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# The economic Case for Geothermal District Heating for Residential and Industrial Applications in Europe – An LCOH analysis

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## ABSTRACT

To reach the EU's climate goal of reducing emissions by 95% by 2050, an immense proportion of the future district heating and cooling sector will need to rely on a steady supply of renewable base-load energy that only geothermal energy can provide in a sustainable way. Accounting for the majority of primary energy use in most countries, surpassing the combined energy use of both the electricity and transportation sectors, the heating sector harbors an immense potential to realize these climate goals. In contrast to other renewable base-load energy sources like hydro power and biomass, geothermal energy can be used both on a large scale and in a considerable number of locations around the world. Geothermal has the added advantage of being the only renewable that is capable of providing base-load heat and electricity supply without involving any combustion processes and the associated greenhouse gas emissions. The thermal energy stored within 3 km of the Earth's crust is estimated at 43 x $10^6$ EJ worldwide, more than 70,000 times that of the world's primary energy consumption in 2012. Pivotal here is project development and the search for investors, but also the intersection with government bodies and the public sector. Next to investment opportunities, the optimisation of legal frameworks and the risk management of matters such as the security in the early development stages is of considerable importance. Presently, however, there is a huge discrepancy between this huge potential of geothermal energy and the current state of development: There are numerous regions around Europe that are suitable for economically viable exploitation of geothermal energy for district heating for both residential and industrial applications. Out of the more than 5,000 district heating systems in Europe, little more than 300 are powered by geothermal energy. The single most important reason for this less-than-stellar level of development so far is a lack of awareness among potential investors that geothermal heat and electricity projects are profitable. It is thus paramount for the industry to prove that geothermal energy is not only environmentally prudent and technologically feasible but that it is, most importantly, economically sound and thus preferable among all heat generating technologies. One economic measure to compare different heat generation technologies that naturally incur very different costs is the levelized cost of heat (LCOH). The LCOH assesses the average total cost of a heating technology over its entire lifetime per MWh, factoring in capital, operating expenditure and income as well as the discount rate. The standardisation of the measurement has seen it adopted internationally as a benchmark for comparing various heating systems. The LCOH may therefore also be considered the average minimum price the heat must incur over its lifetime in order to break even. An LCOH analysis among all heat generating technologies proves that geothermal energy is an optimal choice for district heating for both residential and industrial applications. Although our analysis showcases projects in Europe as the continent leads the world in installed geothermal capacity by region, the study at hand has applications for the rest of the world. Indeed, the economic case for geothermal district heating must be made outside Europe as well in order to accelerate development in other regions of the world, particularly in light of the ever-increasing need to decarbonise the energy sector worldwide.

## I. INTRODUCTION

The heating sector in the European Union accounts for the largest share of final energy consumption. Heating and cooling demand across residential and industrial sectors accounts for half of the total energy demand within the EU. Household hot water and space heating demand alone accounts for 79% (European Commission, 2016) of total final energy use in the residential sector. In industry, around 70% of final energy use is employed for space and industrial process heating. Cooling demand for both residential and industrial sectors represents a very marginal share of final energy use. This figure has been increasing in recent years owing to the increased summer temperatures that Europe has experienced. The increasing global temperatures associated with climate change show no signs of abatement. Hence, higher cooling demand for Europe during the coming years is almost guaranteed.

Despite the huge energy consumption in this sector, it has seen the smallest progress to date in the road towards decarbonisation. The heating and cooling requirements of the EU are still predominantly met by fossil fuel combustion. 75% of heating and cooling is still generated from fossil fuels with only 18% of the generation coming from renewable sources. Natural gas is the primary fuel source for this heating and cooling demand, with 68% of all gas imports to the EU (European Commission, 2016) apportioned to this end.

Clearly there is scope, and a need, to increase the proliferation of renewables in the heating sector. A number of potential solutions will fill the market niche. Solar thermal systems have seen a large uptake in recent years. However, this technology has limited application for heating demand in urban environments. The space requirements for solar installations to generate energy are too high in order to provide sufficient heating to buildings with high occupancy levels in a built up environment.

To successfully complete the clean energy transition in the heating sector, it will be necessary to rely upon a varied mix of renewable technologies to achieve this (Gielen et al., 2019). To date the exploitation of geothermal energy has not seen as high levels of investment as may have been expected. A lack of investor awareness and high initial capital costs have contributed to the slower development of this resource in comparison with other carbon neutral technologies. Presently, less than 1% of heat generation in the EU results from the utilisation of geothermal energy sources, see Figure 1 below.

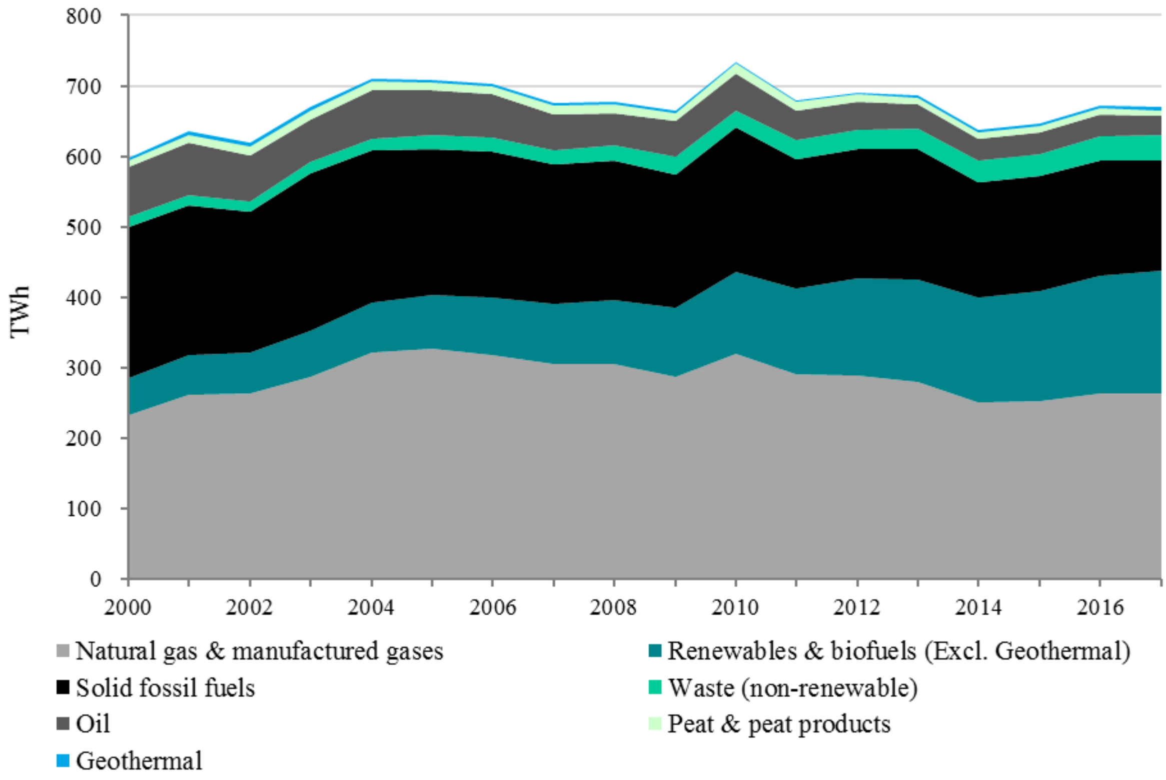


**Figure 1: Gross Heat Generation by Fuel, EU-28, 2000 – 2017. Source, Eurostat (2019)**

Despite knowledge of the potential, strength and opportunities of geothermal energy, the technology is yet to properly assert itself in the heating market. To answer the question as to how this resource can be exploited to help achieve ambitious decarbonisation targets, this paper is structured as follows: firstly, an analysis of the current geothermal heating market in Europe and the changing energy policies are presented. An introduction of the methodology of the LCOH calculation subsequently follows. The results of LCOH analyses are presented in the next step, before being discussed in more detail. A conclusion with an outlook to the future finishes off the paper.

## II. EUROPEAN MARKET REVIEW

### 2.1 HEATING MARKETS

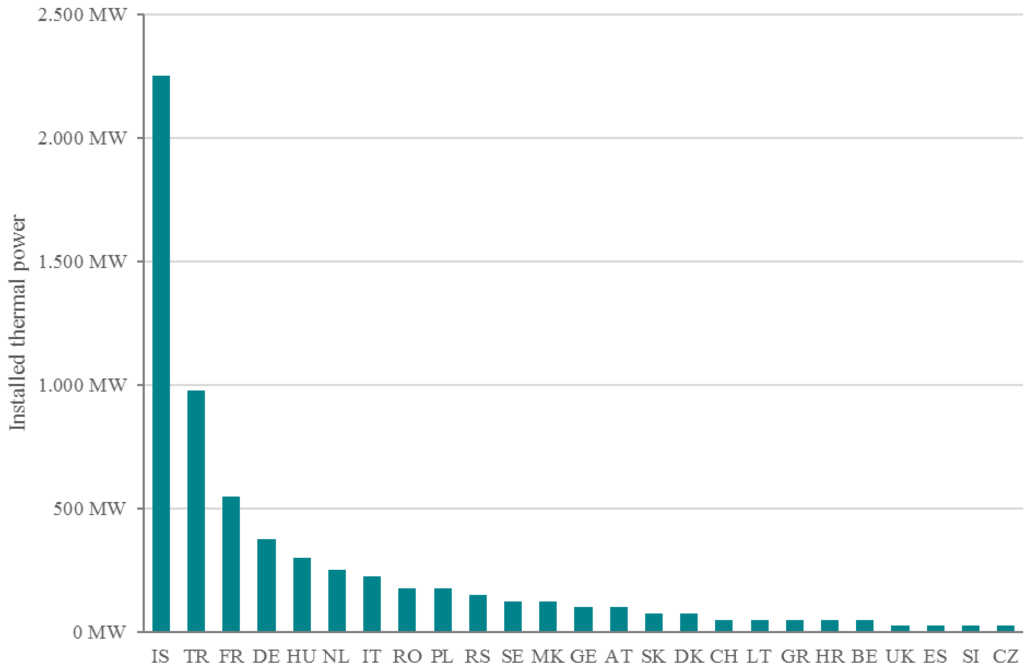


**Figure 2: Installed geothermal district heating capacity per country. Source, EGEC (2019)**

As of 2018, there were in excess of 300 geothermal district heating systems in operation throughout Europe (*EGEC, 2019*). A sustained history of geothermal resource development has to date been confined to only a few nations. This is due in part to early identification of substantial geothermal heat resources within these nations. The most matured European markets lie in Iceland, Italy and Turkey. Today however, geothermal heating and cooling plants can be found in around 30 European nations and represent a total heating capacity in excess of five $GW_{th}$. In 2017 roughly 11.7 GWh of heat was supplied from these plants (*ETIP-DG, 2019*). The installed capacities of geothermal district heating per European nation can be seen in Figure 2 below.

Continually, new exploration-programs are being launched, as the ability of geothermal energy to supply stable heating and cooling load drives continued investment and support from policy makers. During the course of 2018, some 12 geothermal heating plants in Europe were either commissioned or renovated, demonstrating continued growth in the sector. Figure 3 illustrates the state of play of geothermal in Europe with projects currently under development in numerous countries.

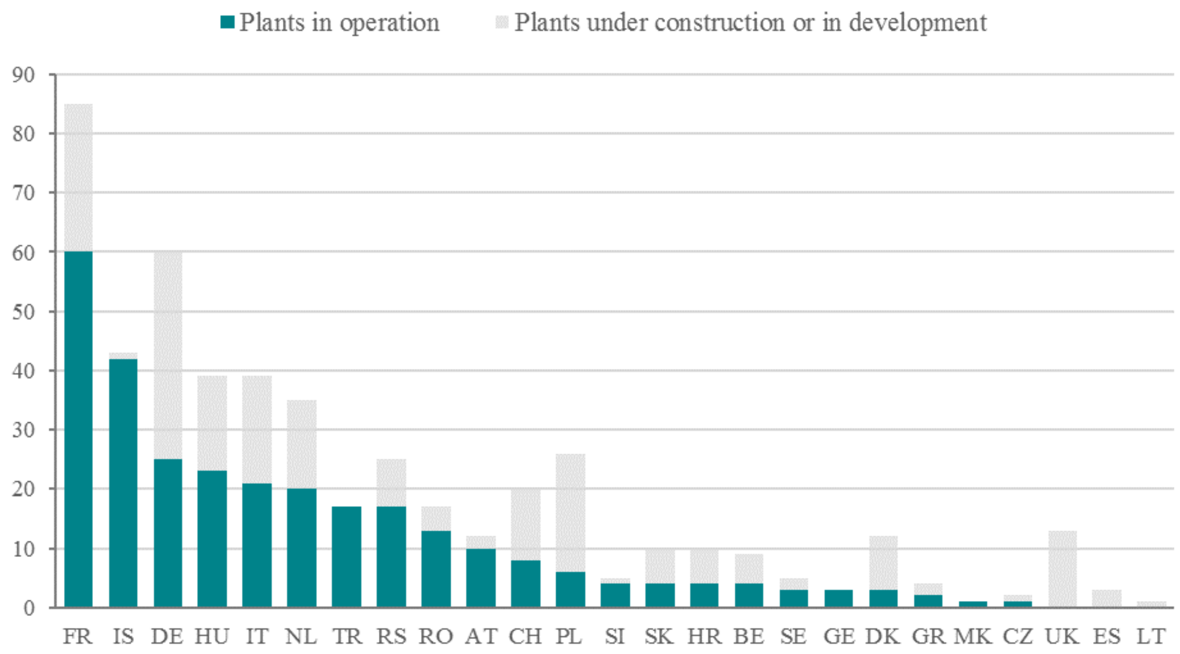


**Figure 3: Number of geothermal heating plants in Europe: operational, in development. Source, EGEC (2019)**

In spite of the increase in development of geothermal resources for heating applications, there is still abundant untapped potential for further exploitation. Approximately over 25% of the EU population lives in areas that are suitable to employ geothermal district heating (ETIP-DG, 2019). Advances in technology have enabled lower temperature aquifers to be developed and utilised in European markets. The relatively small size of the plants has seen them garner widespread public acceptance and demonstrate that the addition of geothermal heat sources to existing grids can make significant contributions to the decarbonisation of the heating sector.

The district heating networks themselves account for a significant share of the total cost involved in the development of a geothermal district heating system. The main challenge facing their implementation often stems from concerns surrounding the financing and the development of this heating grid infrastructure. Changes in energy policy are helping to remove these access barriers and to help with the further development of geothermal, which is able to provide reliable, carbon neutral, heating baseload.

### 2.2 CHANGING ENERGY POLICY

Decarbonisation is an area of increasing focus for future energy policy. The Paris Agreement specifies an objective of a carbon neutral European economy by 2050. Throughout Europe, many countries have made significant progress in increasing the proportion of energy generation that comes from renewable sources in their respective electricity sectors. To date however only modest progress regarding decarbonisation has been achieved in both the heating and transport sectors.

The RE Dir2009/28/EC set legally binding renewable energy targets for each of its member states to reach by 2020. The overarching objectives of this directive were to reduce carbon dioxide emissions by 20% compared to 1990 levels, to increase the share of renewable energy to 20%, and to achieve energy savings of 20% or more, with each EU member state responsible for the creation of their own National Renewable Energy Action Plans in order to achieve this end.

With 2020 approaching, a Revised Renewable Energy Directive (EU) 2018/2001 was published in December 2018, promoting further initiatives to increase the percentage of renewable generation as a percentage of total energy generation to 32% by 2030. Part of this new renewables directive emphasises the mainstreaming of renewables in the heating and cooling sector. The directive proposes to provide member states with options to increase their share of renewable energy in heating and cooling supply, aiming at increasing the share of renewable energy by 1 percentage point per year in their total supply until 2030; and to open access rights to local district heating and cooling systems for producers of renewables, under certain conditions.

The promotion of district heating schemes that employ renewable energy sources provides benefits beyond merely the achievement of decarbonisation targets. There are huge financial incentives to their implementation, combined with an associated increase in national security of fuel supply. When considering the whole of the EU, it is estimated that the savings in avoided fuel import costs could rise to 60 billion Euro per year by 2030 (European Commission, 2018).

## III. METHODOLOGY

The LCOH assesses the average total cost of a heating technology over its entire lifetime per kWh, based on a residual costs approach. The model factors in the amount of initial capital investment, operational and maintenance expenditure as well as the discount rate. The LCOH is similar to the concept of the payback time for an energy system. However, instead of measuring how much time is needed to recoup the initial project investment, instead it provides a means by which to calculate the average minimum price the heat must incur over its lifetime in order to break even. The LCOH is one means of determining whether or not it is profitable to build a project. Potentially prospective investors can use the comparison of LCOH for different heating technologies to determine at a glance as to whether or not a certain project is financially viable.

One of the main factors contributing to the widespread adoption of the LCOH calculation is its ability to make comparative lifetime costs analyses between various energy technologies. This application has seen the metric be adopted by numerous Governments and Inter Government Agencies for evaluating energy policy decisions in relation to differential support schemes between fossil fuel based and renewably based heat generation systems (Williams & Rubert, 2018).

In order to determine the LCOH, it is necessary that parameters such as the lifetime of the project, the heat energy output and the initial and operational costs are known. There are typically two approaches to a LCOH analysis that are employed. One version is based upon a Net Present Value (NPV) approach and the other is based upon an annuity method (Nguyen, 2017). Generally, the NPV method determines the total value of the surplus, or deficit, over the total lifetime of a project, whereas the annuity method aims to determine the value of an investment by calculating the annual average surplus, or deficit, of income - the annuity. All payments related to the investment property are distributed evenly over the years of use using the annuity factor, taking into account the change in the time value of money. The consideration of different payment dates becomes possible because the annuity factor is a function of the calculation interest rate and the useful life.

For the LCOH calculation, the annuity approach is used not to ascertain the yearly residual costs. Additionally, in instances whereby a comparison is being made between pure heating technologies, such as solar thermal, versus gas heating plants with CHP technologies, the yearly revenues for electricity must be subtracted from the total annual costs for a CHP plant. The LCOH as calculated per the annuity method is defined in formula 1:

Formula 1: Levelized Cost of Heat

$$LCOH = \frac{(I_0 + \sum_{t=0}^{t=n} \frac{C_t - R_t}{(1+r)^t}) * ANF_{n,i}}{\frac{\sum_{t=1}^{t=n} E_t}{n}} \quad (1)$$

With the annuity factor being determined by formula 2:

Formula 2: Annuity factor

$$ANF_{n,i} = \frac{i * (1+i)^n}{(1+i)^n - 1} \quad (2)$$

*LCOH: Levelized Cost of Heat (€/kWh)*

*I0: initial investment at t=0 (€)*

*Ct: total annual costs in year t: operational and maintenance, fuel costs, carbon emission costs (€)*

*Rt: annual revenues for electricity or other income in year t (€)*

*r: discount rate*

*Et: energy yield in year t (kWh)*

*ANF: annuity factor*

*i: interest rate*

*n: lifetime of project in years*

When using the LCOH to project future costs, it should be noted that the accuracy of the model is of course dependent upon the accuracy of initial financial projections. Detailed cash flow planning as well as scenario planning can make significant differences to the accuracy of the model over time. Annual operational costs and energy output can be projected on a year by year basis allowing for factors such as improvements in heating efficiency measures or change in demand to be included for consideration. The political framework, such as governmental subsidies for renewables and further taxation on fossil fuels shape the profitability and competitiveness of the various energy technologies in relationship to each other.

Improvements in plant efficiency and learning efficiencies may also be reflected in the projections. The accuracy of the LCOH in determining the lifetime cost per MWh of energy produced is therefore very much dependent upon quality of the initial forecasts provided.

## IV. RESULTS

The heating sector has as of yet seen a slow uptake of renewables enter its fuel portfolio. The energy transition to a carbon-neutral European economy by 2050 will inevitably bring about fundamental changes to this sector over the coming years. Energy efficient building renovation will play a role in reducing overall heating demand. In areas of low population density, decentralized, locally sourced, renewables will see increasing presence. For urban areas, in which district heating schemes are either in place or can be suitably employed, new long-term strategies for the operation of these heating networks will be required.

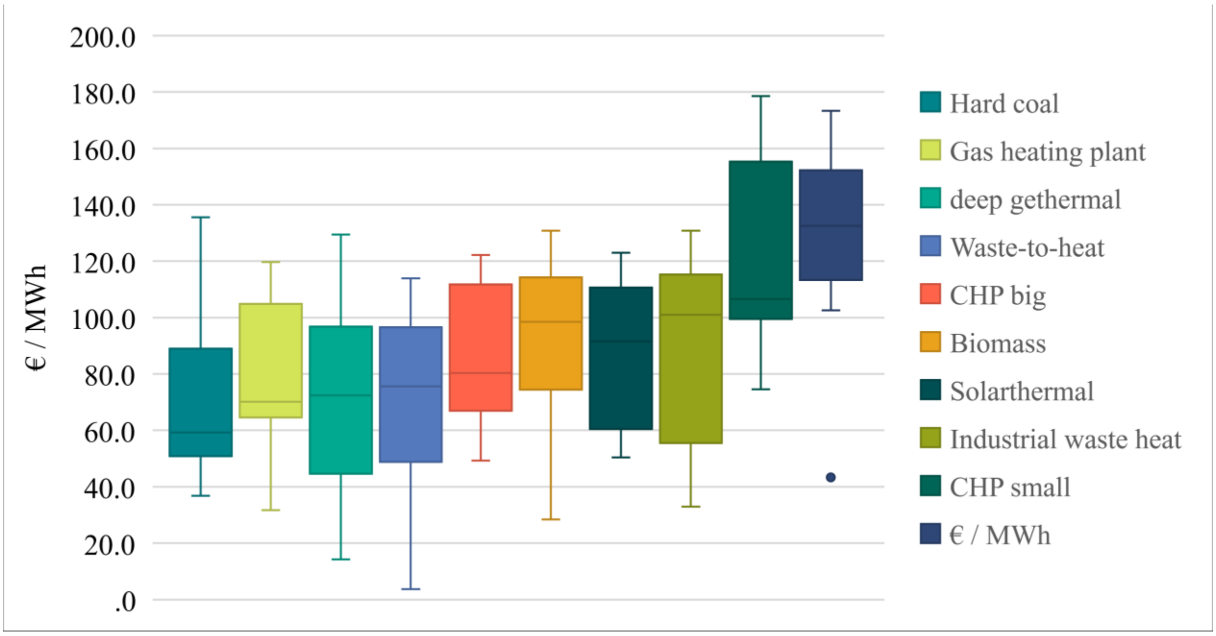


**Figure 4: Comparison of LCOH of different energy sources for district-heating.**

Presently district heating networks are primarily run on fossil fuel combined heat and power plants (CHP). These plants, operating on coal or natural gas, exhibit high levels of overall efficiency through the coupling of electricity generation and heat distribution, and are still as of now economically viable. However, with current economic policy changing in order to meet national decarbonisation targets, district heating networks will have to adapt to accommodate the integration of large amounts of heat from renewable energy resources into affordable heat supply.

Coal fired CHP plants are already the source of strong social objections. Beyond 2040 coal is not anticipated to play any role in the fuel mix for the heating sectors of many European nations. Interim national measures for climate protection and high carbon taxes should also contribute to the end of coal-fired cogeneration plants. Natural gas cogeneration has a longer economically viable shelf-time than coal based generation, owing to its lower associated emissions. However, these too, in time, will offer no economic benefits over regenerative heat generators and will be replaced in favor of carbon neutral technologies.

The transition to decarbonised heating networks must be pursued in the most economically efficient manner possible. It is in this regard that the LCOH method provides an avenue to forecast the most cost competitive technologies by which to achieve this end. By using a LCOH comparison between different heat generation technologies, some renewable alternatives are shown to already be economically competitive with carbon-based technologies.

Based on an LCOH assessment of different fuel types for district heating systems, deep geothermal energy was seen to perform favorably according to this cost metric. This analysis, represented in Figure 4 above, compared the cost effectiveness of ten different heating supply systems on a (€ / MWh heat) LCOH basis. A sensitivity analysis was performed on various heating technologies over their respective operational lifetimes. The analysis consists of the parameters given in Formula 1 and Formula 2 of the last section. The study took in to account projected fuel costs, costs related to plant design and the associated heating grids, the impacts of electricity production where applicable and different costs for CO2 emissions for the technologies.

The findings, as displayed in box plot representation, indicate low median values for the LCOH for coal, gas, waste to heat and geothermal energy primarily. Geothermal and waste to heat systems in particular show a potential for the lowest LCOH under favorable design conditions. In the case of renewable technologies being incorporated into district heating systems, building new grid infrastructure is often necessary. This provides the opportunity for optimized future proof grid designs. In the case of geothermal energy, this allows for design considerations to be given to lower flow temperatures and the intelligent planning of the heating grid layout in relation to customers. The performance of geothermal energy in this study shows it to be competitive today with both traditional fossil based fuels such as coal and gas, both of which are set to play an increasingly smaller role in the energy market of the future. The results of this analysis are further confirmed by a study by Bieberbach and Keller (2015), in which they analyzed the LCOH of different heating options for Munich, Germany.

One major challenge in transforming the heating sector lies in implementing district-heating schemes in areas of high population density. The use of natural gas, oil and coal as fuels will need to be gradually replaced by a diversified mix of locally sourced, sustainable alternatives. Issues may present themselves through the competition of rival renewable sectors competing to fill this void. Consequently, future proof planning, and cooperation, will play a vital role in addressing this issue of providing centralized sustainable heating solutions to urbanized populations.

From an economic perspective deep geothermal energy has been shown in studies such as those cited above to presently be at least equal cost competitive with conventional fossil fuel based heating systems and will, in relative terms, continue to improve out to 2040 and beyond. When price scenarios from the year 2040 were taken into consideration in the study, deep geothermal energy further expanded its cost advantage and demonstrated itself to be one of the cheapest heat supply systems on the market.

The potential of deep geothermal energy to supply entire cities largely with CO2-free heat, coupled with its independence from fuel costs, which are by nature prone to fluctuations in price, make it an optimal energy solution for district heating systems. Where geothermal resources are proven to be available, they present the most economically sound possibility for the transforming of inner-city heating markets. The coupling of deep-geothermal energy plants with heating networks combines the respective strengths of both systems; the district heating network affords the opportunity to serve large numbers of the population efficiently through a centralized heating system and a geothermal plant can deliver this reliable and sustainable energy over a long lifetime.

## V. DISCUSSION

EU member states are pursuing national energy plans that seek to create a carbon neutral European economy by 2050. In this context, the debate on the transition from a conventional fossil fuel based energy system to one based on renewable, carbon neutral sources has never been more politically relevant than it is today. The application of the LCOH methodology offers a very practical and valuable benchmark for the economic comparison of different technologies that can be employed to meet energy demand in the heating sector.

The LCOH is widely accepted internationally as an appropriate benchmark to use in relation to assessing the economic viability of different technology types for heating applications. It allows for the cost comparison of technology types on a standardized basis, hence providing a useful decision-making tool for prospective investors. Ultimately, the results depend on the internal project forecasts made by investors. As seen in the results of the analysis, differences in initial forecasts can lead to significant variation in the LCOH over a project's lifetime.

One of the reasons that this cost-based metric has prevailed over other methods is that it is characterized by a high degree of transparency, whilst simultaneously being capable of reflecting key factors of energy costs over the lifetime of a project. That the levelized cost can be represented in the form of a single number, in €/kWh, allows for quick and uncomplicated comparison between alternatives. This simplicity does not of course allow for robustness in the face of unforeseen risks such as political instability or currency exchange rate risks. The methodology is based on a simplified approach and thus should be sought to be understood as an abstraction of reality. This in turn provides the advantage of being transferable to many technologies and thus allows for a broad field of application. Comparison between different technologies is still possible and practical even in the case that the underlying technologies have differing cost and operational characteristics.

However, the convenient nature of the LCOH method, whereby the economic viability of a technology type can be represented as a single figure, is not without its drawbacks. Limitations in the method arise from the fact that costs for a project's entire lifecycle are by nature forecasts. Real world variations in original assumptions can lead to skewed and misleading results that are open to misinterpretation.

Clearly, there is a high cost of abstraction associated with the LCOH calculation which does not enable it to perfectly encompass all the factors related to stakeholder decision-making. However, the reason why that it has been adopted internationally as an appropriate benchmark for the comparison of heating systems is due in large part to its very clear and transparent nature and its ability to reflect the most important cost components of a project in one measurement.

To date geothermal projects have seen lower levels of investment in comparison with other renewable technologies. This stems in large part from a lack of government subsidies and a lack of awareness by investors as to the feasibility and economic competitiveness of the technology. When comparing geothermal energy production with other technology types on a LCOH basis, the argument to be made in favor of geothermal energy as a fuel source for district heating demand shows clear advantages.

There is a clear impetus from an energy policy-making standpoint to prioritize the decarbonisation of the heating sector in a timely and efficient manner. One avenue whereby this objective could be realized in a fast and effective manner is through the implementation of district heating schemes utilizing renewable energy sources in areas of high population density. In urban environments where an ever-increasing percentage of the populations are electing to live, large numbers of the population can be served from a single district-heating scheme. Today, 74% of the total European population live in urban areas (United Nations, 2018). The high-density areas provide cost efficiencies in heating networks owing to the reduction in the length of pipes required to serve a large number of citizens, often occupying communal buildings. When one such district-heating scheme is coupled with a carbon neutral fuel, the huge number of the households served, help to make great strides towards national decarbonisation targets.

## VI. CONCLUSION

Environmental considerations, and their accompanying political pressures, are forcing the heating and cooling sector to begin in earnest its transition from a carbon-based model to one based on sustainable and carbon neutral heat delivery systems. Presently, over 50% of final energy consumption within the EU pertains to the heating and cooling sector, with only a modest percentage of this heat being generated from carbon neutral sources. Many renewable technologies are set to play a role in the future fuel mix for the heating sector, with each optimized for certain scenarios. For decentralized locations, solar thermal and biomass solutions may be best suited to cater for small-scale demand. For heating systems in areas of high population density however, geothermal energy offers a huge, and as yet, largely untapped resource that could cover the most of the demand for domestic heat and power generation in Europe.

The decarbonisation of the heating sector will necessitate a paradigm shift from a traditionally fossil fuel based sector to locally sourced sustainable alternatives. This change in fuel supply will need to occur in conjunction with increases in energy efficiency in buildings throughout both the residential and industrial sectors. Increasing the prevalence of renewably sourced energy in the heating sector will have the twofold benefit of reducing carbon emissions whilst simultaneously reducing the dependence on energy imports for heating. In the case of most European nations, this reduction in energy imports will namely assume the form of a decrease in imported natural gas and coal, imports that are subject to price fluctuations and artificial supply shortages.

In the energy landscape of the future, heating demand will be met by an interconnection of various renewable systems. Many of these renewables are by nature intermittent in terms of their supply. Geothermal energy has the benefit of being capable of providing reliable and constant baseload supply. Geothermal plants do not require the extensive space requirements of other technology choices, which further ads to their suitability as an appropriate heat system for implementation in cities and build-up environments. Building the necessary network infrastructure for a district heating system was in the past a barrier to entry for lots of project proposals. The introduction of the Clean Energy for all Europeans Packages offers the potential to increase access rights to district heating and cooling systems for producers of renewables. This policy measure, coupled with more ambitious national decarbonisation targets for 2030, should see the implementation of geothermal projects further increase over the coming years. As of 2018, geothermal heating plants are operational in around 30 Europe countries with further projects in development.

Geothermal has proven to be a reliable and affordable source of energy at many locations around Europe. When LCOH comparisons are carried out between geothermal energy and other alternative heat delivery systems, geothermal has been found to perform exceptionally well. It should be noted that geothermal plants have low system costs and negligible externalities. This in effect means that a LCOH calculation accounts for almost the full cost of the project, without having to consider potential variations in fuel costs. Another factor that merits consideration is that geothermal plants typically have extended operational lifetimes when compared with other technology types. This reduces decommissioning costs when viewed over an entire project lifecycle.

In spite of the existence of many long-standing and profitable geothermal heating projects in Europe, there remains a wealth of untapped potential for new investment in the area. The geothermal resource lying beneath our feet in Europe is estimated to be appropriately located for application in district heating schemes that could serve up to 25% of the EU population. The main component to slow investment in geothermal technology in the past stems primarily from a lack of awareness from investors as to the economic competitiveness of the technology. It can be inferred from an LCOH assessment, which indicates the average total cost of a heating technology over its entire lifetime, that geothermal is not only an economically competitive alternative to traditional plants, but in fact an optimum choice.

In spite of scientific studies demonstrating the economic advantages of geothermal energy and the fact that prices for fossil commodities will rise in the near future, geothermal projects are still an underdeveloped resource. Relatively high initial investment costs and long planning periods before the first revenues flow still impede the market penetration. Project developers, who act fast will benefit from market positioning and long-lasting profitable projects. Tentative investors, however, might be rewarded with smaller development horizons but at the cost of market position, which will be assumed by more determined and innovative decision makers.

To further increase the exploitation of the geothermal resources in Europe for heating systems, governmental policies need to establish frameworks. Securing long-term funding and securities at the early investment stages is pivotal, given the sizable costs and uncertainties associated with the early project stages of geothermal development such as the drilling stage. Investor perception of these costs considerably shape the appeal of geothermal development. Thus, to ensure further technological progress and advances in the geothermal sector, further adoption of the LCOH model for heating technology comparison should be encouraged, alongside suitable government led energy policy measures to promote growth in the sector.

## REFERENCES

[1] Bieberbach, F.; Greller, M. (2015). Herausforderungen des Strukturwandels. Energiewirtschaftliche Tagesfragen, 2015(8), 14-18.

[2] European Commission (2016). European Commission – Fact Sheet, p1. Retrieved on 19.07.2019 from: http://europa.eu/rapid/press-release_MEMO-16-311_en.htm

[3] European Commission (2016). Commission launches plans to curb energy use in heating and cooling, p1. Retrieved on 23.07.2019 from: https://ec.europa.eu/energy/en/news/commission-launches-plans-curb-energy-use-heating-and-cooling

[4] European Geothermal Energy Council (EGEC) (2019). 2018 EGEC Geothermal Market Report Key Findings, p4. Retrieved on 25.07.2019 from: https://www.egec.org/wp-content/uploads/2019/05/KeyFindings_MR-18.pdf

[5] European Technology & Innovation Platform on Deep Geothermal (ETIP-DG) (2019). Implementation Roadmap for Deep Geothermal, p8. Retrieved on 23.07.2019 from http://www.etip-dg.eu/front/wp-content/uploads/Roadmap_Final_webVersion_-1.pdf

[6] European Commission (2018). The Revised Renewable Energy Directive technical at a glance. p2. Retrieved on 25.07.2019 from: https://ec.europa.eu/energy/sites/ener/files/documents/technical_memo_renewables.pdf

[7] Eurostat (2019). Gross derived heat generation by fuel, EU-28, 2000-2017 (GWh). Retrieved on 29.07.2019 from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Gross_derived_heat_generation_by_fuel,_EU-28,_2000-2017_(GWh)_T4.png.

[8] Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. Energy Strategy Reviews, 24, 38-50.

[9] Nguyen, H. (2018). Methodische und datentechnische Analyse von Stromgestehungskosten in Deutschland. Karlsruher Institut für Technologie. Retrieved on 29.07.2019 from: www.kit.edu.

[10] Rödl & Partner (2019). Die Wärmezielscheibe – Wärmewende in Deutschland erfolgreich gestalten. Retrieved on 23.07.2019 from: https://www.roedl.de/de-de/de/wen-wir-beraten/energiewirtschaft/documents/2019_w%C3%A4rme_konzeptpapier_web.pdf

[11] Rubert, A. (2018). Levelised cost of energy – A theoretical justification and critical assessment. Energy Policy, 124, 169-179.

[12] United Nations (2018). World Urbanization Prospects: The 2018 Revision [key facts], p2. Retrieved on 23.07.2019 from: https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf