Multidiszciplináris tudományok, 12. kötet. (2022) 4 sz. pp. 61-72 **https://doi.org/10.35925/j.multi.2022.4.7**

INVESTIGATING THE REOPENING POTENTIAL OF LOW ENTHALPY ABANDONED OIL WELLS WITH BAYESIAN NETWORKS

Marcell Kárpi
engineer, University of Miskolc, Institute of Applied Earth Sciences
3515 Miskolc, Miskolc-Egyetemváros, e-mail: **afkkarpm@uni-miskolc.hu**

Szilvia Szilágyiné Sebők
research associate University of Miskolc, Institute of Applied Geosciences
3515 Miskolc, Miskolc-Egyetemváros, e-mail: **szilvia.szilagyine@uni-miskolc.hu**

Renáta Zákányiné Mészáros
senior research fellow, University of Miskolc, Institute of Applied Earth Sciences
3515 Miskolc, Miskolc-Egyetemváros, e-mail: **zakanyine@icloud.com**

Abstract

The study examines the suitability of a new analytical method that can provide reliable results to end users during geothermal investments. The use of individual risks, influencing factors, and evidence with appropriate complexity can support sound, considered decisions. In the research work, we investigated the reopening potential of three barren wells for heat recovery in a sample area in north-eastern Hungary using Bayesian probability-based nets. In our model, the replacement of current fossil energy use with geothermal energy was simulated, the effect of which was expressed in tonnes of CO_2 emissions saved. Our studies confirmed the suitability of reopening and geothermal utilization of low-enthalpy infertile wells.

Keywords: *geothermal, climate change, CO_2 emissions, energy, fossil, renewable, Bayesian network*

1. Introduction

The average geothermal flux in Hungary is 90-100 MW/m^2, which is higher than the continental average. The geothermal gradient on Earth is 30-33°C/km, while the average temperature in Hungary is 42-45°C/km. It can be said that Hungary has a favourable geothermal potential both in Europe and worldwide.

Although the country is not located in an active volcanic region, its geothermal potential is outstanding both in Europe and internationally. The temperature increase with depth is high, at around 45°C/km, compared to an average of 20-30°C/km on Earth. Thus, at a depth of 500 metres, the average temperature reaches 35-40°C, at 1000 metres 55-60°C, at 2000 metres 100-110°C and in warmer areas up to 120-130°C. In more than 70% of the country, hot water with temperatures of 30°C or more can be found at depths of several kilometres underground in the form of debris deposits (sand, sandstone) or fractured limestone and dolomite. In Hungary, the geothermal potential is estimated to be at least ~60 PJ/year, even from low levels (Szita and Kovács, 2015).

Geothermal gradients and thick sedimentary layers create suitable conditions for low and medium enthalpy (30-100 °C) wells in many areas. Among these areas, the southern Great Plain (Nagy-Alföld) stands out, where medium enthalpy systems can be used in almost all municipalities and in some places even extract enough heat from reservoirs to generate electricity. In general, the use of the energy content of hot spring water for agricultural and building heating is the most important, followed by heat pumps without shallow water production. On paper, the use for bathing has the highest extracted energy (352 MW), but the nature of the use is different and is mentioned separately. Building heating and district heating account for 188 MW, greenhouse heating for 271 MW and crop drying for 25 MW.

Most of the wells produce from upper Pannonian reservoirs, mostly in the ascending mode, and only a small proportion of them are located in deep karst reservoirs. According to the well register publications and the Supplement VII of the Hot Water Wells of Hungary with corrections, the number of hot water wells in the country is 1622. In addition, 170 barren hydrocarbon wells certified by the Hungarian Mining Asset Management Ltd. are also considered as potential hot water wells (Tóth, 2016).

A Bayesian network, abbreviated BN (belief networks or causal networks), is a concept first introduced by Judea Pearl in 1988. They are basically a graphical representation based on total probability and Bayes' theorem. Bayesian networks were developed by the British statistician A. Philip Dawid in the 1970s and, based on his pioneering work in the representation of probabilistic independence and probabilistic independence inference, provide an intuitive and efficient way of representing large-scale models, making the modelling of complex systems practical. Bayes nets provide an easy-to-use and coherent way to represent uncertainty, and can be a substitute for representing uncertain or incomplete information. The increasingly widespread use of Bayes nets has changed the way the scientific world thinks about probability.

The condition of abandoned wells can vary widely around the world, from cases where the cost of rehabilitation is close to the cost of a new well, to cases where wells are continuously maintained even after abandonment. Rehabilitation not only reduces costs, but also addresses the potential pollution problem associated with such wells (Cheng et al., 2017). These factors make the feasibility of reusing abandoned wells for geothermal purposes an increasingly important research topic worldwide (Kujawa et al., 2006).

In Hungary, the temporary closure or permanent abandonment of wells is regulated by the Mining Act and other environmental legislation in force. In the event of permanent abandonment of a well, the most stringent measures must be taken to ensure full restoration of the site, in addition to the removal of the uncemented casing stacks. This work can have serious financial consequences and it may be in the operator's interest to find a solution to continue operating the depleted oil and gas wells. However, in the case of technically rehabilitated wells, the possibility of re-use is ruled out, as in the case of wells with cement plugs, the well can be reopened if the cement plug is reopened, but in many cases the well is completely plugged or cemented to the surface.

Three wells were selected for reopening based on several criteria. The criteria used for the classification are the year of drilling, the original function of the well (water production), daily production, discharge temperature, daily geothermal energy production, length of the filter section and distance from infrastructure. On average, the following values were obtained, on a scale of 0 to 5: Demjén K-10: 4.25; Bogács K-9: 4.25; Boconád B-17: 3.87. According to the classification method, all three wells are suitable for reopening for geothermal thermal recovery (Fejes et al., 2021).

2. Selection of the sample area and energy assessment of the municipalities

Around 30% of the wells drilled in Hungary for the exploration and production of hydrocarbons are located in inland areas and 70% are located in the open countryside. For further development, it was considered advisable to investigate wells located in locations suitable for acquiring thermal capacity, to finance the very high investment costs and to obtain appropriate tenders.

The criteria for selecting the three wells suitable for reopening are set out in Table 1. These wells scored a maximum of 5 points: Demjén K-10: 4.25; Bogács K-9: 4.25; Boconád B-17: 3.87. The evaluation method indicates that all three wells are suitable for reopening for geothermal exploitation.

The first well selected for reopening was B-17 in the village of Boconád, with an average score of 3.87. The lowest scores were given for the year of drilling, the temperature of fluid injection and the specific energy extracted at a depth of 1 m in the well's vicinity. Of the three wells selected, this was the one with the lowest temperature but capable of supplying thermal energy to the settlement.

Well B-17 is a water production well with a minimum daily flow of 1152 cubic metres and a maximum daily flow of 2678 cubic metres. The total length of the filtration section is 29 meters and the infrastructure is very close by at 1.33 kilometers, so transportation is not a problem and will not be a significant factor in the final system payback. The values shown in Figure 1 are plotted on polygons and compared with the other wells below. Beetle B-17 is therefore clearly a poorer performer.

Bogács K-9 was the second well selected for reopening, with a rating of 4.25 points. No parameter received a rating below 3. The lowest ratings were given for the liquid outlet temperature, the maximum specific energy extracted from 1 m of well medium and the total length of the filter section. Of the sampled wells, this was the second highest yielding well. The total distance from the infrastructure is 1 km, which is the most favourable of all well locations. The well selected is the second highest in temperature but should supply the largest population. The 246 505 MJ of energy that could be extracted per day would be sufficient to meet the thermal energy needs of the city.

The third well selected is Demjén K-10, which has the highest extraction temperature and the second largest settlement size, with a total of 331 dwellings. Like the Bogács well, it scored 4.25 points. The most outstanding parameters are the year of drilling (the youngest of the three wells), the water temperature and the extracted thermal energy. Only the energy extracted from the well environment and the length of the filter section scored 3 points or less. Although it is the hottest well in terms of water temperature, the economic feasibility of reopening it may be questionable, given the distance to infrastructure of 5 km.

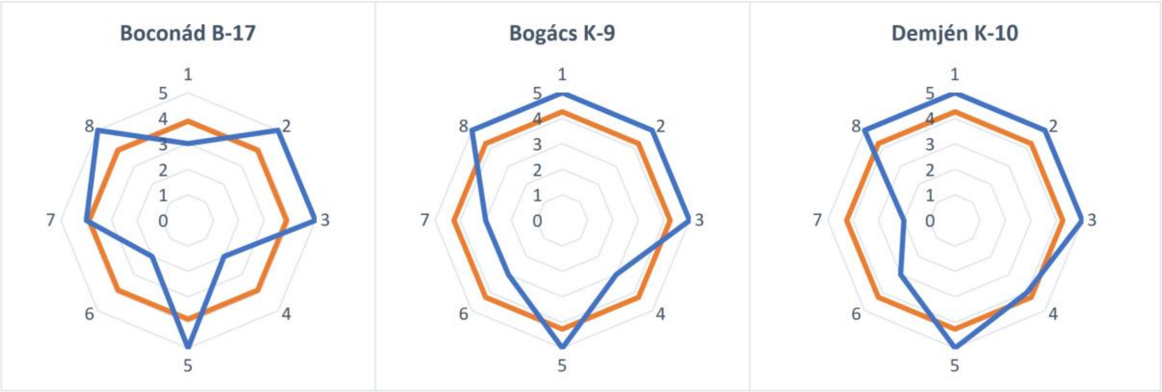

Figure 1. *Graphical representation of the geothermal energy rating of wells*

After re-examining the wells as part of the initial study and assessing the climatic conditions in the vicinity of the wells (about 60 km), we started the energy analysis. This was important because we needed to know whether the new wells to be put into operation would be able to provide energy for the population and how many tonnes of CO_2 emissions could be saved by introducing clean technologies.

According to the database of the Central Statistical Office, the use in Demjén is mainly residential, municipal and agricultural, with a smaller share of industrial installations.

In Demjén, the total CO_2 emissions associated with electricity consumption are 605 tonnes/year, almost equal to the footprint of natural gas consumption, which is 808 tonnes/year. The consumption of natural gas is also predominantly in households and mainly in industry, agriculture does not play a role and utility consumption is negligible.

As for conventional fuels, coal and firewood have a minimal but insignificant impact, with emissions of 101 tonnes of CO_2 per year. In Demjén, the municipality does not use these fuels, only the population. Residents heating data breaks down into 8.5356 TJ of firewood and 0.77562 GJ of coal, for a total of 331 dwellings.

Table 1. *Detailed geothermal energy well parameters tested in the wells (Szűcs et al., 2021)*

1.	***Year of drilling***
	(scale -1970 - 1; 1971-1980 -2; 1981-1990 -3; 1991-2000 - 4; 2001- 5)
2.	***Well function*** *(scale: technically remediated, recultivated - 1; technically remediated - 2; made safe by cement plugging - 3; designed for oil production - 4; water producing, water recovery, gas producing - 5)*
3.	***Fluid volume (m^3 /day) [Measured - Estimated]***
	(scale: 1-20 -1; 21-40 - 2; 41-100- 3; 101-500 - 4; 501- 5)
4.	***Fluid outlet temperature (°C) [Measured - Estimated]***
	(scale: 4-20 -1; 21-40 - 2; 41-60 - 3; 61-85 - 4; 86 - 5)
5.	***Geothermal energy recoverable from fluid (MJ/day):***
	(scale: 0-500 - 1; 501-1e -2; 1e-5e - 3; 5e-10e -4; 10e- 5)
6.	***Maximum specific (average) geothermal energy (MJ) that can be extracted from 1m of the well environment***
	(scale: 0-100 - 1; 101-200- 2; 201-400 - 3; 401-800 - 4; 801- 5)
7.	***Total length of filtered section (m)?***
	(scale: 1-5 -1; 6-10 - 2; 11-20 - 3; 21-40 - 4; 41 - 5)
8.	***Total infrastructure distance (km)?***
	(scale: 0-5 -5; 5-10 -4; 10-20 -3; 20-30 -2; 30- 1)

Bogács is the largest of the municipalities examined, so its electricity consumption is several times that of Demjén. In 2019, total consumption was nearly 16.92 TJ, mainly residential and industrial, as well as utilities and to a lesser extent industrial plants. The annual CO_2 emissions associated with electricity consumption are 1675 tonnes. A review of the city's carbon footprint shows that gas consumption here far exceeds emissions from electricity consumption. The city's consumption is mainly in the domestic and other categories. Total emissions are 2161 tonnes per year. Analysis of municipal and household consumption of firewood and coal shows that the municipality of Bogács does not use these fuels. There are 968 dwellings in the municipality with a consumption of firewood of 1 569 tons, corresponding to 28.9224 TJ per year. Coal consumption is 98 tonnes per year, or 2.4516 TJ. This results in CO_2 emissions of 322 tonnes per year, which is significantly lower than for electricity and natural gas. Looking at Boconád's data, it can be seen that the carbon load from electricity consumption is almost the same as that of natural gas, slightly less, at 1136 tonnes. The total electricity consumption is 11.358 TJ, with residential consumption dominating, other uses accounting for 3.3516 TJ and industry coming third with 0.936 TJ. If we look at the gas consumption of Boconád, we see much lower figures, as the municipality is also relatively small and has no significant industrial activity. In 2019, direct household gas consumption was 2.1492 TJ, excluding industrial and agricultural consumption. The corresponding CO_2 emissions are 1 205 tonnes per year. As for the data on firewood and coal consumption, the 639 dwellings in the municipality of Boconád consume 1009 tonnes of firewood and 68 tonnes of coal per year. In terms of energy, 18.5976 TJ comes from firewood and 1.7028 TJ from coal. The associated CO_2 emissions of 221 tonnes per year are the second highest compared to other municipalities and are related to the size of the city. The municipality does not use this fuel here either. Demjén and Boconád have similar population sizes, which is reflected in the use of conventional energy sources. The municipality of Bogács is responsible for 51% of CO_2 emissions from wood combustion and the switch to geothermal energy will have the biggest impact. Figure 2 shows the combined use of conventional fuels, which shows that Bogács stands out in terms of conventional fuel use due to its size relative to other municipalities. It has wells with the second highest temperature, which would eliminate a significant part of the CO_2 emissions from conventional energy use, and would even leave buffer energy in the wells.

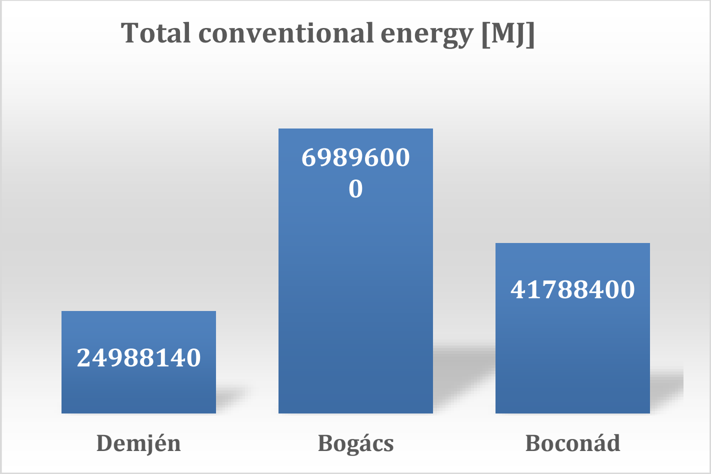

Figure 2. *Aggregate annual consumption of conventional energy in the three municipalities*

3. Meeting the energy needs of municipalities through geothermal wells

Our calculations take into account data and the magnitude of CO_2 emissions from electricity consumption, firewood and coal consumption in cities and residential areas, and natural gas consumption. As shown in Table 2, the well with the most suitable temperature is the Demjen well, which produces the most heat and, according to its calculated capacity, provides the city's heating needs in less than six months. However, this is a fictitious figure, as heat cannot be stored in advance, so in reality this figure means that the wells can supply twice the calculated amount at one time. Bogács is second in terms of the amount of heat that can be produced, but has the worst payback period. This is because it is the largest of the three cities, so it should provide more users. Overall, all three wells are capable of producing enough heat to meet the annual heat demand.

Table 2. *Geothermal energy supply calculated as a function of municipal energy demand*

	Well temperature [°C]	**gas energy [MJ]**	**wood energy [MJ]**	**carbon energy [MJ]**	**Total conventional [MJ]**	**Number of production days to meet annual energy demand?**
Demjén	66.7	14382000	9830520	775620	24988140	157
Bogács	54.5	38522000	28922400	2451600	69896000	284
Boconad	39.6	21488000	18597600	1702800	41788400	222

Table 3 shows the utilisation of the wells, with the Demjen well operating at less than half its capacity when reopened. This also means that there is still enough space in the area for industrial buildings or any kind of institution and the wells will be able to meet the demand.

Table 3. *Utilisation as a function of capacity and municipal energy demand*

	Number of production days to meet annual energy demand	**Well utilisation (%)**
Demjén	157	43.01
Bogács	284	77.81
Boconad	222	60.82

The utilisation rates of the wells are shown in Table 3, with Demjén K-10 having the highest buffer capacity, Boconád B-17 second and Bogács K-9 third. Bogács has the highest annual heat demand as it is the largest municipality, while Demjén is the smallest. As a result, Demjén has the lowest utilisation rate, as shown in Table 3. Although coal use is not significant in any of the municipalities, it is important to discuss in terms of the transition to cleaner technology. In addition, the biggest change in coal consumption is in Bogács, where half of the consumption comes from this municipality.

Table 4. *Annual energy balance of selected wells*

	Annual heating energy demand [MJ]	**Annual energy extraction from wells [MJ]**	**Well free capacity [MJ]**
Demjén	24988140	58242685	33254545
Bogács	69896000	89974325	20078325
Boconad	41788400	68808705	27020305

The buffer energy and the heating energy demand are illustrated in Figure 3. The free capacity of the well is a calculated value, the annual heating energy demand is derived from the conventional fuel use obtained during data collection. It can be seen that Demjén K-10 has the largest free capacity, also due to the fact that it is the smallest of the municipalities studied, but has the highest temperature well. The smallest free capacity is found in Bogács K-9, as it has the highest annual heating energy demand.

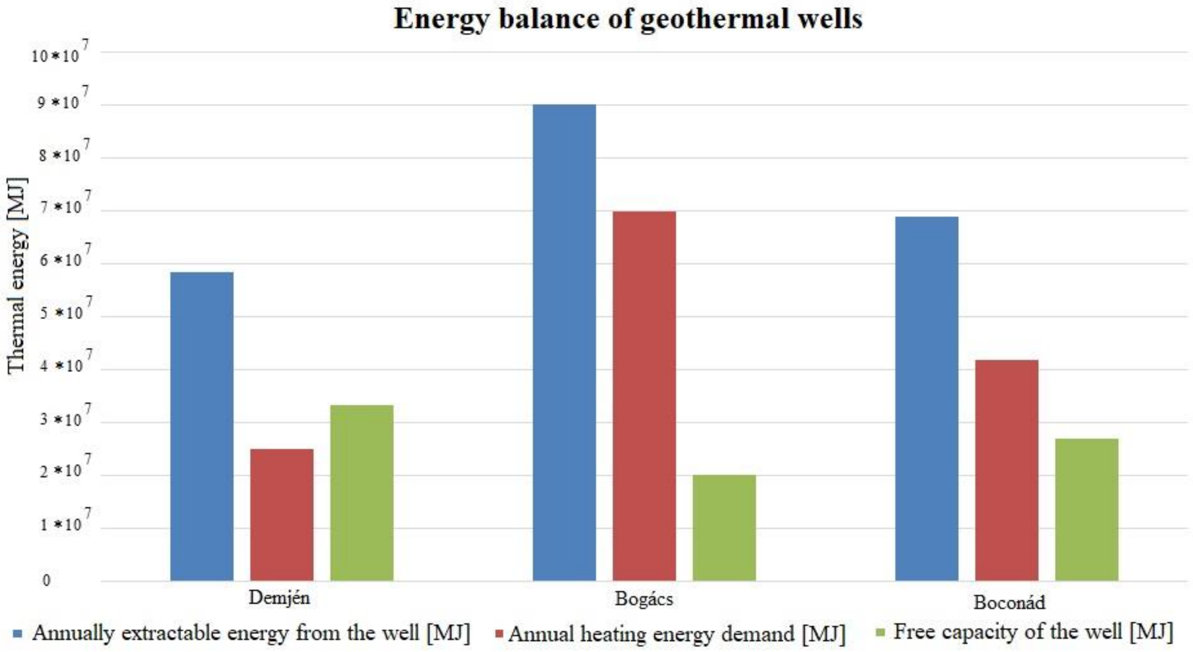

Figure 3. *Production capacity of wells and calculated spare capacity*

In the course of the research work, the heating needs of the three selected municipalities in the North-Eastern study area were analysed and it was found that the heating energy demand calculated on the basis of the consumption of conventional fuels could be fully covered by the reopening of three existing and abandoned geothermal wells. Moreover, the system would operate with a significant buffer capacity to meet the heating energy needs of any future buildings in the municipalities. The reopening of such wells, which are of no interest to the oil industry and have a barren but usable heat potential, would not only be an environmentally sound solution, but would also be in line with the principles of the circular economy model.

4. Application of the Bayesian network

4.1. Theoretical background on the applicability of Bayesian networks

The theoretical view that Bayes nets can be used to represent independence and that the absence of a relationship between any two variables X and Y implies (possibly conditional) independence between them is counter-intuitive and not easy to handle in practice (Aguilera et al., 2011). The traditional approach is that Bayes nets are causal graphs in which each relationship (face) represents a direct causal effect between the variables to which it is related. A directed link from X to Y represents the information that X is a causal factor of Y. Although this view is informal, and it is easy to construct mathematical counterexamples, it is straightforward and widely used by almost all those who apply Bayesian networks in practice. It is a well-established assumption that causal graphs automatically lead to the correct independence scheme. The absence of relationships between pairs of variables expresses the simple fact that there are no causal effects between variables. The independence between pairs of variables is derived from the structure of the graph, i.e. the qualitative part of the network. Thus, Bayesian networks can be constructed solely on the basis of our understanding of the causal relationships between the variables in the model.

The structural properties of Bayesian networks and the conditional probability data tables associated with their nodes allow for probabilistic inference within the model (Molina et al., 2012). In Bayesian networks, probabilistic inference is induced by observational evidence. Observed nodes are called evidence nodes. Observed nodes are instantiated, which in the simplest case means that their outcomes are deterministic. The effect of evidence can propagate through the network, changing the probability distributions of other nodes that are probabilistically related to the evidence.

4.2. Aspects and use of net construction

The design of the network will take into account several aspects: heat use by industry, agriculture and households, sufficiency of heat supply, attitudes to the switchover, cost-effectiveness and the need to encourage public support. As mentioned above, a network can have several nodes. These nodes include opportunity, solution and value nodes. The correct use of these nodes has a significant impact on the proper functioning of the network, and the connections (facets) or lack of connections between them can provide answers to various questions. It is important to include all the questions that may be key to the decision, but if the first question, such as the question of project economics, is answered in the negative, then it is not worth using the network, as the other questions will not make sense.

When designing nodes and links, it is important to note that from a practical point of view, the net will never be complete, i.e. there will always be a set of criteria that allows for further expansion, and therefore existing link networks need to be designed and tested by experts, which is paramount to ensure the complexity of the net, and the above factors may limit its scalability in terms of computational performance. This study aims to assess the state of the art in this area and provide a tool to support the implementation of green energy, provide data to secure its needs and support decision makers.

Figure 4 shows the underlying causal tree, which illustrates the relationships and is complemented by key questions. The causal tree is essentially almost a Bayes net, which can be easily transformed by changing the nature of the nodes (possibility, value, decision) and increasing the probability. However, we use this grid only to represent our ideas.

The initial question is the economics of reopening wells, which requires a yes answer for further investigation. Next comes the question of the sufficiency of the heat produced by the wells, which was answered in the data collection in the chapter above, with a yes answer for all three municipalities, leaving a buffer capacity of 20-40% in some cases. If the user wishes to use this model for other areas, we have included a "open a new geothermal well" node, this is required in case the answer to the previous question is no. These branches converge in the node " renewable energy use increases", in which we have also included solar energy as an addition, as solar energy can also be used to power the pumps. The solar energy node also has an impact on transport, which is not discussed in the communication as we do not have municipal data, so we do not know the impact of the switch to electric transport. The most important impact in terms of geothermal energy is the reduction in the use of conventional fuels and consequently the substitution of coal, wood and gas fuels. This was included in another branch of the model, which also runs into the node of CO_2 reduction. The decreasing CO_2 would eventually lead to changes in the climate maps, which would modify the optimistic and pessimistic projections of

ALADIN, in addition to the RegCM climate models in the area. Based on the CO_2 emissions saved after the switch to clean energy, the climate maps could be modified by the relevant experts.

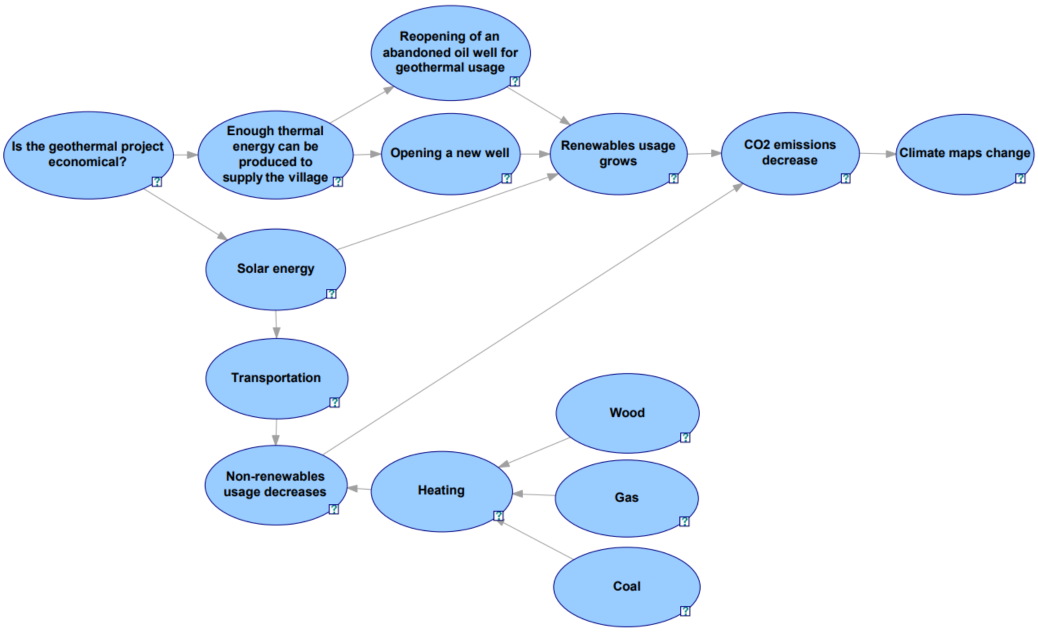

Figure 4. *The geothermal adaptation project flowchart, with issues that arise in the process*

The Bayesian test network we developed is shown in Figure 5, where the final result is that CO_2 decreases in the area.

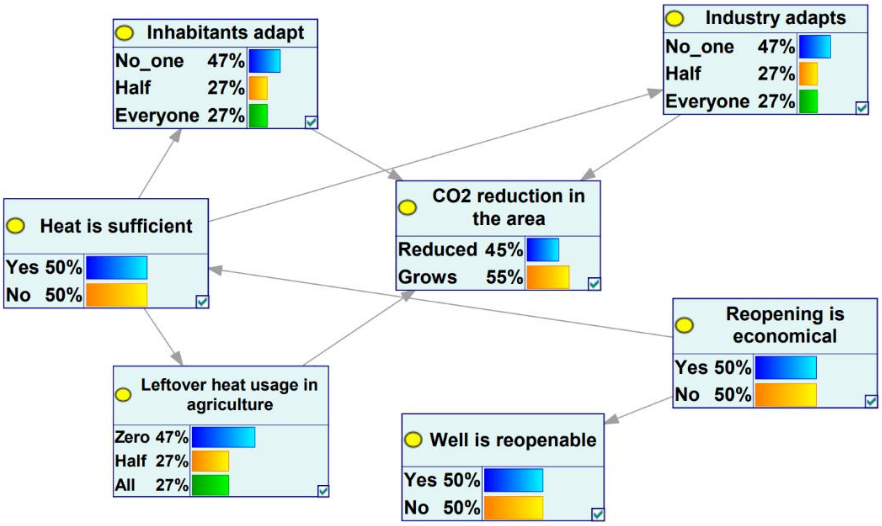

Figure 5. *The Bayesian test network, with estimated values*

Since we know that the Bayes theorem states that we want to know the probability of what happened earlier in the future in light of what happened later, we can use the network to see how the others change by changing the values of this node. It goes without saying that anyone who will later use this network is free to change the other probabilities, as each program may have different, more or less, influencing factors that need to be deleted or added. This net can be considered as a framework, in fact a completely general model based on the simplest environment (rural villages), with a small population, minimal agriculture and negligible or even non-existent industrial activity.

5. The results network

The network produced as a result of our research is shown in Figure 6. By incorporating the key determinants outlined in the causal tree, together with the inferences drawn from the behaviour of the test network, we have constructed a model that gives the saved CO_2 emissions in tonnes as a function of the switch of fossil energy consumers. In the network, a combination of evidence nodes, chance, decision, and value nodes provide the results. The evidence nodes are the suitability of the well for reopening and the sufficient heat quantity, which are supported by the well evaluation method and the energy calculations. The economic viability of reopening depends on the decision of industry experts, the technical condition of the well and the infrastructure. The wells selected are all located in the hinterland of the municipalities. State aid for the relocation was also a factor to be taken into account. The probabilities of the three groups of consumers, population, industry and agriculture, were established by studying the areas under study.

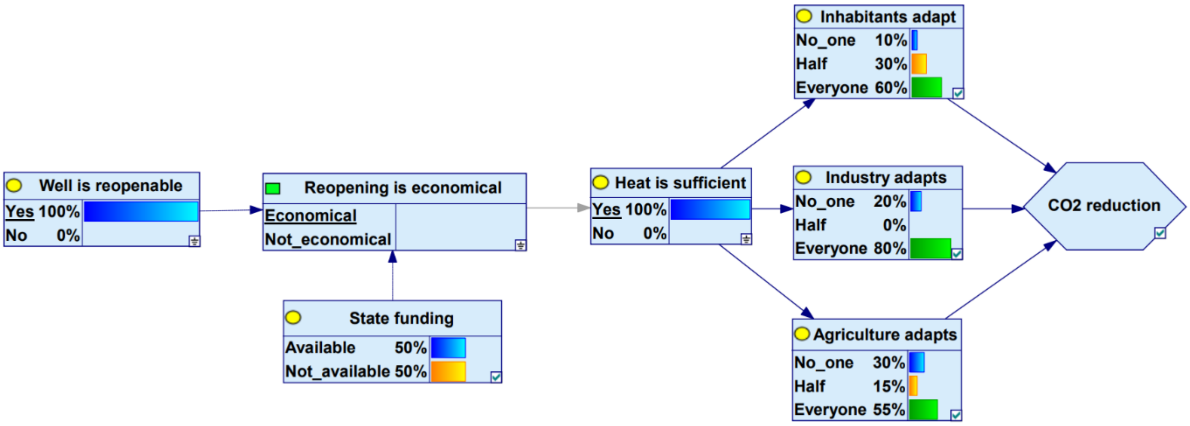

Figure 6. *The results network*

These nodes point to the CO2 saved node, where a total of 27 different cases can occur, illustrated in Table 5. The table is composed of nine cases of three nodes, providing the 27 pieces of data. It can be seen that the first figure shows 0 tonnes of CO2 saved, because neither residential, industrial nor agricultural heat use has been converted to any extent. The figures increase all the way up to over 2,000 tonnes as the switchover becomes more and more realised.

The approach is straightforward, a network of this size does not pose a computational capacity problem for a modern computer, and millions of cases can be calculated. Our example is representative of how illustrative the Bayesian approach can be for such a problem.

Table 5. *CO2 tonnes saved as a function of adapting geothermal heating*

Inhabitants	No one								
Industry	No one			Half			Everyone		
Agriculture	No one	Half	Everyone	No one	Half	Everyone	No one	Half	Everyone
CO2 [tonnes]	**0 t**	**15.165 t**	**30.33 t**	**16.5 t**	**31.655 t**	**46.83 t**	**33 t**	**48.165 t**	**63.33 t**
Inhabitants	No one								
Industry	No one			Half			Everyone		
Agriculture	No one	Half	Everyone	No one	Half	Everyone	No one	Half	Everyone
CO2 [tonnes]	**1097.15 t**	**1112.32 t**	**1127.48 t**	**1113.65 t**	**1128.82 t**	**1143.98 t**	**1130.155 t**	**1145.32 t**	**1160.48 t**
Inhabitants	No one								
Industry	No one			Half			Everyone		
Agriculture	No one	Half	Everyone	No one	Half	Everyone	No one	Half	Everyone
CO2 [tonnes]	**2194.31 t**	**2209.47 t**	**2224.64 t**	**2210.81 t**	**2225.975 t**	**2241.14 t**	**2227.31 t**	**2242.475 t**	**2257.64 t**

6. Summary

In this study, geothermal energy is presented as an optional energy source and evaluated in terms of its applicability in a given sample area. Following the evaluation of several abandoned wells, an area in the North-East of the country was selected for the evaluation and the development of the basic model. Since the area presented above contains several abandoned wells, the local climate was assessed based on climate adaptation model maps available online, with respect to the feasibility of a geothermal investment. Beyond this, the feasibility of a hypothetical programme was assessed over a broad spectrum using Bayesian nets to assess the potential for a geothermal energy transition in the same area. We concluded that the Bayesian network we presented can serve as a great decision support tool for similar types of investment questions or other problems in the natural sciences.

The model we have presented is an idealized, simplified case, but the applicability of the network has been demonstrated for more complex approaches, and we plan to extend the spectrum of the analysis and integrate increasing amounts of data to obtain more and more accurate probability values.

In conclusion, our research has demonstrated and validated the applicability of Bayesian networks in geoscience, including geothermal investments, in supporting the necessary decision support criteria.

Literature

[1] Szita. G., Kovács. Á. (2015). Geothermal energy in Iceland. http://mgte.hu/geotermalis.php?cikkek=1566

[2] Tóth, A. (2016). *The geothermal atlas of Hungary*. Hungaryan Energy and Public Utility Regulatory Authority, Budapest, pp. 8-38.

[3] Cheng, W-L., Li, T-T., Nian, Y-L., Xie, K. (2017). *An analysis of insulation of abandoned oil wells reused for geothermal power generation*.

[4] Kujawa, T., Nowak, W., Stachel, A. A. (2006). Utilization of existing deep geological wells for acquisitions of geothermal energy. *Energy*, 31(5), 650-664. **https://doi.org/10.1016/j.energy.2005.05.002**

[5] Aguilera, P. A., Fernández, A., Fernández, R., Rumí, R., Salmerón, A. (2011). Bayesian networks in environmental modelling. *Environmental Modelling & Software* **https://doi.org/10.1016/j.envsoft.2011.06.004**

[6] Molina, J., Velázquez, D., García-Aróstegui, J., Pulido-Velázquez, M. (2012). *Dynamic Bayesian networks as a decision support tool for assessing climate change impacts on highly stressed groundwater systems*. **https://doi.org/10.1016/j.jhydrol.2012.11.038**

[7] Szűcs, P., Turai, E., Zákányi, B., Ilyés, Cs., Fekete, Zs., Kilik, R., Mádai, V., Móricz, F., Nyiri, G., Szilvási, M., Vass, P. (2021). *Complex evaluation of abandoned hydrocarbon wells for geothermal use in North Hungary*. In: Proceedings World Geothermal Congress 2020+1, Reykjavik, Iceland, April - October 2021, pp. 1251-1257, 7 p.

[8] Fejes, Z., Szűcs, P., Turai, E., Zákányi, B., Szabó, N. P. (2021). Regional hydrogeology of the Tokaj Mountains world heritage site, North-East Hungary. *Acta Montanistica Slovaca*, 26(1), 18-34, 17 p. **https://doi.org/10.46544/AMS.v26i1.02**