



Geothermal energy as a solution to heating demand: Economic analysis vs. conventional supply

La geotermia como solución a la demanda en calefacción. Análisis económico frente a suministro convencional

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CITE THIS ARTICLE AS:

N. Nuño-Villanueva, I. M. Nieto, C. Sáez-Blázquez and A. Farfán-Martín. "Geothermal energy as a solution to heating demand: Economic analysis vs. conventional supply", *Revista Facultad de Ingeniería Universidad de Antioquia*, no. 118, pp. e50259, Jan-Mar 2026. [Online]. Available: <https://www.doi.org/10.17533/udea.redin.20250259>

ARTICLE INFO:

Received: May 10, 2023
Accepted: February 28, 2025
Available online: February 28, 2025

KEYWORDS:

Energy supply; renewable resources; comparative analysis; energy economics

Abastecimiento de energía, recursos renovables, análisis comparativo, economía de la energía

ABSTRACT: Renewable energies lead the energy transition towards a more sustainable and environmentally friendly energy system. Decarbonization and environmental policies, such as Europe's 2030 Climate Target Plan, favor and encourage this change. Geothermal energy as a renewable energy can play a critical role in the decarbonization within the heating sector. It is an efficient, safe, and clean energy that is not being implemented with the same trend as its counterparts. This study addresses two issues in the implementation of geothermal energy: the calculation of thermal needs and the economic difference in implementation compared to conventional supplies. Therefore, this study presents a simple methodology for sizing calculations for housing developments and economic comparison of the same installation powered by natural gas or low-enthalpy geothermal energy. The comparative terms considered are the initial installation and the annual expense. This comparison seeks to calculate the payback period of the initial geothermal installation, which has been carried out considering various economic scenarios.

RESUMEN: Las energías renovables encabezan la transición energética. La descarbonización y las políticas ambientales, como el Plan del Objetivo Climático para 2030 de Europa, favorecen y apremian este cambio. La geotermia como energía renovable puede ser un factor clave para la descarbonización en el sector de la calefacción. Se trata de una energía eficiente, segura y limpia que no se está implantando con la misma tendencia que sus homólogas. Este trabajo aborda dos problemáticas de su implementación: el cálculo de las necesidades térmicas y la diferencia económica respecto a los suministros convencionales. Para ello, se propone una metodología sencilla de dimensionamiento aplicada a urbanizaciones y una comparativa económica de la misma instalación alimentada por gas natural o por geotermia de baja entalpía. La comparación considera la inversión geotérmica inicial y el gasto anual, con el objetivo de estimar el periodo de retorno bajo distintos escenarios económicos.

1. Introduction

Geothermal energy has proven to be a valuable source of renewable energy for supplying not only Domestic Hot Water (DHW) [1] but also for heating purposes [2]. Considering the current state of the fossil fuel market and

its fragility due to recent events, this type of energy is even more recommended as an alternative to commonly used sources such as natural gas. In fact, geothermal energy systems can play an essential role in decarbonizing the heating and cooling sector, contributing to the reduction of greenhouse gas emissions [3].

Over the years, some research has been carried out on the efficiency of geothermal-based supply installations [4, 5], including studies on the advantages of collective

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ISSN 0120-6230
e-ISSN 2422-2844

installations compared to individual ones [6]. This has led to the development of a heating system known as District Heating (DH), whose objective is to supply an entire group of buildings. DH has been used in Europe since the 14th century [7], with more weight in northern European countries, where installations of this type currently exist. Additionally, new models are being investigated [6, 8, 9]. In addition to being a mature technology with its fourth generation (4GDH) [10–12] and the development of its fifth generation (5GDHC) [13–16], this type of heating offers various advantages compared to the conventional model, including the reduction of fossil fuel consumption with its consequent reduction in CO₂ and greenhouse gas emissions [17]. Thanks to the successful research activities in the field, more and more 5GDHC have been built in Europe during the last years, serving as heat distribution networks with temperatures below zero up to 20°C, and commonly low temperature spreads [18].

Despite the above, the use of geothermal district heating has been restricted to local systems, particularly in China and Europe [19], considering the limiting factors, including the spatial mismatch between heat sources and heat sinks. However, the direct heat use in these systems usually has a temperature level sufficient to satisfy the energy needs of the set of buildings that make up these heating networks. In any case, geothermal district heating systems have numerous advantages, such as those mentioned above, which have made their development significant in recent times [20], especially in those areas with favourable geological conditions. However, despite these benefits, the initial investment in geothermal DH represents an important limitation factor when compared to other conventional fossil sources. Costs related to the required drillings of the well field and the geothermal heat pump are usually responsible for the high initial investment commonly attributed to these energy solutions [21]. Beyond this aspect, it is mandatory not only to consider this initial cost but also the operating costs associated with the system, which, in general terms, are much more advantageous in the case of geothermal energy [22].

For all of the above, and in order to clarify the limitations and advantages of the aforementioned geothermal DHs with respect to a conventional natural gas installation, this study intends to consider the annual expenditure of both heating solutions during the same period of years in order to verify the payback period and observe in general terms which solution is the most economical.

2. Methodology

This research employs a simplified approach to calculate the demand for an entire urbanization, allowing for a comparison between two heating supply sources:

geothermal energy and natural gas. The methodology is presented through a workflow diagram, as shown in Figure 1, which outlines the various stages and software tools used in the study. The economic comparison is reached through this process and serves as the primary conclusion of the article.

The starting point of this methodology consists of selecting a residential area that can be classified in such a way that the houses can be individualized. The Geographic Information System of Agricultural Parcels (SIGPAC)[23] from Spain is a tool that allows the visualization and measurement of desired zones on a map. However, any Geographic Information System (GIS) can be used to define a zone of interest as long as it uses geographically referenced information. This is a key concept in order to make the replicability of the methodology feasible. After selecting the residential state, the subsequent stage is to designate a solitary plot along with its distinct house as the foundation for the calculations. The greater the resemblance between houses within the residential development, the lesser the margin of error in the demand calculation. Since this calculation will be later applied to all the houses, having a minimum error is desired.

There are numerous programs for calculating the energy demand based on the building construction, which perform the calculations based on the current regulations of the normative building code. This software is usually based on the energetic certification of the building studied. Some examples of these tools are LIDER/CALENER (HULC), CERMA, CEX, CE3 and CYPETHERM HE Plus. In this case, the software used for the calculation is CEX.

As previously stated, this study proposes an economic comparison between two methods of meeting heating demand: the conventional and widely-used natural gas, and an alternative renewable energy source such as geothermal energy. Both methods will be evaluated using the same time frame. The cost of installation will be considered to arrive at a comprehensive conclusion on the economic disparities in terms of initial investment and the upkeep.

3. Suitable study locations

The research can be duplicated and executed in residential communities where the homes are either identical or similar. This study analyses a single house in the community, which will then be scaled to all houses. Consequently, any existing or planned residential community whose houses are designed as replicas could benefit from this calculation. Although it remains feasible to estimate the calculation in other types of residential developments, the likelihood of error increases.

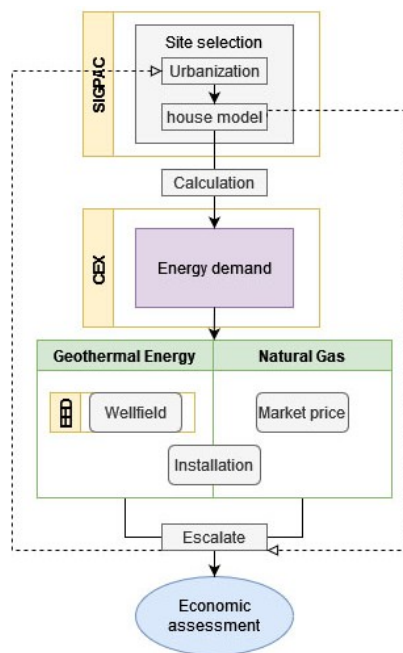


Figure 1 Methodology workflow

It should be noted that geothermal energy is highly dependent on the terrain in which it is located since it affects the performance of the geothermal heat pump installations. As this research intends to create the wellfield within the residential area, the calculations will be more favourable when the thermal conductivity of the land on which the urbanization is built is higher. The study site selected in this research is based in Ávila in the autonomous community of Castilla y León, Spain. The exact location is presented in Figure 2 using SIGPAC.

This urbanization has the same type of house built despite the change in the distribution of its individual plot, which does not interfere with the calculations. It consists of 83 houses, as shown in Figure 3.

Furthermore, using the geothermal map of the Ávila region [24], the thermal conductivity of the terrain in which the urbanization was built can be obtained (Figure 4), resulting in approximately 2.8-3W/m·K.

4. Calculation, results, and discussion

4.1 Calculation of energy demand

As specified in Figure 1, the selection of a core house must be made in order to ease the calculation of the demand. Therefore, the example house plot consists of an area of 783m² (27x29m). This area remains approximately the

Table 1 Building data entered in CEX software

Building characteristics	Value
Construction year	1999
Usable living area	525 m ²
Number of habitable floors	2
Daily DHW demand	84 l/day

same for the rest of the houses, even if the length and width of the plots change. The house itself is 210m² as seen from above (15x14m), and consist of 3 floors where one of them is half the surface due to the indoor parking. These measures result in 525m² in total.

In order to calculate the demand with the CEX software, it is necessary to make some estimations and previous calculations:

- The corresponding factors included in the Spanish Technical Building Code will be applied. In this scenario, the reference demand of DHW for buildings of private residential use will be obtained considering needs of 28l/day-person [25].
- The average distribution of the house will be two bedrooms that are equivalent to 3 people [25].

Considering the advantages of CEX in autocompleting based on regulations and climatic zones, only the general data of the house and its facade structure need to be provided. The estimated values of building thermal characteristics, including enclosures and other parameters affecting energy efficiency, are determined by CEX according to current thermal regulations during project development (building construction year). This estimation guarantees the minimum thermal properties of the different components forming the building envelope. In this case, Table 1 presents the data used as input for the calculation.

The model used to calculate the DHW demand is based on the following Equation (1) as stated in its manual:

$$\text{DWH Demand} \left[\frac{\text{kWh}}{\text{m}^2} \right] = 360 \cdot \rho \cdot C_p \cdot Q_{DHW} \cdot \frac{(T_{ref} - T_{AF})}{3600 \cdot \text{area}} + P_{ac} \quad (1)$$

Where:

- ρ : water density
- C_p : specific heat capacity of water
- T_{ref} : reference temperature (60°C)
- T_{AF} : mean annual reference cold water temperature (based on climate zone designated by the Spanish Technical Building Code)
- $area$: usable living area
- Q_{DHW} : Domestic Hot Water flow rate (28l/day-person)
- P_{ac} : energy losses.

A heating demand of 99.1 kWh/m² has been calculated for a single house, resulting in 52MWh. It must be considered



Figure 2 Study site selected as example (Ávila, Castilla y León, Spain)



Figure 3 Single selection of the houses



Figure 4 Selected study site with its thermal conductivity (W/m·K) presented

that the orientation of the houses influences this heating demand, so it will be adjusted to 55MWh of heating demand per house per plot annually.

Table 2 Price of natural gas installation in single-family homes [26]

Description	Total (€)
Individual receiver facility	
Technical calculation report and individual gas installation certificate	
Management and processing of licenses, permits, and commissioning	1,420
Regulation cabinet	
Connection steam to service	
Condensing boiler	1,000
TOTAL	2,420

4.2 Natural gas installation

Calculating the installation and maintenance of natural gas for heating is simpler than calculating the geothermal counterpart. Since natural gas is the most widely used in Spain, there are more estimated prices for the calculation of the facilities. An example of the cost of an average natural gas installation in single-family homes is presented in Table 2. Scaling the cost to the 83 total homes that make up the urban complex is a total of € 200,860.

4.3 Geothermal installation

In order to adequately meet the heating demand with geothermal energy, it is necessary to calculate two factors: (I) the design and sizing of the wellfield and (II) the installation.

The EED[27] (Earth Energy Designer) software has been used as a tool for designing ground source heat pump systems and borehole thermal storage. The input for this software is the estimated annual heating demand of 55MWh. The monthly distribution with the corresponding consumption factors can be seen in Figure 5.

In Figure 6, different optimized configurations created by EED can be seen. The first part has as priority the least number of boreholes, whereas the second prioritizes the depth of the boreholes. In both cases, the first option is

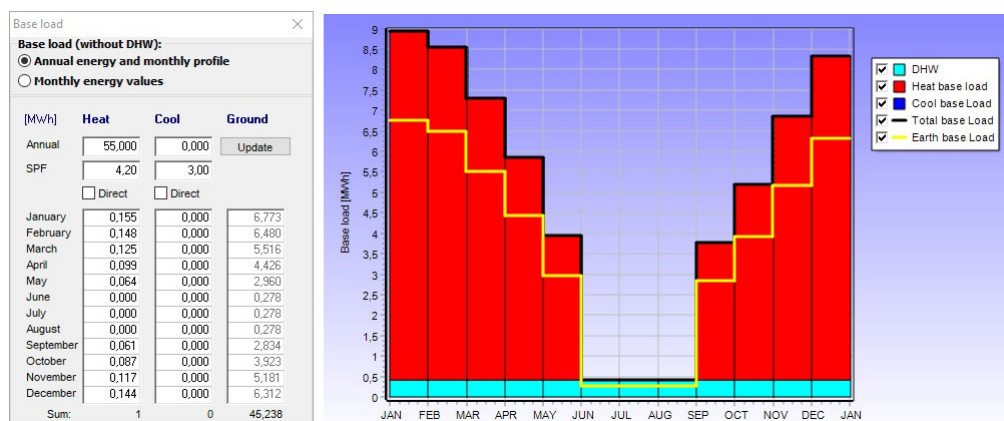


Figure 5 Base load of heating demand and its graphic representation

highlighted in grey as they are considered the optimal solution.

For this comparison, the first configuration of 2 boreholes of 115m depth will be used. This configuration is presented in Figure 7, as its fluid temperature curve for 25 years. It can be verified that the final temperature (approximately -6°C) is far from the freezing point of the selected fluid (Monopropylenglycole and water at 33% with a freezing point of -17°C).

Having the calculation of the wellfield allows an easy calculation of the heat pump needed. An estimated calculation with a Coefficient of Performance (COP) of 4 and 2,400h of work a 0.01MW of pump power is obtained. A COP of 4 is used as a standard to indicate good energy efficiency and to meet regulatory requirements and performance expectations in the Heating, Ventilation, and Air Conditioning (HVAC) industry. Table 3 shows the summary of the design selected.

Table 3 Summary of design and installation per house

Wellfield	Depth (m)	Spacing (m)	No. of boreholes
	115	15	2
Heat pump	COP	Operating hours	Power (MW)
	4	2,400	0.01

CYPE engineers [22] has an extensive library of Spanish work prices, which will be used for the estimated calculation of the installation work. Table 4 breaks down the required budget for the wellfield installation using CYPEs registered data.

Doing the calculations with the design selected of 2 boreholes of 115m each (total of 230m) and scaled to the totality of the 83 houses results in €763,600, the cost of the total wellfield.

Regarding the necessary heat pump, it must be considered that larger heat pumps work with higher COP. Therefore, the COP used will be changed from 4 to 4.5, as estimated. The operating hours are maintained. In order to calculate the heating power needed, the demand obtained per house will be multiplied for the total number of houses in the housing development (83) divided by the COP of the heat pump. This results in a total demand of 1,015MWh or 0.43MW, which for this study purposes it will be rounded up to 0.5MW.

As an example of a geothermal heat pump, the geotherm variant of Vaillant [28] will be used as an estimated price, as shown in Table 5. This geothermal heat pump has an associated COP of 5.2 under optimal conditions. Therefore, the estimated value used of a COP of 4.5 falls within a valid and safe estimation.

As a result, the geothermal installation costs are shown in Table 6.

4.4 Comparison result

The difference obtained in the initial installation of each energy vector is shown in Table 7. This difference was expected due to the wellfield design and excavation, which significantly increased the initial cost.

However, the comparison presented in this article is not only developed with the initial investment but also with its prolonged use. This calculation is complex since it depends on the market price of electricity and natural gas. As the objective of this research is the comparison in general terms of the cost, the values presented in Table 8 are estimations of the mean market value. The years selected for this study coincide with stages in the market that define variations in price. The year 2019 has been considered the normative price trend. The year 2020 has been marked by the global COVID-19 pandemic, creating a

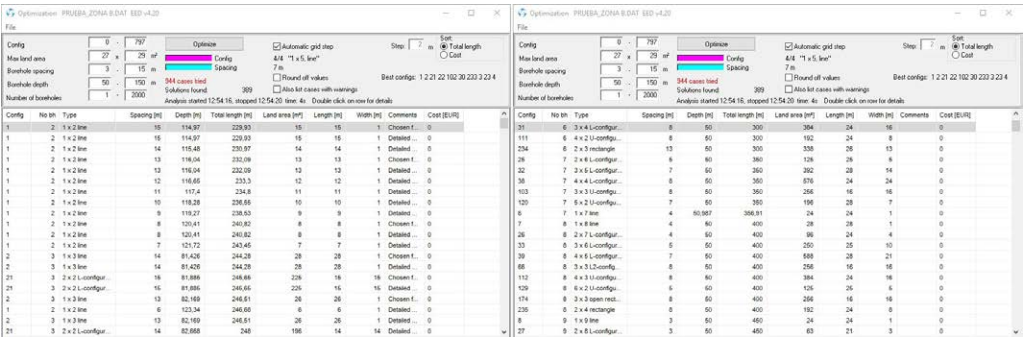


Figure 6 Design solutions provided by EED software

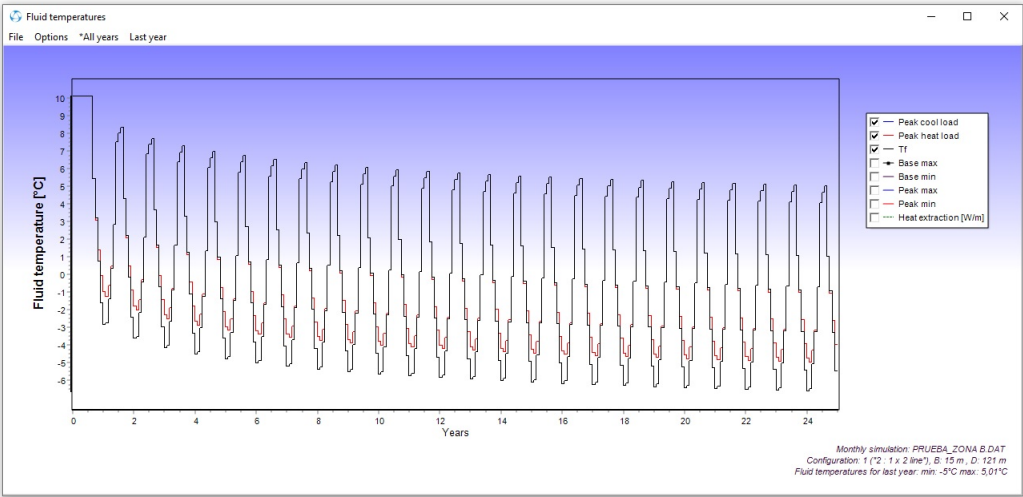


Figure 7 Temperature evolution in 25 years provided by EED software

Table 4 Estimated price of the wellfield installation per house

Unit	Description	Efficiency	Unitary price (€)	Total (€)
h	Hydraulic equipment on crawler carriage [...]	0.13	105.84	13.76
h	Injection equipment for geothermal drilling	0.13	34.16	4.44
			Equipment subtotal	18.20
h	Official construction of civil works	0.46	19.93	9.15
h	Civil works construction assistant	0.46	18.92	8.68
			Workforce subtotal	17.83
%	Additional direct costs	2	36.03	0.72
			TOTAL	36.75*

Table 5 Price of heating pump for the housing development

Description	Heating power kW	Quantity	Unitary (€)	Total (€)
Vaillant geoTHERM VWS 460/3 400 V	49.9	10	8,235.91	182,359.1

Table 6 Summary of total cost of geothermal installation

Description	Total (€)
Wellfield installation	763,600
Heat pump installation	182,359.1
TOTAL	945,959

Table 7 Summary of the initial cost of installation

Description	Total (€)
Natural gas initial installation	200,860
Geothermal initial installation	945,959

Table 8 Market value of electric kWh and natural gas in different significant years

Year	Electricity (€/kWh)	Natural gas (€/kWh)
2022	0.2773	0.2166
2020	0.1214	0.0480
2019	0.1115	0.0736

Equation (2) has been used to determine the cost for the geothermal installation, whereas equation (3) has been used to calculate the natural gas cost

$$IC_{geo} + \left(C_{elec} \cdot \left(\frac{AHD}{COP} \right) \right) \quad (2)$$

Where:

- IC_{geo} : initial cost of the geothermal installation
- C_{elec} : cost of the electricity
- AHD: annual heating demand
- COP: coefficient of performance.

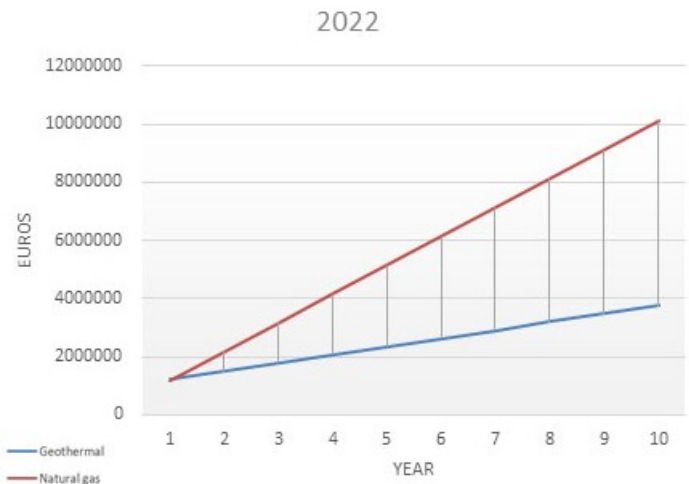
$$IC_{NG} + (C_{NG} \cdot AHD) \quad (3)$$

Where:

- IC: initial cost of the natural gas installation
- C_{NG} : cost of the natural gas
- AHD: annual heating demand.

In both equations, the factor added to the initial cost is considered the value of the annual usage cost. Figure 8 and Figure 9 are the graphical representation of the cost of both systems, starting with the initial investment detailed in Table 7, plus the annual cost of covering the heating demand and maintaining this coverage for 10 years

The cut-off points of the graphs presented (year 1 in 2022, year 8 in 2020, and year 3 in 2019) represent the years when the geothermal system matches the natural gas system and initiates the payback period. As seen in the graphs, the savings are significant once this point is surpassed.

**Figure 8** Graphic representation of the cost of both systems in 10 years (2022)

4.5 Market evaluation and discussion

The scenarios presented in the previous section show evidence of variation in the return period. From 2019 to 2020, within a one-year period, the return period extended from 3 years to 8 years. It should be noted that there is a variation of 5 years just by considering the average price of the year, without intermediate market fluctuations. If it was evaluated with the daily prices, it would be a complex calculation that would not allow for a quick comparison of the two energies.

The fluctuation of the natural gas market is determined by factors such as supply and demand, production, government policy, and weather conditions. In addition, considering that the main natural gas-producing countries are Russia, the United States, Canada, and China, and the main consumers are the United States, China, and the European Union, it can be deduced that any significant event affecting producers will be reflected in the market price. In recent history, the following events modified the market prices:

- In the mid-2000s, the price of natural gas in the United States increased significantly due to growing demand and declining production. However, starting in 2008, the introduction of new extraction technologies, such as hydraulic fracturing, allowed the extraction of natural gas from previously inaccessible deposits, leading to a significant increase in supply and a drop in prices.
- Between 2010 and 2014, natural gas prices in the United States remained relatively low because of increased production and reduced demand for heating due to warmer-than-usual winters.
- In 2014, natural gas prices rose due to a cold wave in the United States and an increase in heating demand.

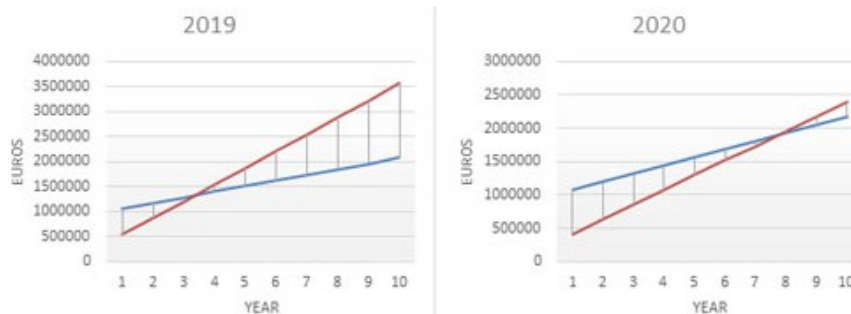


Figure 9 Graphic representation of the cost of both systems in 10 years (2020 and 2019)

However, in the following years, natural gas prices fell again due to increased production and lower demand.

- In 2020, the price of natural gas plummeted to historically low levels due to the COVID-19 pandemic and the resulting decrease in energy demand. In addition, the price war between Russia and Saudi Arabia in the oil market also contributed to the fall in natural gas prices.
- In 2022, the market was affected by the war between Russia, the main producer, and Ukraine. This event increased the natural gas value since Ukraine is an important transit country for natural gas transported through Russian pipelines to Europe, a main consumer. This reasoning is why only the average annual price is taken into account.

To assess when the electricity used to power geothermal systems becomes less profitable than natural gas, one could analyse a scenario with a fixed price. While this approach might illustrate the general trend in cost comparison between the two energy sources, it would not reflect a realistic scenario due to the price fluctuations of natural gas, as previously discussed.

However, the following scenarios are presented using the average prices of both natural gas and electricity in 2019 and 2020 (Table 9 and Figure 10, 11, 12). The year 2022 is excluded from this average, as it represents a peak price in the historical prices caused by the current Russia-Ukraine war.

As observed in this first scenario, the cut-off occurs at more than 10 years, so it would not be a scenario that favours the inclusion of geothermal energy. In this case, the electricity price is twice that of natural gas.

If we analyse scenarios 2 and 3 together (Figure 11), we can see that the payback period is achieved before 4 years in both cases. The difference in the amount once the payback period is reached is more pronounced the lower the price of both, as in scenario 3, both take the value of natural gas, which was the lowest price value.

In Figure 12, the comparison between scenarios 4 and 5 is shown. In these scenarios, an extreme situation is presented where one price becomes three times higher than the other. This representation aims to show some boundary scenarios.

As can be seen, if the price of natural gas is significantly higher, the payback period occurs instantaneously, as it surpasses the geothermal installation. In the case that the price of electricity is significantly higher than natural gas, the payback period still occurs, but in more years.

Finally, in Figure 13, the extreme scenario of triple the electricity price from Scenario 5 is preserved, but for the representation of Scenario 6, the values are exchanged. This comparison highlights the importance of the specific price of the energies as well as the difference between them.

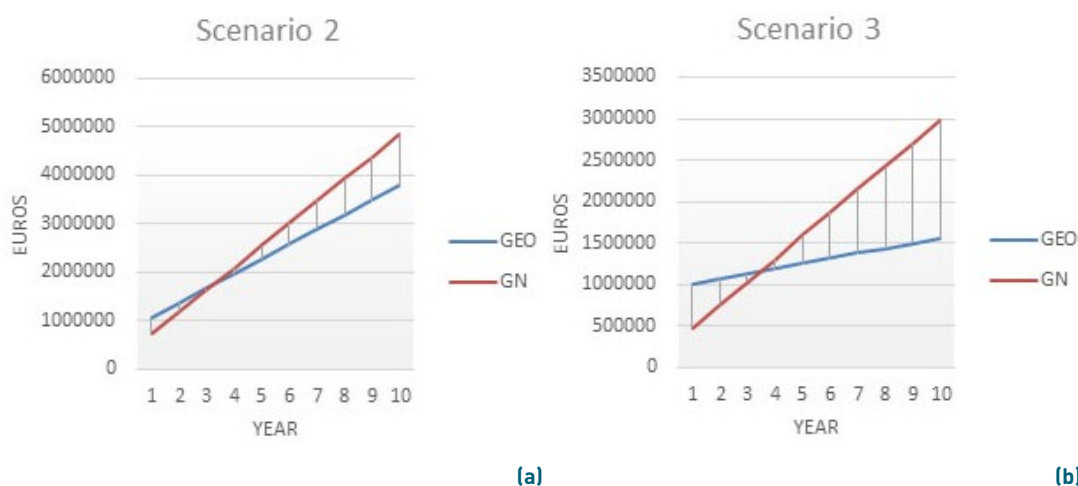
The situational graphs shown are not enough to evaluate different scenarios, once it has been proven that the price unit must be taken into consideration. The graph represented in Figure 14 shows the payback period (years) according to the price of natural gas (GN) and the price of electricity (GEO), both in a range up to 0.50 €/kWh.

A viable alternative to consider would be the installation of photovoltaic panels on the rooftops of houses as a solution to reduce electricity consumption from the grid. In the case study of this research, 0.01 MW must be supplied for the heat pump of the 83 houses. This results in a generation capacity of 121W per house, which, for engineering and market purposes, results in a commercially sold 150W panel. Although this measure would increase the initial investment in geothermal installation, it would also decrease the annual maintenance cost due to the reduction in electricity consumption. It is important to note that light-solar factors condition electricity production from photovoltaic panels, so it would not allow for a completely independent installation from the grid but a reduction in energy consumption.

Based on the results obtained in the research, if the

Table 9 Market fluctuation scenarios

Scenario	Description	Electricity (€/kWh)	Natural gas (€/kWh)
1	Maintaining the mean prices	0.1165	0.0608
2	Equalizing with the price of electricity	0.1165	0.1165
3	Equalizing with the price of natural gas	0.0608	0.0608
4	Triple the price of natural gas	0.1825	0.0608
5	Triple the price of electricity	0.1165	0.3494
6	Scenario 5 interchanged	0.3494	0.1165

**Figure 10** Graphic representation of the market fluctuation scenario 1**Figure 11** Graphic representation of the market fluctuation scenarios equalizing prices]

investment cost per house in geothermal energy is approximately €9,200 and the price of a 150W panel installation kit is around €300, then the total cost would increase by 3.26%. *Therefore, an initial increase of 3% would result in a continued benefit over the lifespan of the installation.*

Hence, it is important to emphasize that the results obtained in this research are broad comparisons that demonstrate the feasibility of using geothermal energy as a solution to heating demand in urban areas. Prices can be adjusted by including the measures, such as generating electricity through photovoltaic panels or programming the heat pump to work during off-peak hours. This would further reduce the difference between conventional

natural gas and geothermal installations. However, the initial investment for geothermal installation will always exceed the initial investment for natural gas installation. The benefit of geothermal installation lies in its annual consumption and maintenance.

5. Conclusions

An undeniable point of geothermal energy is its significant initial cost (Table 7), being approximately five times the initial cost of the natural gas installation. However, this initial outlay is compensated by the annual cost of its use, highly dependent on the market and its stability. Due to the influence in this market of political disputes, it can be seen in the period of 4 years how prices have

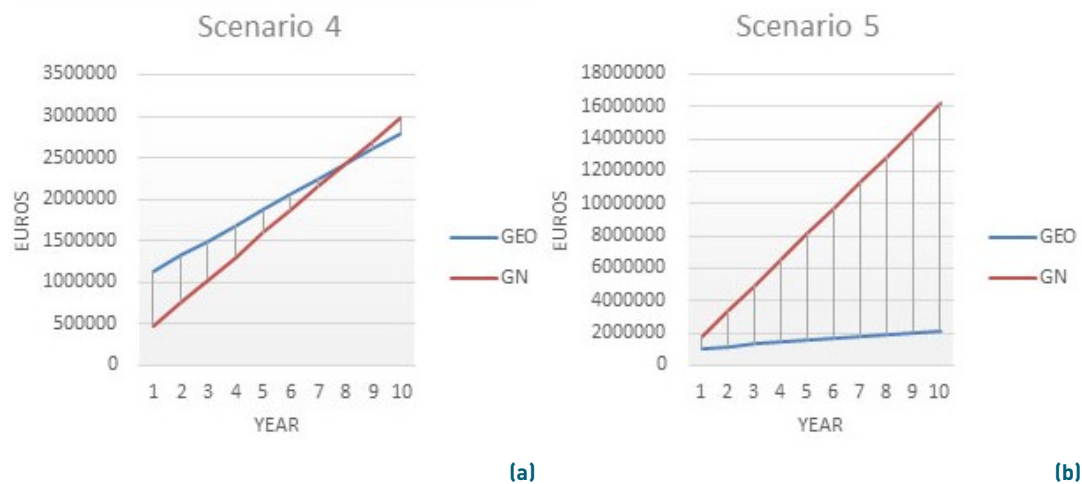


Figure 12 Graphic representation of the market fluctuation scenarios triplicating the base prices

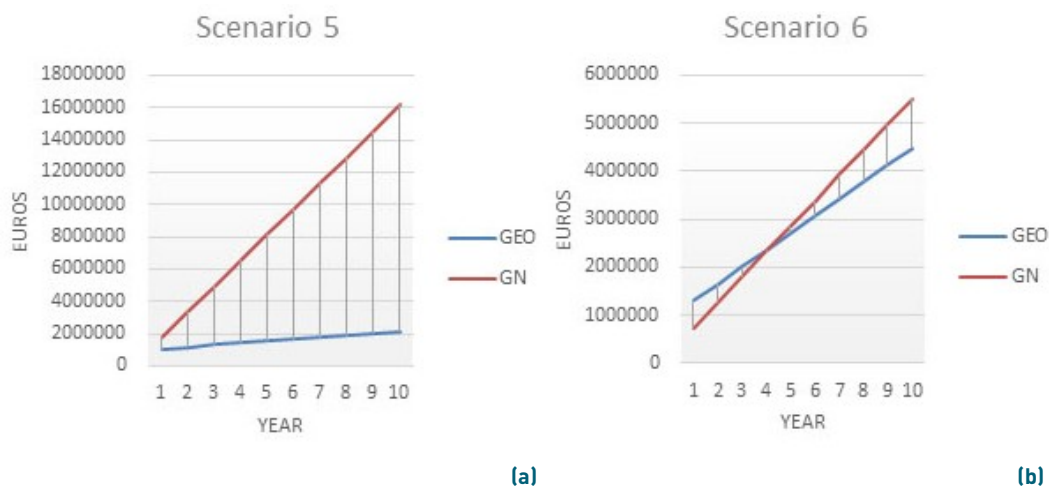


Figure 13 Graphic representation of the market fluctuation scenarios triplicating the prices but maintaining the same prices

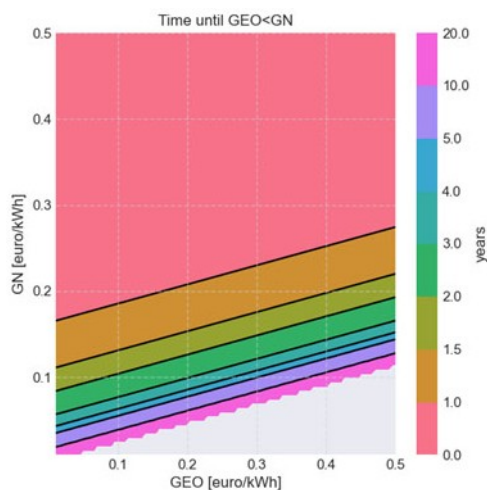


Figure 14 Graphic representation of the return point in the investment based on market price

varied. Compared to 2019, there has been an increase of 149% in the case of electricity and a rise of 195% in the case of natural gas. However, within the most stable period between 2019 and 2020 prices hardly vary. Even so, the return period is reached early, considering that the temperature of the fluid and the installations are guaranteed for 25 years, since none of them reach 10 years.

A more conservative approach considering other factors ignored in this study, such as the fluctuation of the market or selecting the electric kWh during off-peak hours since the heat pump can be programmed to work on determined hours, can be taken and expect a payback return around half the years needed to maintain the heat pump or the boiler (25 years approximately depending on the model, not counting the annual revisions for both systems).

This study is noteworthy not only as an exploration of investment potential in this type of technology but also

as a demonstration of geothermal energy's viability as a renewable resource accessible to any country, highlighting its feasibility and practical application. Suppose the correct study of the construction zone is done, and it results in an acceptable thermal conductivity. In that case, it is a system to consider for any country that is not a primary producer of natural gas, thus making it less dependent on the supply conditions. The methodology outlined for calculating the demand and designing the geothermal installation presented in this study provides a quick method for evaluating the potential feasibility of implementing a geothermal district heating system. The evaluation of potential areas for this type of energy and the subsequent calculation of the wellfield are critical points for the implementation of geothermal-powered systems. Consequently, being able to detail specific cases and then scale them to find an appropriate solution represents significant progress.

Declaration of competing interest

We declare that we have no significant competing interests including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

Acknowledgment

This research was supported by the research projects support program, cofinanced by the European Regional Development Fund (ERDF), under the order of the Ministry of Education from Castilla y León. (Project ref.: SA102P20) and is been carried out withing the framework of the main research "Development and integration of a new district heating system using low-energy geothermal energy (GEO-DISTRICT 3.0)". Authors would also like to thank the TIDOP Research Group of the Department of Cartographic and Land Engineering of the Higher Polytechnic School of Ávila (University of Salamanca)

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Author contributions

Conceptualization, methodology, investigation, and wrote the paper: N. Nuño-Villanueva; formal analysis, investigation, and looked for resources: I. Martín Nieto; conceptualization, methodology, and software. C. S.

Blázquez; data curation, contributed data, and carried out the formal analysis: A. Farfán-Martín

Data available statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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