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GIS-based selection methodology for viable District Heating areas in Castilla y León, Spain

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ABSTRACT

The present research presents a novel methodology that using geospatial tools is intended to facilitate the inclusion of geothermal energy in the urban sector by selecting viable zones for geothermal district heating's The methodology is a three-step screening process based in Castilla y León (Spain), whose starting point is taking the information needed from the spatial data infrastructure about its geology, provinces and buildings and further adding selected criteria to narrow the results such as thermal conductivity, population density, energy consumption, etc. This process is intended to help with site selection of district heating's as a tool that can be applied everywhere as long as the base material is available and its key point is its agility to study multiple sites and display the information in a visual representation. As a result, the methodology provides a range of suitable sites that can be studied in detail in the future, based on the needs that the user seeks to cover.

1. Introduction

In recent years, concepts such as circular economy and sustainable development have gained more weight in society, driven by climate change. This implies a change in the energy model based on fossil fuel to a model based on renewable energies, meaning that policies are developed that guide society towards sustainable development, with renewable energy as the protagonist.

A clear example of these policies is Europe's 2030 Climate Target Plan (2030 Climate Target Plan 2022) which aims to lower the greenhouse gas emissions by at least 55% by 2030, setting Europe in a path to becoming climate neutral by 2050. Due to this tendency there are currently numerous projects and lines of research on the transition from certain sectors that historically consume fossil fuels to other renewable energy alternatives (Mutezo y J. Mulopo, 2021; Ediger, 2019). However, the urban sector is the largest demander of energy since it consumes more than a third of the world's energy and consequently produces a third of global CO_2 emissions (World Energy Investment 2021 2021). Certain measures have been taken such as the development of specific policies, but these have focused on the building envelope rather than heating and cooling equipment (Energy efficiency 2017 – Analysis 2022), which, although it represents indirect energy savings, is in the latter where it can be produced direct energy savings since consumption and emissions can be reduced with renewable alternatives.

In the Spanish scenario, the urban sector consumes approximately 30% of the final energy, of which 20% is used in domestic hot water (DHW) (ERESEE 2017 | Ministerio de Transportes, Movilidad y Agenda Urbana 2022). District heating (DH) is the efficient alternative to individual DHW installations, and even though in recent years investments in the development of this type of installation have increased by 23% since 2018 (ADHAC - Censo de redes 2022), Spain is still far from below for other European countries (Guia Basica Redes de Calor y de Frio 2022). The current trend of DH is to be powered by natural gas, yet it is expected that there will be a gradual shift to biomass and other emerging renewable energies. The considered renewable energies are: solar, energy produced by suns light or heat; or geothermal energy, renewable energy based on the use of the internal heat of the Earth and being used through geothermal exchangers under the ground and a heat pump that can distribute this energy. The usage of geothermal energy currently represents 1% of all registered networks in Spain (ADHAC - Censo de redes 2022; EU Reference Scenario 2020 2022), being the majority

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Nomenclature

Acronyms

DH	District Heating
DHW	Domestic Hot Water
GIS	Geographic Information System
GSHP	Ground Source Heat Pump
GWHP	Groundwater Heat Pump
HERS	Home Energy Rating System
SDI	Spatial Data Infrastructure
TC	Thermal Conductivity

shallow geothermal energy systems (Walch et al., 2022; Ramos-Escudero et al., 2021) that do not surpass the 150m depth of drilling nor temperature levels of 0 - 30°C.

The viability and development of DH continues to advance and is being referenced (Soltero et al., 2022; Soltero et al., 2016; Balboa--Fernández et al., 2020), perfectly visible in the evolution of generations of DH (Fabozzi et al., 2022; Lund et al., 2021; Jodeiri et al., 2022; Lindhe et al., 2022). Visually innovative design solutions are being proposed, taking advantage of residual heat through Geographic Information System (GIS) tools whose valuable utility has already been demonstrated (Ali et al., 2018; Lumbreras et al., 2022; Gils et al., 2013; Torabi Moghadam et al., 2018). GIS-tools are rapidly increasing its usage for DH in Europe, not only giving a preview of the network design (Jebamalai et al., 2019) but also helping with the optimization of the system by recalculating the routes in a visual way that facilitates the decission of chosing a route topology (Schmidt y P. Stange, 2021). However, even though there are many researchs about DH using

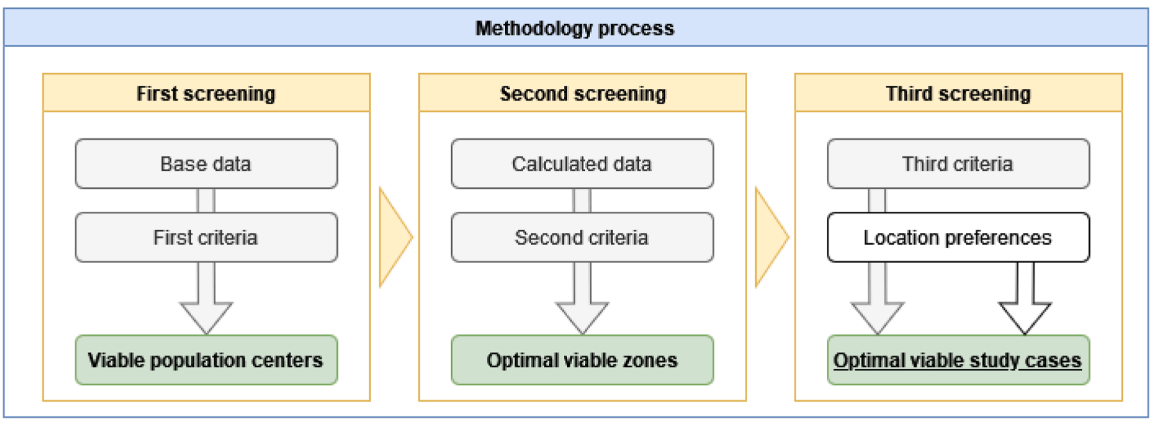


Fig. 1. Methodology process scheme.

Fig. 2. Study location, autonomous community of Castilla y León and its provinces, Spain.

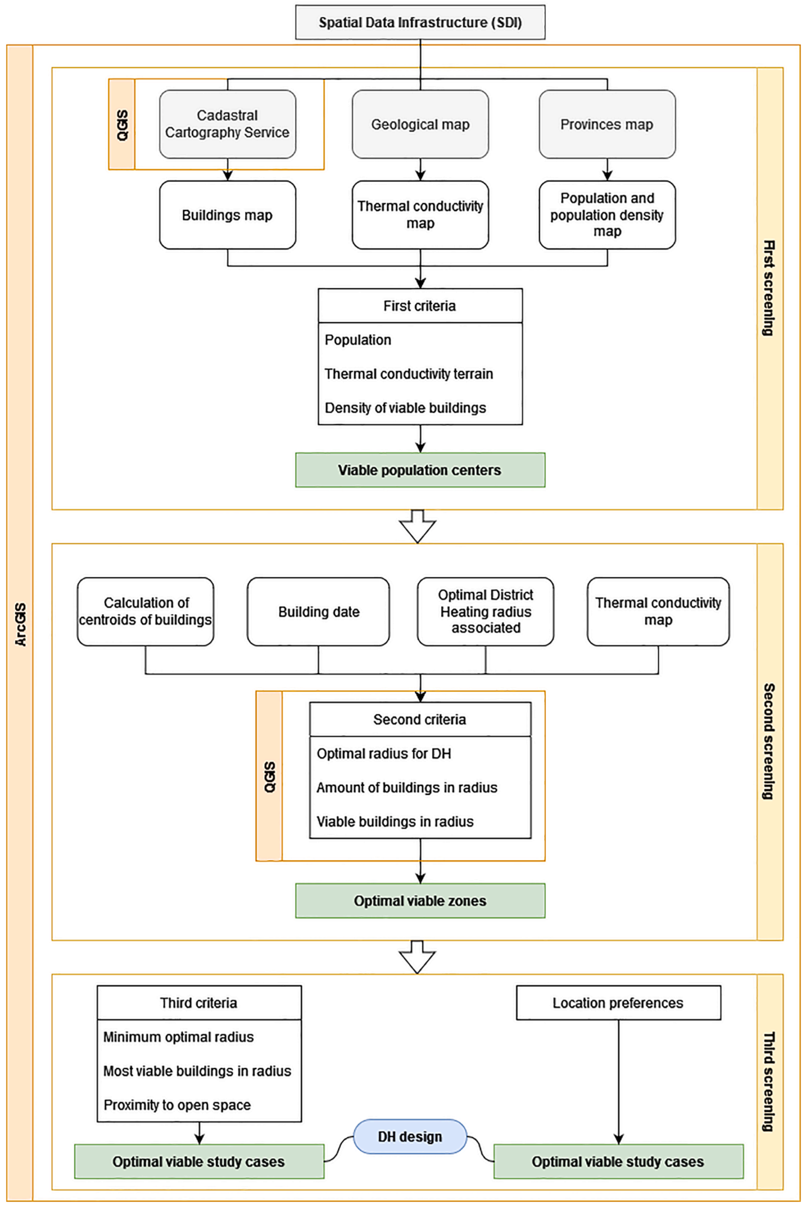


Fig. 3. Flow chart of the selection process.

GIS-tools, these are focused on DH supplied by natural gas or pellets in its majority (Nielsen y B. Möller, 2013) there are only a few pilots supplied solely by geothermal energy. For all the above, this research presents a novel methodology that using geospatial tools is intended to facilitate the inclusion of shallow geothermal energy in the urban sector, especially in DH networks, assuming an improvement in the efficiency in the implementation and use of these resources and promoting the diversity of renewable energy supply thus helping to create a safer and more resilient energy network, considering that the more diverse energy suppliers, the lower the risk of a cut in the supply.

The novel methodology presented is based on a three-step screening process in which different criteria are applied limiting the results until the areas of greatest interest for the development of DH supplied by shallow geothermal energy are found. Fig. 1 summarizes the mentioned process.

The research is part of the GEODISTRICT 3.0 project whose main objective is to develop a Spatial Data Infrastructure (SDI) that can be accessed by any user and that shows the possibility of a selected building in a DH system. This highlights the importance of a methodology that can discern the optimal locations. The final result of the methodology will be optimal location zones that can be further studied or limited by personal criteria, with the possibility of being visually represented through GIS software. As result, the research is divided in the following sections: starting with Section 2.1 the study site where the research is located; Section 2.2 establishes the base resources and materiales used and needed in order to replicate the methodology; in Section 2.3 the methodology followed is developed; Section 3 presents some representative results; Section 4 comprises the general discussion of the process; Section 5 ends with the conclusions drawn as a result of the process of applying the methodology. Lastly, in apendix A and B the rest of the results can be found.

2. Materials and methods

2.1. Study site

The study site, as stated in the title of this article, is the autonomous community of Castilla y León, formed by its nine provinces: Ávila,

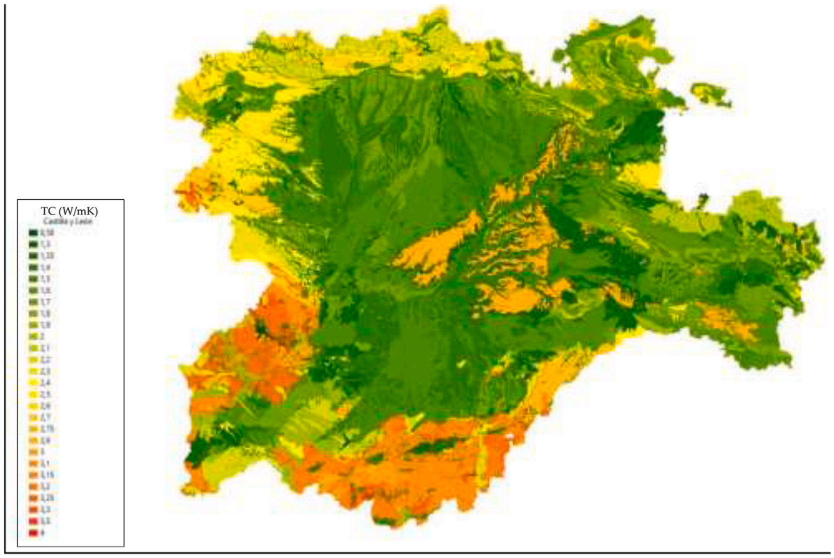


Fig. 4. Thermal conductivity map of Castilla y León, Spain.

Burgos, León, Palencia, Salamanca, Segovia, Soria, Valladolid y Zamora (Fig. 2). It is located in the northern part of Spain with an area of 94,225km^2 (CyL, 2022), and it is known for the largest region in Spain and the third one of the EU.

This research is part of a grant program by the Junta de Castilla y León co-financed by the European Regional Development Fund whose thematic objective is to promote technological development and innovation for Castilla y León, which is why it is located in the same autonomous community.

2.2. Base resources and materials

The Quality and speed given by this selection process is based in the pre-existence of a SDI of Spain (IDEE, 2022), which is part of the European SDI defined in The European Inspire Directive (Directive 2007/2/EC, Infrastructure for Spatial Information in Europe). The SDI consists of a set of data and metadata, among other geological information, that are harmonized and integrated into a virtual system. Its function is to share geographic information on the network through a geoportal for which the National Geographic Institute (IGN, 2022) is responsible.

Having noted that the study case is Castilla y León, the information extracted from the Spanish SDI will focus in that Autonomous Community. Catilla y León has its own node of the SDI with its own geological information, from which the geological map of each province and the municipalities map can be extracted and worked on by geospatial data processing programs. ArcGIS and QGIS are the programs selected that will allow further operations with said maps and information.

2.3. Methodology of the selection process

As stated in the introduction and in Fig. 1, the methodology is a three-step screening process whose starting point is taking the information needed from the SDI of Castilla y León (CyL, 2022) about its geology, provinces and buildings. The detailed process is shown in Fig. 3.

For the geological map there is nine different maps availables, one for each region of the Autonomous Community. They can be found in the Geological and Mining Institute of Spain (IGME) portal. The information associated to those geological maps have a code for each geological material that can be linked to its thermal conductivity (TC). In this research this link is based in the study made by Eugene C. Robertson about thermal properties of rocks by Eugene C. Robertson (1988). TC is an essential parameter that can determine the viability of a geothermal wellfield considering the utilization of the borehole heat exchangers. The result of this correlation between geology and thermal conductivity results in a TC map of Castilla y León as shown in Fig. 4.

Table 1
Reclassification of ranges of population and conductivity.

Population[1]		Value	Thermal Conductivity[2] (W/mK)		Value
0	5000	**1**	0	0,4	**1**
5000	85000	**2**	0,4	0,8	**2**
85000	140000	**3**	0,8	1,2	**3**
140000	175000	**4**	1,2	1,6	**4**
175000	205000	**5**	1,6	2	**5**
205000	225000	**6**	2	2,4	**6**
225000	245000	**7**	2,4	2,8	**7**
245000	265000	**8**	2,8	3,2	**8**
265000	280000	**9**	3,2	3,6	**9**
280000	295000	**10**	3,6	4	**10**

[1] Distributed with a linear regression
[2] Ranges by proportional distribution

In order to continue the methodology the provinces map of Castilla y León is needed and it can be downloaded directly from its SDI as stated in point 2.2. Since it is important to calculate the population density, population per km^2, for further screening in the selecction, the population of each municipality can be found in the General Institute of Statistics, in this case the Spanish Statistical Office (Spanish Statistical Office 2022).

As a result, the population density and the population per municipality is obtained. This information is needed for further iterations such as the reclassification of the municipalities using two pairs of variables: population per municipality and geology per TC (Table 1). These two variables are the basis of the screening process. The first variable influences the amortization and the justification of the DH construction whereas the second variable affects the sizing of the geothermal wellfield.

Population and conductivity layers were converted and reclassified individually so both layers can be compared and used accordingly by values as shown in Fig. 5.

The intersection of both maps will result in the first viable municipalities where the DH can take place. To carry out the weighted sum of the variables involved in the study the percentage selected was 50-50.

Having the 50-50 weighted map of population and TC (Fig. 6a) and

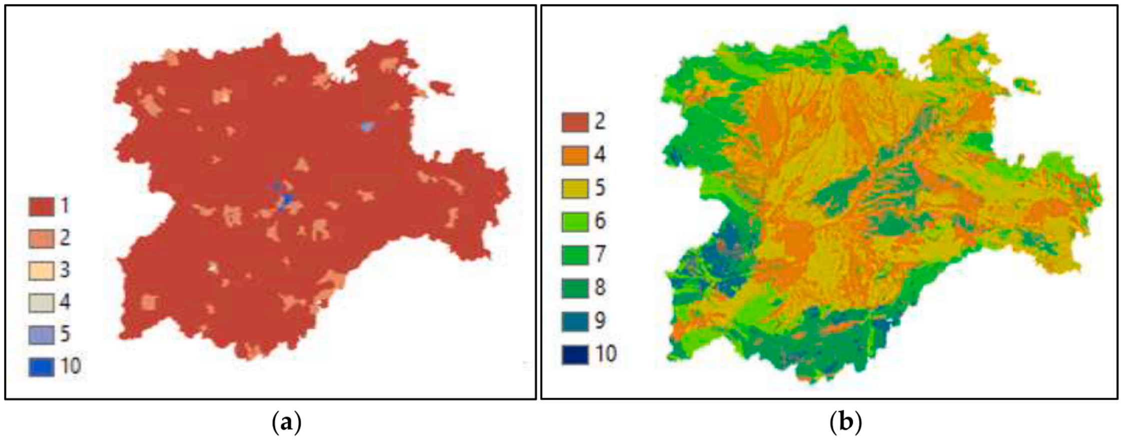


Fig. 5. Population and thermal conductivity maps reclassified with Table 1 values. **(a)** Population raster **(b)** Thermal conductivity raster.

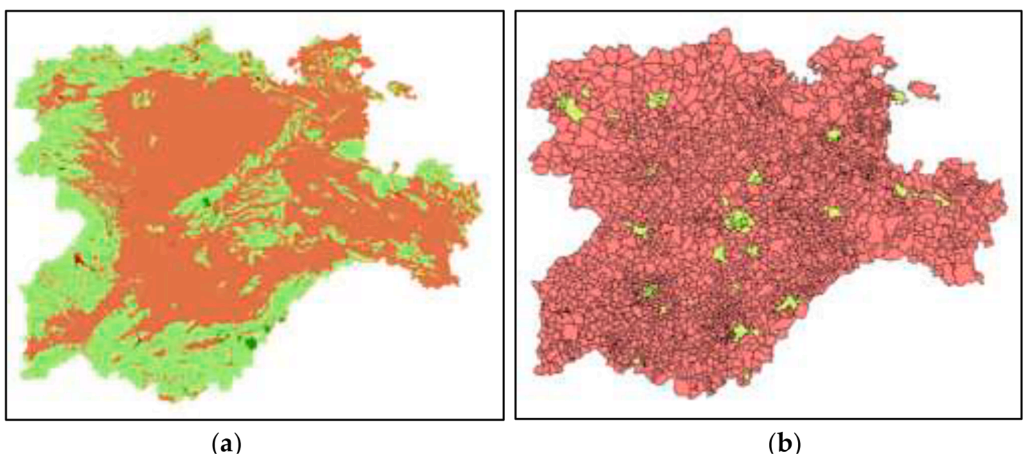


Fig. 6. Map used for the first screening. **(a)** Population-conductivity 50-50 weighted map, result of Fig. 2a and Fig. 2b **(b)** Selected zones with high population density.

selecting in the population map those population densities greater than 100 inhabitants per km^2 with more than 5000 inhabitants (Fig. 6b), the first selection on viable zones is possible by crossing both maps by their green zones.

Consequently, the first screening narrowed the possibilities to 59 viable population centers (2%) as listed in Table 2 from the original 2298 municipalities studied.

This process already determined the first viable DH areas, so in order to narrow this selection to achieve what the optimal areas would be, further investigation and processing of data is needed. Consequently the next step would be adding a new discerning criteria which will significantly reduce the number of viable areas: buildings. Having the buildings incorporated would mean that building-criteria can be established to discard some of the areas selected since the amortization period is directly influenced by the type of buildings selected.

Using the Cadastral Cartography Service (Services INSPIRE of Cadastral Cartography 2022) (SDI) the data of the buildings can be obtained under ATOM buildings (BU) from ATOM Services INSPIRE of Predefined Data Sets. These files have important information for building classification such as “FID”, “shape”, “localId”, “numberOfFl” and “heightBelo”; where “numberOfFl” dictates the number of floors of the building and “heightBelo” shows the meters below the surface of the building, meaning that a 3 is only one floor below the surface.

The duplicated data included in the information sheet given by the downloaded layer has been removed to minimize errors in the selection. The kept data is those buildings with the highest value of “numberOfFl”or number of floors of the building. As a result the layer will contain a list of unrepeated references.

The next layer needed is the building layer, in which the columns that contain the important information are stated in Table 3.

The layers that will serve as the basis of work to carry out the methodology are the union of the previously obtained layers. Therefore the process detailed previously has been repeated for the rest of the cities selected in Table 2, thus forming the base layer of work.

The next exclusion criteria is an analysis by geological environment, with six different scenarios as shown in Table 4 where the minimum number of dwellings and minimum area of public/industrial buildings are considered depending on the specific range of TC.

The information presented in Table 4 is the result of an estimation combining information provided by the Technical Building Code (TBC) (DBHE, 2022) and the use of GES-CAL software (Sáez Bláquez et al., 2020). The premise on which it starts is the amortization period. Using the information described above, the point where the DH installation is more favorable than the case of a conventional natural gas installation has been calculated for each conductivity range, hence giving those results.

Using ArcGIS and the base layers, the selection done in Table 2 can be eye-sorted based on thermal conductivity by selecting the range where the majority of the buildings are built on. It is known that since this process of selection is eye-based there is ought to be an error but considering that the error might be one range up or down it would not affect significantly the selection. As a result, the sorting of Table 2 is

Table 2
First selection of viable population centers by population order[1].

1	Valladolid	21	Ciudad Rodrigo	41	Venta de Baños
2	Burgos	22	Astorga	42	Villares de la Reina
3	Salamanca	23	La Bañeza	43	Peñaranda de Bracamonte
4	León	24	Cuellar	44	Zaratan
5	Palencia	25	El Espinar	45	Guardo
6	Ponferrada	26	Cisterniga	46	Medina de Pomar
7	Zamora	27	Bembibre	47	Guijuelo
8	Ávila	28	Villablino	48	Almazan
9	Segovia	29	Tordesillas	49	Aldea mayor de San Martín
10	Soria	30	Toro	50	Palazuelos de Eresma
11	Miranda de Ebro	31	Tudela de Duero	51	Valencia de Don Juan
12	Aranda de Duero	32	Arévalo	52	Real Sitio de San Idelfonso
13	San Andrés del Rabanedo	33	Valverde de la Virgen	53	Simancas
14	Laguna de Duero	34	Villamayor	54	Alba de Tormes
15	Medina del Campo	35	Carbajosa de la Sagrada	55	Cigales
16	Arroyo de la Encomienda	36	Aguilar de Campoo	56	Las Navas de Marques
17	Villaquilambre	37	Briviesca	57	Cacabelos
18	Benavente	38	Villamuriel de Cerrato	58	Peñafiel
19	Santa Marta de Tormes	39	Arenas de San Pedro	59	Sariegos
20	Béjar	40	Íscar	-	

[1] The order is among the selection of the population centers.

Table 3
Columns present in the building sheet file.

FID	localId	currentUse[1]
shape	namespace	numberOfBu[2]
gml_id	horizontal	numberOfDw[3]
conditionO	horizont_1	value
Reference	horizont_2	value_uom

[1] Use of the building: residential, agriculture, industrial, public service, retail or offices.
[2] Number of buildings associated to the shape
[3] Number of dwellings per building

shown in Fig. 7.

This sorting will be used to determine which buildings will make the DH viable by the minimum dwellings and area of public/industrial building, furthermore those buildings can be selected in ArcGIS. An example of the block code is detailed in Fig. 8(a).

At this point a new selection screening can be made based on population (Table 5), TC (Table 6), and density of viable buildings (Table 7).

This screening made the first 59 viable zones into 15 viable zones, the ones that will be used for the continuation of the process, and 12 possible zones.

Given the 15 chosen zones as a new working base, the date of the building can be considered since it is important to the DH connection and amortization for its energetic consumption based in its Home Energy Rating System (HERS) index. Since the layer downloaded from the SDI already contains the year of construction, a code similar to Fig. 3b was used to classify those buildings. The new criteria is selecting the buildings that has been built in 1980 (RD 2429/1979) or after (RD 314/2006). If it also meets the requirement to be a positive building due to its dwelling number or area, depending if its private or public, it will be selected.

As stated in Fig. 3, for the second screening, the calculation of the building centroids is necessary so as to apply the next criteria. In order to do so some calculations and transformation of the information already obtained is needed. This process has been developed by triangulating the centroids of the building themselves. Having obtained the Thiessen polygons, whose boundaries define the area that is closest to each point relative to all other points, a conversion from line to point was used in order to obtain its centroid. These calculated centroides generate a layer with optimal points where the installation of the DH could be built. These points will have an associated TC that itself has an optimal radius of DH as shown in Table 9.

These radius have been obtained through a comparative study of demand between natural gas and geothermal energy. The key point of this comparision was finding the radius with the number of estimated users that will allow in 10 years to reduce the cost curve of the installation below the cost curve of the same installation supplied by natural gas. Since the TC is taken in ranges the optimal radius is an approximation. It is estimated around 10 years since, even though the heat pumps are supposed to operate for 20 years, actions are expected to be necessary on their compressors after 10 years of operation.

An excel was elaborated with a 0,01 step of thermal conductivity with its associated radius and it was joined using the conductivity as base variable. Lastly, the building dates layer and the building centroids can be fused. The three layers that remain so as to be used with the information needed in order to allow the screening process are the following:

Table 4
Thermal conductivity ranges with associated information.

Case	Thermal conductivity (W/mK)	Limit thermal needs (kWh/year)	Amortization period (years)	Min. number of dwellings[1]	Min. public or industrial area (m^2)
1	3 – 3.5	900.000	5	30	3.000
2	2.5 – 3	1.500.000	6	50	5.000
3	2 – 2.5	3.000.000	7	100	10.000
4	1.5 – 2	6.000.000	8	200	20.000
5	1 – 1.5	15.000.000	10	500	50.000
6	0.5 – 1	30.000.000	15	1000	100.000

[1] Considering 30.000 kWh/year per dwelling

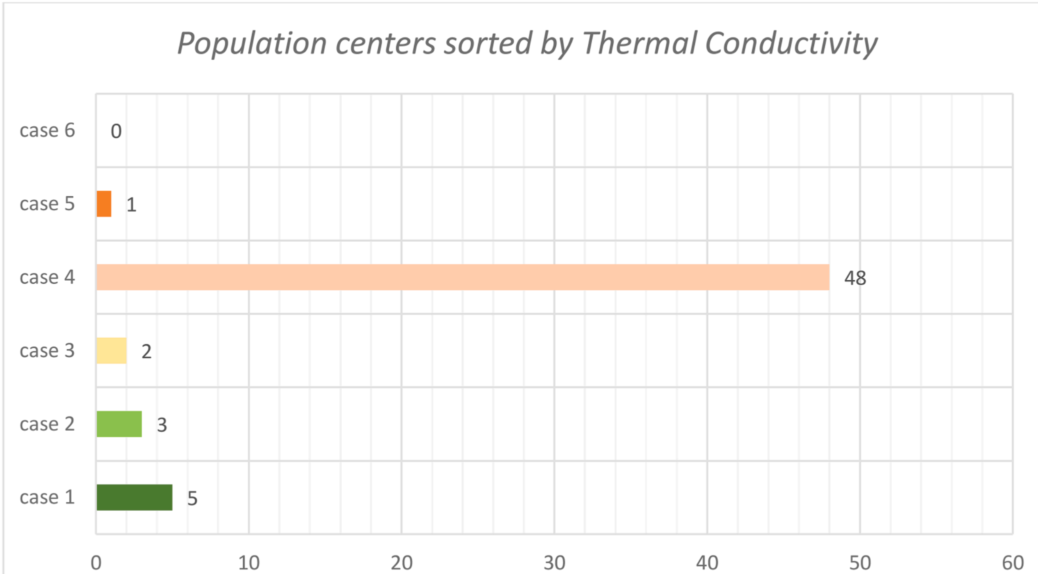


Fig. 7. Graphical representation of the population centers based on the cases related to Table 4.

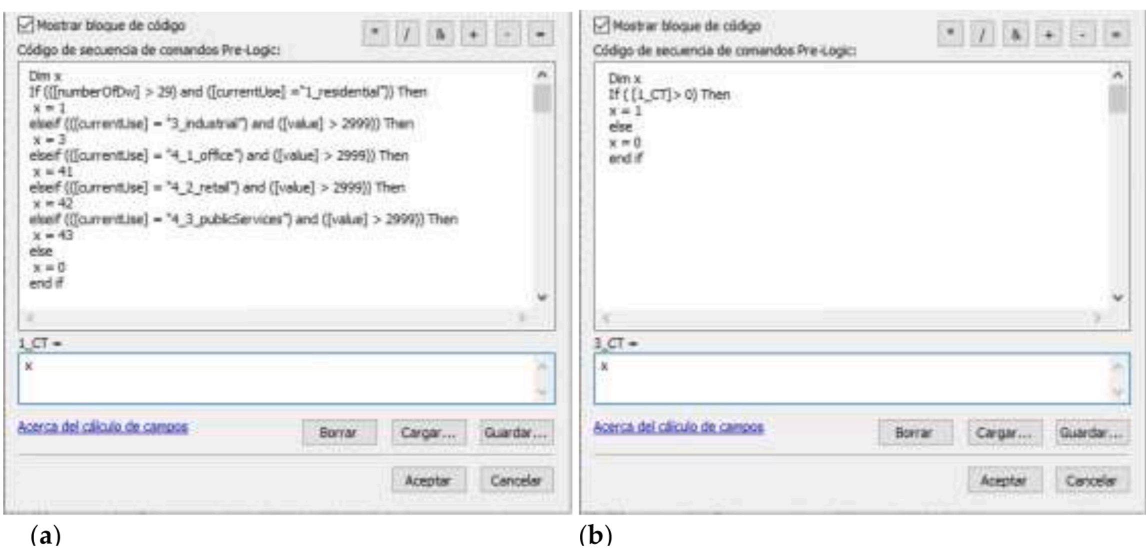


Fig. 8. Example of the code used for case 1 of Table 4. **(a)** Code that will maintain the value of the current use of the building that meets the requirement **(b)** Code that will sort by 0 if the building does not meet the requirements or 1 if it does meet them.

Table 5
First selection of viable population centers sorted by population.

	Viable							Possible
Result	9							1
Population centers	1	2	3	4	5	7	8	6
	9	10						

- Layer with the optimal radius depending on the thermal conductivity per viable centroids.
- Layer that contains all the centroids with the building date associated.
- Layer that contains the centroids of those buildings that meet the established criteria.

A plugin was made for QGIS that helps with the selection of the best placements for the DH based on those layers.

The operational process of the plugin is based in a four-step sequence starting with the layer that contains the optimal radius. Firstly, the plugin will search for the possible radius and it will internally draw the circles with each radius. Secondly, the plugin will associate the centroids of the layer will all the building centroids with each internally drawn radius. Thirdly, it will count how many centroids of those that are inside a radius are associated with buildings that met the criteria. Lastly, it will show a table with the centre of the radius sorted by maximum number of centroids of those buildings that met the criteria.

The plugin menu is shown in the following Fig. 9.

The plugin contains the following fields:

1 Button used for refreshing the layers loaded in QGIS so the plugin can use them without having to load them again after opening the plugin.
2 Field in which the layer with the radius must be selected.
3 Dropdown menu that shows the possible radius to select.
4 The selected radius will also show in this field.
5 Field in which the layer with the centroids of all the buildings must be selected.
6 Field in which the layer with the buildings that met the criteria must be selected.
7 Button used for saving the spreadsheet calculated by the plugin.
8 Button that starts the plugin.
9 Display of the results based on the radius selected; OBJECTID is the identification in the layer of the center studied, RADIO is the radius selected previously, and REPETICIONES is how many buildings that meet the criteria are inside the drawn radius.
10 Once you select the result you want to further study from 9, you can press this button and it will show it in the screen with the radius drawn and the centroids that are inside the radius.

Using this plugin will result in a visual representation of the optimal zones.

3. Results

This section will present the results from the application of the methodology shown with the final visualization using the plugin described previously.

The next figures are a selection of those 15 population centers with some cases drawn so as to show the best possibilities. Those population centers are: Segovia (Figs. 10a 10b), Valladolid (Figs. 10c 10d), and Palazuelos de Eresma (Figs. 10e 10f), the rest of the results can be seen in Appendix A.

As observed, the plugin colours the radius selected and shows different coloured circles: brown circle is represented as the centre of the radius, blue and green circles are building centroids where the green circles are those buildings that meet the criteria.

Therefore, this visual representation shows the maximum area of effect of the district heating keeping the optimal parameters and showcasing those buildings that could potentially be part of the design of the DH.

4. Discussion

This three-step process is intended to help with site selection of DHs as a tool that can be applied everywhere as long as the base material is available. Once the site is chosen a further investigation and study about the technical viability and design of the DH will be required.

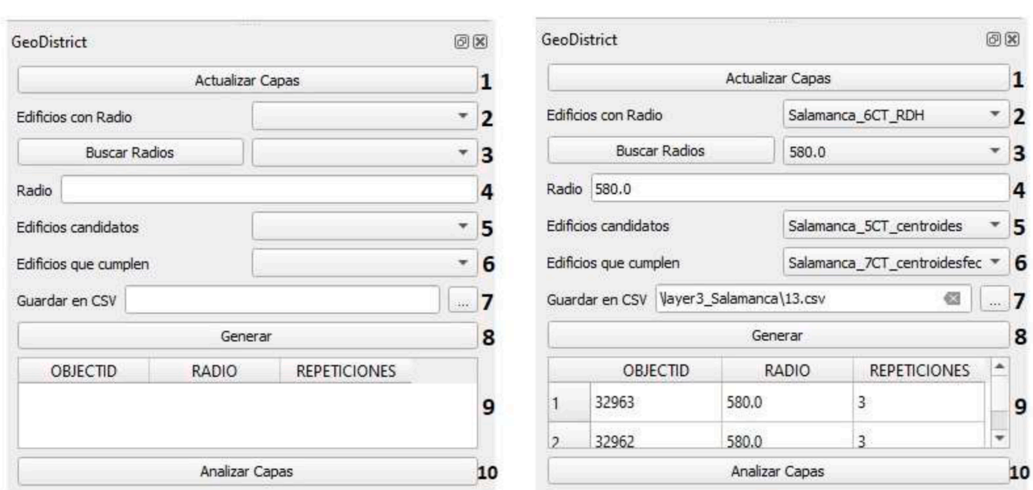
As it is a wide-ranging methodology in terms of initial data pro-

Table 6
First selection of viable population centers sorted by thermal conductivity.

	Viable							Possible						
Result	8							8						
Population centers	8	9	20	25	39	50	52	22	23	26	28	46	47	54
	56							57						

Table 7
First selection of viable population centers sorted by density of viable buildings.

	Viable							Possible						
Result	12							7						
Population centers	1	2	3	4	5	7	8	6	11	12	30	39	47	50
	9	20	25	52	56									



(a) (b)

Fig. 9. Detail of the QGIS plugin menu. **(a)** Base of the menu display of the plugin. **(b)** Example of the menu display using Salamanca as a working example.

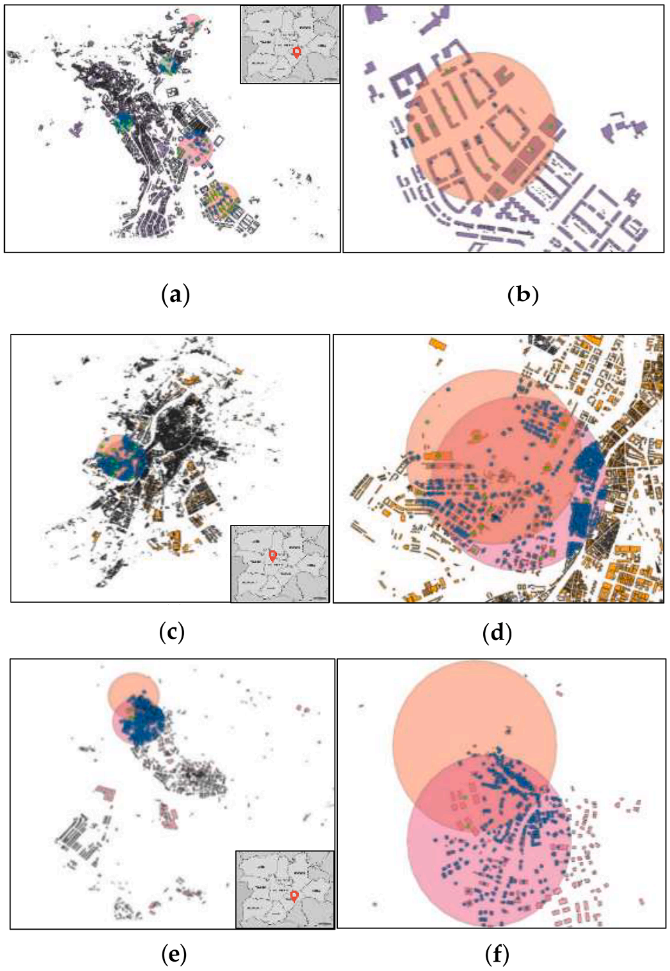


Fig. 10. Results given by the QGIS plugin. (a) Segovia (b) DH radius detail from Segovia (c) Valladolid (d) DH radius detail from Valladolid (e) Palazuelos de Eresma (f) DH radius detail from Palazuelos de Eresma.

cessed, the optimal way to simplify this process was selecting a geothermal criteria which could be easily accessed without the need to carry out field samples. Regarding this case the authors selected the thermal conductivity of the terrain, which as mentioned in the introduction, is an essential parameter for the efficiency and utilization of borehole heat exchangers. This is due to the fact that this type of DH system is based on ground-source heat pumps (GSHP) in a closed circuit. It is not intended for groundwater heat pumps (GWHP) nor takes into consideration the possible hydrothermal resources. Nonetheless, authors aknowledge that geothermal installations could vary depending on different parameters not taken in consideration in this research, such as geological structure and hydrothermal properties. However obtaining those parameters implies an in-depth approach that moves away from the objective of this methodology, the rapid processing and discarding of multiple zones. This methodology seeks to considerably reduce the number of samples and delimit those that are viable only due to thermal conductivity, regardless of the efficiency that can be obtained with the presence of different intersection geological formations or the presence of an underground water flow.

The importance of this methodology is based on the agility to study multiple sites and display the information in a visual representation that allows the user to pinpoint either a place of interest or a place based in another screening criteria. An example of this final selection is shown in Fig. 4 where the cases shown in Fig. 9 are based in the application of three criteria: the minimum optimal radius, the most viable buildings in radius and the proximity to open space.

In addition to this representation, the plugin makes easier the identification of those buildings of interest that the user wants to connect to the DH network since the information of the layers that were worked on in ArcGIS are contained in these layers in QGIS. The purpose is so when the user selects a building a menu on the right will display all the information for easy access in the same tool, this menu can be seen in Fig. 11.

Certainly, some cases will not be of interest even if they met all the criteria of the methodology since the design of DH depends on different value criteria such as length of the pipes, number of connections, type of DH structure and so on. As an example, Segovia (Figs. 10a 10b), based on its geology and conductivity, and therefore its optimal radius, shows different zones with optimal radius such as 160m and 300m, whereas

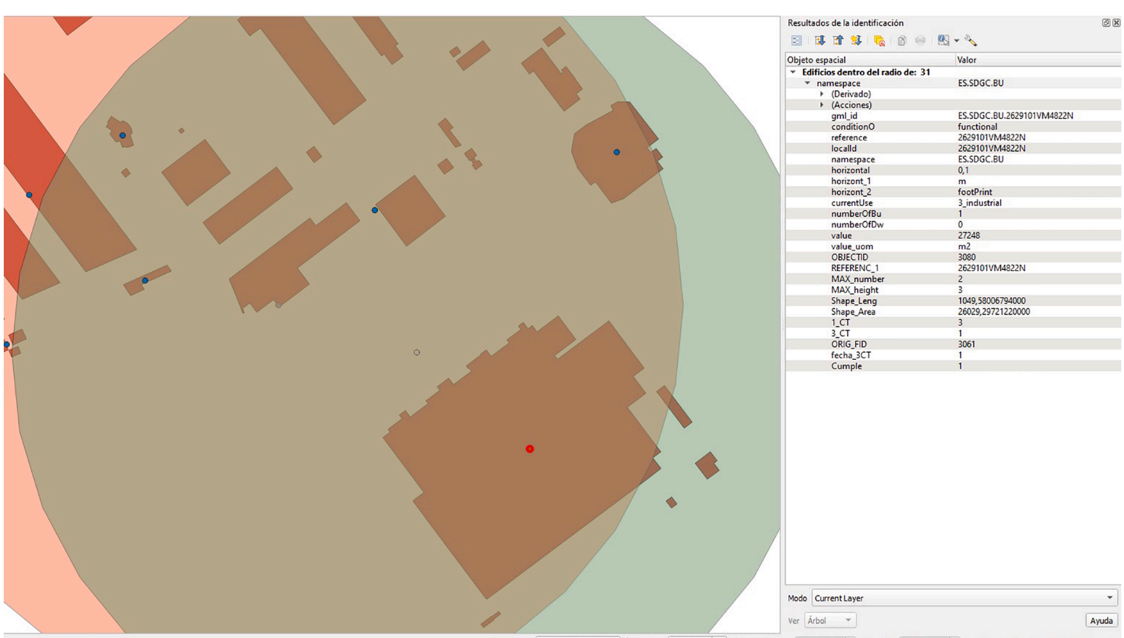


Fig. 11. Example of detailed information based on a selected building in the QGIS plugin.

Table 8
Final summary of selection based in Tables 5, 6 and 7.

	Viable							Possible						
Result	15							12						
Population centers	1	2	3	4	5	7	8	6	11	12	22	23	26	28
	9	10	20	25	39	50	52	30	46	47	54	57		
	56													

Table 9
Thermal conductivity ranges with associated optimal radius.

Case	Thermal conductivity (W/mK)	Optimal radius (m)
1	3 – 3.5	160
2	2.5 – 3	300
3	2 – 2.5	580
4	1.5 – 2	1050
5	1 – 1.5	1750
6	0.5 – 1	2468

Valladolid (Figs. 10c 10d) it starting optimal radius is 1050m. This itself acts as a discerning criterion based on the associated cost of construction. It does not necessarily mean it is not feasible since there are different design types of DH networks such as looped, circular, branching or in some sort of grid, but it is definitely a defining moment where the user should consider a different approach if that is the place selected.

Other cases will be similar to Palazuelos de Eresma (Fig. 10e) where the starting optimal radius is 300m but there are only a few buildings that meet the criteria of selection as shown in Fig. 6f with the green circles.

Another important point is related to its energy supply, since although this methodology is based in the alimentation of the system purely by geothermal energy, the cogeneration of other power supplies will undoubtedly affect the radius and the space taken for the geothermal well field needed. Consequently, the parameters of the plugin can be altered to show the reduction of radius based on the cogeneration and it would also work under those circumstances. It is also necessary to highlight that the existence of the possibility of cogeneration also benefits the designed network since it would have different energy supplies making the network more secure, as stated in the introduction.It would also guarantee the supply and it would create a more resilient energy network, objective of a Smart Energy System.

Speaking in economic terms, it must be considered that systems supplied by geothermal energy requires a greater initial investment than those planned for natural gas. However, the economical benefit is found in the yearly usage of the system. Nonetheless a more detailed economic study will be presented in future phases of the GEODISTRICT 3.0 project, since as it was discussed, this approach is only based in the selection of viable zones due to their thermal conductivity.

In summary, the authors consider that this methodology could be used for the study of future locations of district heating networks, already proven as an efficient system for heating and cooling. Furthermore this process and methodology could be reproducible in other cities and countries as well, facilitating the agility of zone selection provided the base data input is available. However it should be taken into account that the selection of the criteria has been based on those that could most exclude population centers, but not necessarily this means that they are the only ones that could be used. In addition, this methodology begins with the premise of total supply through geothermal energy, currently an underdeveloped concept as stated in the introduction since only 1% of DH networks operate with geothermal energy.

Application of this methodology is currently being used by the authors for further design of DHs in selected areas.

5. Conclusions

This selection methodology consists of streamlining the selection and screening of viable areas for the development of DH using the autonomous community of Castilla y León as pilot case. Nonetheless, it can be used for any other place of interest as long as the user has the required base information specified in Fig. 3: buildings, population and geological map. These maps must be able to be manipulated by GIS software.

General conclusions based in this investigation of the methodology done are:

- The geology of the area, and therefore its thermal conductivity, has a great impact on the optimal radius, it being: the higher the conductivity, the smaller the required radius.
- The joint work of the professionals and the methodology is essential since the final decision rests with the former. This process will show the best location; however, it may not be of interest to the user due to personal criteria.
- It is likely that most of the viable areas can be found in the outer radius of the cities since the parameter of the year of construction, and therefore its HERS index, is considered.
- The more criteria to apply for the selection of the area, the greater the degree of adjustment of the selection. Hence the importance of having a multi-step screening process based in technical criteria.
- Even thought cogeneration is not considered in this investigation, this methodology can be used as basis for those projects that have geothermal resources in mind.

The present investigation, from which this methodology results, seeks to favor the construction of DHs whose base power source aim to be geothermal by simplifying the first steps of its development and study.(Table 8 and Table 9)

CRediT authorship contribution statement

Natalia Nuño Villanueva: conceptualization, methodology, validation, investigation, resources, data curation, writing-original draft preparation; Ignacio Martín Nieto: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing-review and editing, supervision; Cristina Sáez Blázquez: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing-review and editing, supervision; Arturo Farfán Martín: conceptualization, validation, investigation, resources, writing-review and editing, visualization, supervision, project administration, funding acquisition; Miguel Ángel Maté González: methodology, software, investigation, data curation; Diego González-Aguilera: writing-review and editing, visualization, supervision. All authors have read and agreed to the published version of the manuscript.

Data availability

The scripts involved in this work are open-source and can be found in the following GitHub link: https://github.com/TIDOP-USAL/GEODISTRICT3.0.git.

Declaration of Competing Interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.geothermics.2023.102767.

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