

Article

Assessment of Geothermal Fields in the South Pannonian Basin System Using a Multi-Criteria Decision-Making Tool

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Abstract: This paper analyses potential geothermal sites in North-East Croatia which is part of the Pannonian Basin System where a substantial geothermal potential was discovered during hydrocarbon exploration using the Multi-Criteria Decision-Making Tool specially developed for the purposes of the Horizon 2020 project: Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials (H2020 MEET). Most of these sites use available geothermal energy potential for commercial purposes, mainly for balneology and more recently for agriculture and electricity generation. The case study involves five different geothermal locations chosen according to their geothermal potential, the current state of production and possible future development, including one oil field that is at the very end of its production life. Three potential final users' types; agriculture demand, electricity generation demand and district heating have been evaluated for each of the five chosen geothermal sites. The conducted analysis should be of great benefit for further analyses which will be carried out using the aforementioned Multi-Criteria Decision-Making Tool. The performed study showed high consistency of obtained results and actual usage of five geothermal fields.

Keywords: case study; final users; geothermal potential; Multi-Criteria Decision-Making; Pannonian Basin System

1. Introduction

Currently, as climate change is setting new demands on the power sectors, mainly due to the new concept of decarbonisation, many countries including the Republic of Croatia are aspiring to include more renewable energy sources in their energy production portfolio. The growing demand for energy consumption and restriction of fossil fuels utilisation, set the need to identify potential new energy sources. Renewable energy resources are one of the most prominent options for the decarbonisation and means to mitigate the surging climate change problems, such as population and industry growth. In order to make geothermal utilisation popular, some obstacles have to be overcome, like social awareness, legal framework and economic competitiveness [1,2].

Until recently, hydro energy was the only renewable energy source, which was utilised for energy production in the Republic of Croatia. Eventually, the energy of the wind, sun and biomass, considering the great potentials of the area and market prices, came out as a replacement solution for the declining fossil fuel reserves. In addition to the above-mentioned renewables, geothermal potential came out as a new, possible source of the energy. Until 2019, geothermal energy utilisation was used only for the balneology purposes, which started with the well-known Roman remains at the Pannonian area.

This mainly involved the Hungarian remains, but also the Croatian Varaždin thermal springs, where geothermal potential was mainly used for balneology purposes as spas.

Considering the geological and geothermal perspective, Croatia consists of two geothermal regions; the South-East Dinarides mountain region predominantly consisting of Mesozoic carbonates where no significant temperature ranges are noticed; and the Croatian part of the Pannonian basin system (PBS) where temperatures are over 100 °C at the particular locations. PBS is located in the North-East part of the country, where fractured carbonate rocks and clastic sediments were formed as a result of the African plate movements caused by the subduction. Due to the tectonic movements, the continental crust became thinner, enabling high amounts of the heat flow to easily influence the subsurface temperatures.

The national oil company, INA d.d., conducted a geological and geophysical investigation during the 20th century for thousands of wells in the Croatian part of the PBS, which is well known for its numerous oil and gas fields. Even though the boreholes on some locations came back as “negative” for oil and gas, high temperatures have been discovered that led to a conclusion that the geothermal gradient on these locations might be high enough for geothermal exploitation [3].

The existence of numerous wells drilled by INA d.d., which today exceeds 3.500, makes the construction of geothermal power plants more and more likely, considering the fact that no additional funding is needed to find moderate or hot water sources. Many of these boreholes have not yet been adequately tested for geothermal purposes because of the existence of oil or gas deposits in the wells. The “negative” wells were abandoned and the ones in current usage are almost at its final hydrocarbon production what ease the utilisation of geothermal potentials in the oil and gas reservoirs and old abandoned boreholes [4].

During the last decade, the idea of using the high geothermal gradient for electricity generation, district heating, and heating for agricultural purposes has risen. So far, the geothermal field, Velika Ciglena, near the town of Bjelovar is the only electricity-producing power plant with an installed capacity of 16.5 MW_e where the temperature of the geofluid reaches 170 °C [3]. Several other locations have had consistent geothermal usage, like Zagreb (80 °C) for heating purposes; Bošnjaci, Sveta Nedjelja (60 °C) for agricultural purposes; and Daruvar spa (46.6 °C), Krapinske spa (40.85 °C), Varaždin thermal springs (57 °C), which are between 25 naturally occurring hot springs that are mostly used for medical treatments and recreation. It can be concluded that the total capacity of the utilised geothermal energy for heating purposes in Croatia is around 85 MW_t distributed on the district heating (42.3 MW_t), heating of the swimming and bathing areas (24 MW_t), greenhouses (6.5 MW_t) and space heating (12.6 MW_t). According to the literature, the quantification of the geothermal potentials of Croatia has been made on more than 500 wells. It showed that 750–1300 MW_t could be produced and also cover $\frac{1}{4}$ of Croatian natural gas consumption [5].

Increasing environmental problems, especially release of the Non-Condensable Gasses (NCG) to the atmosphere and the climate change, have led to new solutions in energy sectors long term planning, i.e., the geothermal energy utilization has been imposed as one of the possible solutions [6]. For this planning process and investment options, the Multi-criteria Decisions making Methods (MCDM) are used to help the decision-makers, particularly for the conflicting perspectives by combining different standpoints by using preferred criteria.

To achieve the minimum environmental impact, costs reduction and energy independence, it is necessary to lower fossil fuel utilization in the energy sector. MCDM could also help to attain the optimal solution for the researchers, policymakers, stakeholders, banks, industries and local communities prior the project development. The following MCDM methods, which are gaining in popularity, are widely used in the MCDM analyses. Mostly, the MCDM analysis becomes more valuable when there exists the possibility that the user add weights to the preferable criteria [7].

PROMETHEE (Preference Ranking Organization Method on Enrichment Evaluation) is one of the few existing methods of MCDM for comparing different criteria. Giving different ranges from 0 to 1, some criteria become neglected, while the value of 1 gives significance to the preferred criteria

following the final grade and decision of the matrix [8]. This method gives the result according to the available data and its type for the requested operation. Collected data, criteria weights and correlated alternatives construct the matrix, thereby giving the DM a complete overview of a tool for clarifying the limits for its preferences [9].

The *ELECTRE* (fr. *Elimination Et Choix Traduisant REalite*) method is relevant for the final decision on the renewable source's usage, either for electricity generation or for heating purposes, water management, economic studies, transportation and others [7,8].

To confirm the outcome of the method, Polatidis [10] used both mentioned methods for comparison of the results for the evaluation of the geothermal field that corresponds to the DM's preferences, which is mainly intended for agricultural purposes. The study showed how weighted factors affected the results at a certain point, but the results are almost the same when using identical criteria, which has an impact on further project development [11,12].

Analytic hierarchy process (AHP) is a Multi-criteria decision-making method, where a matrix is used by adding weights to each criterion. The process consists of three steps; defining the goal by determining the problem; adding the criteria; and selecting the alternatives to the criteria. The final result indicates the priority of the comprehensive preferred criteria analysis. Because of its simplicity, it is often used for renewable energy usage purposes, mostly at the "idea" stage of the process while prioritizing the final energy demand. The method itself is not enough for the final decision and project development so further evaluation and verification are required [13].

The *Multi-Criteria Decision Analysis* (MCDA) presented in [14] is based on the available sources for the power generation by means of the conventional and non-conventional sources. The MCDA gives the special weights to the LCOE, related to establishing new installations at the site, costs and its minimization, operation, maintenance (O&M) and the capacity of the power plant. Also, besides the LCOE, it considers the water consumption for the cooling system by each energy source. Minimizing the greenhouse gas emissions (GHG) and land footprint intensity are considered as well.

For the purpose of this paper, an independent MCDM analysis is made for five geothermal sites located in Croatia. Two of them, Varaždin thermal springs and Bizovac thermal spa, are in current usage for the spa treatments because of their beneficial health purposes and water quality. The Beničanci oil field is observed as a potential geothermal field which is in current usage for the oil and gas exploration and exploitation. The potential geothermal field Beničanci is observed since one of the tasks within the MEET (Horizon 2020) project that should be accomplished is the observation of the mature oil fields where a huge amount of water is resisted in the reservoir [15]. Finally, the last two sites, Karlovac and Lunjkovec—Kutnjak are observed since their great geothermal potential was determined during drillings for the hydrocarbon exploration purposes. They are in the project preparation at the moment, so the MCDM analysis has to confirm its potential for further utilization.

The main objective of this work is to compare the Croatian geothermal sites and different end-use applications via the MCDM analysis. The methodology might give an idea on the future geothermal investment locations and its utilization. Assigning weights to the identified and evaluated criteria defines the relative importance of one criterion compared to the other, creating thereby the correlations between all the criteria. The MCDM matrices enable the comparison of different sites enabling a comprehensive overview of all the advantages and disadvantages of the sites and to giving an idea on how to use this valuable resource of energy. This methodology is the preliminary work that has to be done before any investment, and serves as a suggestion for the investors, easing their final decision for the chosen location.

The first contribution of this work is to prove the consistency of the chosen criteria by evaluating the real site's data. Within the paper, we observed sites that are located in different areas of the Republic of Croatia and evaluated for different end-use application. To perform the analysis and to evaluate the criteria, deep research and data collection have been done. The second contribution is the literature research on the end-user preferences so the weighted system could be set up appropriately and presented to the readers and future investors. Moreover, this could also be observed as a novelty

since the weights and matrices also include the social and environmental impact evaluation. Namely, since the geothermal energy utilization is still under enlargement in Croatia, these two aspects are one of the main interests for the local community, local or state government, and for the potential investors.

The rest of the paper is formed as follows. The theoretical background is presented in Section 2 and mainly based on the criteria description that is evaluated within the MDCM analysis. Section 3 describes the methodology of the weighted decision matrix (WDM) that is sub-process of the MCDM analysis. Every criterion is separately described in detail for each end-use application. Moreover, the assumed weights for each criterion depending on the end-use application, are defined and later used in calculations. Section 4 describes locations that are observed within this study, and carefully chosen according to their current conditions. The performed analysis gave results that are presented and discussed in Section 5. Finally, Section 6 concludes the results and gives the overview of the future work that will be done within the project.

2. Theoretical Background

The energy generated from geothermal power plants in relation to conventional electricity production is more environmentally acceptable. Firstly, it is a renewable source of energy, which makes it a sustainable energy source. However, the natural potential of geothermal energy so far is not fully exploited, mostly because of the risks related to the drilling and exploration phases of each geothermal project. Moreover, geothermal energy has a lower impact on the environment since, compared to conventional sources of energy, it has significantly lower GHG emissions, smaller land-use intensity and noise pollution during the operational phase of the power plant. Besides environmental benefits, the economy should also be mentioned. Its usage is not influenced by the outside ambient conditions which make the geothermal energy available most of the time, consequently making it a baseload power plant. In addition, geothermal heat pumps have high efficiency and require low maintenance cost during its lifetime. Integrated with other sources of energy, the efficiency of the plant could be even higher. Along with electricity production, the geothermal energy could be simultaneously used for various direct usage applications, depending on the range of temperatures and mass flows [16,17].

When implementing the proposed methodology, some previous steps had to be made. The first, base step was a selection of the criteria, which will be included within the MCDM matrix for the final site selection. The criteria have been comprehensively described in the papers [14,15]. The second step, which is the main contribution of this paper, is defining the weighted factors for each criterion according to the specific demands and priorities, i.e., the greenhouse owner requires the shortest distance to the borehole, etc. The next step is adding the previously defined weight to the quantified criteria and the final one is setting the matrix out for the final evaluation and further project development.

2.1. Criterion Evaluation

As mentioned, Croatian part of the Pannonian basin has a great potential for geothermal energy utilization. For testing the MCDM matrix, which is part of the Decision-making tool (DMT) in the scope of MEET (Horizon 2020) project, the general overview of the Croatian geothermal sites, has been done. The used criteria and sub-criteria are listed in Table 1 and briefly described in the following text.

Table 1. Used criteria.

Geological	Technological	Economic	Environmental	Social
Geothermal gradient Temperature at the wellhead Fluid heat flow	Installed power	LCOE/H	Subsidence	Social Acceptance
	Load factor		Potential seismicity	Costs of Direct use/Electricity production
	Theoretical maximum efficiency		Land use	Social Acceptance
	Global Efficiency		Noise	Costs of CHP
	Corrosion and scaling		Potential water contamination (TDS/pH)	Employment FT
	Distance from the grid (heat/power) Load factor		Radioactivity	Employment C&M

2.1.1. Geological Criteria

The first and most important criterion, which indicates the initial possibility for the geothermal utilization, is the high value of the geothermal gradient, the amount of the Earth's temperature that increases with depth. Higher initial reservoir's temperature means the higher fluid temperature at the wellhead and also a higher amount of heat that can potentially be transferred to the second (working) fluid for end-use purposes. Geothermal resources can be divided into three groups. In the first, the lower temperature deposits, up to 65 °C, are used mostly for agriculture purposes and balneology. Secondly, there are reservoirs with the temperature in the range from 65 to 100 °C used mainly for district heating purposes. The third group includes reservoirs with a temperature of 100 up to 180 °C used for the electricity generation [18,19]. Related to the chosen technology, the heat flow rate is also one of the selected criteria. For the purposes of this analysis, the heat flow is modified by means of corresponding temperature range, flow rate and chosen technology. The main goal is to emphasize the importance of flow rate and temperature.

2.1.2. Technological Criteria

Temperature and pressure loss related to transferring the fluid could be significant, therefore the geothermal power plants should be located near the geothermal reservoir exploiting sites. For these requirements, the criteria that are usually observed are distance to the grid and/or pipeline, which makes up a significant part of the costs, whereby the very small distance between the plant facility and connection point is the most favourable. Moreover, the area covered by the plant is lower compared to other renewables (i.e., solar, wind) so the area occupied by the pipes is minimal but the effectivity losses from long distances to the user could result in doubtful profit [20].

The next criterion is the possible installed power which is the most important parameter that determines both the costs and revenues. The load factor, a measure of the utilization rate is typically 0.8 or higher for electricity production. A high load factor links the low costs of delivered heat, which affects the attainability of the project.

The next criterion is the theoretical maximum efficiency that needs to be considered. It depends on the temperatures and the geological site features, and also technology and environment features. The global efficiency criterion evaluates the multi-stage heat loss within the energy conversion cycle and the impact of the ambient temperature of the stored heat. Coefficients of different stages of the conversion cycle address the total heat loss, defined through several equations.

The corrosion and scaling hazard are evaluated with the LSI index (Langelier Saturation Index) which determines the O&M costs. The performance will be better if the LSI is lower.

2.1.3. Economic Criteria

Currently, the current state of the DMT and MCDM analysis evaluation observes one economical criterion depending on the final utilization of geothermal energy Levelized Cost of Electricity (LCOE) and Levelized Cost of Heat (LCOH). LCOE represents the annual average revenue expressed as related costs per generated electricity (€/MWh) in a certain year during the power plants lifetime, mainly observed between 25–30 years. Crucial inputs for the calculation of LCOE for the geothermal energy consumption are capital costs (CAPEX), usually represented as exploration, drilling costs and power plant investment costs and OPEX represented as percentage amount (7–20%) of CAPEX. This analysis excludes the drilling costs since all the geothermal sites already have the doublets, only the power plant infrastructure is required and is approximated by the 20% of initial costs. Similarly, LCOH presents the costs related to the evaluation of the direct utilization of geothermal energy for heating purposes, i.e., agriculture, space heating/cooling, industry, balneology, etc.

2.1.4. Environmental Criteria

The sub-criteria for the final environmental impact is the potential subsidence caused during drillings or the reservoirs pressure decline during larger extractions of the geothermal fluid. Also, while enhancing the geothermal reservoirs for the better hydraulic performance or while making the artificial heat exchanger (in low permeability bedrock, i.e., granites), the possibility for induced microseismic occurrence exists [21]. Additionally, the land used per installed kW is included as an impact on the landscape expressed as land use intensity (LUI). Any kind of effect on sustainability also includes the level of noise, atmospheric emissions, water contamination and production of radioactive scaling [22]. For the noise impact, the typical acceptable levels are 71–83 dB at 900 m distance from the facility. Atmospheric emissions in the geothermal systems are close to zero, so the impact on surface waters can mostly be excluded.

High corrosion and scaling potentials could affect the casings during the lifetime, so the groundwater contamination may occur at the lower levels of the ground. Considering that, total dissolved solids (TDS) and pH value are considered since the quality of drinking water is measured in these amounts according to the WHO. Various types of rocks can contain different radioelements (uranium, thorium, potassium) which can affect the geothermal fluid by interaction that causes small amounts of the natural radioactivity to occur at the surface [23].

2.1.5. Social Criteria

Since renewables are a new way of energy utilization, social acceptability has a significant role in project development, so the lack of public involvement could cause resistance to the project realization. The environmental communities, social media and public have an influence on the local or regional authorities, therefore, the society needs to be informed and involved in the project progress and its reflection on the environment and the local community [24]. The social acceptance costs are represented as external costs of the geothermal project. Moreover, the employment rate is one of the influencing factors for the community, especially local, considering the acceptance of the project. Therefore, the employment rates are divided into the employment rate of the full time (FT) jobs and construction and manufacturing (C&M) employment rate dependent on the plant size and type. Consequently, the final, social criteria are the average value of the sub-criteria based on the social acceptance costs related to the type of the plant, FT and C&M employment rate [14].

3. Methodology

Within this study, the MCDM analysis is carried out considering the investor's, i.e., decision maker's, preferences. Namely, the weighted criteria are carried out separately for the agricultural demands, district heating demands, and electricity generation demand-oriented users. The analysis presented in this study is the continued methodology of the approach presented in papers [13,14], which consisted of evaluating the geothermal sites that are using mentioned and described criteria by using the same weights for the final site evaluation. Further development of the site evaluation matrix is the WDM. The WDM utilizes different influencing criteria but it is intended to have a high effect in terms of the preferred end-user preferences. Therefore, each criterion is multiplied with a different weight that emphasizes the relative importance of one criterion to another. Within this study the equation for the criteria evaluation will be:

$$X_i = \sum_j^J w_j \cdot x_{ij} \quad (1)$$

where X_i is the final grade of the i^{th} evaluated site, $i \in I$, where I is the number of observed sites. Moreover, w_j is the weight dedicated to each criterion j . Corresponding weight $w_j \in \{1,10\}$ is multiplied with x_{ij} performance of site i on criterion $j \in J$, defined with values from 1 to 5. The higher the value of x_{ij} the better the performance.

Since the weighted system of the MCDM is a delicate part of DMS-TOUGE [18], adding the preference to some criteria is left to DM's itself and this analysis has been made for three reasons:

1. Tool testing,
2. A proposition to future investors,
3. Literature overview of the tool upgrading process.

Considering these reasons, the workflow has been done in the following way:

1. Literature overview
2. Site choosing
3. Data collection
4. Calculation
5. MCDM input
6. Results
7. Further investigation via DMT

Important criteria are given a weight equal to 10 and less important criteria are evaluated with smaller grades. Considering different weights, affected criteria will consequently reflect the investor's preferences and final grade. According to the available literature, data for five sites in Croatia were collected, which currently have the highest final demand. Data required for processes in the MCDM analysis that are not available or do not exist are estimated according to the already existing data and available literature. Some of the sites are currently exploiting the available heat (for the balneology and heating purposes) while others have a high possibility of exploration in the future.

The MCDM analysis could be used for various renewable sources analysis and this methodology is applied to facilitate the process of making the final decision on which renewable option is best suited. It has to be mentioned how this methodology supports the stakeholder's ideas, leaving the space for evaluating its necessities and subjective perspective in the decision matrix. In most cases, the MCDM weights are assigned to the proposed criteria such as technological criteria, costs of integration, land and water usage, and GHG emissions in an environmental manner [25]. In this methodology, the less important criteria are the land use considered under the environmental impact the same as the social one (community acceptance) according to the [26]. Non-condensable gases (NCG) pollution seems like a very important issue according to the reviewed literature [27], so the weighted criteria for the environmental impact will not be less than half of the weighted system analysis. All of the mentioned criteria have a relative impact on the final score as depicted in Figure 1 as it is possible to see the technological and geological criteria have a relatively high impact while the economic one has a medium impact and social and environmental have the lowest impact on the final grade. In addition, the higher value of the grade means the lower risk on the final investment related to the observed criteria. The final score and the range of the proposed locations are observed as the aggregated score of the geothermal sites.

It is valuable to mention how the weights in the presented case studies are from the author's standpoints according to the observed literature and realized projects or MCDM methods conducted on other renewables [28–30]. For getting the realistic grades, some values have a minimal impact weight so the most crucial ones could gain in importance. The advantage of this method is its simplicity, so the end-users could estimate their preferences and evaluate the criteria. However, the lack of exact site data could lead to wrong assumptions, giving the uncertain results about the possible energy production. In this case, the various computer software could help in the reservoir modelling, or default values for a specific project site could be used [31].

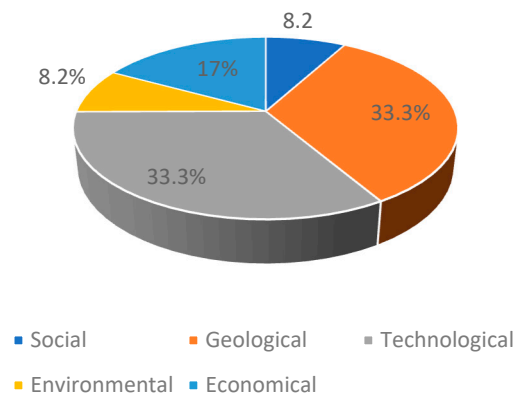


Figure 1. Sensitivity of the final score result on each criterion.

3.1. Agriculture

Besides electricity generation and district heating, one of the most important utilizations of geothermal energy is agriculture. Except for the greenhouse heating (growing mostly tomatoes, sweet peppers, cucumbers, lettuce, etc.), it could be used in the aquaculture (for fish farming), soil heating, food drying and agricultural industrial purposes. Agriculture geothermal energy usage means the artificially making preferable climate conditions for growing the crops for the market necessities even out of the season. Mainly, the crops require stable conditions mainly by means of constant temperature which ensures the high quality of the final product. Using the geothermal energy in the agricultural purpose also reduces the utilization of fossil fuels in the diesel generators and enables the energy cost savings [1,6].

3.1.1. Temperature

During the cold seasons and nights, adequate temperature could be achieved only by using an additional energy source, i.e., geothermal energy. The lower (40 °C) to intermediate (100 °C) geothermal fluid temperature range is required for making the stable conditions in the greenhouse. Greenhouse heating stands out as the most popular geothermal resource end-use and afterwards, fish farming, fruits, vegetables, meat drying, algae cultivation, soil heating and others. Using the geothermal energy in the greenhouse has its advantages such as the low enthalpy resource available in many areas, energy independency, installation simplicity, software climate control, economic competitiveness (tax benefits), locally available, small distance and land use [24,25].

Many issues could arise as an obstacle while investing in these projects. The most important are construction activities and costs as well as the environmental impact. A special significance will be added to the calculated heat flow and theoretical maximum efficiency for enabling better feasibility of the predicted future project.

3.1.2. Theoretical Maximum Efficiency

The connection between geological parameters, meaning outlet temperature at the wellhead and technology, is given by the Carnot's efficiency. The efficiency presents the thermal exchange that took place in the heat exchanger (HEX), which is the infallible part of the geothermal potential usage. Possibility to evaluate the thermal exchange has an important role in the decision making so the given weight is 7.

3.1.3. Heat Flow

The highest value is added to the heat flow since it emphasizes preferable conditions of the reservoir and technology parameters, mainly based on the flow rates and temperatures.

3.1.4. Corrosion and Scaling

As an element for the geothermal site comparison, the geochemical content of the geothermal fluid was observed. Its content could harm the surface waters and groundwater along with air pollution. Therefore, the chemical content is important in terms of discharging the (NCG) and dissolved mineral [32,33]. In the case of direct geothermal fluid consumption, harming the pipes could arise as a potential problem since corrosion and scaling are usually present [34]. In terms of solving this problem, the stainless-steel pipes are preferable as well as adding the inhibitors if needed, and constant monitoring of the chemical composition of the geothermal fluid [33,35]. For that reason, the highest grade of 10 will be given to the corrosion and scaling criteria.

3.1.5. Distance to the User

Distance to the final geothermal energy consumption for the purposes of this study has been chosen as a highly influencing factor. This locally available source of energy could reduce costs because of the simplicity in operation and maintenance (O&M) and distance to the final user (i.e., greenhouse) in consequence of cost reductions as well as temperature and pressure loss in long pipelines [32].

3.1.6. LCOH

All of the costs are taken into account with the economic metric LCOH, which is usually used as beneficial criteria for the agricultural demands, so the chosen weight is significantly lower.

As seen, for the purposes of this paper, in Table 2 some weights are completely reduced so that the most preferable criteria could properly affect the final grade. The criteria that are not taken into account are excluded from the description of the given weight.

Table 2. Agriculture assigned weights.

Criteria	Weights
Installed capacity	1
Heat flow	10
Th. Max eff	7
Geothermal gradient	1
Fluid temperature	3
Corrosion and scaling	10
Distance from the final user	10
Load factor	1
Environmental impact	1
Social impact	1
LCOH	3
Global efficiency	1

3.2. Electricity Generation

Solving a complexity of the energy investment issues, the MCDM analyses using the conceptual criteria help a decision maker's development of the sustainable energy system at the initial stage of the project. Mostly, methods such as this are applicable for choosing the right renewable source for energy production and cost savings or for choosing the most appropriate site. Within this study, the MCDM analysis is applied to the geothermal energy production for choosing the most appropriate location for further energy project development.

For electricity production, the most appropriate technical solution is the closed-loop binary cycle exploitable in high potential geothermal sources. The most-used energy conversion for low (70–100 °C) to medium (100–220 °C) temperature is the Organic Rankine Cycle (ORC). Different from the direct use, the heat of the geothermal fluid is transferred to the low-boiling, secondary, fluid in the heat exchanger

where it is vaporized and sent to the turbine. After this, the geothermal fluid is reinjected back to the reservoir [36].

3.2.1. Temperature

Having temperature high enough is the initial starting point for electricity production planning, which is the reason for giving the highest weight to the temperature criteria. For the ORC construction planning the required temperatures are from 100 °C up to 160 °C, but within the scope of the H2020 MEET project the range is extended to the lower temperature of 40 °C [37].

3.2.2. Installed Capacity

The most prominent criteria within the electricity generation are the technological parameters, among which the installed capacity is the major one. The seven parameters are included in the installed power performance, such as the inlet and outlet temperature, flow rate, fluid density and specific heat capacity.

3.2.3. Theoretical Maximum Efficiency

The efficiency parameter is also the most common criterion for the evaluation of the energy generation giving the percentage of the conversion efficiency in the heat exchanger while transferring the heat from the primary fluid (geothermal fluid) to the secondary fluid (working fluid).

3.2.4. Environmental Impact

Strong restrictions regarding gas emissions are imposed because of the increased CO₂ emissions from using fossil fuels. Within the environmental criteria, production of the NCG, which consists mainly of carbon dioxide (CO₂), hydrogen sulphide (H₂S) and hydrogen (H₂), is highlighted since the geothermal reservoirs contain relatively high concentrations of it. Geothermal energy production has grown in the last decade what leads to the high suspicions of the NCG production, mainly contained within the carbonate base rocks [38]. Since environmental criterion is consisted of six separated sub-criteria and not all of them strongly affect the DM's final decision, this criterion is given the middleweight of 5.

3.2.5. Social Impact

Mostly, the social aspects have a positive influence on the society since systems as this are contributing to the local community development generating people jobs; from initial (C&M) and direct ones towards the chained ones, i.e., triggering the industry growth [39]. Because of its positive impact, the social criterion is degraded.

3.2.6. Distance to the Grid

If the geothermal resource is in the unpopulated area, the electricity generation is the best option for the investor since the costs related to the grid connection are less than to the heating system if the temperatures are high enough. Costs related to the allocated substation are consisted of routing the lines (possibly across the private lands), electricity pillars and substation [40]. The middleweight is given to distance criterion in the case of electricity production since routing the grid lines does not affect the quality and quantity of a delivered source, unlike the heat transport where losses could be significant. In addition, studies showed how distances to the roads, settled areas and especially to the transmission lines are valued criteria in decision-making mostly obtained by GIS analysis what will not be applied in this analysis.

3.2.7. LCOE

The LCOE describes the cost of the power produced over a period of time, i.e., it is the average cost of producing a unit of electricity during a generating plant's lifetime since it is the only criterion where the costs are included, the maximum weight is given to the LCOE criterion.

3.2.8. Global Efficiency

For the power plants, the global efficiency of the energy conversion has been incorporated into the MCDM analysis. This criterion is used to show the overall heat loss, which consists of losses at different stages of the cycle. For better performance of the power plant, second HEX could be added to the system for exploitation the remaining heat for other direct use purposes [41]. For a better overview of the power plant performance and its possible upgrade, the global efficiency criterion was assigned with a weight equal to 4 since there are still no power plants at the case study sites so some data must be estimated.

The final MCDM analysis for the electricity generation end-user is performed according to the given weights within Table 3, estimated following the observed literature and author's standpoints where necessary.

Table 3. Electricity assigned weights.

Criteria	Weights
Installed capacity	10
Heat flow	10
Th. Max eff	10
Geothermal gradient	1
Fluid temperature	10
Corrosion and scaling	1
Distance from power grid	5
Load factor	1
Environmental impact	5
Social impact	1
LCOE	10
Global efficiency	4

3.3. District Heating

To support higher energy independence and security, using the renewable sources for the district heating (DH) purposes, is gaining in importance. Besides better thermal insulation of building, energy savings, energy efficiency could be increased with long term planning of DH system, which mainly depends on the number of end-users, connection pipes, spatial concerns and available technologies. Namely, energy planning depends on area climate conditions and available source, meaning the northern regions require higher heat transfers that could be reached by increasing the mass flow rates and/or high temperatures [42]. The residential sector requires relatively low temperatures, lower than 70 °C, with a prominent trend of seasonality, unlike the industry heat consumption which is not affected by yearly climate changes. On account of the proposed influencing assumption weights for each criterion for DH purposes are presented in Table 4 [43].

Table 4. District heating assigned weights.

Criteria	Weights
Installed capacity	10
Heat flow	10
Th. Max eff	10
Geothermal gradient	1
Fluid temperature	5
Corrosion and scaling	1
Distance from power grid	10
Load factor	1
Environmental impact	5
Social impact	1
LCOH	5
Global efficiency	3

3.3.1. Installed Capacity

Depending on the ratio of the installed capacity, it could be predicted if any additional energy supply is necessary; following that, the highest weight is given to the installed capacity.

3.3.2. Heat Flow

Heat flow presents a certain amount of the energy that could be transferred to the fluid in the secondary loop, i.e., heat demand side loop, strongly dependant on the heat extracted from the reservoir which is influenced by the flow rate and resource temperature what makes a relation between the surface and subsurface conditions. Therefore, this criterion is assigned the highest possible weight.

3.3.3. Distance

In the DH system, the distance plays a significant role since the temperature and the pressure drop depending on the total pipeline length. Distances between residential buildings and the available heat source for the small-scale networks are a few hundred meters, the medium-scale is supposed to be around 200–300 m and large-scale networks consider long pipeline networks where heat loss is significant, approximately 15% [42]. For this reason, this criterion is also assigned with the highest weight.

3.3.4. Load Factor

Load factor and the usage intensity is hereby the ratio of the energy consumption that varies according to the climate conditions and maximum possible energy supply. If the demand profile of the consumer is known, the average load factor per area could be calculated [42]. Since the load factor is the same for all sites, it will be minimized to the weight of 1, so the other performed criteria could have a higher influence on the final score.

3.3.5. LCOH

The economic parameter, LCOH considers the direct utilisation of the heat extracted from geothermal brine evaluating the pumping and electricity utilisation costs. Since this is only the operation cost the middle weight is given for the final calculation performance.

3.3.6. Environmental Factor

Weight 5 is given to the environmental impact since it includes the ratio of the potential NCG. Since the considered systems are closed circles the amount of NGC is not really high, but the small amounts still exist. Because of its physical properties, it is difficult to reinject it back to the reservoir.

Moreover, the radioactivity, potential water contamination, subsidence, seismicity and noise are taking part in the environmental impact criterion.

3.3.7. Global Efficiency

In [19], the authors have presented the global efficiency of the system by calculating the losses within the system. This performance includes the heat losses related to the NCG as well as the parasitic load and parasitic losses within the long pipes. Since it is mainly connected to the electrical power production, the given weight of this criterion is assigned with the weight 3 since the global efficiency of the system producing only heating power is assumed to be relatively high for all the case study sites.

4. Case Study

Different applications for the end-use of geothermal energy vary according to the geothermal water temperature and the borehole capacity at a particular location. Regarding the possibilities of high-temperature geothermal water applications, the first option is usually electricity generation and afterwards the industry, i.e., the production of alumina and paper industry, the preservation of food, the drying of agricultural products and others. Energy obtained from a geothermal source at lower temperatures can also be used both in greenhouse or greenhouse cultivation of food and flowers, in large refrigeration systems, for fish farming and in the wood industry [44].

The Croatian part of the PBS is well known for its high geothermal potential. At this area, it has been utilized since ancient Roman times mainly for balneology purposes near naturally occurring thermal springs (Varaždin and Daruvar thermal springs, Lipik, Topusko). The location of observed sites analysed in this study is shown in Figure 2. Geologically, the sites belong to the three different depressions, Savska, Murska and Dravska developed during the Alpine orogenesis. Table 5 presents the observed sites and its current state of proposed use [3].

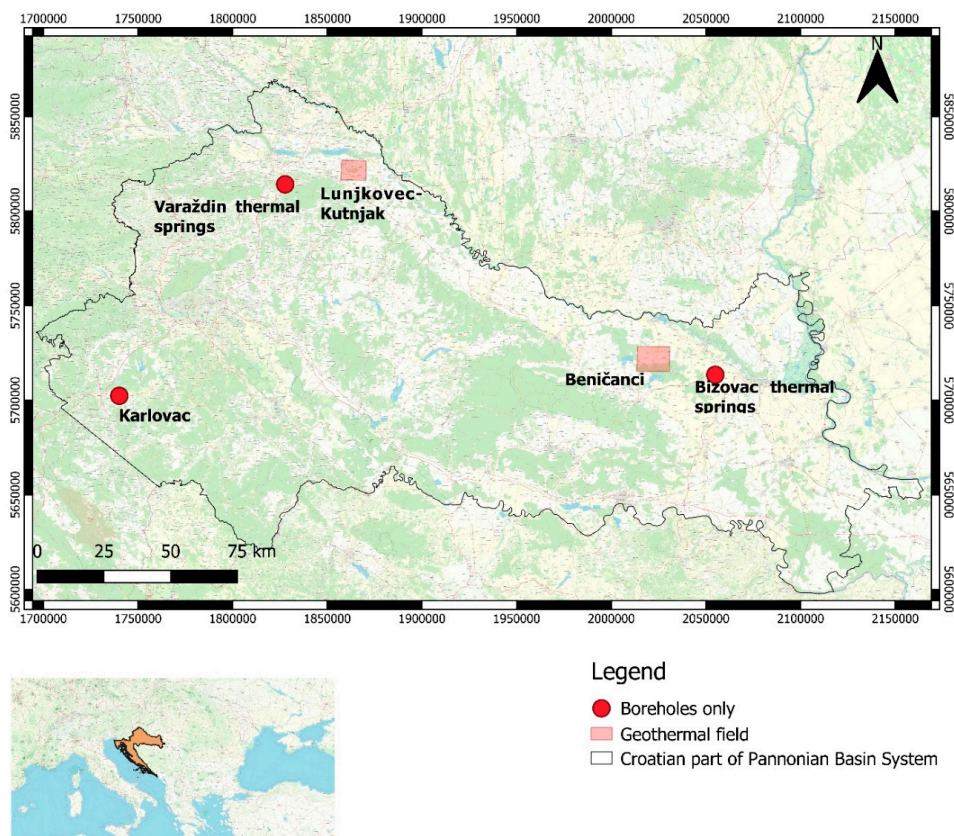


Figure 2. Observed sites.

Table 5. Observed sites current and proposed utilisation.

Site	Current Use	Proposed Use
Beničanci	Oil and gas exploration	Electricity generation
Bizovac	Balneology	Spa and district heating system
Lunjkovec—Kutnjak	No usage—exploration status	Electricity generation
Karlovac	No usage	Electricity generation and district heating system
Varaždin thermal springs	Balneology	New spa

4.1. Beničanci

Besides the usual geothermal reservoirs (either hydrothermal or the enhanced ones) there is huge potential in exploiting the existing energy located in the oil and gas fields. The high potential for geothermal exploration and exploitation could be seen in the oil field Beničanci located within the Drava river depression. The observed oil field is among the five largest hydrocarbon production fields in Croatia. While exploring the oil and gas, the conventional watering of the reservoir was conducted for the reservoir's pressure maintenance. At the Beničanci field, 106 wells were drilled for oil and gas exploitation and only 25 of them are still producing it [45]. After a decade of oil exploitation, the injected water began to appear within the oil recovery that was maintained with the reservoirs works. The oil reservoir is found in the limestone and dolomite *breccias* from Miocene lying at a depth of 1700 m. The reservoir is significant for its high porosity and permeability in amounts of 9.2% and 162–901 mD respectively. The current state of the oil field the almost end of its production life. Before its geothermal usage, the EOR (Enhanced oil recovery) method will be carried out at this field by means of CO₂ injection [46]. For reservoir development, two boreholes could be used for forming the closed-loop system. The temperature at the wellhead was measured and amounts to 126.2 °C. The temperature has a high potential for electricity generation via Organic Rankine Cycle (ORC) so the side consumer (i.e., the greenhouse or spa) can use the remaining amounts of heat. Since the pressure of the reservoir is less than the hydrostatic one, the submersible pump is installed in the production well for discharging enough flow rate for feeding the ORC unit [47,48].

4.2. Bizovac

Other hyperthermal water has been found in the Drava depression, in the village of Bizovac, Osijek-Baranja county. Three boreholes were drilled to the two high-quality water reservoirs, which were settled in the gneissic basement and the upper Miocene clastic sediments. The water of both reservoirs has a moderate mineralisation content of dissolved solids, the gneiss reservoirs contain 30 g/L and the sandstone layer 2 g/L and therefore the inhibitors should be used during the geothermal water production [49,50].

The temperature of the 98 °C has been reached while exploring the hydrocarbons, which was a starting point for its utilisation. So far, reservoir pressure issue has been solved with the freshwater injection so the production could be constantly using the submersible pump. The water used directly for the balneology purposes is discharged to the surface sewage system, which means there is no closed-loop system, which makes this method inappropriate for wastewater treatment [51,52].

The annual heat production for heating the health care facilities is 900 MWh and, in addition, the gas that is produced is used in the kitchen of the spa resort. The amount of dissolved gas reaches 1.5 m³/m³ in the gneiss reservoir and 1.3 m³/m³ in the sediments [3].

4.3. Karlovac

In the case of Karlovac, the boreholes are located in the area of the Croatian Forest Authority but are not under concession. The geothermal field site "Rečica" was discovered by the geophysical exploration of Karlovac-2 (1983) and Karlovac-3 (1988) located 10 km from Karlovac in the East-Northeast. Hot water temperatures of 139 °C were obtained from the carbonate rock complex with a depth of 3344 m. At the total bottom depth of 4145 m of the Karlovac-2 borehole, it is estimated that the temperature is

about 170 °C. According to the results of chemical analyses, the salinity of basin water is less than 1 g NaCl/dm³ and falls into the drinking water category, which will significantly simplify the cascading use of heat energy after the production of electricity in the geothermal power plant. After heat recovery, the cooled geothermal water is returned to the reservoir to support the reservoir's pressure and compliance with ecological criteria.

Potential geothermal resources of the Karlovac valley have not yet been adequately researched. According to the experts, it is possible to cross over from the fossil fuels using the geothermal hot water as a fuel, in the district heating purposes. Further steps, such as establishing the district heating system and connect it to the city of Karlovac are required. In such perspective areas, a great interest of the investors has recently been seen in investing in exploration and use in other purposes of geothermal water (from Karlovac City Administration to foreign investors) [3,53].

4.4. Lunjkovec—Kutnjak

The extremely high geothermal potential has been detected in the Koprivnica-Križevci County area. It is a result of the large normal fault in the Drava depression where the sedimentation of the sandy layers has happened above the Palaeozoic shales and Mesozoic carbonates. Therefore, the two potential locations were chosen for the geothermal energy potential utilisation so far. Near the centre of the town of Križevci, a domestic oil company found a high geothermal potential during hydrocarbons exploration in the 1980s. The project is under development in terms of district heating, swimming pools heating, and the three schools and the school's greenhouse [3].

This analysis will be focused on the other location within this area, mainly located in the mentioned county—Lunjkovec-Kutnjak geothermal field that is under development. During the last century, three wells were drilled at the mentioned area where fractured limestone and dolomites were discovered. Wells were hydrocarbons negative but the temperatures above 100 °C were measured such as the high permeability according to high drilling fluid losses via localized faults. According to the geological estimations at the depth of 3.500 m to 4.000 m, the temperature should reach 150 °C to 200 °C. The investors' plan is to drill new wells and perform well testing.

The performed tests confirmed expectations of the possibility of geothermal reservoir potential utilization in energy purposes. Boreholes under the eruptive mode gave the 53 L/s at the 6-bar pressure at the wellhead. Hydrodynamic measurements on the reservoir were conducted and showed high reservoir pressure of 217 bar. Nevertheless, it is concluded that in the perspective area the natural fluid income is small, or it is completely absent, so fluid injection is required for enhancing the hydraulic connections between the well and the reservoir.

Along with the hydrodynamic measurements, chemical tests were performed, and it was deducted that water could be used in balneology purposes as well, for rehabilitation and in healthcare. The reserves are categorised as C1 and the accumulated heat capacity amounts to 518,000 kJ/m³. The primary idea is to use the high geothermal energy potential while reaching temperatures high enough for using it in electricity generation via the Organic Rankine Cycle and second fluid consumption, and the second utilisation possibility is in agriculture and tourism [51,54].

4.5. Varaždin Thermal Springs

There were four thermal springs in Varaždin thermal springs. The hottest and most intensive is the Klokot. There was a large amount of tuff and all the buildings of the Roman period were built there, after which a deep water well was planted at a source of 2.05 m in which the water level was 0.45 m. The well allegedly gave 18 L/s of hot water. It was later buried, and thermal water was generated from the B-1 well. This has proven that thermal water flows are coming from the low temperature Triassic dolomites, and the largest quantities of water have appeared at a depth of 20–26 m. To the west of the spring Klokot, along the rocks, there were three smaller and colder springs. The distance from the main source was 700–1100 m and the temperature was 24–25 °C. They used to get a healing sludge consisting of small particles of 0.02 mm [55]. In 2000, two boreholes were drilled, namely B-5

exploitation borehole and B-6 borehole. However, the thermal water is still penetrating the outer wall of the well, and the tens of litres of water per second are lost in the submerged well.

In Varaždin thermal springs, all available resources that are beneficial to human health are used naturally for balneotherapy. The historical medical importance of the geothermal system of spa continued to the present day through the activity of the Special Hospital for Medical Rehabilitation. The importance of the use of sulphur thermo-mineral water in the Varaždin thermal springs should be emphasized, which, in addition to healthcare, also includes local, county and state frameworks. At the source of Klokot, the sulphur thermo-mineral water temperature is 56.5–57.5 °C, with a yield of 20 L/s [56]. Table 6 presents the parameters of the five observed sites located in the Croatian part of PBS presented in Section 4. The table presents parameters based on which criteria have been calculated for the final insertion into the MCDM matrix. The final calculation was made by multiplying the special weights as presented in Tables 2–4 and grades that were obtained from the calculated values and ranges obtained in the work [19]. The 5 proposed sites have been selected according to the range of resource temperatures, the current state of usage and location so their upgrade potential could be determined, e.g., if it is in current usage for balneology purposes, the MCDM shows potential for agricultural purposes.

Table 6. Site calculated data.

Parameter	Unit	Beničanci	Bizovac	Karlovac	Lunjkovec—Kutnjak	Varaždin Thermal Springs
Geothermal gradient	°C/100 m	5.7	6.1	4.3	6.2	6.2
Temperature at the wellhead	°C	126.2	96.8	140	140	57.2
Outlet temperature	°C	60	56.8	80	80	25
Flow rate	L/s	46.3	3.17	50	53	35
Corrosion and scaling	LSI	−2	0.54	1.5	2.17	0.41
Theor. Eff (electricity)	%	4	2.15	4.72	4.72	−1.63
Max. Eff (heat)	%	16.58	10.82	14.53	14.53	9.75
Global efficiency	%	4	2.15	4.72	4.72	−1.516

5. Results and Discussion

Considering global warming environmental issues as well as the growing of the market competitiveness in all sectors of the economy, renewables are recognized as a good solution for increasing energy sustainability. The Republic of Croatia already uses wind, solar, biomass and water but most of these potentials are at the coastal part of the Republic. The north-eastern part of Croatia has great geothermal potential that is used for several different final applications. Among many, five potential sites are carefully chosen according to their current state of utilization and potential considering various influencing factors such as mass flow and temperature, for instance. Implementing weights for each criterion and calculated data into a tool that is part of the DMS-TOUGE, investors are provided with the comprehensive analysis that eases their judgements. Within this study all the sites are evaluated from three different standpoints of the end-user so that the tool could be tested in an appropriate and effective way. To ease tool testing and data collection, the assumed heat extraction technology is production-injection doublet even though in some of the case study sites the number of production or injection wells is somewhat different, i.e., Bizovac thermal springs consist of three boreholes as well as the Varaždin thermal springs where four thermal springs occurred and two boreholes were drilled. Beside technical evaluation, because of the indirect impact, social and environmental influence are also observed so that the project could be developed successfully and accepted among the local community.

The sensitivity analysis of the final score on each criterion is given in Figure 2. Equal influence on the final score have the technological criterion, due to technology efficiencies, and a geological criterion which values geothermal gradient, water temperature and flow. The next most influential parameter is the economic criterion, i.e., LCOE or LCOH. Social and environmental impact are the less influential parameters that have the smallest contribution in the final evaluation of each site.

The final evaluation of the sites regarding agricultural purposes has been shown in Table 7. As it can be seen here, high temperature is not a significant parameter for these purposes, but corrosion and scaling are. These sites could be observed for agricultural and for balneology purposes, used separately or simultaneously. However, in this way, usual costs regarding inhibitors used for solving the corrosion problems are minor according to the other sites where corrosion and scaling parameters are significant. In cases such as this, it is possible to consider direct usage without transferring heat to the other fluid. The Varaždin thermal springs geothermal site is such example with the final grade 3.551 and the thermal water is used directly for the balneology purposes. The lowest grade includes the sites where the temperature is high enough, but chemical composition and distance are substantial in terms of cost and energy efficiency.

Table 7. Weighted scores for agricultural purposes.

Criterion	Beničanci	Bizovac	Karlovac	Lunjkovec-Kutnjak	Varaždin Thermal Springs
Installed capacity	4	1	5	4	3
Heat flow	20	10	20	10	10
Th. Max eff	35	35	35	35	35
Geothermal gradient	4	5	4	5	5
Fluid temperature	12	9	12	12	3
Corrosion and scaling	10	40	40	30	50
Distance to the grid	40	50	30	30	50
Load factor	2	2	2	2	2
Environmental impact	4	4	4	4	4
Social impact	4	4	4	4	4
LCOH	3	3	3	3	3
Global efficiency	4	5	3	4	5
Final Score	2.898	3.429	3.306	2.918	3.551

The essential criteria for DH and electricity generation are temperature, the efficiency of the energy conversion and overall profitability. Theoretically, the final score for some locations could be good enough for the further energy planning because of its good and stable input parameters such as distance, water quality and others but if the temperature is not high enough the potential site has to be excluded. Within this analysis, the theoretical maximum efficiency for the electricity generation is calculated as a logarithmic function what gave the negative value for efficiency, at the Varaždin thermal springs site. That means that temperatures below 100 °C have no effective usage and the sites have to be excluded from any energy usage except for agriculture, balneology and DH, which has been done, as shown in Tables 8 and 9.

In terms of DH (Table 8) Beničanci and Lunjkovec-Kutnjak sites have the highest grade; 3.677 for Beničanci and 3.403 for Lunjkovec-Kutnjak. The moderate temperature end usage, temperature difference and distance to the local users are contributing to the final evaluation of the sites. This could mainly be seen for the Karlovac site where the distance of the well is significantly far away from the first settlement what consequently affected the final score. The Bizovac site has the lowest score (2.903), which is probably unexpected since the resource temperature is high enough, but obviously, the mass flow rate had a bigger influence on the installed capacity which was one of the most important criteria. Enhancing the mass flow rates to some significant values as well as taking care of the conditions of the reservoir, i.e., maintaining the pressure at acceptable rates, is making a site feasible also for the district heating usage, since the reservoir is well developed for spreading its utilisation.

At the sites where the temperature reached a certain value, the electricity generation could be an economically feasible option in the future energy planning businesses. In addition, the other favourable conditions such as the resource temperature, distances or load factor indicate a good location for the DM's final decision on investment. Results (Table 9) showed how the sites Karlovac (2.588), Lunjkovec-Kutnjak (2.412) and Beničanci (2.265) have great potential for the electricity generation while two other sites could be diminished. In the specific cases, the site Bizovac could be considered

for the potential electricity generation site since the moderate temperatures ($>90\text{ }^{\circ}\text{C}$) are feasible for the ORC systems what will be tested within the MEET project.

Table 8. Weighted scores for electricity generation.

Criterion	Beničanci	Bizovac	Karlovac	Lunjkovec-Kutnjak	Varaždin Thermal Springs
Installed capacity	20	10	20	20	10
Heat flow	20	10	20	10	10
Th. Max eff	10	10	20	20	10
Geothermal gradient	4	4	4	5	5
Fluid temperature	40	30	40	40	10
Corrosion and scaling	1	4	4	1	5
Distance from power grid	15	25	15	15	25
Load factor	5	5	5	5	5
Environmental impact	20	20	20	20	20
Social impact	5	5	4	4	4
LCOE	10	10	20	20	10
Global efficiency	4	4	4	4	4
Final Score	2.265	2.015	2.588	2.412	1.735

Table 9. Weighted scores for district heating utilisation.

Criterion	Beničanci	Bizovac	Karlovac	Lunjkovec-Kutnjak	Varaždin Thermal Springs
Installed capacity	50	10	40	50	30
Heat flow	20	10	20	10	10
Th. Max eff	50	40	50	50	50
Geothermal gradient	4	5	4	5	5
Fluid temperature	20	15	20	20	5
Corrosion and scaling	1	4	4	3	5
Distance from power grid	40	50	30	30	50
Load factor	2	2	2	2	2
Environmental impact	20	20	20	20	20
Social impact	4	4	4	4	4
LCOH	5	5	5	5	5
Global efficiency	12	15	9	12	15
Final Score	3.677	2.903	3.355	3.403	3.242

Based on the good business practice of the first power plant in Croatia, Velika Ciglena, as well as the positive feedback of the local community, the Lunjkovec-Kutnjak site, because of its qualitative conditions and confirmed reserves, is currently in the power plant development process. With the proposed methodology this end-use application was confirmed.

6. Conclusions

The comprehensive MCDM analysis on geothermal sites settled in the Croatian part of the PBS was performed to help the investors when developing a long-term investment strategy in renewables since costs for energy supply are increasing. For the purposes of the MEET project, the analysis was performed on five different sites which are located at different parts of the country, meaning that they differ in geological conditions as well as in their current state of the usage. To achieve further economic development, all the aspects should be considered. Beside techno-economic evaluation, the environmental and societal analysis are included within this study, which might help the potential investors/industries to reach a cost-effective business strategy.

All the sites are assumed to have potential for all end-use applications. For the agricultural purposes, the main criteria that have been observed and highlighted within the MCDM analysis are heat flow, distance to the grid, and corrosion and scaling appearance. According to the existing sites (Bošnjaci, Sveta Nedelja) and discovered sites, high geothermal potential that has been found in the area of the Croatian part of PBS the renewables. In particular, geothermal energy could guarantee an adequate source of energy for a sustainable development of the agriculture in an environmental and economic manner.

Based on the results, the best-suited site for the agricultural purposes is at the Varaždin thermal springs site where the temperature is almost neglectable but still exploitable. The other parameters are distance and water quality, which give a significant advantage of this site compared to the other sites where the temperature is above 100 °C. Future development of the site in agricultural purposes is a potential strategy plan. The proposed use would be the greenhouse heating used for vegetables and flowers cultivation, as well as the extension of the spa capabilities.

The final examination of the MCDM analysis for the electricity generation purposes has been done according to the several substantial criteria, i.e., installed capacity, heat flow, theoretical maximum efficiency, fluid temperature and LCOE. The performed analysis showed that Karlovac (2.588), Lunjkovec-Kutnjak (2.412) and Beničanci (2.265) sites have great potential for the electricity generation while two other sites could be diminished. As a specific case, the site Bizovac might be considered since potential electricity generation could be feasible at low to moderate temperatures (60–90 °C) using ORC systems, which will be observed within Horizon2020 MEET project.

The main parameters that have been observed for the MCDM analysis for the direct heat utilization in the DH purposes are installed capacity, heat flow, theoretical maximum efficiency and distance to the final user. The site where the mass flow is high enough should be approached first since it is one of the main and most crucial parameters for the DH performance. The Beničanci site (3.677) has the greatest potential with the high flow rate (46.3 L/s) and available resource temperature (126 °C) as well as the site Lunjkovec-Kutnjak (4.403) where resource temperature reaches 140 °C and the flow rate is 53 L/s.

Concerning environmental and current climate awareness, geothermal energy in the energy sector has brought positive social, economic and environmental feedback. First, the geothermal power plant in Croatia (Velika Ciglena) has opened the opportunity for the future development, exploration and investigation into the geothermal energy sector in Croatia. To help to make decisions, a tool developed within the H2020 MEET project will help stakeholders to conduct the techno-economic analysis via multi-criteria decision analysis for selecting the most appropriate micro-location. Dealing with renewable and sustainable energy solutions, this kind of analysis could help to point to the most doubtful parameters that should be taken care of in the final economic, environmental and visual manner. Further development of this matrix will proceed by adding more criteria (geological, technological and economic) for the site evaluation considering also the oil fields where the exploitation of the hydrocarbons will not be possible in the near future since most of the infrastructure as well as the boreholes already exist. Moreover, future work on the MCDM analysis development will include the optimization model as well as the methodology where criteria become variable. Also, the methodology and tool itself provide the comparison of a several scenarios and sites at the same time, providing the investor with an overview of the final scores in the actual time frame and allowing for suitable strategy development.

Analysing the obtained results of the MCDM analysis, this study showed numerous advantages for geothermal energy utilization. Since utilization customs already exist, as well as the boreholes and data, only further development and investment is necessary. Utilization of geothermal energy could increase the employment rate, which is the one of the most significant parameters, since the observed areas are situated in undeveloped areas in Croatia. Awareness of geothermal energy as clean energy, as confirmed by this analysis, could attract investors, thereby increasing the living standard of the local community.

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Abbreviations

C&M	Construction and Maintenance
CAPEX	Capital Expenditure
CHP	Combined Heat Power
DH	District Heating
DM	Decision Maker
DMS-TOUGE	Decision-Making System-T
EOR	Enhanced Oil Recovery
FT	Full Time
GHG	Greenhouse Gas Emissions
HEX	Heat Exchanger
H2020	Horizon 2020
LCOE/H	Levelized Cost of Electricity/Heat
LSI	Langelier Saturation Index
LUI	Land Use Intensity
MCDM	Multi-Criteria Decision-Making
MEET	Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials
NCG	Non-Condensable Gasses
O&M	Operating and Maintenance
OPEX	Operation Expenditure
ORC	Organic Rankine Cycle
PBS	Pannonian Basin System
TDS	Total Dissolved Solids
WDM	Weighted Decision Making

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