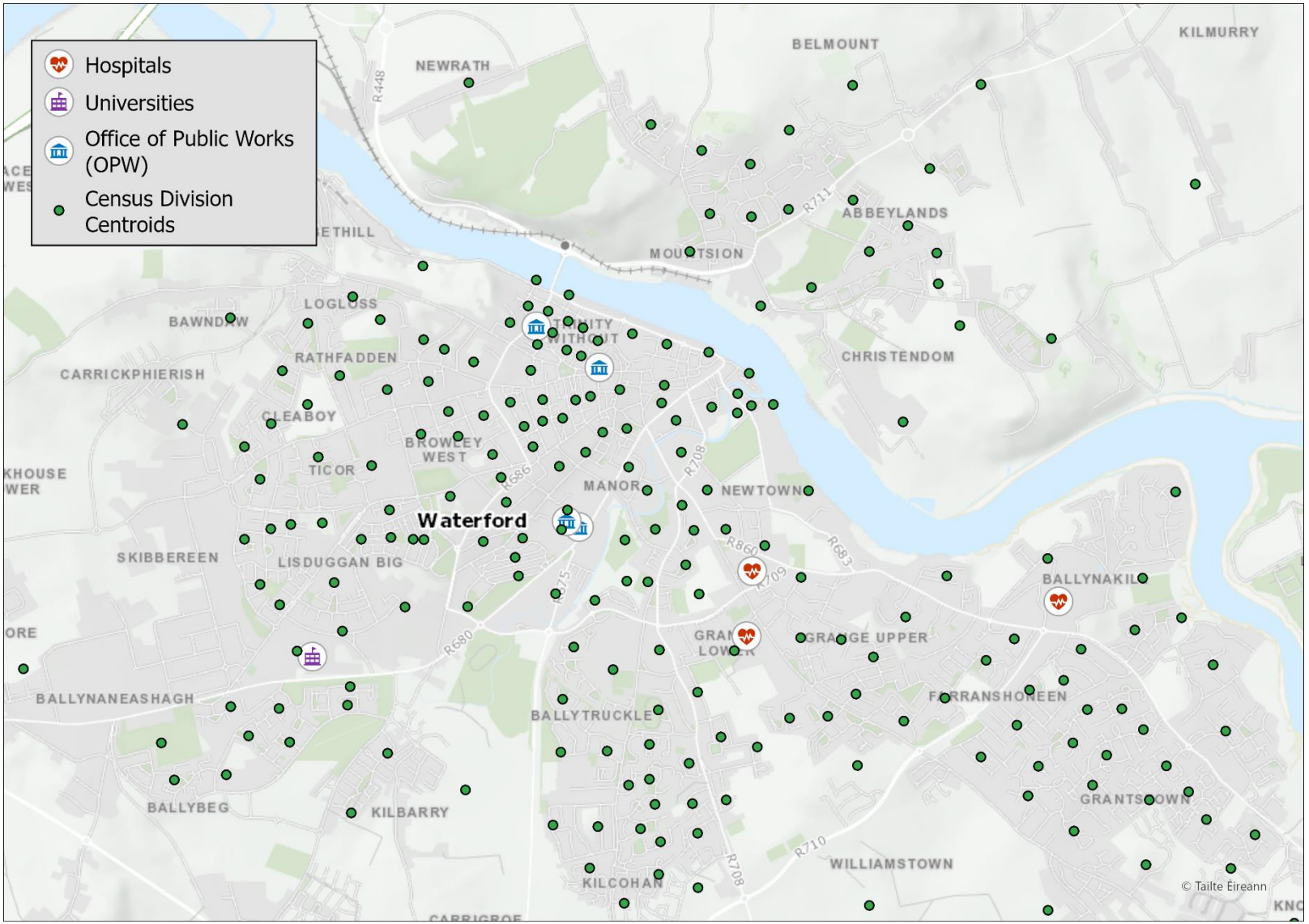

Figure 4: Centroids of Census Divisions in Waterford City.

Figure 5: Side profile of Waterford City showing locations of significant energy users.

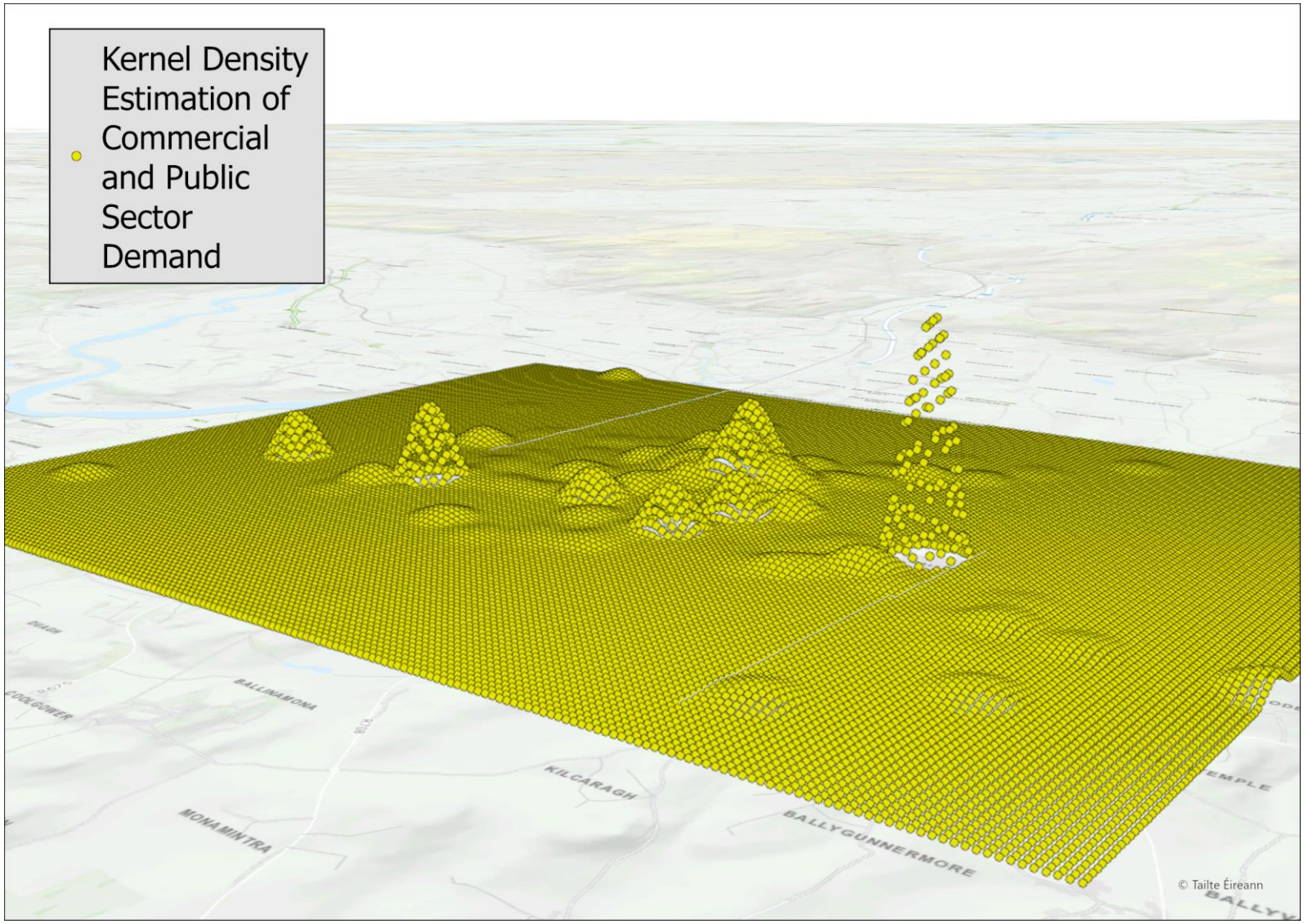

Figure 6: 3D-Visualisation of kernel density estimation for Waterford City using only heat demand from the commercial and public sector.

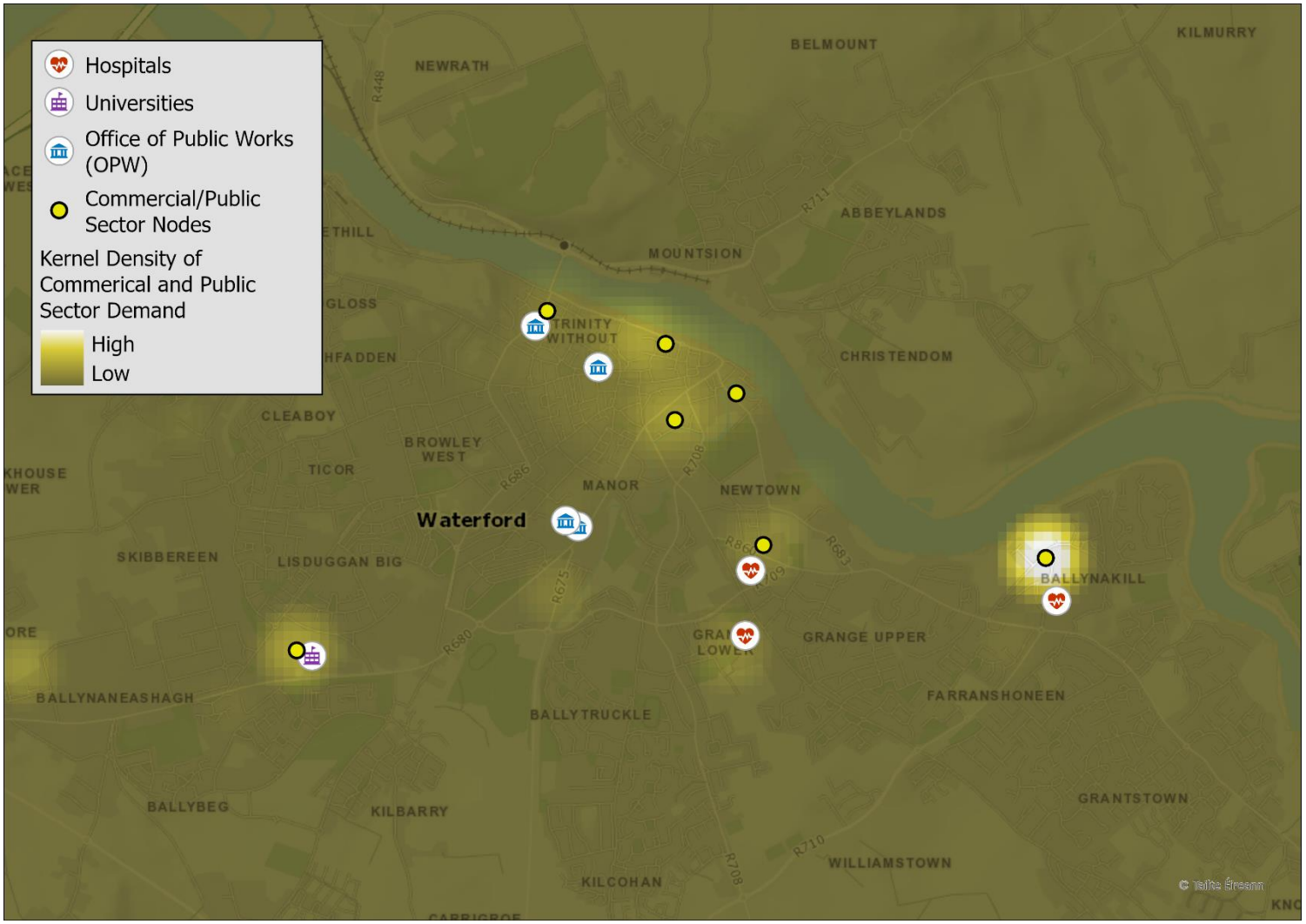

Figure 7: 2D-Visualisation of kernel density estimation for Waterford City using only heat demand from the commercial and public sector. Also shown are node points which represent the peaks of demand in the commercial and public sector. Nodes are used as a potential starting point for a new Candidate Area for district heating.

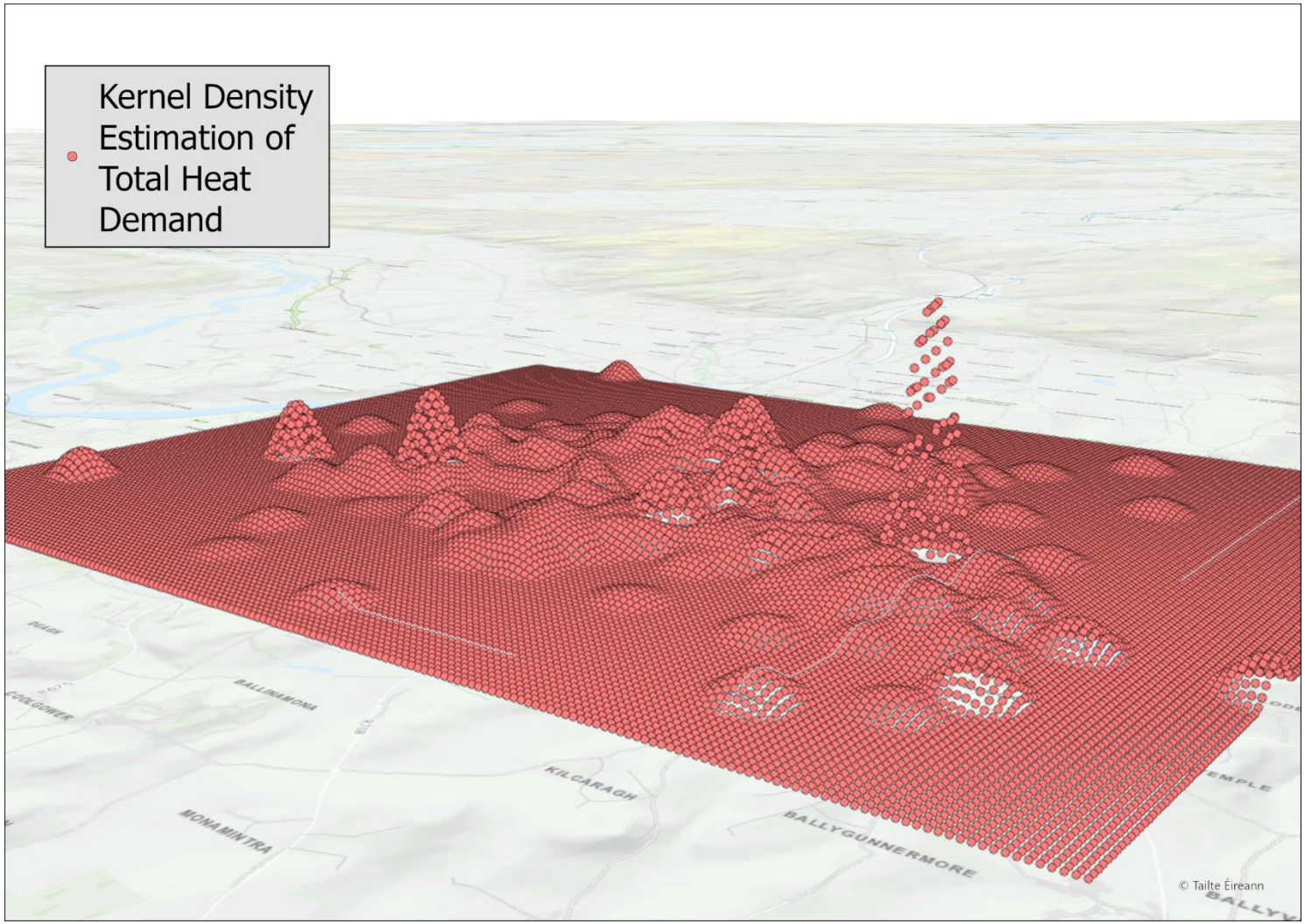

Figure 8: 3D-Visualisation of kernel density estimation of total heat demand suitable for district heating in Waterford City.

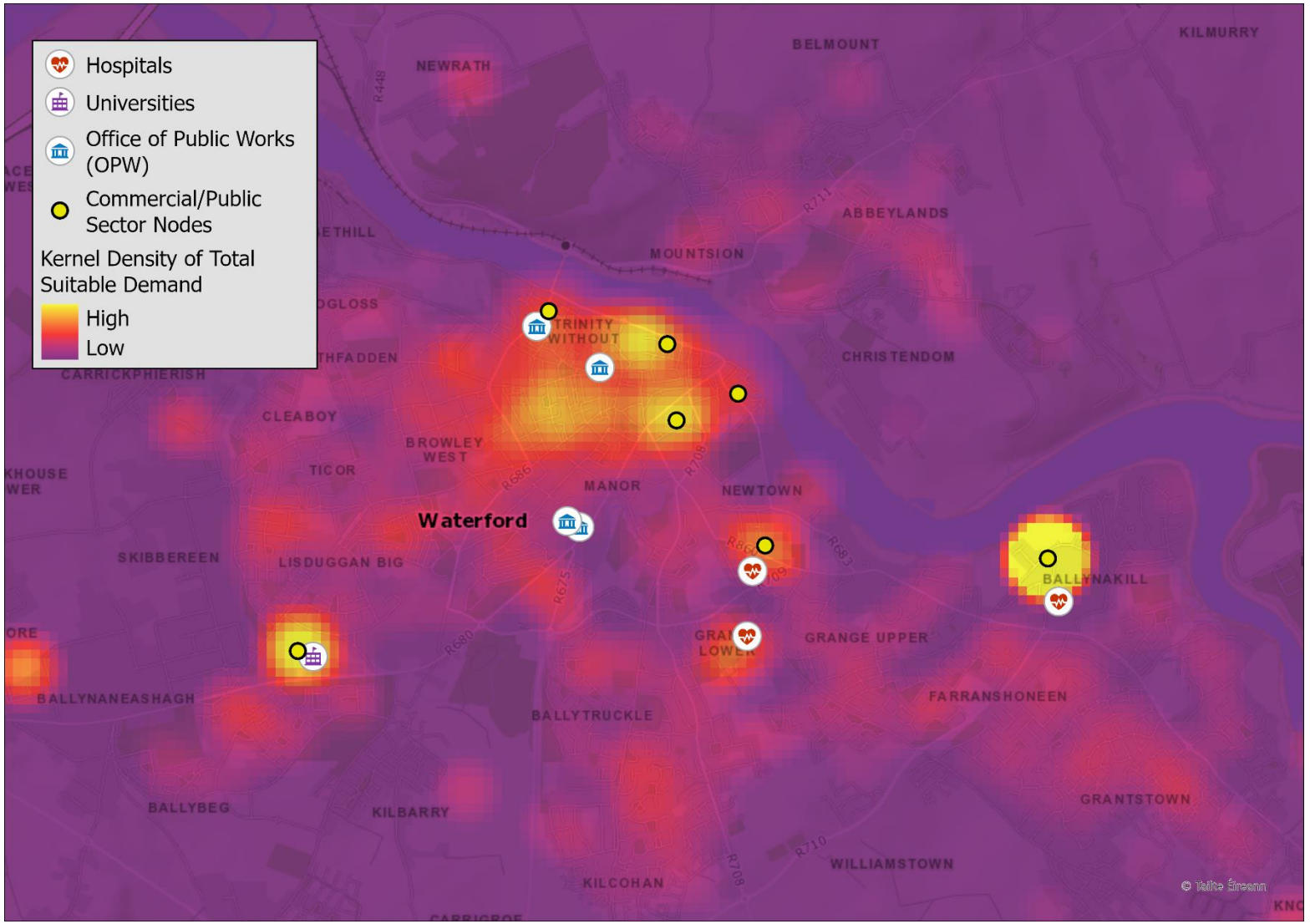

Figure 9: 2D-Visualisation of kernel density estimation of total heat demand suitable for district heating in Waterford City.

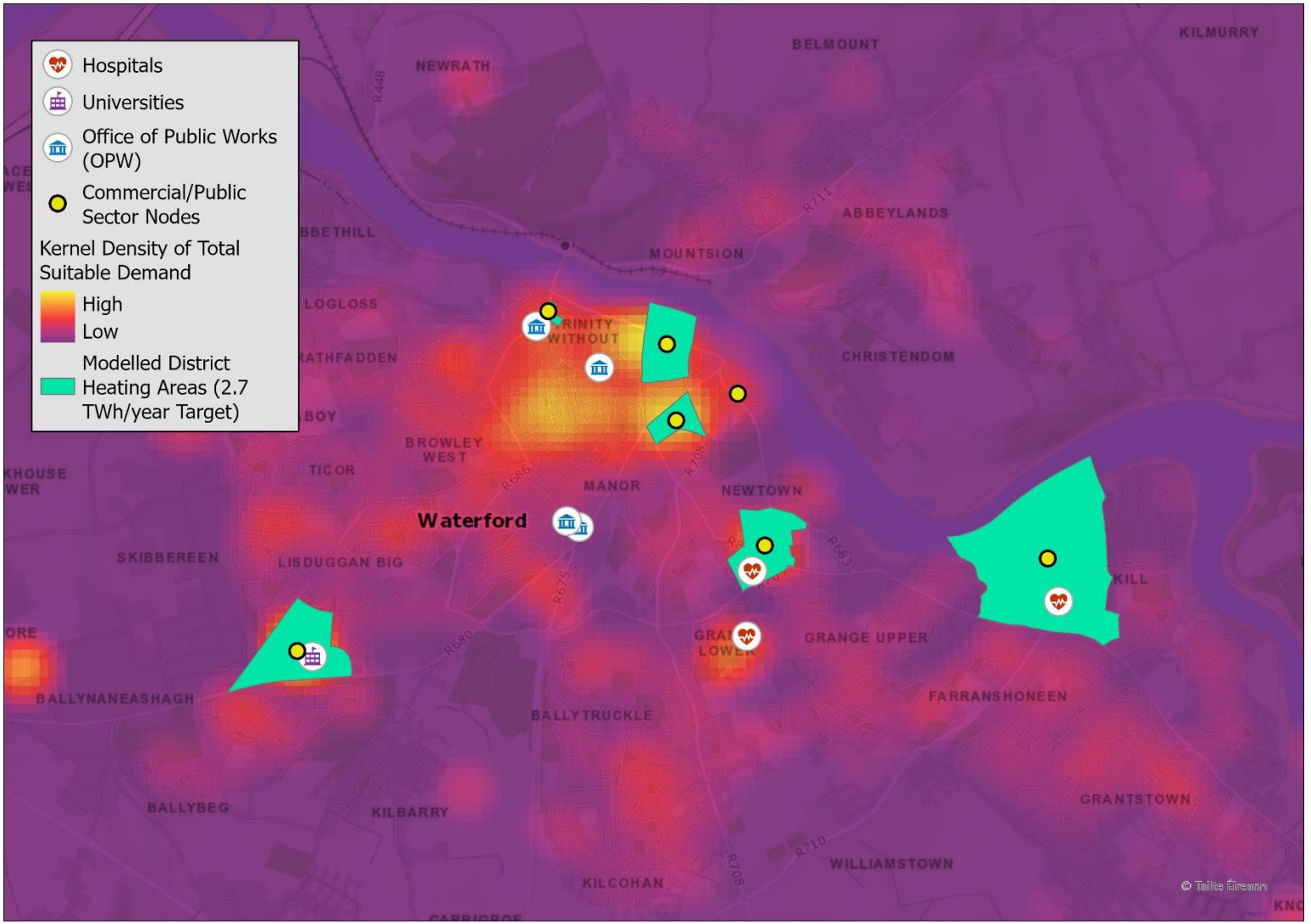

Figure 10: Census Divisions determined by the spatial model to be most suitable for district heating.

Figure 11: A potential district heating network for Waterford City (Census Divisions suitable for district heating areas manually joined by roads).

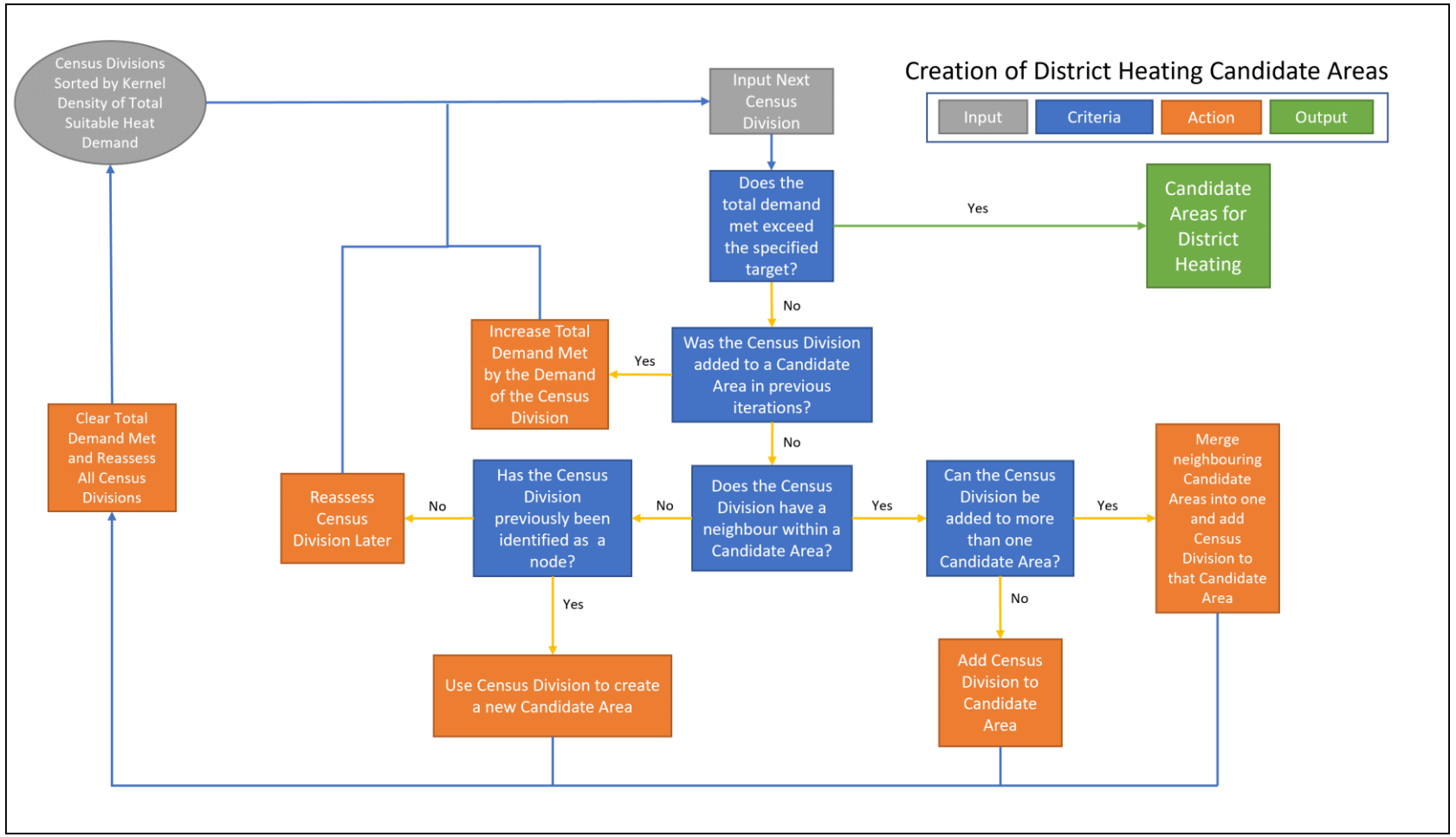

Figure 12: Processing flow chart for the aggregation of Census Divisions into Candidate Areas. Census Divisions are first ordered from highest to lowest density value for total heat demand suitable for district heating. The model then processes one Census Division at a time – if the Census Division directly neighbours an existing Candidate Area, it is added to that Candidate Area. If it does not neighbour an existing Candidate Area but it has been previously identified as a node, it can be used to create a new Candidate Area. If it cannot be added to a Candidate Area or create a new Candidate Area, it is continuously reassessed in case it can be added at a later point. The model stops adding Census Divisions to Candidate Areas once a specified target has been met.

3. Results

3.1 Linear Heat Density of Census Divisions Within Candidate Areas

The number of Census Divisions that form part of Candidate Areas for each target is shown in Table 1, along with their linear heat densities. Note that a value of 1,000 MWh/km/year is indicated to be a critical density threshold for district heating economic viability in the *District Heating and Cooling Report* (3) of the National Heat Study.

Table 1: Number of Census Divisions Supplying District Heating by Linear Heat Density

Linear Heat Density (MWh/km)	2.7 TWh/year	5.1 TWh/year	8.1 TWh/year
Less than 1,000	17	60	205
1,000 - 4,000	744	2,345	4,542
4,000 - 8,000	428	608	702
8,000 - 16,000	154	197	228
16,000 - 100,000	84	102	118
Greater than 100,000	10	12	13
No Road Data	39	46	62
Total Census Divisions	**1,476**	**3,370**	**5,870**

Table 1: Linear Heat Density in Census Divisions that form part of the modelled Candidate Areas. 1,000 MWh/km/year is indicated in the National Heat Study to be the critical density threshold for district heating economic viability.

3.2 Sectoral Share of National District Heating Supply

Figure 13 summarises the breakdown of suitable demand in Census Divisions that form part of Candidate Areas for the 2.7 TWh/year modelled target.

3.2 Sectoral Share of National District Heating Supply by Local Authority

Table 2 and Figure 14 – 16 summarise the breakdown of suitable demand in Census Divisions that form part of Candidate Areas by sector, Local Authority and target.

3.3 Estimated Connections to District Heating Networks by Local Authority

Table 3 summarises an estimation of the number of connections per sector required in each Local Authority to meet modelled district heating targets. The model suggests that 102,181 connections are required to meet a modelled target of 2.7 TWh/year, with 10,717 of these being in the non-domestic sectors i.e. commercial and public sectors. **It is important to highlight that while the non-domestic sector only accounts for approximately 10% of estimated connections, these connections correspond to 67.9% of the 2.7 TWh/year target.**

Note that a connection in this context refers to an individual address point rather than an entire building. One building may consist of multiple address points e.g. apartment complexes. Also note that the estimation of connections assumes that all address points that are suitable for district heating in a Candidate Area will connect to a district heating network.

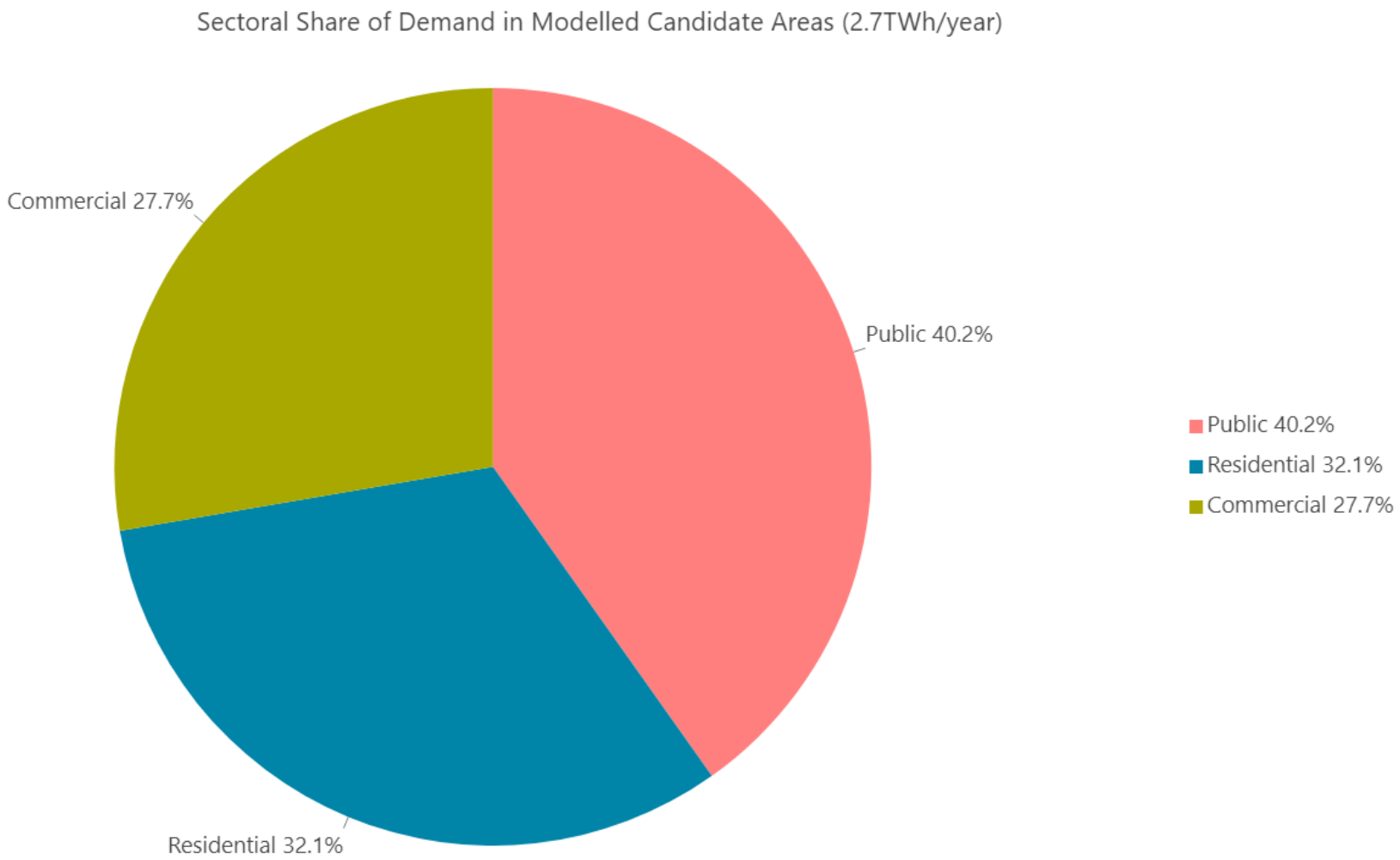

Figure 13: Sectoral share of total national district heating supply for modelled target of 2.7 TWh/year.

Table 2: Share (in TWh/year) of National District Heating Supply by Local Authority

Local Authority	2.7 TWh/year	5.1 TWh/year	8.1 TWh/year
Dublin City	1.08	1.69	2.09
Cork City	0.31	0.43	0.56
Galway City	0.17	0.25	0.35
Limerick City and County	0.15	0.24	0.34
Dún Laoghaire-Rathdown	0.14	0.33	0.64
Cork County	0.09	0.22	0.39
Waterford City and County	0.09	0.15	0.25
Louth	0.08	0.13	0.25
Kerry	0.08	0.13	0.18
Tipperary	0.06	0.12	0.16
Mayo	0.05	0.08	0.11
Kilkenny	0.05	0.10	0.14
Fingal	0.04	0.26	0.56
Donegal	0.03	0.04	0.07
Wexford	0.03	0.09	0.15
Laois	0.03	0.04	0.06
Wicklow	0.03	0.09	0.20
Sligo	0.02	0.05	0.08
South Dublin	0.02	0.26	0.67
Clare	0.02	0.08	0.13
Kildare	0.02	0.12	0.26
Offaly	0.02	0.03	0.05
Meath	0.02	0.04	0.13
Carlow	0.01	0.03	0.07
Westmeath	0.01	0.04	0.08
Monaghan	0.01	0.02	0.03
Galway County	0.01	0.02	0.06
Leitrim	0.01	0.01	0.01
Longford	0.00	0.01	0.02
Roscommon	0.00	0.00	0.02
Cavan	0.00	0.00	0.01
	2.70	**5.10**	**8.10**

Table 2: Total district heating supply for each local authority and for each modelled target.

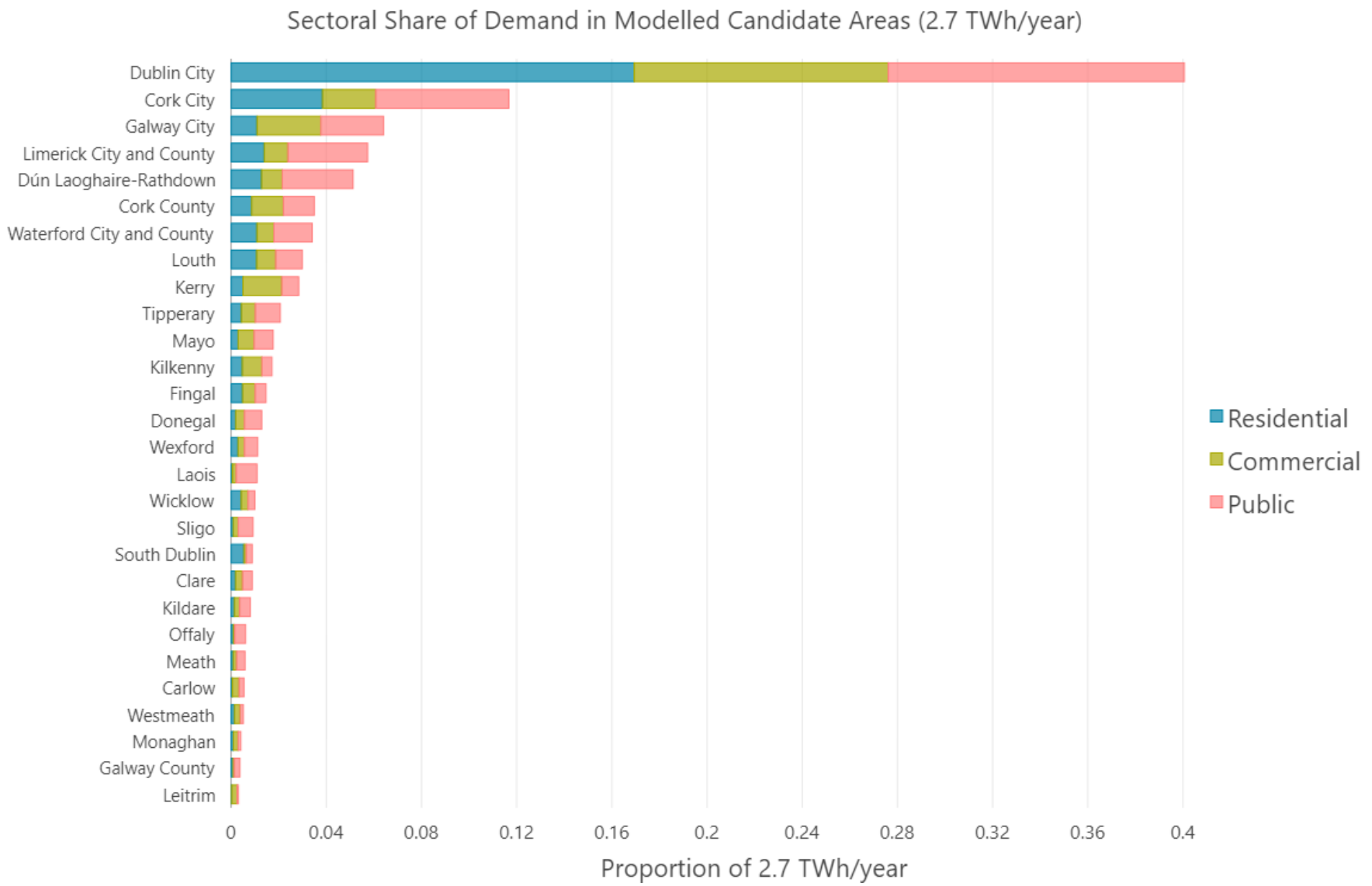

Figure 14: Share of total national district heating supply for each local authority as well with sectoral breakdown for modelled target of 2.7 TWh/year.

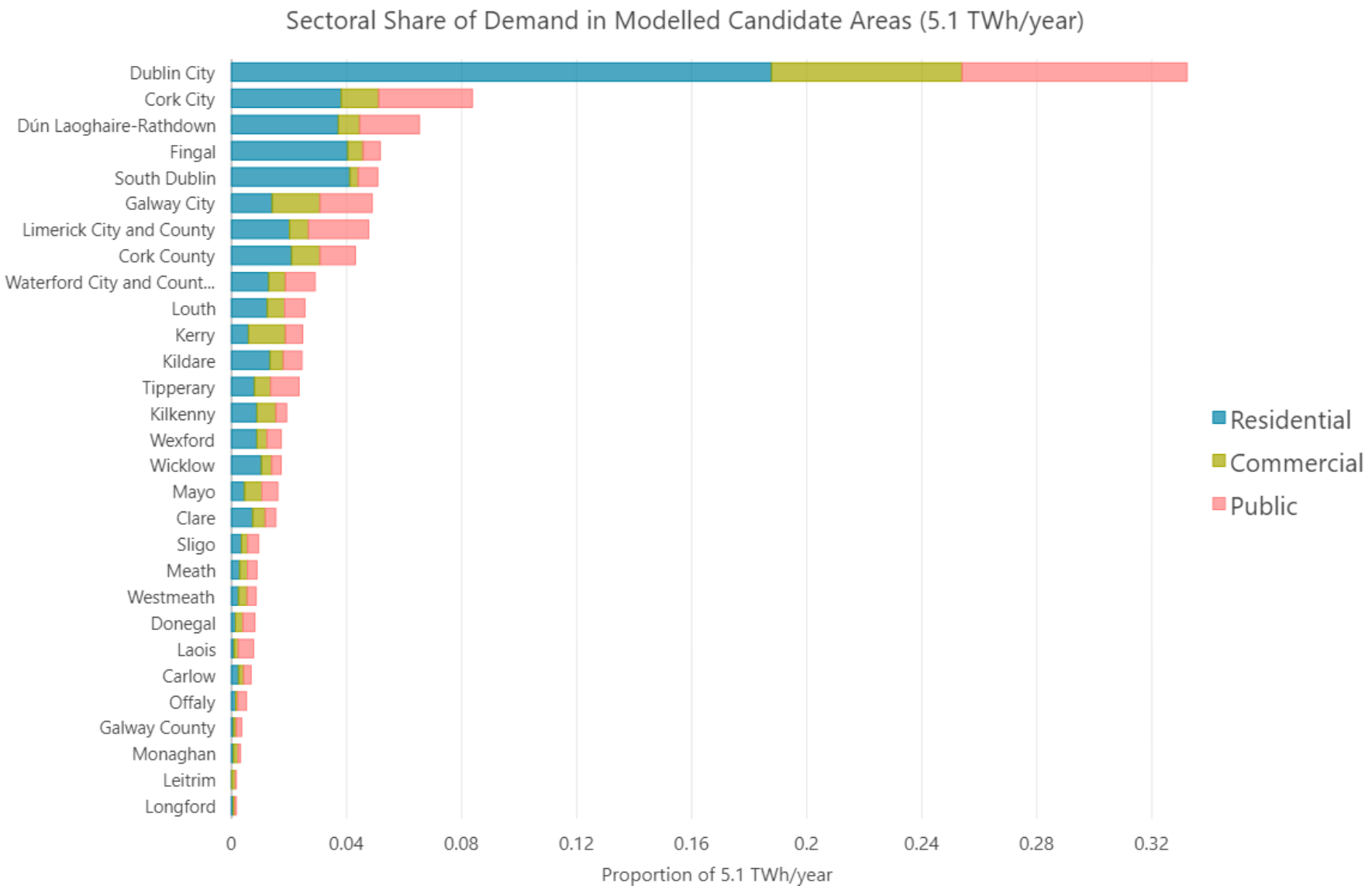

Figure 15: Share of total national district heating supply for each local authority with sectoral breakdown for modelled target of 5.1 TWh/year.

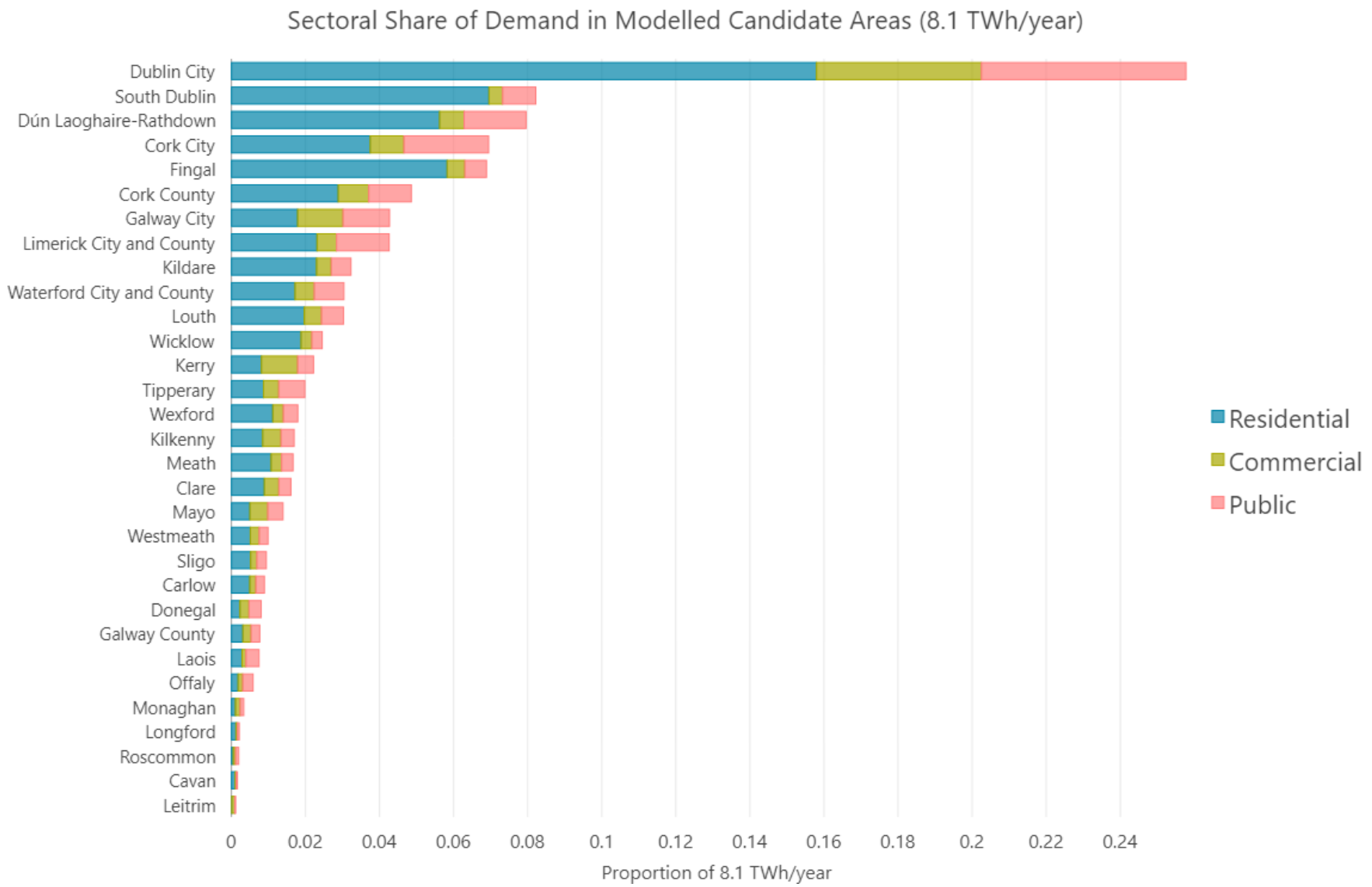

Figure 16: Share of total national district heating supply for each local authority with sectoral breakdown for modelled target of 8.1 TWh/year

Table 3: Estimated Suitable Connections by Sector in Modelled District Heating Candidate Areas

	2.7 TWh/year		5.1 TWh/year		8.1 TWh/year	
Local Authority	Residential	Non-Residential	Residential	Non-Residential	Residential	Non-Residential
Dublin City	52,101	3,864	106,489	4,758	142,514	5,293
Cork City	11,337	1,053	20,668	1,203	32,227	1,404
Dún Laoghaire-Rathdown	3,782	458	19,784	761	46,133	1,134
Limerick City and County	3,469	492	9,283	630	16,828	779
Waterford City and County	2,723	310	6,053	437	12,736	636
Louth	2,569	379	5,525	499	14,075	589
Galway City	2,535	668	6,435	784	13,409	952
Cork County	1,962	639	9,128	977	20,056	1,369
South Dublin	1,411	80	21,368	401	58,117	754
Fingal	1,313	233	20,821	493	49,176	718
Kilkenny	1,125	263	3,883	392	5,929	431
Wicklow	1,087	134	4,584	290	13,096	386
Kerry	1,023	400	2,323	693	5,034	847
Tipperary	1,017	229	3,331	473	5,777	572
Wexford	641	131	3,650	357	7,326	480
Mayo	622	252	1,786	360	3,074	464
Donegal	442	127	615	162	1,499	295
Clare	369	141	3,025	310	5,710	442
Westmeath	334	90	1,062	206	3,484	294
Kildare	330	118	5,888	418	16,398	557
Monaghan	213	75	302	115	703	163
Meath	206	77	1,159	233	7,690	383
Offaly	194	47	631	90	1,273	199
Sligo	192	172	1,430	232	3,370	259
Carlow	180	127	1,106	166	3,582	232
Galway County	148	30	248	86	1,828	302
Laois	109	69	368	118	2,100	136
Leitrim	32	60	32	60	38	74
Longford	0	0	240	57	770	79
Roscommon	0	0	0	0	297	89
Cavan	0	0	0	0	650	46
	91,465	**10,717**	**261,216**	**15,761**	**494,898**	**20,359**

Table 3: Estimated number of connections per sector within each local authority required to meet modelled targets for district heating.

4. Concluding Remarks and Next Steps

This analysis uses a national dataset to carry out a first-pass assessment of areas that might be suitable for district heating network development from a heat demand density perspective. The analysis is not driven by economic factors, detailed technical factors or the stakeholder related aspects of DH development within the identified Candidate Areas. Such factors include:

- The cost for consumers of district heating when compared to other options for renewable heat e.g. domestic heat pump installations.
- The proximity of Candidate Areas to renewable, low-carbon or waste heat sources e.g. geothermal, biomass, industrial CHP.
- The primary heating fuel to be displaced by district heating in Candidate Areas.
- Social and environmental factors which might prevent district heating network development.

Significant further work is therefore required to establish the viability of project developments with the Candidate Areas identified in this report. To help facilitate this, SEAI will share the results of this analysis within an online mapping tool to allow local authorities and other stakeholders to explore the boundaries of the Candidate Areas identified. This map will be overlaid with various features which will aid the planning of district heating networks. Such features will include the precise locations of buildings (along with their associated sector and function), potential waste heat sources, geothermal suitability, biomass availability and information on potential fuel displacement through district heating.

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Appendix: Stepwise Illustration of the Creation of a Single Candidate Area from Census Divisions

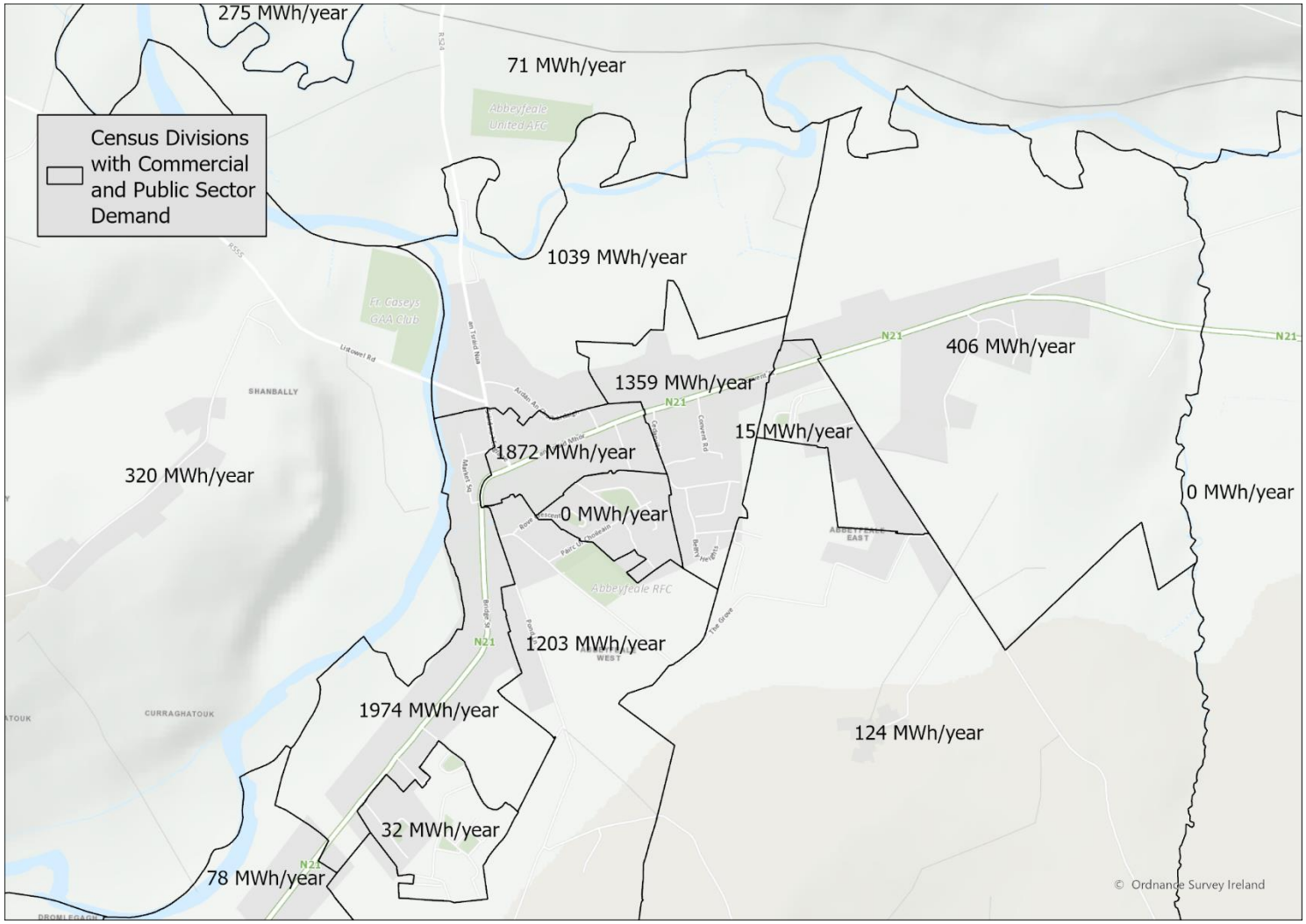

Figure 1: Census Divisions with their suitable commercial and public sector heat demand

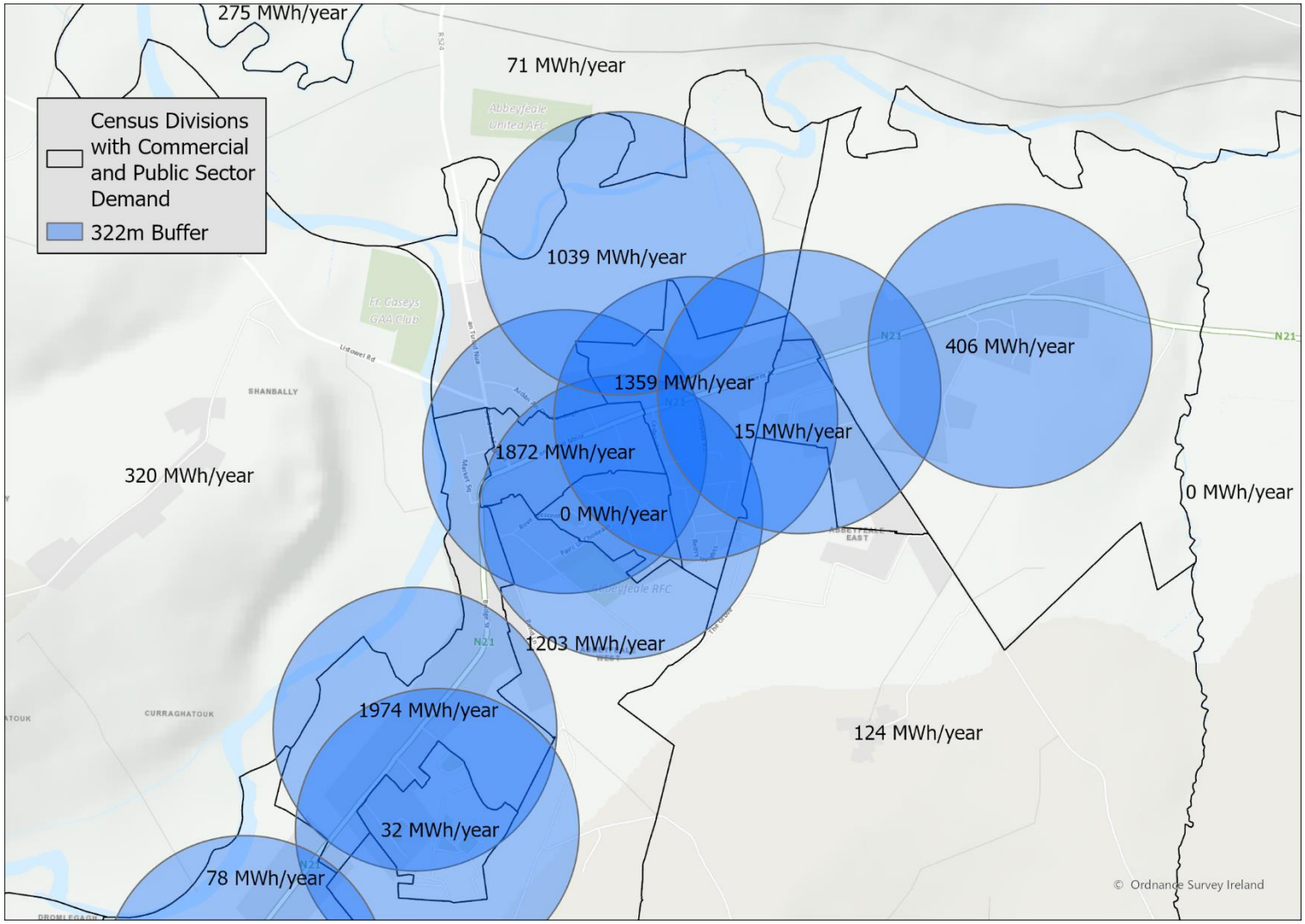

Figure 2: A buffer of 322 meters extends from the centroid of each Census Division. If the buffer of one Census Division extends into the boundaries of another Census Division, then the latter's kernel density calculation will be weighted by the former's heat demand (the exact weighting depends on the distance between the two areas).

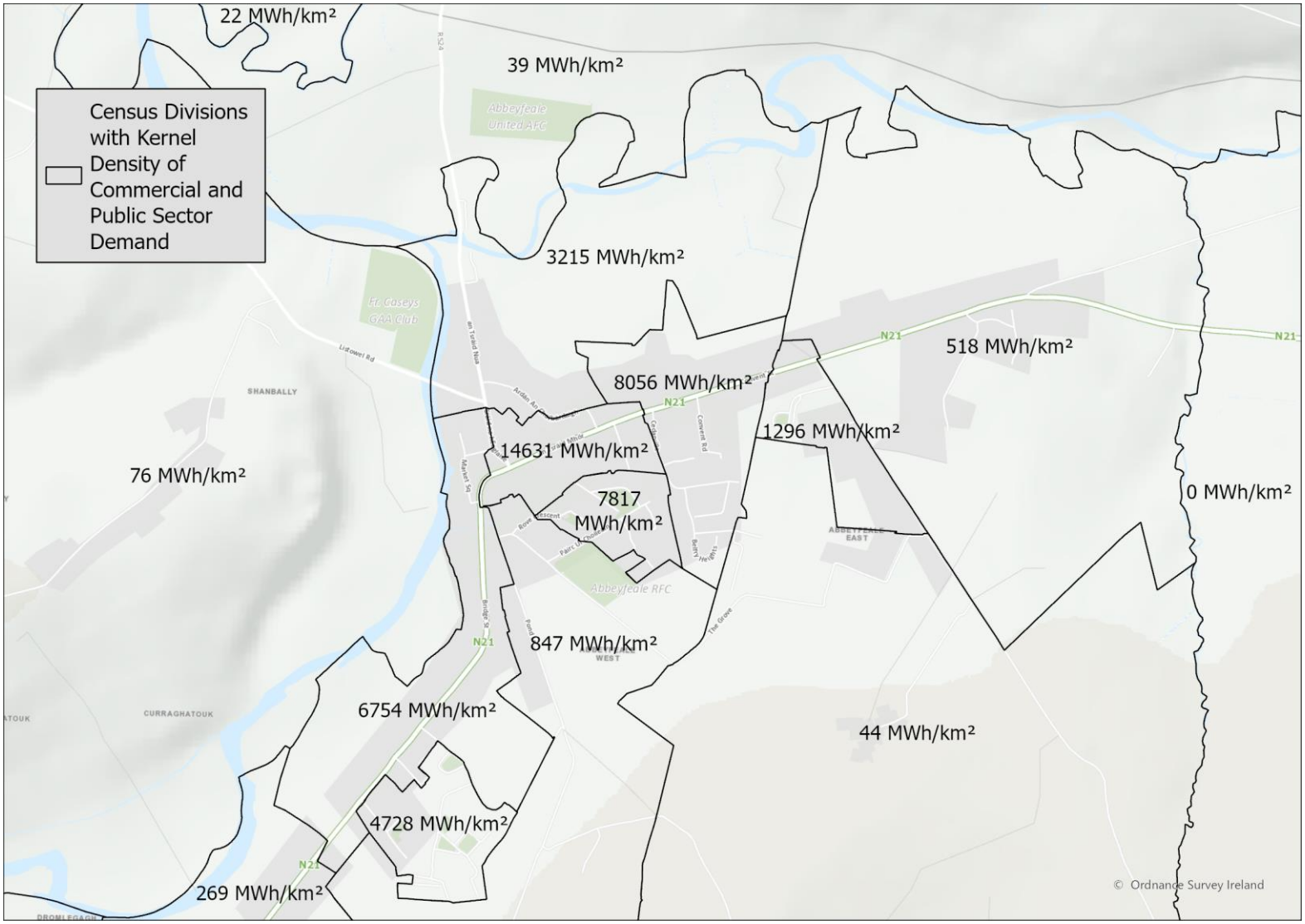

Figure 3: The kernel density estimation of suitable commercial and public sector heat demand for each Census Division.

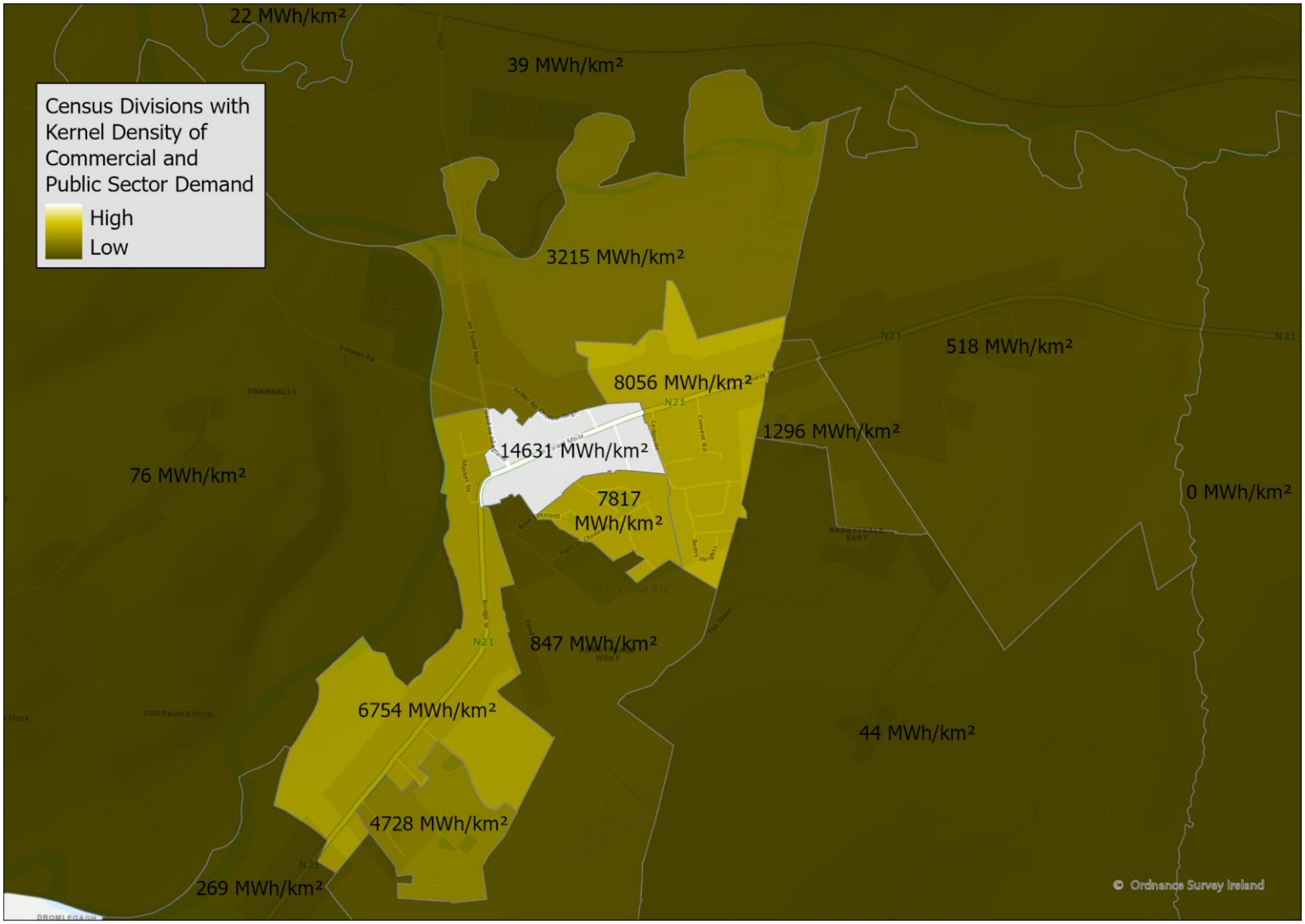

Figure 4: The kernel density estimation of suitable commercial and public sector demand for each Census Division with colour classification. The central division in white/grey is the spatial peak of suitable commercial and public sector demand for all the divisions shown.

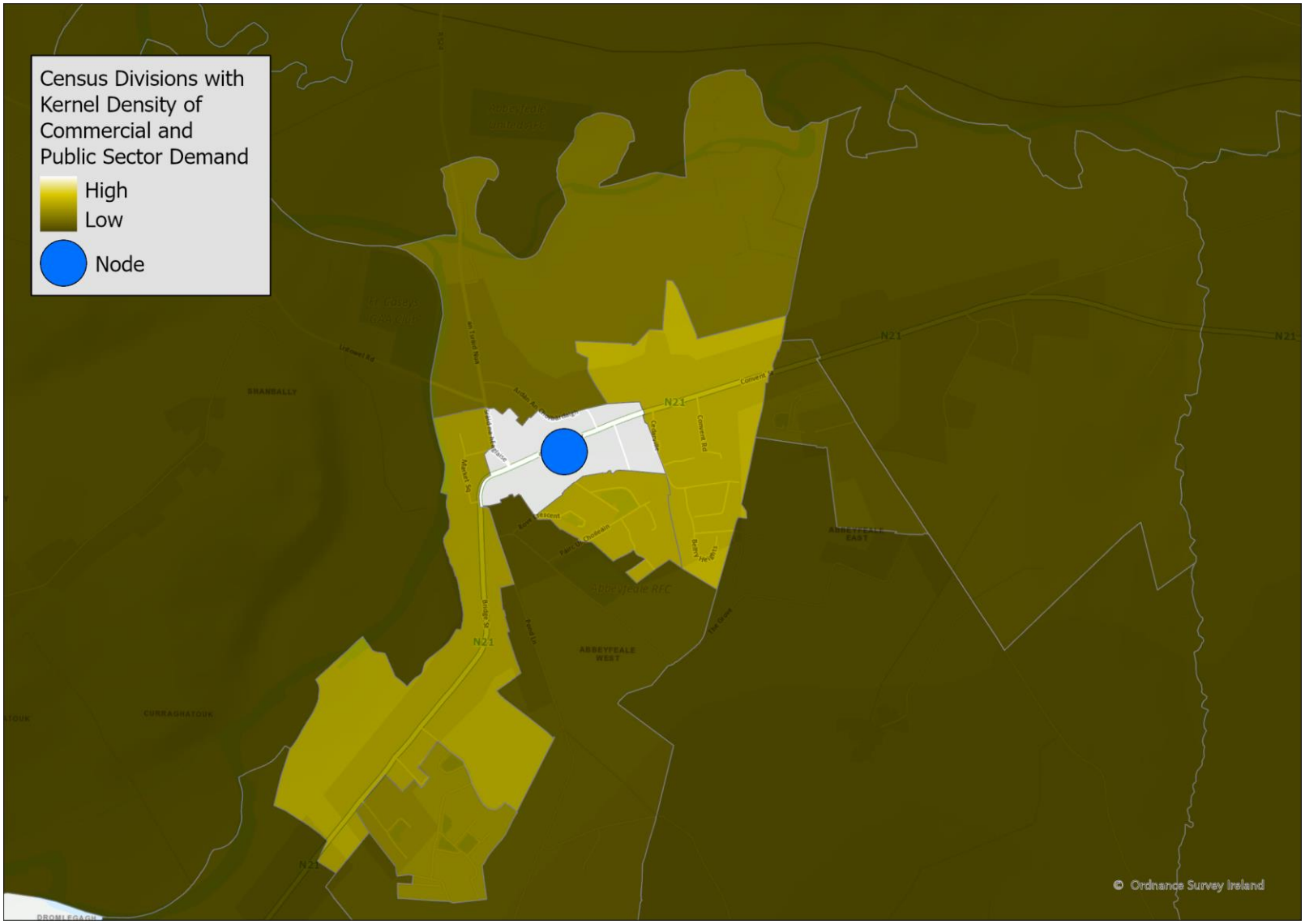

Figure 5: Node point which represents the spatial peak of suitable commercial and public sector demand for all the divisions shown.

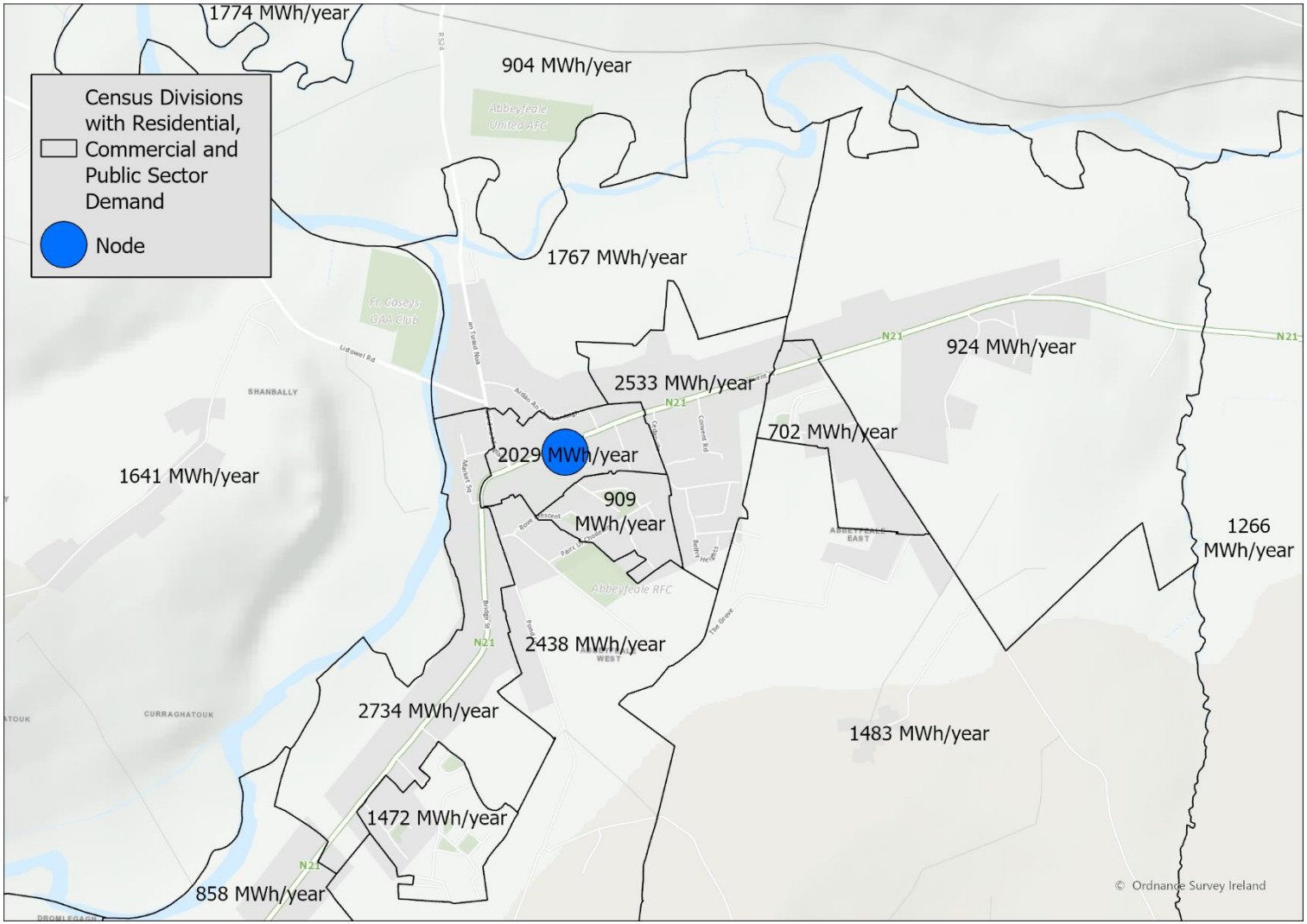

Figure 6: Census Divisions with their suitable domestic, commercial and public sector heat demand values. While the determination of node points is based on suitable commercial and public sector demand alone, the final aggregation of Census Divisions into Candidate Areas is based on total demand suitable for district heating i.e. demand in the domestic, commercial and public sectors.

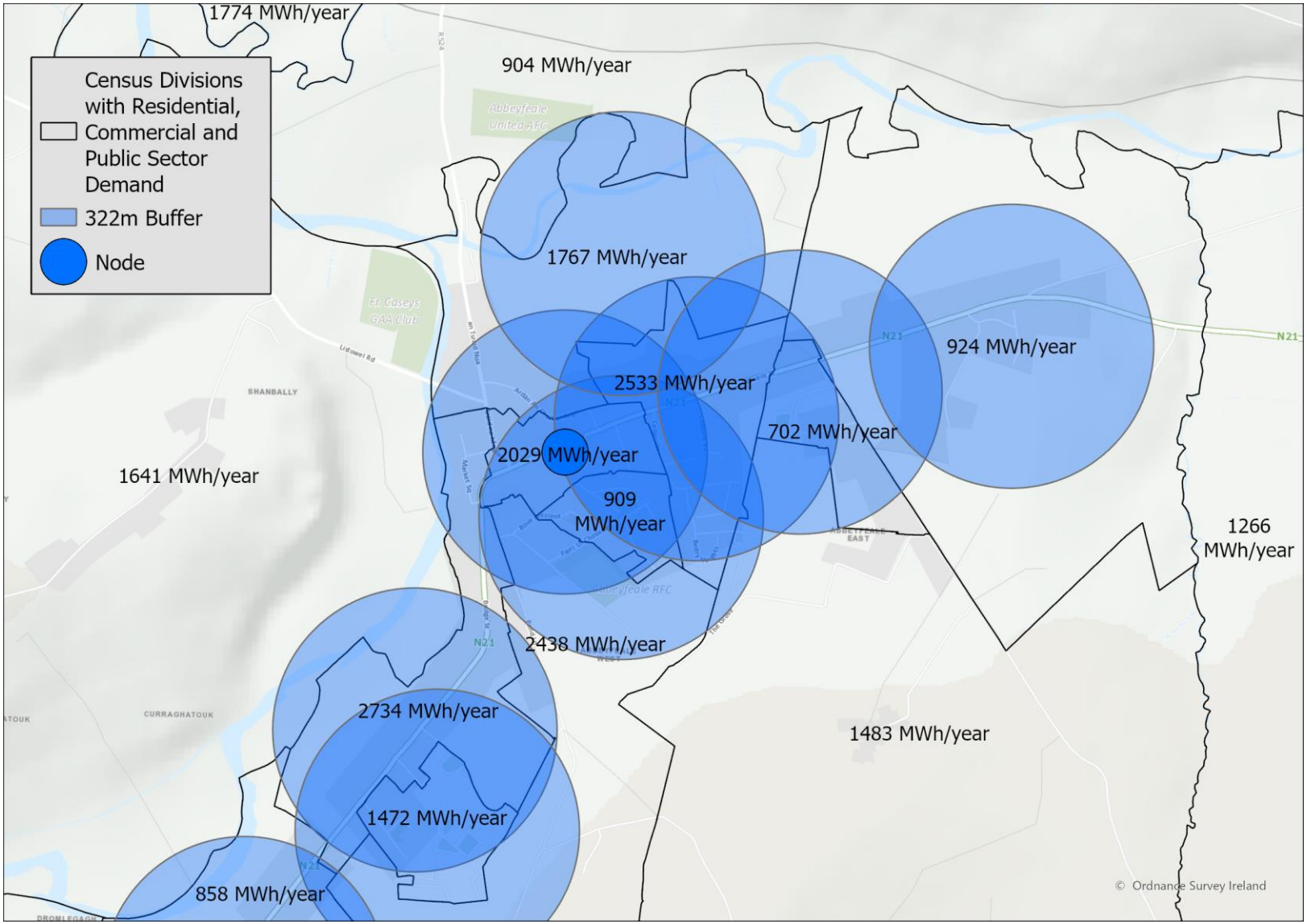

Figure 7: A buffer of 322 meters is used again for the kernel density estimation of total suitable heat demand.

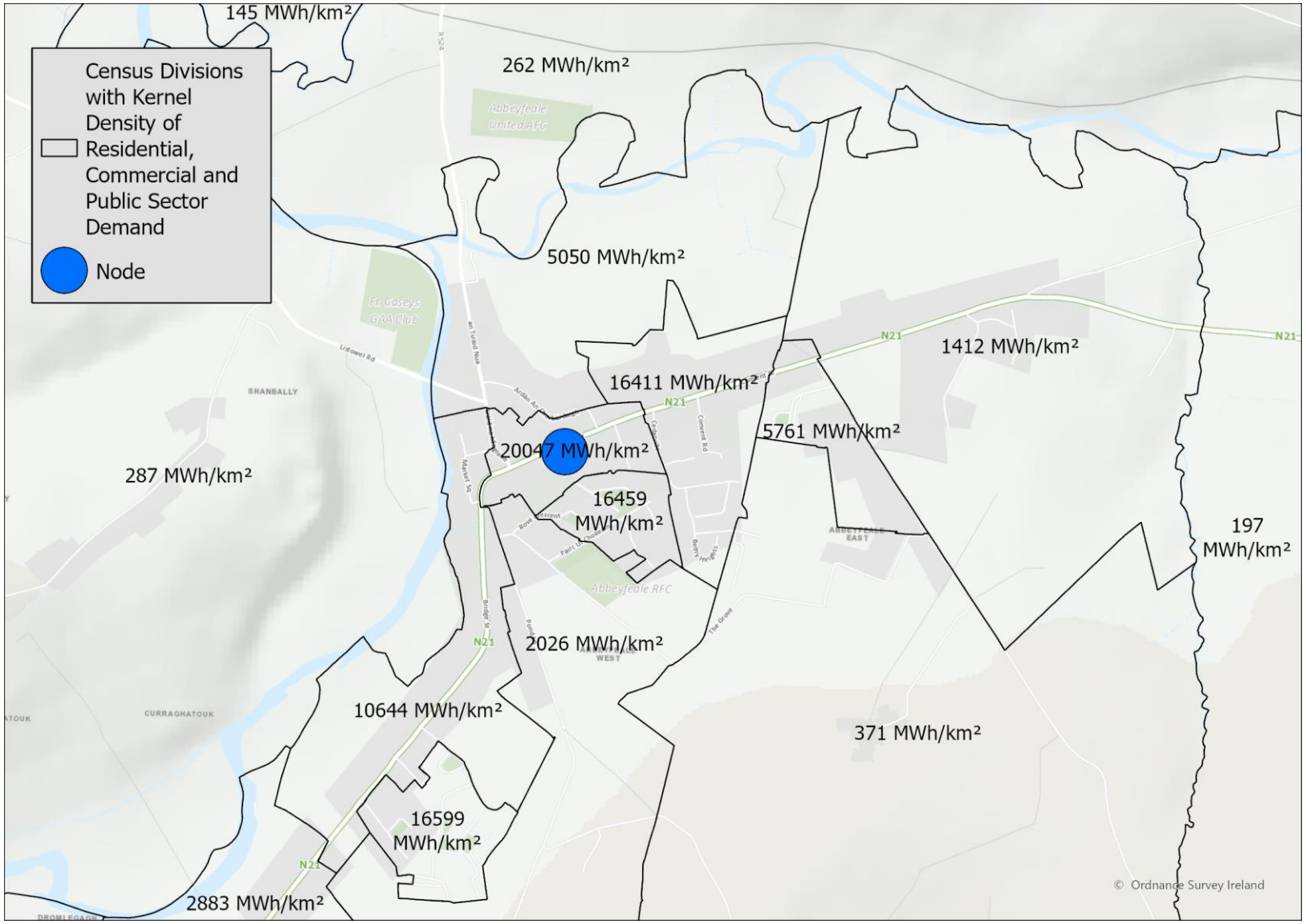

Figure 8: The kernel density estimation of total suitable heat demand for each Census Division.

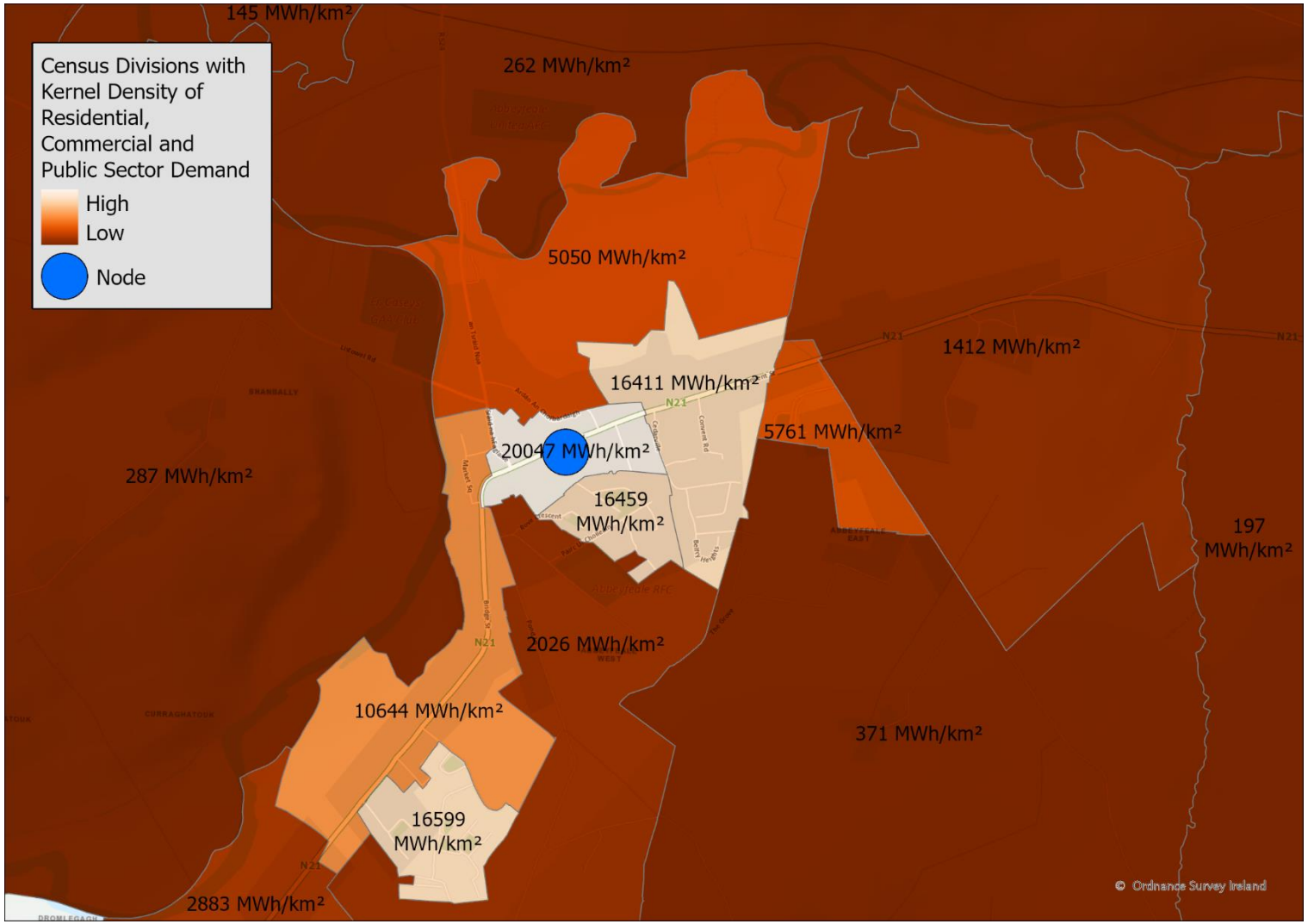

Figure 9: Kernel density estimation of total suitable heat demand for each Census Division with colour classification. Note that in this case the spatial peak of total suitable demand for the divisions shown is also the commercial and public sector node point. There are cases where the node point does differ from the division with the highest kernel density.

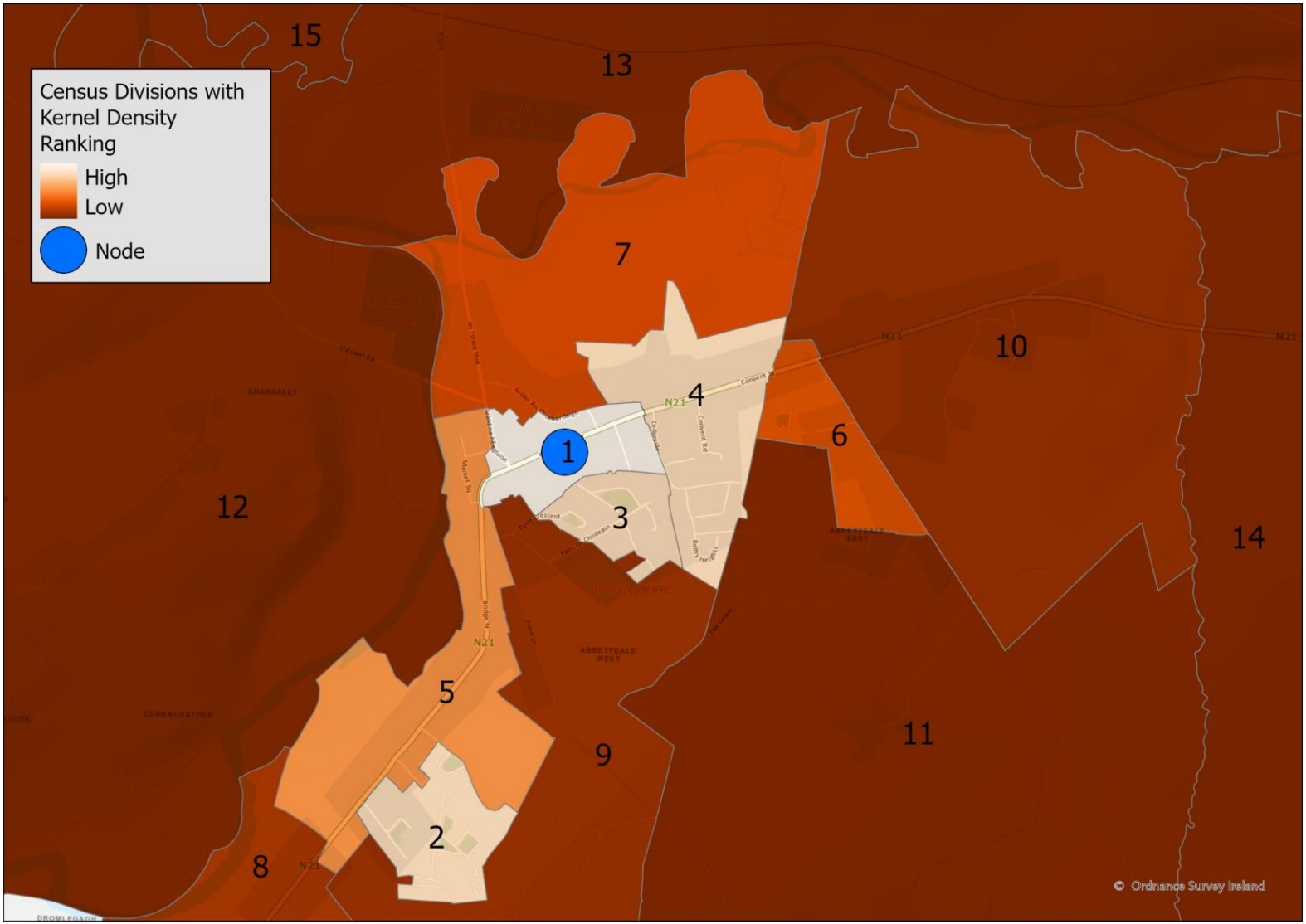

Figure 10: Census Divisions ranked according to kernel density estimation of total suitable heat demand. The model will process each Census Division in order of ranking and assess its eligibility to either create a new Candidate Area or be added to an existing Candidate Area.

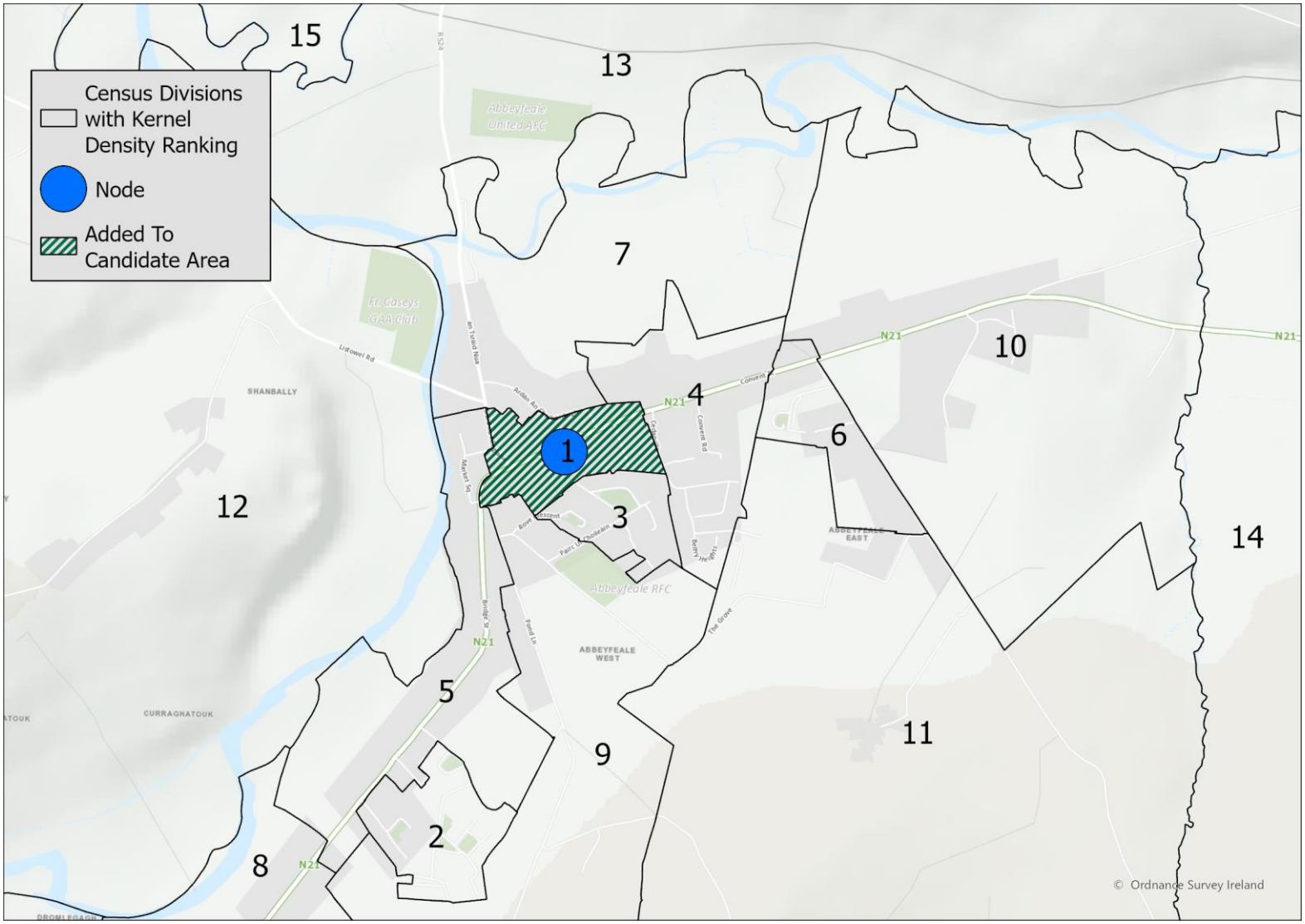

Figure 11: The first Census Division to be processed by the model is the one with the highest ranking. While this division does not neighbour any existing Candidate Area, it is a node point and therefore the model uses it to create a new, distinct Candidate Area.

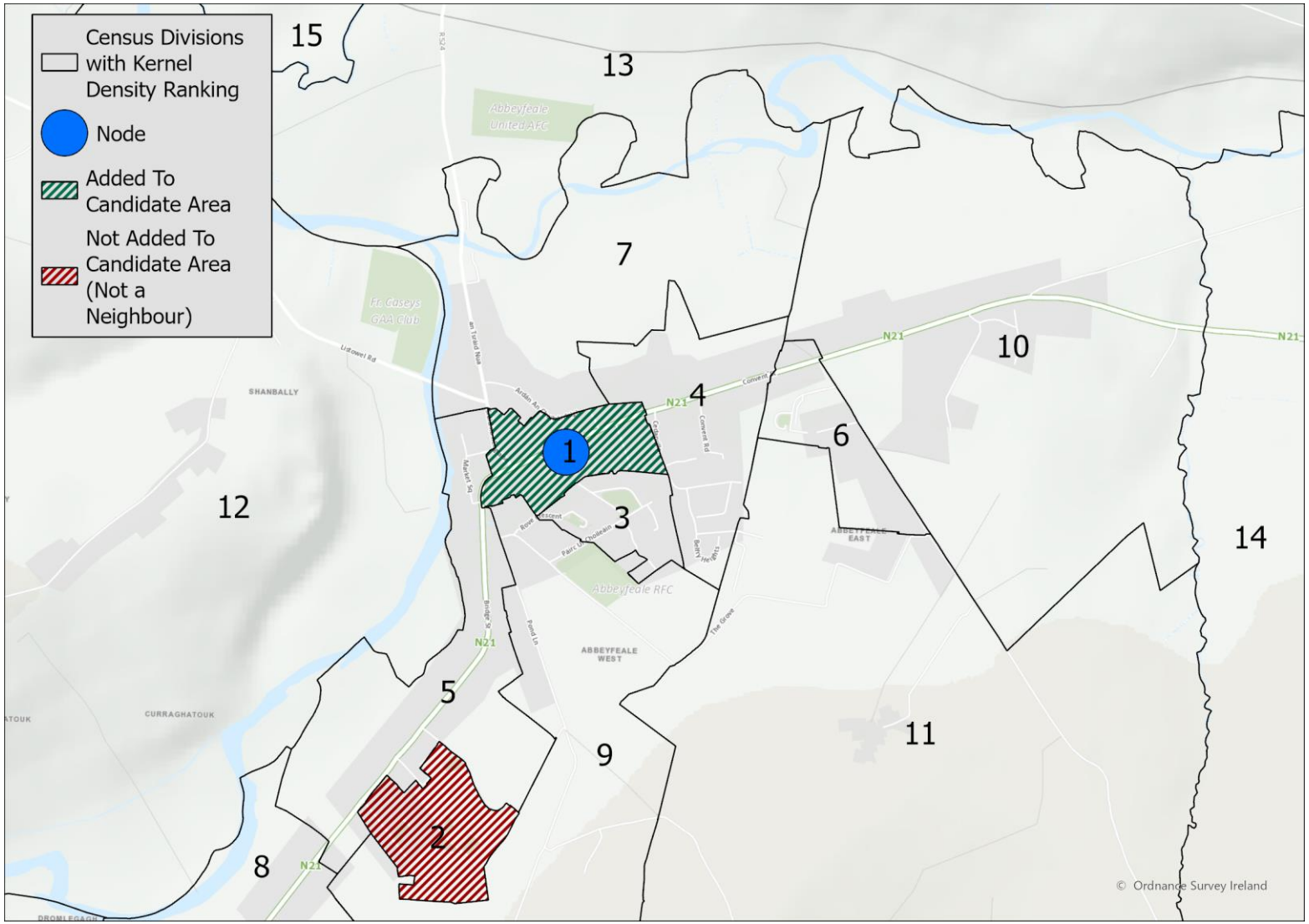

Figure 12: The next Census Division to be processed is the division with the second highest ranking. This division does not neighbour an existing Candidate Area, and it is also not a node point, so it is not eligible for district heating at this juncture.

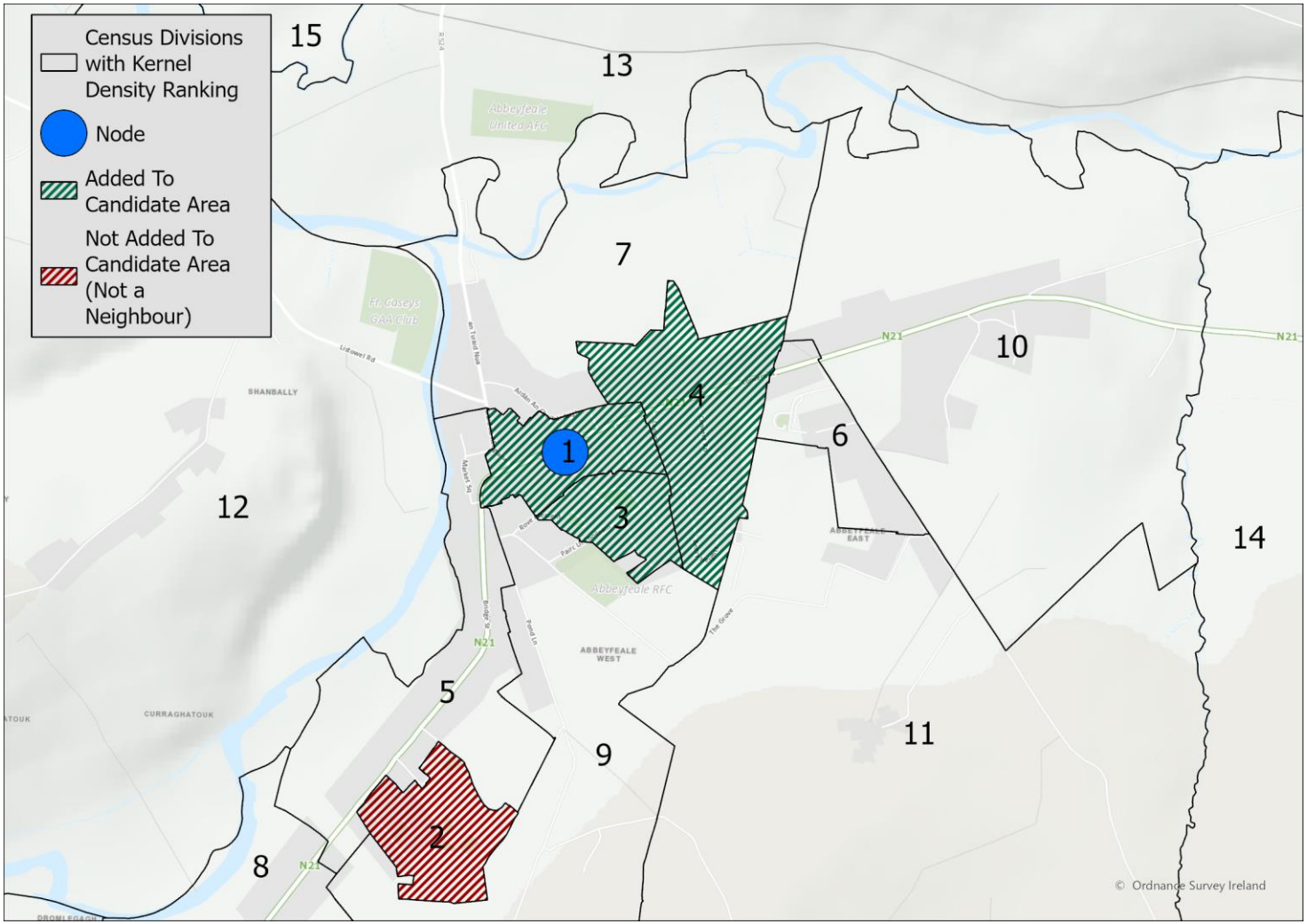

Figure 13: The 3rd and 4th ranked Census Divisions both neighbour an existing Candidate Area and so they can be added to that area by the model. Note that if the 5th ranked division was next added to the Candidate Area, this would connect the previously processed 2nd ranked division to the Candidate Area, meaning it would now be eligible to be added to that area. For this reason, with every addition of a Census Division to a Candidate Area, the model reassesses all previously processed divisions.

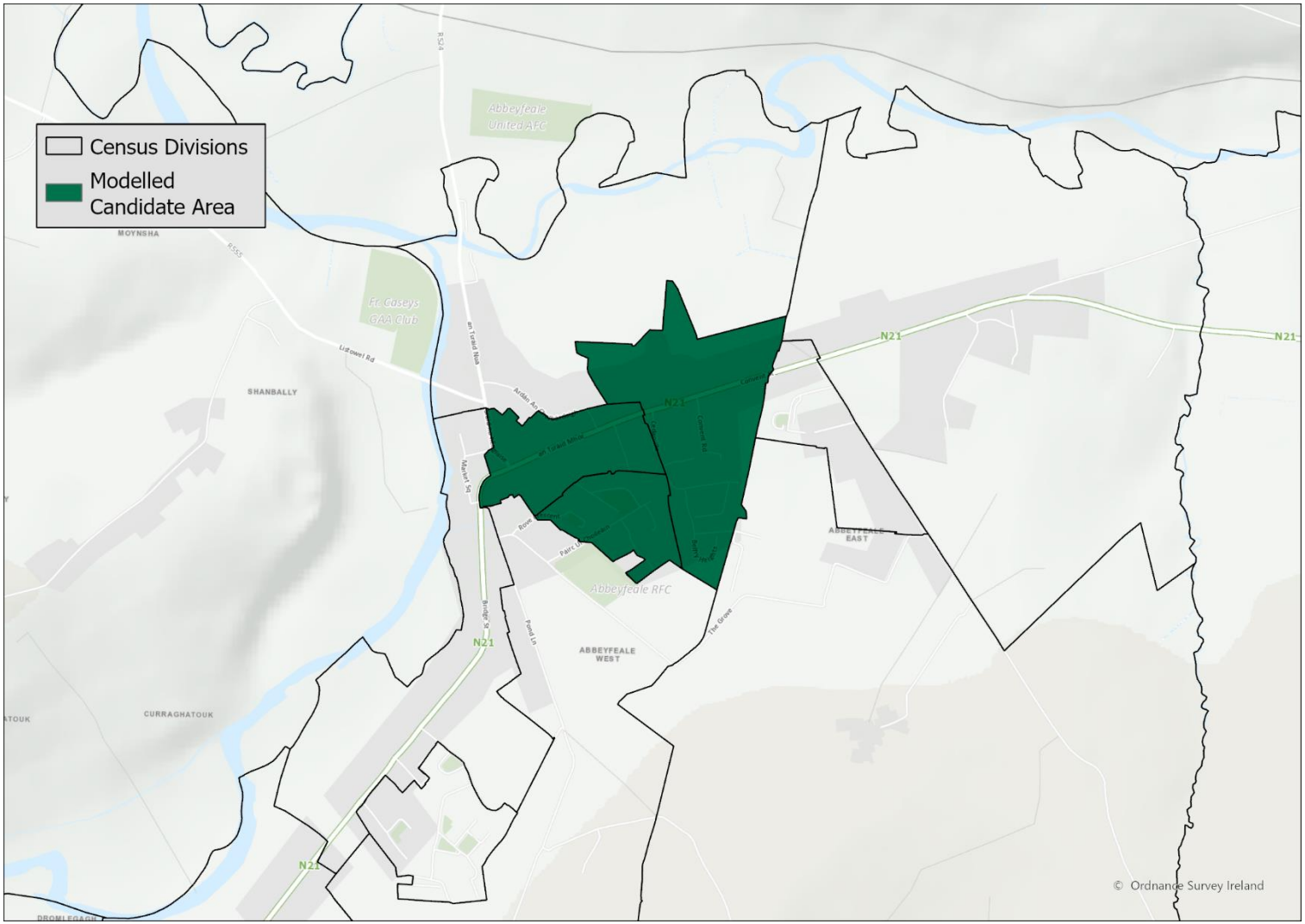

Figure 14: In practice, every Census Division in Ireland receives a ranking according to its kernel density estimation of total suitable demand i.e. a ranking between 1 – 18,641. This means that multiple, distinct Candidate Areas are simultaneously created by the model across the country. Once the Census Divisions within all Candidate Areas account for a specified target, as is the case in the above image, the model stops aggregating new divisions.