Report on
Assessment of the geothermal resources of Albania

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Executive summary

Technology developed remarkably during the 20th century, especially in the second half. All these developments made unbelievable progress possible regarding the population's living standards. Still, having a good quality of life with an energy supply is only possible with unintrupted access to energy. Thus, the planetary energy demand is increasing very rapidly. Different energy and raw materials sectors and countries adopted various approaches to classify and manage the resources. However, new challenges to the production distribution and utilization of energy and raw materials have emerged in recent years, demanding innovative approaches for an integrated management system. The 2030 agenda for Sustainable Development defines a clear pathway to address the challenges holistically. Earth, our planet, which provides us with the only living environment, represents a significant energy source in and above ground.

The lack of worldwide standards, guidelines, and codes has hampered consistent and comparable estimation and reporting of the geothermal potential, especially in small countries such as Albania, leading to ambiguities and limiting the understanding of the viability of potential projects in the sector. The United Nations Framework Classification for Resources (UNFC), constituting a voluntary, three-dimensional system (feasibility, economic viability, and geological assessment) with the common goal of developing international schemes for the classification, reporting, and management of energy and mineral resources, was the guideline for the preparation of this report.

Albania is a small country with only 28 787 km^2 surface area and around 4 500 000 inhabitants, situated in the southwestern part of the Balkan Peninsula. Though it is, a small country could be considered relatively rich in natural resources, including fossil and renewable fuels. Like the other Balkan countries, Albania is next to the subduction boundary between the African and Euro-Asiatic plates. This is the basis that allows having as part of the renewable resources also the geothermal ones, which are not used for their energetical features for the time being. Still, their use is limited only to their health values. The study aims to show that the use of the Llixha Elbasan springs, part of the 12 natural geothermal springs of the country, but among the essential geothermal resources of Albania, as an energy resource if entirely feasible, besides their utilization for health purposes. The respective calculations include the outdoor swimming pool.

The same calculations are also made for geothermal springs. In this Lëngarica creek are located eight springs, known and used for their curative values since the Roman Empire. Still, they can be efficiently used for greenhouses, aquaculture, and mineral salt extraction.

The country has also drilled approximately 6 200 wells for searching oil and gas, 5 000 before 1990 and the rest after 2 000. Among them, 11 wells have blown out, and continue to do it, hot brine, with temperatures varying from slightly less than 30°C to a maximum of 67°C. The economic analyses show that this resource is entirely competitive and unjustified. It’s further “waste.” It will also help to improve the living standards of the local community.

Less important is also the soil temperature regime of the country. Measurements show that the temperatures at 100 m are within the limits of heat exchangers in water-water systems or through heat extraction. The study answers some critical problems such as energetic calculations, including heat loss, setting of the geothermal heating system based on their viability, vertical heat exchanger capacity evaluation and their design, economic analyses, and the related calculations as the initial installation costs, water production, and injection wells costs, the comparison with the coal heater and air conditioners as part of the viability study.

Geothermal energy

Geothermal resources

Earth ensures independently that it is heating, and combined with solar radiation, creates the appropriate environment for life continuation. The age of the “elite fossil fuels” and other non-renewable energies looks to end. This is not only to the reserve’s exhaustion, to the problematic attitude of the largest producers toward the western economies, and last but not least to the added care regarding environmental protection. The continuous increase in the energy demand could be better balanced if even a tiny part of the Earth's internal heat could be used.

Geological background of Albania

Although a small territory, Albania has not only geological events and characteristics but is also favoured for having both kinds of heat sources: internal and external.

Tectonic zones of Albania

Geological and geophysical regional studies, based on facial-structural criteria, have distinguished the following tectonic zones:

- Internal Albanides: Korabi, Mirdita, Gashi tectonic zones,
- External Albanides Albanian Alps, Krasta-Cukali, Kruja, Ionian,
- Sazani tectonic zones and Peri Adriatic Depression.

Geothermal energy in Albania

Albania's geothermal fluids found as natural springs and wells are located in Kruja, Ardenica, and Peshkopia. The three zones differ in their geological characteristics and thermo-hydrogeological features.

Kruja geothermal zone

Kruja geothermal zone represents a zone with ample geothermal resources. The Kruja Geothermal Zone extends 180 km from the Adriatic Sea in the North, down to the Southeastern area of Albania, and further S-E to the Konitza area in Greece. Wellhead temperatures in the Tirana-Elbasani zone vary from 60 - 65.5°C. The temperature at the top of the aquifer reaches 80°C in the Kozani-8 hole. The Lëngarica river thermal springs, near the Vjosa River Valley, Postenani steam springs, and the Sarandaporo springs can be found south of the Kruja geothermal area. For the Tirana-Elbasani subzone, heat in place (Ho) is $5.87 * 10^{18}$ - $50.8 * 10^{18}$ J, identified resources (Hi) are $0.59 * 10^{18}$ - $5.08 * 10^{18}$ J, while the specific reserves range between values of 38.5-39.6 GJ/m^2. The second subzone, Galigati, has a lower concentration of resources, 20.63 GJ/m^2, while geothermal resources amount to 0.65×10^{18} J.

Ardenica geothermal zone

Ardenica geothermal zone is located in the coastal area of Albania, in sandstone reservoirs. The Vlora-Elbasan-Dibra transversal fault intercepts it. The temperature in the aquifers at a depth of 1935-1955 m is 45.8°C. Ardenica reservoir has energy reserves in the $0.82 * 10^{18}$ J. Resources density varies from 0.25-0.39 GJ/m^2.

Peshkopia geothermal zone

Peshkopia geothermal zone is located in the Northeast of Albania, in the Korabi hydrogeologic location. At two kilometres east of Peshkopia, water at 43.5°C flows out of a group of thermal springs on a river slope composed of flysch deposits.

Temperature

A relatively low value of temperature characterizes the geothermal field. The temperature at 100 meters depth varies from less than 10 to almost 20°C, with the lowest values in the mountain regions of the Mirdita zone, the Albanian Alps. In these areas, there is intensive circulation of underground cold water, of 5-6°C temperature.

The geothermal gradient of Albania

In the External Albanides, the geothermal gradient is relatively higher. The geothermal gradient displays the highest value of about 21.3 m°K/m in the Pliocene clay section in the centre of the Peri-Adriatic Depression. The most significant rises are detected in the anticline molasses structures of the centre of Pre-Adriatic Depression. The gradient decreases by about 10-29per cent, where the core of anticlines in the Ionic zone contains limestone. In the Ionian zone, the gradient is mostly 15 m°K/m. In the Albanian Sedimentary Basin, the geothermal gradient changes from one formation to another. The most significant geothermal gradient values were observed in the clay sections. At the same time, decreases in the geothermal gradient are marked by an increasing sand content.

Heat Flow Density

There are observed two particularities of the distribution of the thermal field in Albanides:

- The maximal value of the heat flow is equal to 42 mW/m^2 in the centre of the Peri-Adriatic Depression of External Albanides. The 30 mW/m^2 value isotherm is open towards the Adriatic Sea Shelf. Heat flow density values are lower than 25-30 mW/m^2 in the Albanian Alps area. This phenomenon has taken place owing to the great thickness of sedimentary crust, mainly carbonate, in this zone;
- In the ophiolitic belt in the eastern part of Albania, the heat flow density values are up to 60 mW/m^2. The contours of Heat Flow Density give an explicit configuration of the ophiolitic belt. The contours of 45 mW/m^2 in the Northeast and 40 mW/m^2 in the South-East of Albania remain open toward the ophiolitic belt continuation beyond the Albanian border.

Country Update on the Energy Generation and Geothermal Use for Albania, 2015-2022

During this period, Albania approved several laws:

- Law No. 124/2015 “On Energy Efficiency,” whose aim is to: Compile regulatory and national policies on the promotion and improvement of energy efficiency with a primary focus on energy saving, supply reliability, and removal of barriers on the electrical energy market; Setting of National Target regarding the energy efficiency; Increase of competition between different operators.
- Law No.116/2016, “On the Energetic Performance of the Buildings,” whose aim is to: Establish the legal framework regarding the energetic performance of the new buildings, considering the local and climatic conditions, buildings' comfort as well as cost-effectiveness.
- Law No. 7/2017, “On Promotion of the Renewable Energy Resources usage,” whose aim is to: To promote the generation of electrical energy from renewable resources of energy; Decrease the import of organic fuels, greenhouse gas emissions & environmental protection; Promote the development of the electrical energy market, generated from the renewable resources as well as the regional integration; Support the diversification of the energy resources; Support the rural and remote areas development by improving their energy supply.
- DoCM No. 179, dated 28.3.2018, “On Approval of the National Action Plan on the Renewable Energy Resources, 2018-2020”.

In the frame of diversifying the energetic portfolio in Albania have taken place some important development in the sector of solar energy by issuing and having constructed and/or under construction a number of photovoltaic parks: Karavasta Photovoltaic Park – Voltalia (voltalia.com). The expected investment is above 100,000,000 Euros for an installed capacity of 140 MW. PPA is signed for 70 MW pricing 24.89 Euros/MW for a duration of 15 years; Spitalla Photovoltaic Park – Voltalia. The expected investment is around 80,000,000 Euros for an installed capacity of 100 MW. The PPA is signed for 70 MW pricing 29.89 Euros/MW for a duration of 15 years; Sheq Marinas, Topojë, Fieri Region: “LM Energy Corporate - installed capacity is 50 MW; Floating Photovoltaic Implant of Banja – Statkraft (www.stakraft.al): In the frame of the Devolli Cascade development, Statkraft make an investment of 2,000,000 Euros for an installed capacity of 2 MW (finalized on June 2021) nearby the Banja HPP damp. The implant is composed of 4 floating units (0.5 MW/unit). Each unit has a diameter of 70 m. Still, there is so much to do regarding the legal basis and, most importantly, to incentivize the development of the renewable energies sector and not remain focused on hydro and solar energies.

Geothermal direct use potential of Albania

The Llixha Elbasan hot springs in Albania study temperature conditions and utilization calculations, aiming to demonstrate that the thermal water flowing from the Llixha springs is usable for direct utilization. This utilization would mitigate the electricity supply in the region and help improve living conditions for the local community.

Kozani-8 Low Enthalpy Geothermal Water Use Through a Cascade and Hybrid System, the Geological Structure of the Region, Energetic Reserves Evaluation of the Kozani Limestone Structure, the Scheme for the Integral, Cascade, and Hybrid Use of the Kozani-8 Geothermal Waters - Heat Looses, Environmental Analyses and Positive Impact of the Scheme, Economic Analyses is assessed in details in the report.

The potential of Bënja Geothermal Springs for Direct Utilization - Katiut Bridge (Ura e Katiut), Lëngarica-Përmet Geothermal Springs, the Geothermal Complex- Katiut Bridge (Ura e Katiut), Lëngarica, Përmet is also assessed in details in the report. The economics and risk assessment of the proposed project is part of the evaluation process.

In Albania is also possible to use the heat of the rocks. Two examples regarding the district heating of the Tiran University and Korca University campuses give a very good idea of their feasibility.

Sustainable Development Goals and the fact that the Albanian government has ratified the Resolution adopted by the General Assembly on 25 September 2015, being committed on:

1. Recognition that social and economic development depends on the sustainable management of our planet's natural resources;
2. Recognition that sustainable urban development and management are crucial to the quality of life of our people;
3. Sustainable development cannot be realized without peace and security, and peace and security will be at risk without sustainable development;
4. Pledging to foster intercultural understanding, tolerance, mutual respect, and an ethic of global citizenship and shared responsibility. We acknowledge the natural and cultural diversity of the world and recognize that all cultures and civilizations can contribute to and are crucial enablers of sustainable development;
5. Promoting sports as an important enabler of sustainable development.

Conclusions

Based on the calculations presented in this report, the following can be concluded regarding the utilization of the hot springs of the **LLIXHA-ELBASAN** hot-spring area in Albania: The water temperature is expected to be stable in the future; The geothermal reservoir temperature at 4500-5000 m depth is thought to be about 220°C; The water starts to cool down when it reaches 160 m depth; The geothermal water from the Llixha hot springs fulfills all requirements for district heating's in the region; Considerably higher temperature expected through further well drilling.

KOZANI 8 - The Kozani-8 water temperature is suitable for the supply of a recreational centre, including geothermal indoor and outdoor pools; The water temperature is ideal for feeding two cascades; The hybrid system will improve the economic efficiency of the project; The construction of the centre will improve the energetic balance of the region; The structure of the centre will help on diversifying the energy resources in Albania; The degasified and desalination line will improve the environmental status of the area, as is highly polluted; It will improve the living standards of the community; The economic analyses show that it is feasible. The risk analysis shows very optimistic data for the future of the investment.

BËNJA GEOTHERMAL SPRINGS - Based on the calculations presented in this report the following can be concluded regarding utilization of the hot springs in Albania: Albanian geothermal regime allows different scale borehole heat exchangers applications; Use of the low and middle enthalpy geothermal waters is economically viable in Albania and they can be successfully used; Use of the low enthalpy geothermal waters in Albania can mitigate the economic problems, improve the living standards of the communities and diversify the energy resources; The Bënja springs, water temperature is suitable for the supply of a recreational center, including geothermal indoor and outdoor pools; The water temperature is ideal for feeding of two cascades; The hybrid system will improve the economic efficiency of the project; The construction of the center will improve the energetic balance of the region; The construction of the center will help on diversifying the energy resources in Albania; The degasified and desalination line will improve the environmental status of the area, as actually is highly polluted; It will improve the living standards of the community of the Bënja village; The economic analyses shows that it is feasible; The electricity generated by the combined scheme will improve its efficiency; The geothermal systems are environmentally friendly;

Risk analysis indicates that there is not any added risk for the proposed investment; Direct utilization of the low enthalpy geothermal resources of Albania will help in diversifying of the energetic resources mitigating so the supply problems faced in the near past.

KORÇA & TIRANA DISTRICT HEATING - Albanian geothermal regime allows different scale borehole heat exchangers applications; The heating system of the “Fan S. Noli” University campus was discussed between the oil and geothermal systems; The geothermal regime of Korça allows the use of both geothermal systems: Water-Water and Earth-Water; The Water-Water system is the most viable; The Oil Heating systems are the less feasible, despite the oil price; The geothermal system also has tremendous environmental impact; This project application will help the diversification of the energetic Albanian system; Demographic and geological features of the student’s city (Tirana) allow, and are feasible the borehole heat exchanger’s utilization. The location, stakeholders’ engagement, technical data, land properties rights and issues, proximity with the capital of Albania (Tirana), and economics shows that the best location to start with the completion of the pre-feasibility and feasibility study is Kozani – 8 geothermal well. These studies shall prove that in Albania, despite the unfavorable geothermal regime, under the latest development of the energy sector, these immense resources are fully competitive and shall support the entire country's sustainable development.

To achieve all these is very much important to follow the UNFC and UNRMS guidelines and standards to develop adequate geological models of the geothermal aquifers, but this can’t be done without understanding and explaining the conditions of the reservoir, temperatures, permeability, and porosity, flow rate and geothermal fluids chemistry. Only after having an in-depth knowledge of the resources in place the potential developer could conduct extensive studies to make possible the realistic evaluation of their possible further development. The socio-economic viability, but only after and completing the ESIA studies, which shall entail extensive public hearings and consultations with residents, local and central government, and other stakeholders as per international & national laws and regulations, shall be a valuable tool to the potential developer, given that the project implementation shall require the commitment of funds and installation of all equipment’s, as for the design, to start with the resources extraction and plant/facility operation/utilization.

Indeed, the geothermal energy utilization in the country can’t resolve all problems related to the energy sector. Still, without any doubt, it can help in their mitigation. The relief of social problems such as employment, immovable properties related issues, and environmental and portfolio diversification is not less important. It can be a good step toward the decarbonization of the Albanian economy as well.

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Finally, and last but not least goes to Mr. Harikriishnan Tulsidas and Mr. Oleg Dzioubinski, UNECE, for their restless support.

Introduction

The technologies developed remarkably during the 20th century, especially in the second half. All these developments made unbelievable progress possible regarding improving the population's living standards. Still, they are never likely to have a good quality of life without an assured energy supply. Thus, the planetary energy demand is increaing very rapidly. The world is witnessing a new revolution driven by various trends and technologies. The primary goal is to identify and implement new transformative models in energy and material flows. The 2030 Agenda shapes all these transformations for Sustainable Development and the Paris Agreement on climate actions. As new policies, approaches, and business models emerge to reshape production, consumption, transportation, and delivery systems, modernized and unified ways of managing the resulting energy and material flows are needed. The increase in consumption has driven the reduction of natural reserves, especially if referring to fossil fuels. The consumption of fossil fuels is unbalanced with the exploration of new ones, at least every year. Alternative energy resources emerging after WW2, especially nuclear energy, had substantial negative impacts, i.e., human health, environment, etc., and this source also can not be neglected. The efforts of the scientific communities as well as the political decision-makers of the G7, OECD, EU, etc., are more and more focused on the diversification of the energy portfolios, emphasizing the renewable ones, including the geothermal energy.

These are the primary facts why the United Nations Framework Classification for Resources (UNFC) is probably the most useful tool for the consistent and coherent classification and efficient management of all natural resources. It allows the quantitative classification based on the following criteria:

- Social, Environmental, and Economic viability (E);
- Field Project Status and Feasibility (F);
- Estimation of the recoverability of the reserves (G).

Following these criteria is possible to conclude that Earth, our planet, which provides us with the only living environment, represents, besides this, a huge source of energy, in and above ground.

Albania is a small country with only 28 787 km^2 surface area and around 4 500 000 inhabitants, situated in the southwestern part of the Balkan Peninsula. Though it is, a small country could be considered relatively rich in natural resources, including fossil fuels and renewable ones. Like the other Balkan countries, Albania is located next to the subduction boundary between the African plate and the Euro-Asiatic one. This is the basis that allows having as part of the renewable resources also the geothermal ones, which for the time being are not used at all for their energetical features, but their use is limited only to their health values. Surface manifestations of geothermal resources are found throughout Albania, ranging from the region of Peshkopia in the northeast, where hot springs with a water temperature of about 43°C and inflow above 14 l/s are found, through the central part of the country with different sources (including the springs of Llixha-Elbasan) with temperatures above 66°C, to the Peri-Adriatic depression with a number of wells (drilled for oil & gas exploration) producing water with temperatures around 40°C at variable yields. Estimated temperature measurements based on different geothermometers indicate that the temperature of the waters in the formation of the Llixha reservoir may be above 220°C.

The use of the geothermal fluids in Albania dates back to early in history, since the time of the Roman Empire (i.e., the Sarandaporo’s thermal baths). The aim of the study is to show that the use of the Llixha Elbasan springs, part of the 12 natural geothermal springs of the country, but among the most important geothermal resources of Albania, as an energy resource if fully feasible, besides their utilization for health purposes. The respective calculation includes the open swimming pool.

The same calculations are also made for geothermal springs, the Lëngarica creek, where eight springs are located, known and used for its curative values since the time of the Roman Empire. The eight springs blow out mineral water with temperatures in the range of 23÷30 °C and yield in the range of 8 up to more than 40 l/s. These waters, even though with relatively low temperatures, represent a competitive energy resource. Their flows directly to the river of Lëngarica, similar to the other geothermal resources of Albania, can be “translated” as “throwing in the creek” of considerable monetary value, delay in the economic development, infrastructure, and also social of the area.

Below will be shown that these waters are not only a competitive energy resource by using a combined and cascade system, but they can be efficiently used for greenhouses, aquaculture, and mineral salt extraction.

In the country, have also been drilled approximately 6 200 wells for searching oil and gas, 5 000 of them before 1990 and the rest after 2 000. Among them, 11 wells have blown out, and still continue to do it, hot brine, with temperatures varying from slightly less than 30°C to a maximum of 67°C. Their yields vary from less than 1 l/s to a maximum of 30 l/s. Due to the temperature (65.5°C), the steady yield for more than 35 years (10.3 l/s), and, most important, very good location (very close to corridor 8) are the basic parameters for choosing these waters for the designs and calculations of a Geothermal recreational centre of the Kozani 8 well. The design provides information and calculations on the cascade and integral use, but not only. The centre shall allow electricity generation through a hybrid system. The recreational centre will also be equipped with SPA, open and closed pools, fitness, massages, and greenhouse & also aquaculture pools. The economic analyses show that this resource is completely competitive and unjustified. It's further "waste." It will also help to improve the living standards of the local community.

Not less important is also the soil temperature regime of the country. Measurements show that the temperatures in the depth of 100 m are within limits for heat exchanger utilization in both ways: water-water systems or even through heat extraction. The climate of Korça, especially the winter season, enforces the use of the heating system for more than four months/per year. The Korça university campus had been chosen not only for its characteristic but also because this is the biggest public building in the region, so the economic profit can be significant. The study gives the answer for some important problems such as energetic calculations, including heat loss, setting of the geothermal heating system based on their viability, Vertical heat exchanger capacity evaluation and their design, economic analyses, and the related calculations as the preliminary installation costs, water production, and injection wells costs, the comparison with the coal heater and air conditioners as part of the viability study.

Although not presented in the study in Albania, there is also good potential for geothermal greenhouses. So, Albania has good potential, but also the structure of the report gives the opportunity of choosing the best and more viable one to start with the real investment.

Based on the calculations presented in this report, the following can be concluded regarding the utilization of the hot springs of the Llixha-Elbasan hot-spring area in Albania results that the geothermal water from the Llixha hot springs fulfills all requirements for district heating in the region.

The Kozani-8 water temperature is suitable for the supply of a recreational centre, including geothermal indoor and outdoor pools, and will improve the living standards of the community.

The use of the low and middle enthalpy geothermal waters of Bënja geothermal springs is economically viable in Albania, and they can be successfully used. It can mitigate economic problems, improve the living standards of the communities and diversify the energy resources portfolio in the country. One of the key benefits of the UNFC – is its flexibility and ability to be adapted to diverse national and regional requirements and conditions.

Albanian geothermal regime allows different scale borehole heat exchanger applications, like in Korça & Tirana, and makes possible an efficient way for the district heating.

The location, stakeholders' engagement, technical data, land properties rights and issues, proximity with the capital of Albania (Tirana), and economics shows that the best location to start with the completion of the pre-feasibility and feasibility study is Kozani – 8 geothermal well. These studies shall prove that also in Albania, despite the unfavorable geothermal regime, under the latest development of the energy sector, these immense resources are fully competitive and shall support the entire country's sustainable development.

To achieve all these, it is very much important to follow the UNFC and UNRMS guidelines and standards in order to develop adequate geological models of the geothermal aquifers, but this can't be done without understanding and explaining the conditions of the reservoir, temperatures, permeability, and porosity, flow rate, and geothermal fluids chemistry. Only after having an in-depth knowledge of the resources in place, the potential developer could conduct extensive studies, which shall make possible the realistic evaluation of their possible further development. The socio-economic viability, but only after conducting the ESIA studies, which shall entail extensive public hearings and consultations with residents, local and central government, and other stakeholders as per international & national laws and regulations, shall be a useful tool to the potential developer, given that the project implementation shall require the commitment of funds and installation of all equipment's, as for the design, to start with the resources extraction and plant/facility operation/utilization.

Surely the geothermal energy utilization in the country can't resolve all problems related to the energy sector, but without any doubt, it can help in their mitigation. Not less important are also the relief of the social problems such as employment, immovable properties related issues, environmental and the diversification of the portfolio. It can be a good step toward the decarbonization of the Albanian economy as well. Their use shall be a good start regarding the reduction of poverty in the country, promotion of sustainable agriculture, ensuring healthy living and well-being of the population, ensuring the sustainable management of water resources, ensuring affordable, reliable, sustainable, and modern energy systems for all, promoting the sustainable economic development and employment and protecting the terrestrial ecosystems, in full alignment with the 2030 Agenda for the Sustainable Development.

United Nations Framework Classification for Geothermal Energy and Resources Management System

The lack of worldwide standards, guidelines, and codes has hampered consistent and comparable estimation and reporting of geothermal energy potential, leading to ambiguity and limiting the understanding of the viability of geothermal energy projects among potential investors. To overcome this barrier, the International Geothermal Association (IGA) and the United Nations Economic Commission for Europe (UNECE) jointly set out to develop specifications and guidelines following the broader United Nations Framework Classification (UNFC) for the geothermal sector. This constitutes a voluntary, three-dimensional system with three key axes describing ***feasibility, economic viability, and geological assessment***. Resource classification is the basis on which coherent and reliable energy policies are formulated by governments to sustainably manage their resources. Classification also makes it easier for industry players to assess natural resource prospects and appropriately allocate capital. The United Nations Framework Classification for Resources (UNFC) is a global tool for consistent and coherent classification and efficient management of all resources. It applies to minerals, petroleum, nuclear fuel resources, renewable energy, anthropogenic resources, and for injection projects for geological storage of CO_2. It provides a single framework on which to build international energy and raw material studies and policies, supports government resource management policies, plan innovative industrial processes, and allocate capital efficiently. UNFC is a generic principle-based system in which quantities are classified by three fundamental criteria:

- Social, environmental, and economic viability (E),
- field project status and feasibility (F), and
- level of knowledge/confidence in estimates of the potential recoverability of the quantities (G).

Users of the UNFC geothermal specifications now have a comprehensive system that provides coherent, reliable, and globally comparable data, which has the potential to facilitate increased efficiency in policymaking and public resource management. In addition, users from industries across the world operating in energy markets now have a concise way of evaluating investment prospects in the sector, thereby providing information to secure financing from international capital markets.

Geothermal resources

Geothermal Energy Source, Products, and Resources

- In the geothermal energy context, the Renewable Energy Source is the thermal energy contained in a body of rock, sediment, and/or soil, including any contained fluids, which is available for extraction and conversion into energy products. This source is termed the Geothermal Energy Source and is equivalent to the terms ‘deposit’ or ‘accumulation’ used for solid minerals and fossil fuels. The Geothermal Energy Source results from any influx to outflux from or internal generation of energy within the system over a specified period of time.
- A Geothermal Energy Product is an energy commodity that is saleable in an established market. Examples of Geothermal Energy Products are electricity and heat. Other products, such as inorganic materials (e.g., silica, lithium, manganese, zinc, sulphur), gases, or water extracted from the Geothermal Energy Source in the same extraction process, do not qualify as Geothermal Energy Products. However, where these other products are sold, the revenue streams should be included in any economic evaluation.
- Geothermal Energy Resources are the cumulative quantities of Geothermal Energy Products that will be extracted from the Geothermal Energy Source from the Effective Date of the evaluation forward (till the end of the Project Lifetime/Limit), measured or evaluated at the Reference Point.

The planet Earth ensures independently it is heating and combined with solar radiation; it creates the appropriate environment for life continuation. The age of the “elite fossil fuels” and other non-renewable energies looks to go to an end. This is not only to the reserve’s exhaustion, to the problematic attitude of the largest producers toward the western economies, and last but not least to the added care regarding environmental protection. The continuous increase in demand for energy could be better balanced if even a small part of the Earth's internal heat could be used. Geothermal means “Heat of/from Earth.” It is very easy to differentiate zones with very high heat flux above and underground in different areas of the planet, mostly driven due to convection. Obviously, the mantel convection is the engine for the tectonic plate’s displacement. The convection forces are the main cause of the lithosphere displacements, aside from the subduction zones. All displacement in the asthenosphere is thought to be strongly related to the lithosphere. All models of convection theories consider the tectonic plates as active participants in the process. The lithosphere is considered the “Upper Cold Boundary” of the “Convective Cells.” The size and shape of the convective cells are still the objects of debate [20]. Despite the differences, there is a common understanding that the most important convention models are: stratified and massive convection.

There are very good examples of each one of them. The first model provides two clearly split layers of the mantel, as given in Figure 1. (A) [20]. The upper layer is located in between the asthenosphere and lithosphere. In the second model, Figure 1. (B) [20], the convection is supposed to take place in all mantels with the support of the heat convection of the outer core. The third model, Figure 1. (C) [20], shows the low-density materials (plumes) flowing from the boundary between the outer core-mantel.

Fusion of the radioactive elements, the gravitational differentiation, the phase transforming processes, the exothermic reactions, and the release of heat forms the friction forces (tidal activities) of the solid layer’s displacement, the spatial radiation, heat entrapped since the planet's creation [20] as well as the hypothesis about the existence of a pure uranium sphere with 10 km of diameter makes possible that the temperature goes at the level of 5000°C. All this heat is in continuous circulation, mostly due to the induction and convection within the melted mantle underneath the Earth's crust.

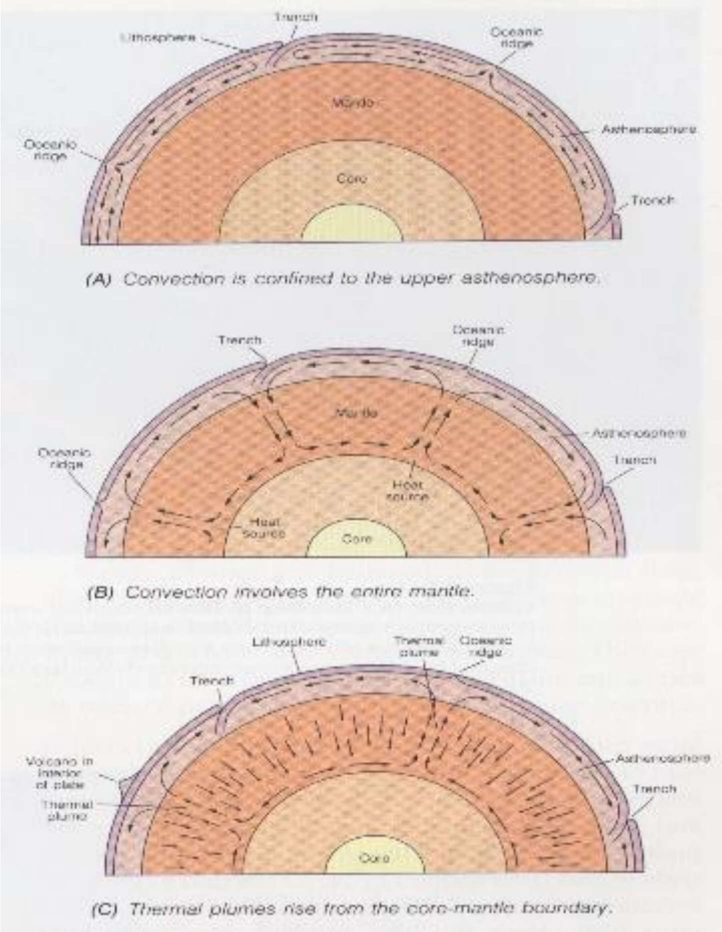


Figure 1: Earth Convection Models

All these factors generate a heat flux of about 16 kW/km^2, which goes entirely to the earth's surface. This flux is not uniformly distributed but tends to be higher to the tectonic plate’s boundaries, whereas volcanic activity is much higher. Just a small part of melted rocks (lava) flows on the Earth's surface. The remaining part of the heat remains trapped in a depth of 5-20 km, whereas it is released via the hydrological convection, thus creating high temperatures of geothermal resources in a depth of 50 – 3000 m. Figure 2 [38] shows the link between the high-intensity volcanic activity of the tectonic plate’s boundaries.

Despite the above statements, even in other parts of the planet, far beyond these boundaries is possible to be found zones with

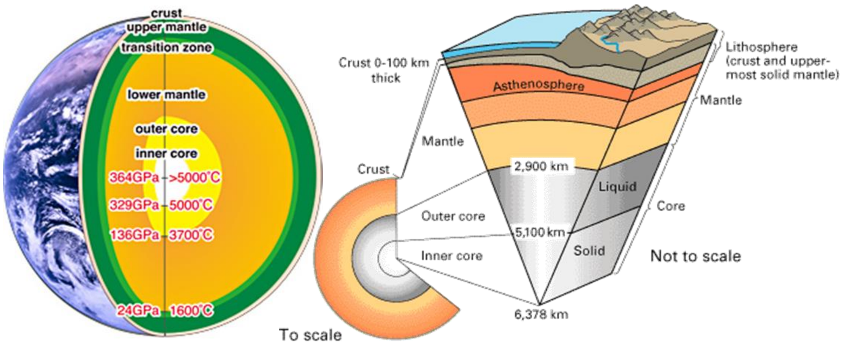


Figure 2: Earth dynamic

heat intensity much higher than the average. This is mostly due to the underground geothermal water’s circulation, which makes possible their surface appearance in the form of the hot springs. Even though with lower temperatures if compared with the volcanic systems, these springs can be successfully used for district heating. The geothermal resources differ in different locations, strongly relating to the source depth and temperature, the chemical composition of rocks, and water reserves. The nature and typology of the geothermal sources will very strongly impact their utilization method, especially if combined with the technology, as shown in Figure 3 (Lindal diagram).

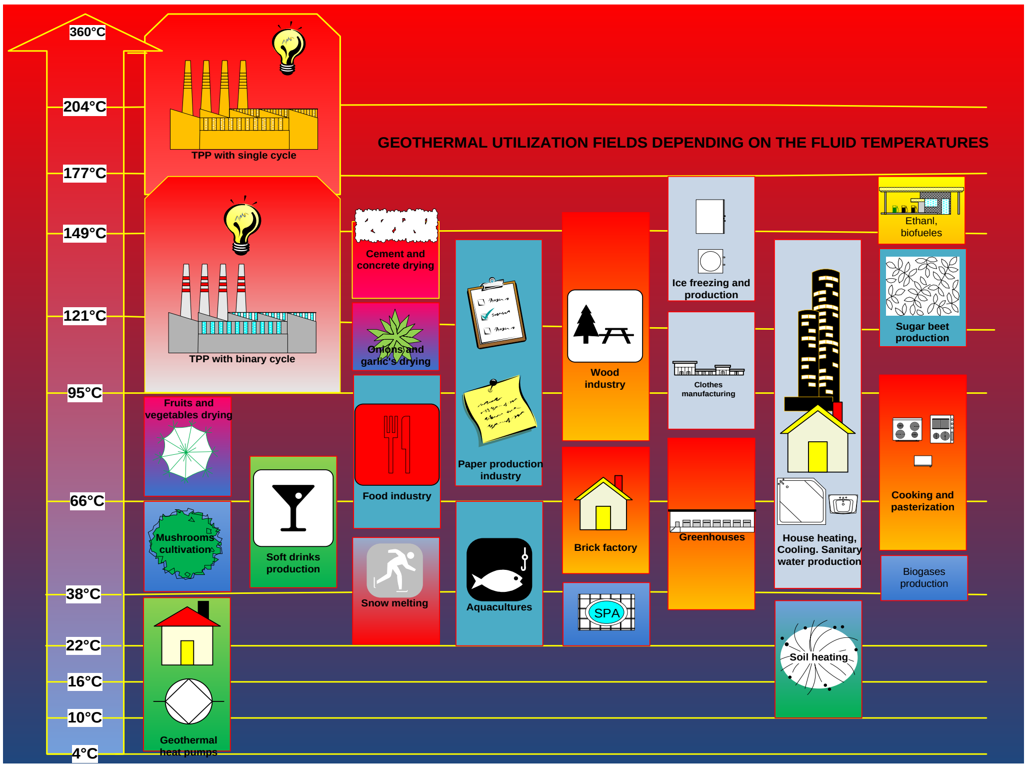


Figure 3: Lindal diagram

Figure 4 [33] shows in a very expressive way all thermal activities that take place on and on planet Earth.

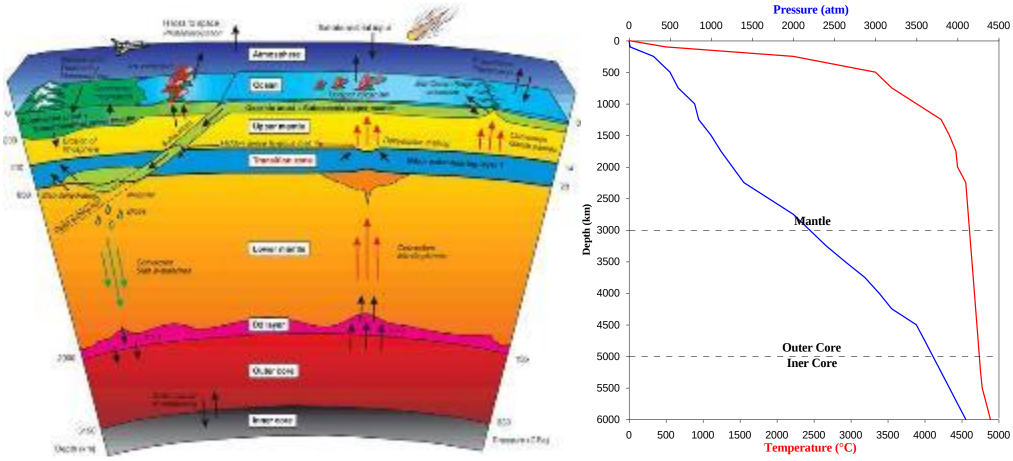


Figure 4: Earth heat resources

The lowest impact regarding the thermal gradient is of the hydro-chemical processes, which release heat, underground waters, and other heat underground flows. There are other regions of the planet with very intensive volcanic activity, as well as high content of radioactive elements and added presence of high and very high-temperature hot waters above ground. In the north of New Mexico, the late tertiary volcanism [33] and the active intrusions make possible geothermal gradients of about 100°C/km, 200°C/km, or even more than 300°C/km in the height of 150 asl. This energy can be extracted and used via the direct drilling of wells, as in Larderelo, Toscana of Italy, where it is possible to extract fluids with temperatures in the range of 200°C up to 220°C for over nine decades. Figure 5 [21] represents a general and simplified sketch of the water circulation on the planet and their heating way through contact with the hot rocks deep underground. So, the surface water flows to the ground, whereas contacts with the hot rocks take their heat and go back to the surface with higher temperatures in the form of geothermal resources. Geologists are of the opinion that the heat of Earth shall be one of the primary energetic resources of the future. These reserves are inestimable. The volcanic emissions and the radioactive decay are continuous processes, and consequently, the internal heat of the planet is inexhaustive. It is estimated that the magmatic rocks, which go up to a depth of 10 km, store at least 5000 more energy than the USA's yearly consumption. Thus, the very sensitive problems related to the energy sector could be easily solved via the utilization of the Earth's internal heat.

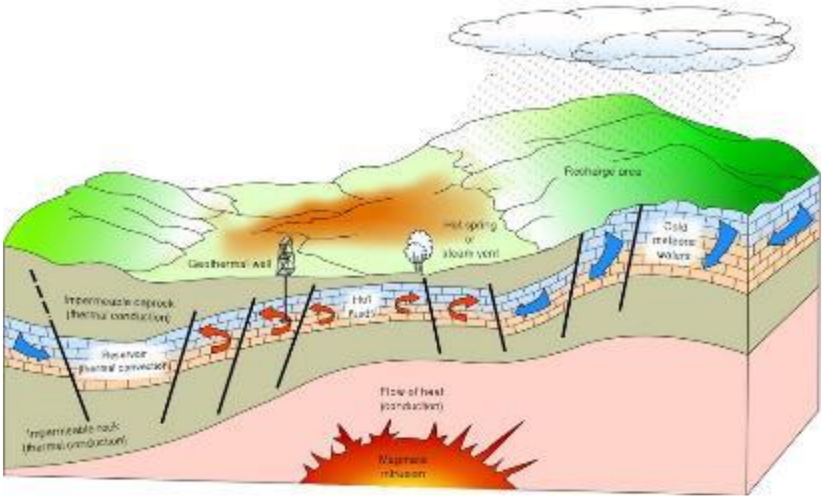


Figure 5: Water circulation sketch

Geological background of Albania

Albania, although a small territory, has not only simple geological events and characteristics but is also favoured for having both kinds of heat sources: internal and external ones. Consequently, in this small area is possible to find a wide specter of sedimentary rocks, magmatic and metamorphic ones, of different geological ages and with high geothermal capacity, in the form of structural chains, which tend to create some tectonic zones, clearly different from each other due to the very active longitudinal and transversal tectonics. The structural scale, tectonic regimes, and neo-tectonic activity are strongly related to the east Orogen and Adria Plate in the West and wider, in the frame of the African Plate (South) with the Euro-Asiatic one in the North collision, as shown in Figure 6 [13] Some of these tectonic faults goes some tenth kilometers deep below the Earth crust, changes their status to liquid due to the fact that the temperature and pressure go to extremely high values.

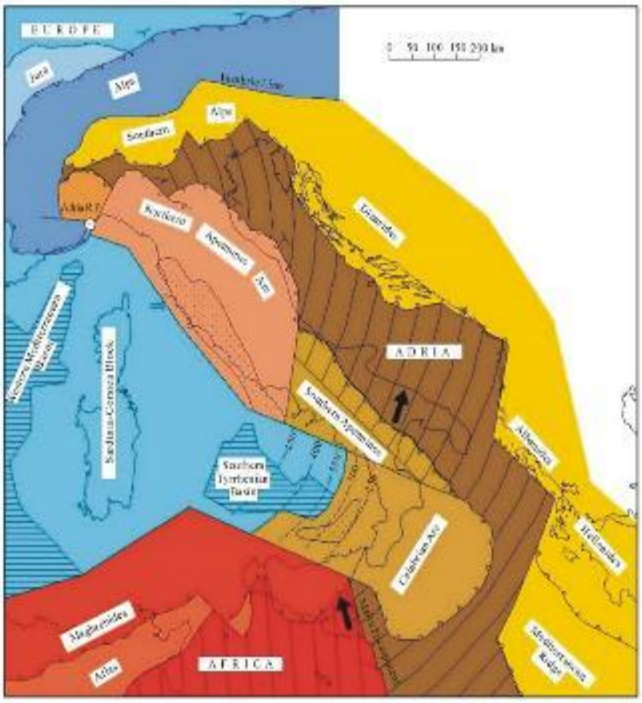


Figure 6: Adria tectonic plate sketch

Tectonic zones of Albania

The Albanides represent the assemblage of the geological structures in the territory of Albania, and together with the Dinarides at the North and the Hellenides at the South, have formed the southern branch of the Mediterranean Alpine Belt (see Figures 6 & 7) [1, 8, 9, 13, 14, 15, 24, 25, 26, 27, 28, 29]. Two major paleogeographic domains form the Albanides: The Internal Albanides in the eastern part and the External Albanides in the western part of Albania. The Internal Albanides are characterized by the presence of the immense and intensive tectonic ophiolitic belt, which is displaced from east to west as an overthrust nappe. There are two viewpoints about the tectonic setting of the ophiolites: the Allochthones character of the ophiolitic nape and the autochthon ophiolitic belt. The External Albanides developed beside the passive western margin and continental shelf of the Adriatic plate. The External Albanides are affected only by the later paleotectonic stages and are characterized by regular structural belts, which are associated with thrust and over-tectonic. Seismological studies, regional gravity, and magnetic survey data reflect the Earth's Crust configuration. Geophysical data reveal that the Earth's crust becomes thicker from the central regions of the Adriatic towards Albanides inland. The sedimentary crust has about 10 km thickness in the Adriatic seashore and reaches up to 15 km in the northwestern regions of Albania. Rocks, with a seismic wave velocity of 5.9- 6.2 km/sec, present the lower part of the sedimentary crust. These rocks have a very consolidated structure. In the Albanides are fixed four third-order trends of the Bouguer anomalies: two maximums and two minimums. The main gravity maximum is extended on the northeastern part of the Mirdita tectonic zone and on the Korabi one. The second maximum, which is located in the Vlora district in the southwestern part of Albania, has a sub-transversal strike with geological structures of the Ionian tectonic zone. These regional gravity maximums are attributed to a crust thinning toward the Mirdita tectonic zone and in the Vlora district. The main gravity minimum is extended from the southeastern region of Albania to the northwestern littoral of Albania. The second minimum is located in the Alps tectonic zone, by a strike in the SE-NW direction. Generally, the Bouguer anomaly increases from the Adriatic Sea Shelf to the Eastern part of the Albanides. The geological-geophysical profile of Albanides the roof sinking of the Moho discontinuity in the Adriatic Sea region. The Moho discontinuity plunges from 25 km in the central part of the Adriatic Sea to 43- 52 km in the eastern part of Albanides. Regional gravity anomalies are caused by a block construction of the crust, which comes out from the results of seismological studies. This tectonic setting of the deep levels of the earth's crust in the Albanides finds its reflection even in the distribution of the magnetic fields. The interpretation of the regional magnetic anomalies shows that the top of the crystal basement plunges toward the littoral of the Albanides up to their central areas. The Earth's crust in the Albanides is interrupted by a system of longitudinal fractures in the NW-SE direction and transversal fractures that touch the mantle. The geothermal energy of the Albanides is linked with these deep fractures. The tectonic setting of the deep levels of the Albanides Earth Crust and their dynamics has conditioned the geology and tectonic style Albanides.

Tectonic Zones

Geological and geophysical regional studies, based on facial-structural criteria, have distinguished the following tectonic zones:

- Internal Albanides: Korabi, Mirdita, Gashi tectonic zones,
- External Albanides Albanian Alps, Krasta-Cukali, Kruja, Ionian,
- Sazani tectonic zones and Peri Adriatic Depression.

Intensive Bouguer anomalies and a very turbulent magnetic field, with weak anomalies, characterize the ophiolitic belt of the Mirdita tectonic zone in the Internal Albanides. The ophiolitic belt has its biggest thickness, about 14 km at its northeastern extreme, in the ultrabasic massif of Kukës. This thickness is reduced up to 2 km towards the west and the southeast. This interpretation is demonstrated an allochthons character of the ophiolite belt and the covering character of the western contact of ophiolites with the formation of the Krasta-Cukali zone of External Albanides. The relations between the Internal and the External Albanides have a nappe character. The split of the gravity and the anomalous magnetic belts in the central region of the Internal Albanides at the Shëngjergji flysch corridor argue the presence of the Dibër-Elbasan-Vlora transversal fault. A joint characteristic of a structural belt of Ionian and Kruja zones in the External Albanides is their westward thrusting, too.

The thrusting process is helped by the presence of the Triassic evaporite sheet under the carbonate section. According to the integrated geological-geophysical studies and deep well data results that two tectonic styles are observed in the Ionian tectonic zone: duplex and imbricate tectonic. Traversal faults have separated the Ionian basin into several blocks. Following the limestone top of the south Adriatic basin and Sazani, Ionian, and Kruja zones are observed that the limestones of the southern Adriatic basin are extended under the last units. Peri-Adriatic Miocene and Pliocene molasses deposits partly cover the Sazani, Ionian, and Kruja tectonic zones. They are placed transgressively over the older section down to the limestone of the Eocene, creating a two-stage tectonic stage. The molasses post-orogenic deposits have covered transgressively Mirdita and partially Krasta–Cukali tectonic zones in Korça and Burreli basins.

Internal Albanides

The tectonic zones of the Internal Albanides extend to the eastern part of Albania Korabi zone (K) continues as the Pelagonian zone in Hellenides and as the Golia zone in Dinarides. In the Korabi zone, the field of Bouguer anomaly is normal, and this reveals that the structures are of low order. The quiet gravitational zone of Korabi in the west is in contact with the anomalous zone on the ophiolites of the Mirdita tectonic zone. The contact between Korabi and Mirdita zone *fits* with the deep *seismogenic* structure Ohrid – Qarishtë – Qafë Murrë – Kukës [35]. In this zone outcrops the oldest formations of Albania. Mirdita zone (M) represents a wide belt along the whole length of the country, from northwest to southeast. The ophiolitic belt is characterized by intensive anomalies of the Bouguer anomaly and by a magnetic field with weak anomalies, which are very turbulent. There are three characteristics of this anomalous belt:

- They are divided into two parts, at the north and at the south of Shëngjergji flysch's corridor;
- There are five gravity maximums, with epicentres set one after the other in an anomalous chain from Tropoja - Kukës ultrabasic massifs in the northeast part of Albania to the Morava massif in the southeastern area. The anomalies have maximal amplitude up to 105 mgal, and strong gradients separate them one from the other. The anomalous belt undergoes a powerful turn of 60°-70° toward the direction of the Dinarides ophiolitic belt in the northern part of Albania;
- The biggest amplitudes of the anomalies came from the northern part of ultrabasic massifs of the eastern belt. While the southern part of the Albanides ophiolitic belt has a more limited thickness, and it keeps developing southwards in Hellenides.

The ophiolite belt has its biggest thickness, about 14 km on its northeastern edge, in the Kukës ultra magmatic massif. The northwestern sector of the ophiolitic belt is extended to the east of Shkodra town. The amplitude of Bouguer anomaly on the Gomsiqe ultrabasic massif is 12 mgal. Decreasing of the Bouguer anomaly amplitude correspond with a small thickness of the western part of the ophiolitic belt, down to 2 km. The graphic of the magnetic anomaly presented in the profile shows that the ophiolite contact has eastern dips with an angle of about 45°. This interpretation demonstrates the covering character of the ophiolite belt in the Mirdita zone, under which lies directly a nappe composed of volcano-sedimentary and tectonic mélange formations, as well as the nappe of the Krasta-Cukali zone below [35]. Such a geological setting of the nappe character of the ophiolite belt comes from the fact that the seismological studies have not proved the presence of any deep fracture between the Mirdita and the Krasta-Cukali zones. The separation of the gravity and the anomalous magnetic belts in the Shëngjergji flysch's corridor present another argument in favor of the nappe character of ophiolites and the presence of Dibër-Elbasan-Vlora transversal fracture. In the Shëngjergji flysch corridor, no magnetic anomalies are fixed, which would testify to the absence of ultrabasic rocks beyond the east of massif's margins and under the flysch deposits. The Bouguer anomaly in this region is due to the presence of a limestone anticline under the flysch. Vertical electrical soundings have revealed that the flysch deposits have a thickness of 2000–2500m. The Gashi zone (G) continues into the dormitory zone of the Dinarides beyond the Albanides. It consists of metamorphic rocks, terrigenous rocks, limestone, metamorphic vulcanites, and basic intermediate and acidic rocks.

External Albanides

The tectonic zones of the External Albanides outcrop chiefly in the western part of Albania.

- Alp’s zone (A) is an analogue of the Parnas zone in Hellenides, and it continues with High Karst in Dinarides. Sandstone and the conglomerates of Permian are the oldest rocks that outcrop in this zone. In general, the Alps represent limestone monoclines, as well as smaller anticlines in their background. A regional gravity minimum extends on the Alps zone;
- Krasta-Cukali zone (KC) continues in the Pindos zone in Helenides and in the Budva zone of the Dinarides. It is divided into two subzones:
    - Cukali subzone: extends in the north of the zone question. It is composed of Triassic-Cretaceous carbonate rocks, some middle Triassic effusive rocks, and a few radiolarites on the top of the Upper Jurassic. These rocks are covered by the Maastrichtian-Paleocene-Eocene flysch. The Cukali subzone represents a big anticline with small folds. The Alps and Mirdita zones over thrust this subzone;
    - Krasta subzone: which lies from Shkodra in the North to Leskoviku in the southeast. In this subzone, three formations are outcropped: the Albian-Cenomanian early flysch, Senonian limestone series, and Maastrichtian – Eocene flysch. The flysch of the Krasta subzone appears as a tectonic window, even in the Shen Gjergji corridor, between two ophiolitic belt parts.
- Kruja zone (Kr) continues into the Dalmate zone in Dinarides and into the Gavroro one in Helenides. The Kruja zone consists of a series of anticline structures with Cretaceous-Eocene carbonate cores of neritic limestones, dolomitic limestones, and dolomites covered with Eocene to Oligocene flysch deposits. In some of the structures, Tortonian molasses overlies the carbonate rocks transgressively, while in other structures; the Burdigalian marls transgress over the flysch section. The flysch and limestone section plunge down to 10 km, where they are underlain by the Triassic evaporite formations. The main folding of this zone took place in Middle Oligocene and Lower-Middle Miocene. Anticlines are linear, with a length of 20-30 km. Anticlines are asymmetric, and their western flanks are separated from disjunctive tectonics;
- The Ionian zone (Io) extends in the southwestern part of Albania. This is the biggest zone of the External Albanides and has been developed as a deep pelagic trough since the upper Liassic. The upper Triassic evaporites are the oldest rocks of this zone. Over this formation lies a thick sequence composed of upper Triassic- lower Jurassic dolomite limestone and Jurassic-Cretaceous-Paleogene pelagic cherty limestone. The limestones are covered by Paleogene flysch, Aquitanian flyschoidal formation, the section of Burdigalian-Langhian, and partially of Serravallian-Tortonian that mainly fill the synclinal belts. Burdigalian deposits often lie unconformably on anticline belts. This has brought about a set of two tectonic stages of architecture. The Liassic rifting and later folding phases have affected the External Albanides, including the Ionian zone, which has formed the three following structural belts:
    - The Berati anticline belt, in the eastern part of the zone;
    - The Kurveleshi anticline belt, in the central part of the zone;
    - The Çika anticline belt represents the western edge of the Ionian zone.

Integrated geological-geophysical data show the presence of many anticline carbonate structures, often seated with flysch deposits inside these tectonic belts. These structures are fractured by longitudinal tectonic faults along their western flanks, which go up to thrusting of 5-6 km horizontal displacement [35]. Two main tectonic styles are distinguished in the Ionian zone: Duplex tectonics and imbricate one. The back-thrust faults have happened owing to the retro tectonic phenomenon. The regional tectonic faults condition the geodynamic evolution of the Ionian zone. These faults have separated the Ionian basin in several units since the rifting time of the lower and middle Jurassic. The periodical tectonic revitalizations of the regional faults have played an important role in the over thrusting phenomenon, too. The regional reflection seismic lines across the Ionian zone show that the underlying limestones of the southern Adriatic basin and Sazani Zone has taken place during the structuring process of the Ionian zone, from upper Oligocene to Langhian.

- Sazani zone is the eastern continuation of the Apulian platform. A thick Cretaceous-Oligocene dolomite and limestone section build up this zone. Marl deposits of Burdigalian lay transgressively on the carbonate formation;
- Peri-Adriatic Depression. This unit covers a transgressively considerable part of the Ionian, Sazani, and Kruja tectonic zones. This is a foredeep depression filled with middle Miocene to Pliocene molasses, mainly covered by Quaternary deposits. The thickness of the molasses increases from southeast to northwest, reaching 5000 m. Sandstone-clay deposits of Serravallian and Tortonian are placed transgressively over the older ones, down to the limestone, creating a two-stage structure.

The interpretations of the geological and geophysical data lead to a new structural model and tectonic style of the External Albanides. Tectonic zones of the External Albanides have been in compression tectonic regime since the upper Jurassic-Cretaceous, whereas the western part of the Apulian zone and South Adriatic basin happens in continuous extension tectonic regime. Over thrusting style of the southeastern part of the External Albanides, with a great southwestward over the thrust of the anticline chains, and the presence of the old transversal faults are already well known. Evaporite deposits have been the lubrication substratum during the over-thrusting movement.

A regional neotectonic phenomenon is also the back-thrusting tectonics in the Ionian and Sazani zones. The formed structural-tectonic models have come out owing to interference of two main effects, southwestward over thrusting and newly northwestwards back thrusting.

The structure and structural chains of the Ionian, Kruja, and Sazani (see Figure 7) zones have increased the thrusting and back thrusting amplitude as a result of a powerful tectonics development during the molasses cycle.

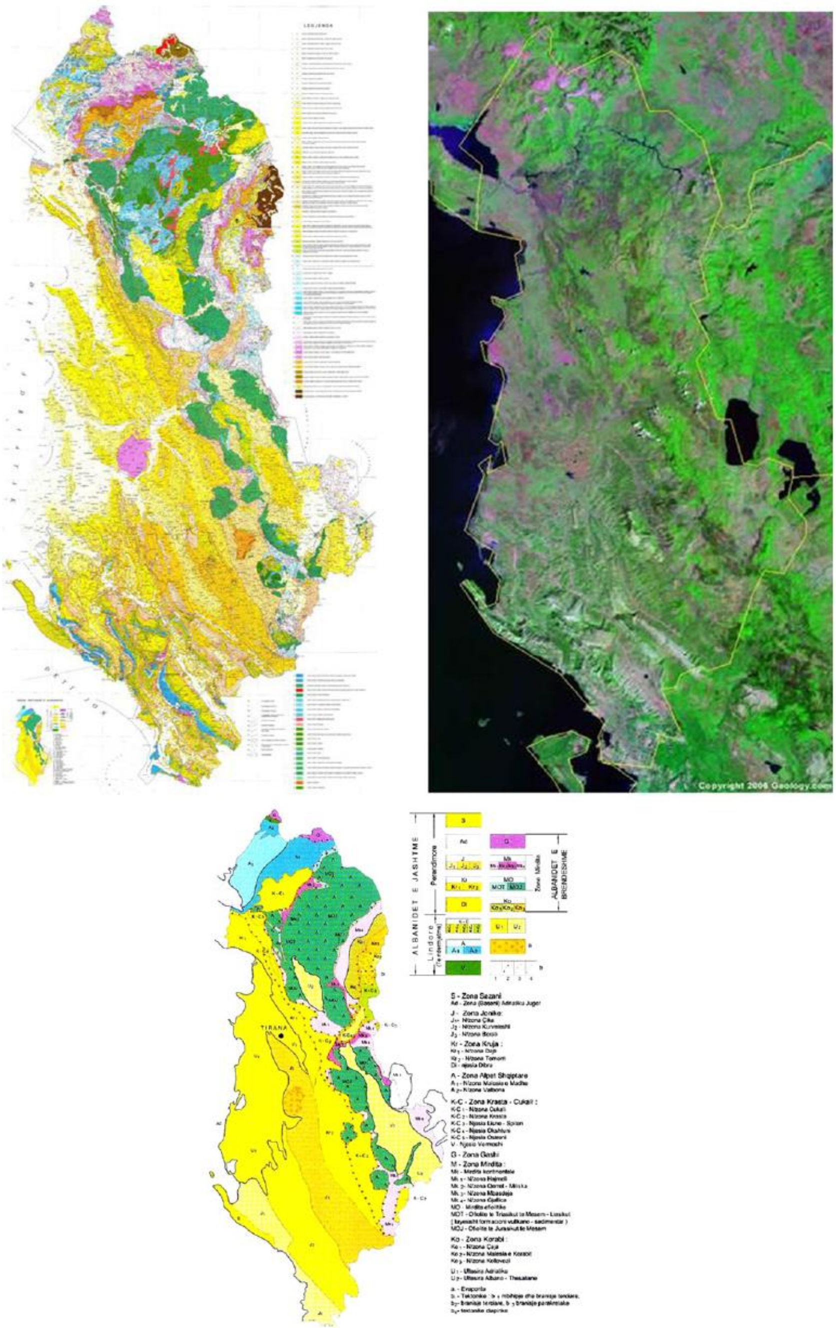


Figure 7: Geological, Hydrological and Geo-tectonic map of Albania

This phenomenon led to the formation of tectonic blocks of imbrication nature within the carbonate section of the western flanks of some anticline structures and sometimes to the partial or complete covering of the expected anticline structures with the evaporites of the adjacent eastern eroded structures. The Albanian sedimentary basin continues even in the Adriatic shelf with carbonate and terigenic formations. In the different profiles, it is noticed that there exist some local Bouguer and magnetic anomalies in the Adriatic shelf [36, 37].

Geothermal energy in Albania

The geothermal fluids, which are found in natural springs and wells of Albania, are located in three zones: Kruja, Ardenica, and Peshkopia [13]. The three zones differ from each other by the geological characteristics and thermo-hydrogeological features, as shown in Figure 8. They are related to regional tectonic and seismological activities.

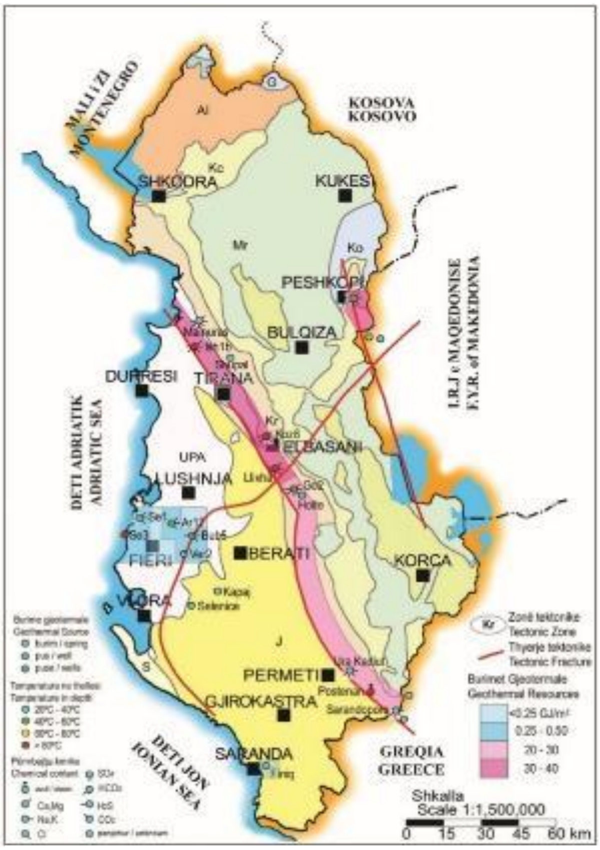


Figure 8: Geothermal map of Albania

The main geothermal springs of Albania and some technical data on them are presented in Table 1 [13].

Table - 1: Geothermal springs of Albania

No	Spring and location	Temperature (°C)	Coordinates		Yield (l/s)
			Latitude (N)	Longitude (E)	
1	Mamurras 1 & 2	21÷22	41°42'24"	19°42'48"	11.7
2	Shupal	29.5	41°26'9"	19°55'24"	<10
3	Llixha, Elbasan	60	41°02'	20°04'20"	15
4	Hydraj, Elbasan	55	41°1'20"	20°5'15"	18
5	Peshkopia	43.5	41°42'10"	20°27'15"	14
6	Katiut Bridge, Lëngarica, Përmet	30	40°14'36"	20°26'	>160
7	Vronomer, Sarandaporo, Leskovik	26.7	40°5'54"	20°40'18"	>10
8	Finiq, Sarandë	34	39°52'54"	20°03'	<10
9	Holta Creek, Gramsh	24	40°55'30"	20°33'36"	>10
10	Postenan, Leskovik	Steam source	40°10'24"	19°48'42"	N/A
11	Kapaj, Mallakastër	16.9÷17.9	40°32'30"	19°39'30"	12
12	Selenicë, Vlorë	35.3	40°32'18"	19°39'30"	<10

During the second half of the XXth century in Albania, there has been very intensive drilling for oil and gas exploration. During the drilling, some of the wells “accidentally” blew out “hot water” or brine. Table 2 presents all “geothermal wells” of Albania as well as some important technical data about them [13].

Table - 2: Geothermal wells of Albania

No	Well	Temperature (°C)	Coordinates		Yield (l/s)
			Latitude (N)	Longitude (E)	
1	Kozani 8	65.5	41°06'"	20°01'6"	10.3
2	Ishmi 1/b	60	41°29'2"	19°40'4"	3.5
3	Letan	50	41°07'9"	20°22'49"	5.5
4	Galigati 2	45÷50	40°57'6"	20°09'24"	0.9
5	Bubullima 5	48÷50	41°19'18"	19°40'36"	
6	Ardenica 3	38	40°48'48"	19°35'36"	15÷18
7	Semani 1	35	40°50'	19°26'	5
8	Semani 3	67	40°46'12"	19°22'24"	30
9	Ardenica 12	32	40°48'12"	19°35'42"	
10	Verbasi 2	29.3			1÷3

The hydric potential of Albania has the following main characteristics [13]:

- The volume of the underground water is estimated to be in the range of 12.8 km^3;
- The underground water flow width is estimated to be in the range of 295 mm;
- The average modulus of the underground water yield is estimated to be in the range of 9.5 l/(s*km^2);
- The groundwaters of Albania make up 31per cent of the total hydric reserves of the country.

Thus far, geothermal resources have been used only for their balneological values and, unfortunately, not at all for their energy potential. Albanian geothermal fluids have temperatures up to the lower limits of the middle enthalpy, with the exception of the Postenani steam spring, which gives hope to finding resources with temperatures in the range of 80°C.

Kruja geothermal zone

Kruja geothermal zone represents a zone with large geothermal resources, as shown in Figure 9. The Kruja Geothermal Zone extends over a length of 180 km from the Adriatic Sea in the North, down to the Southeastern area of Albania, and further S-E to the Konitza area in Greece [12, 13, 16]. The geothermal aquifer is represented by a carstified neritic carbonate formation with numerous fissures and micro-fissures. Three boreholes produce hot and mineralized water, Ishmi - 1/b (Ishmi - 1/b), Kozani - 8 (Ko - 8), and Galigati - 2 (Ga - 2). The thermal springs of the Llixha Elbasani spa are located about 12 km S from Elbasani city [13]. The Ishmi - 1/b is the northernmost borehole of the Kruja geothermal field, about 20 km NW of Tirana. Ishmi 1-b well was drilled in the upper part of the fissured and karstified limestone in 1964. The borehole intercepts the limestone section at 1300 m depth and continues through more than 1000 m of carbonate strata. Effective porosity is less than 1per cent, and the permeability ranges from 0.05 - 3.5 mD. The hydraulic conductivity of the limestone section varies between 8.6 x 10-10 - 8.8 x 10-8 m/s, and the transmissivity ranges from 8.6 x 10-7 - 8.5 x 10-5 m^2/s. The Kozani - 8 well was drilled in 1989 and is located 26 km SE of Tirana. It encounters limestone strata at 1819 m, penetrating 10 m into the section. Hot water has continuously discharged from the Ishmi-1/b and Kozani - 8 boreholes at rates of 3.5 l/s and 10.3 l/s, respectively, since the end of drilling operations in 1964 and 1988, respectively. Galigati-2 borehole is located on a hill about 50 km SE of Tirana. At a depth of 2800 m, it discloses an 85 m thick limestone section. Elbasani Llixha watering place is about 12 km South of Elbasani. There are seven

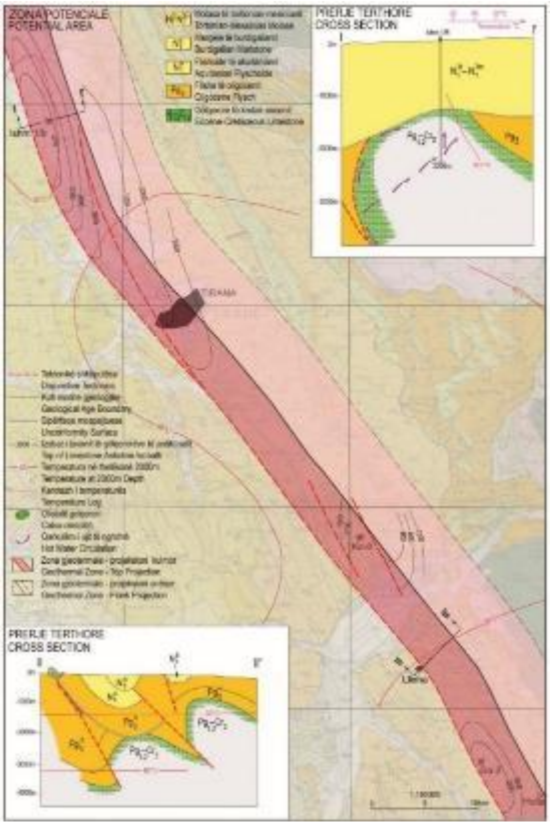


Figure 9: Kruja geothermal zone map

spring groups that extend like a belt with 320° of azimuth. All of them are connected with the main regional disjunctive tectonics of the Kruja zone. Thermal waters flow out through the contact between the conglomerate layer and the calcolistolith layer, as shown in Figure 10 [13].

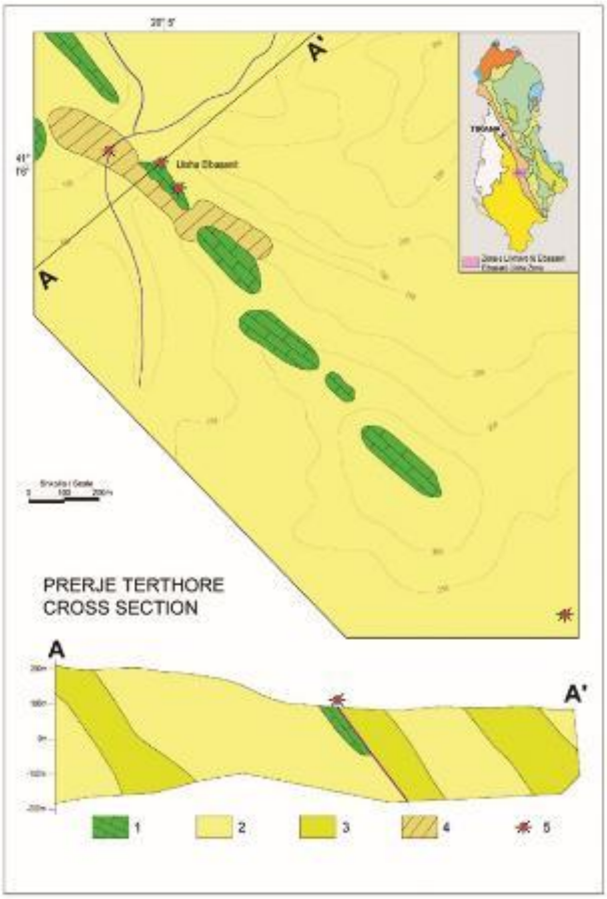


Figure 10: Geological map of the Llixha Elbasan geothermal springs

In this area, the reservoir is represented by the Llixha limestone structure. These springs have been known since before the Second World War. Surface water temperatures in the Tirana-Elbasani zone vary from 60°C to 65.5°C. In the aquifer top in the good trunk of Kozani - 8, the temperature is 80°C. Hot water has a salinity of 4.6-19.3 g/l. Elbasani Llixha water contains Ca, Na, Cl, SO_4, and H_2S [1, 2, 3, 6], while in the Tirana-Elbasani, thermal waters are of Mg-Cl type. They contain the cations Ca, Mg, Na, and K, as well as the anions Cl, SO_4, and HCO_3 with pH of 6.7-8 and density of 1.001 - 1.006 g/cm^3. Elbasani Nosi Llixha water has the following formula [1, 2, 3, 6]:

$$H_2S_{0.403}M_{7.1}\frac{Cl_{59}SO_{38}^{4}}{Na_{46}Ca_{35}}$$

Wellhead temperatures in the Tirana-Elbasani zone vary from 60 - 65.5°C. The temperature at the top of the aquifer reaches 80°C in the Kozani-8 hole. According to the temperature logs in Ishmi - 1/b and Galigati - 2, temperatures at depth in the carbonate section are 42.2°C and 52.8°C, respectively. The difference between the temperature of thermal water gushing at the surface and of the limestone section at depth shows that a mixture of waters from different depths and temperatures has occurred. The Lëngarica river thermal springs, near the Vjosa River Valley, Postenani steam springs, and the Sarandaporo springs can be found south of the Kruja geothermal area. Thermal water flows out from the contact between the Eocene fissured and karstified limestones and the flysch section. The stream flows from a tectonic fault. On both sides of the Lëngarica River, shores are located Bënja thermal springs, well known from the Roman era, as shown in Figure 11. These waters are much different. They do not contain H_2S or CO_2 and are a factor of 7-9 times less mineralized than waters from the Tirana-Elbasani zone. The mineral water of these springs is drinkable. The water temperature is 29°C. Yield is 30-40 l/s [13]. Nearby the Albanian-Greek border is located Sarandaporo's thermal spring with drinkable mineral water, and the temperature is 27.6°C and yields more than 40 l/s. Geothermal springs at Kavasila in Greece are located in the southern part of the Sarandaporo riverside. Kavasila thermal springs and

Sarandaporo on the Albanian side are springs that belong to a single geothermal system. On the northern side, it continues with the steam springs of Postenan Mountain in Leskovik and the Bënja geothermal springs of Përmet. Table 3 shows the temperature of the fluid measured with different geo-thermometers.

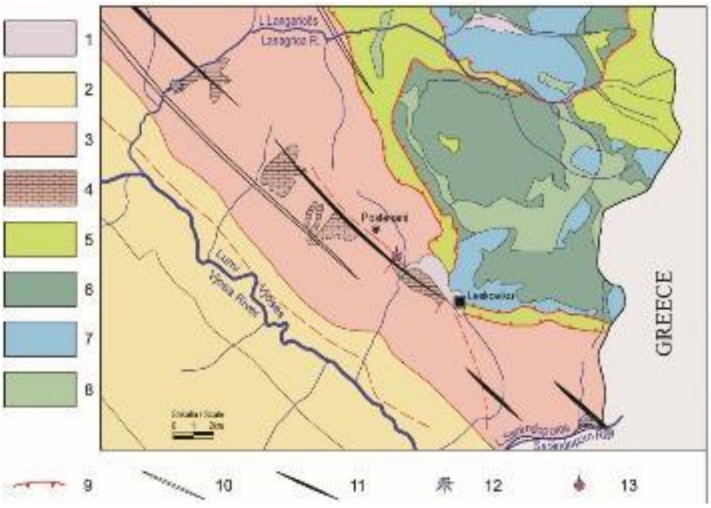


Figure 11: Lëngarica geothermal springs geological map

Table - 3: Kruja zone geothermal springs temperatures

Geo-thermometer	Llixha Elbasan springs	Mamurrasi springs	
		Spring 1	Spring 2
Fournier	254	241	220
Truesdell	235	184	191
Na+Ka+Ca	143	130	132

The Kruja geothermal area concentrates most geothermal resources in Albania. The most important resources explored until now are located in the Northern half of Kruja Geothermal Area, from Llixha-Elbasan in the South to Ishmi north of Tirana. For the Tirana-Elbasani subzone, heat in place (Ho) is 5.87 * 10^{18} - 50.8 * 10^{18} J, identified resources (Hi) are 0.59 * 10^{18} - 5.08 * 10^{18} J, while the specific reserves range between values of 38.5-39.6 GJ/m^2. The second subzone, Galigati, has a lower concentration of resources, 20.63 GJ/m^2, while geothermal resources amount to 0.65 x 10^{18} J. These reserves have been extrapolated for this whole subzone up to the Albanian-Greek border [13].

Ardenica geothermal zone

Ardenica geothermal zone is located in the coastal area of Albania, in sandstone reservoirs, as shown in Figure 12. The Ardenica geothermal area is situated 40 km N of Vlora within the Peri-Adriatic Depression. It's comprised of the molasses Neogene branchy anticline Ardenica, the Semani anticline, the northern pericline of the Patos-Verbasi carbonate structure, and the overlying Neogene molasses. The Ardenica geothermal area is intercepted by the Vlora-Elbasan-Dibra transversal fault. The Ardenica geothermal reservoir comprises sandstone sections of the Serravalian, Tortonian, and Pliocene ages. These sandstone layers are composed of coarse, medium, and fine grains. The effective porosity of the aquifers is about 15.5per cent, and the permeability reaches 283mD. Hydraulic conductivity is 4.98 m/s, and transmissivity has a value of 8.9 x 10-5 m^2/s. These reservoir properties translate into an output of 5-18 l/s. Hot water discharges from the boreholes Ardenica-3 (Ard-3) and Ardenica-12 (Ard-12), both situated in the Ardenica brachy anticline, Semani – 1 (Sem - 1) and Semani - 3 (Sem - 3) boreholes in the Semani anticline structure, in the Verbasi - 2 (Ver - 2) drilled in the Patosi monocline and the Bubullima - 5 (Bub - 5) borehole that intercepts the carbonate section of the Patos-Verbasi structure. At the surface, the boreholes discharge waters at temperatures of 32-67°C. Water flows into these boreholes at depth intervals of 1200 ÷ 1700 m (Ard - 3), 1935-1955 m (Ard - 12), 2250-2275 m (Sem - 1), 2698-2704 m and 3758 m (Sem - 3), 875-1935 m (Ver - 2) and 2385-2425 m (Bub - 5). Ardenica thermal water is Ca-Cl type, with 21.2 mg/l iodine, 110 mg/l bromide, and 71 mg/l boric acid, and has a formula [1, 2, 3, 6]:

$$M_{58.8}\frac{Cl_{98}}{Na_{86}}$$

Electrical resistivity and SP logs in the Ardenica – 12 and Semani - 1 boreholes show that the sandstone section has a thickness of 445-1165 m. As an example, these geophysical logs for the Ardenica - 12 boreholes are shown together with the temperature log and lithologic column. It is clearly shown that the aquifer temperatures are higher in the sandstone layer than above or beneath it. At the wellhead, temperatures are 32°C for Ardenica - 12 well, 35°C for Semani - 1 well, 38°C for Ardenica - 3 well, and 67°C for the well Semani - 3. However, the temperature in the aquifers at a depth of 1935-1955 m is 45.8°C. Ardenica reservoir has energy reserves in the range of 0.82 * 10^{18} J. Resources density varies from 0.25-0.39 GJ/m^2. The boreholes have been abandoned for a long time and await renewed investments to be converted into geothermal exploration [13].

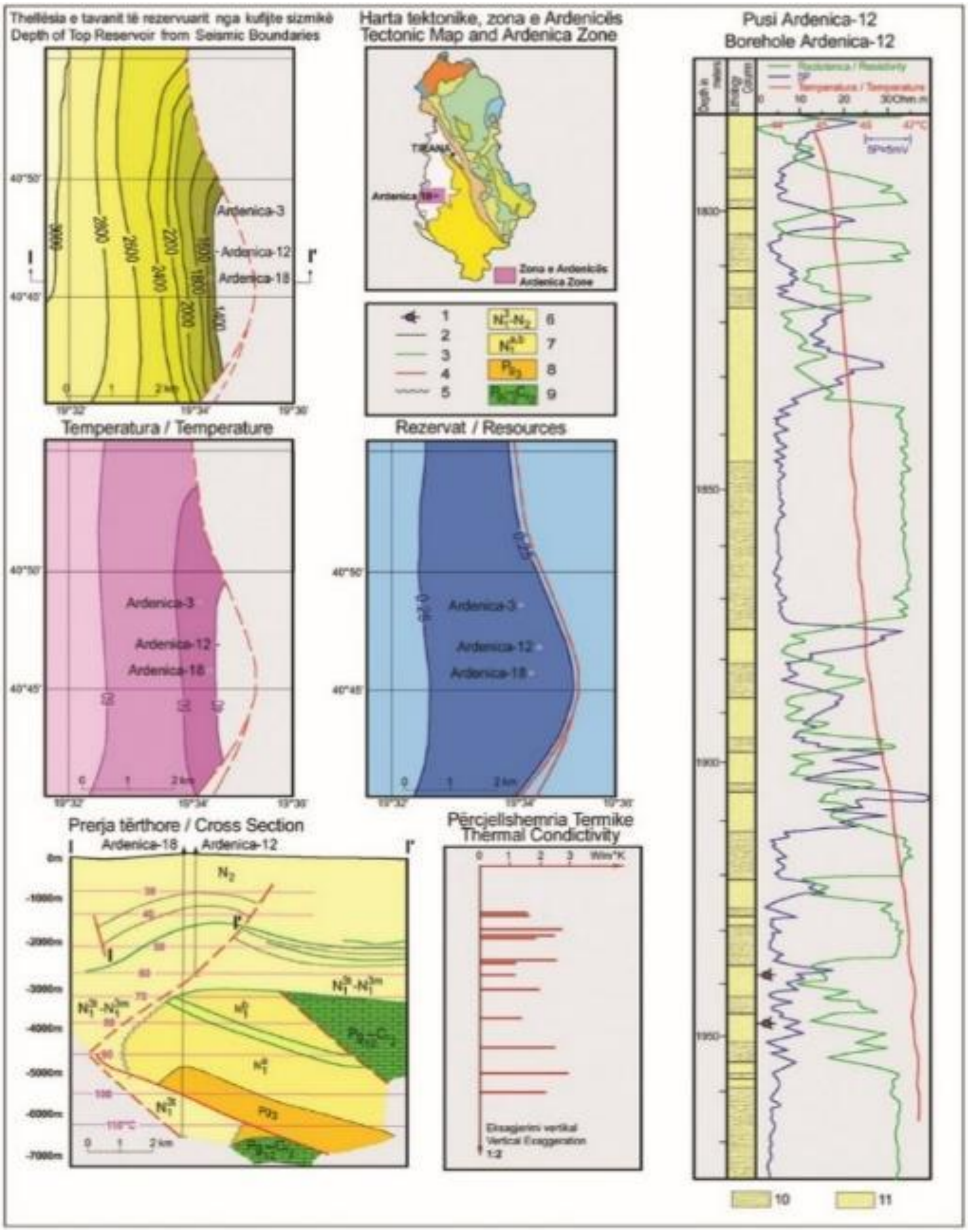


Figure 12: Ardenica geothermal zone map

Peshkopia geothermal zone

Peshkopia geothermal zone is located in the Northeast of Albania, in the Korabi hydrogeologic zone, Figure 13 [12, 13, 16]. At a distance of two kilometers east of Peshkopia, water at 43.5°C flows out of a group of thermal springs on a river slope composed of flysch deposits. Some of the springs yield flow rates up to 14 l/s. The occurrence of these springs is associated with a deep fault at the periphery of a gypsum diapir of the Triassic age that has penetrated the Eocene flysch, which surrounds it like a ring. These springs are linked with the disjunctive tectonic of the seismic-active belt Ohrid Lake-Dibër at the periphery of the gypsum diapir. This tectonic belt links the Banjishte and Kosovrasti thermal springs, which are located in the North Macedonian territory, close to the Albania-North Macedonia border [12, 16, 18].

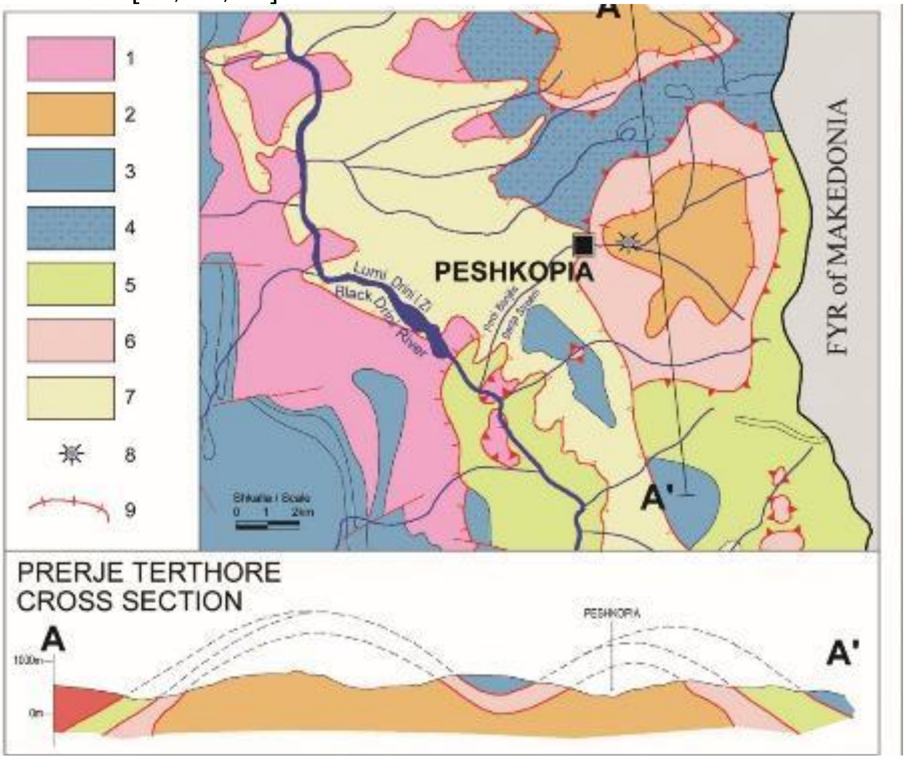


Figure 13: Peshkopia geothermal zone map

Evaporite diapir extends vertically over 3-4 km [22, 23, 25, 28] and comprises the main aquifer of this geothermal system. The occurrence of thermal waters is connected with the low circulation zone always under water pressure. Where gypsum plunges, under the level of the free circulation zone, the presence of H_2S can be detected in the water. The thermal waters are of sulfate-calcium type, with a mineralization of up to 4.4 g/l, containing 50 mg/l H_2S. Their chemical formula is [1, 2, 3, 6]:

$$H_2S_{0.0495}M_{4.4}\frac{SO_{56}^{4}}{Ca_{65}}$$

In the riverbed, outcrops of anhydrides and gypsum are located, also with a big yield of cold mineralized water springs, sulfate-calcium type. The temperature is 12°C. Different geothermometers indicate the reservoir temperatures are 140 - 270°C. Considering the regional geothermal gradient, temperatures of 220°C would be found at a depth of 8 - 12 km. However, the gypsum diapir represents e high thermal conductivity body focusing heat from its surroundings. Therefore, water could become warmer at shallow depths, suggested by the geothermal gradient. The water temperature, big yield, stability, and also aquifer temperature of the Peshkopia Geothermal Area are similar to those of the Kruja Geothermal Area. For this reason, the geothermal resources of the Peshkopia Area have been estimated to be similar to those of the Tirana-Elbasani area [13].

Temperature

The geothermal field is characterized by a relatively low value of temperature. The temperature at 100 meters depth varies from less than 10 to almost 20°C, with the lowest values in the mountain regions of the Mirdita zone, as well as in the Albanian Alps. In these areas, there is intensive circulation of underground cold water, of 5-6°C temperature. The highest temperature values at 100 m characterize the Adriatic coastline and the southern part of the country (Figure 14). The characteristic temperatures at 500 meters depth range from 21 - 20°C. The highest temperatures, up to 36°C, have been measured at 1000 meters depths in Peri-Adriatic Depression wells. The temperature is 105.8°C at 6000 meters depth in the central part of the Peri-Adriatic Depression. The isotherm runs parallel to the Albanides strike. The configuration of the isotherm doesn't change down to a depth of 6000m. Going deeper and deeper, the zones of highest temperature move from southeast to northwest, towards the center of the Peri-Adriatic Depression and even further towards the northwestern coast. The described geothermal field, with relatively low values of temperature, is a characteristic of the sedimentary basins with a great thickness of sediments. The temperatures in the ophiolitic belt are higher than in the sedimentary basin at the same depth.

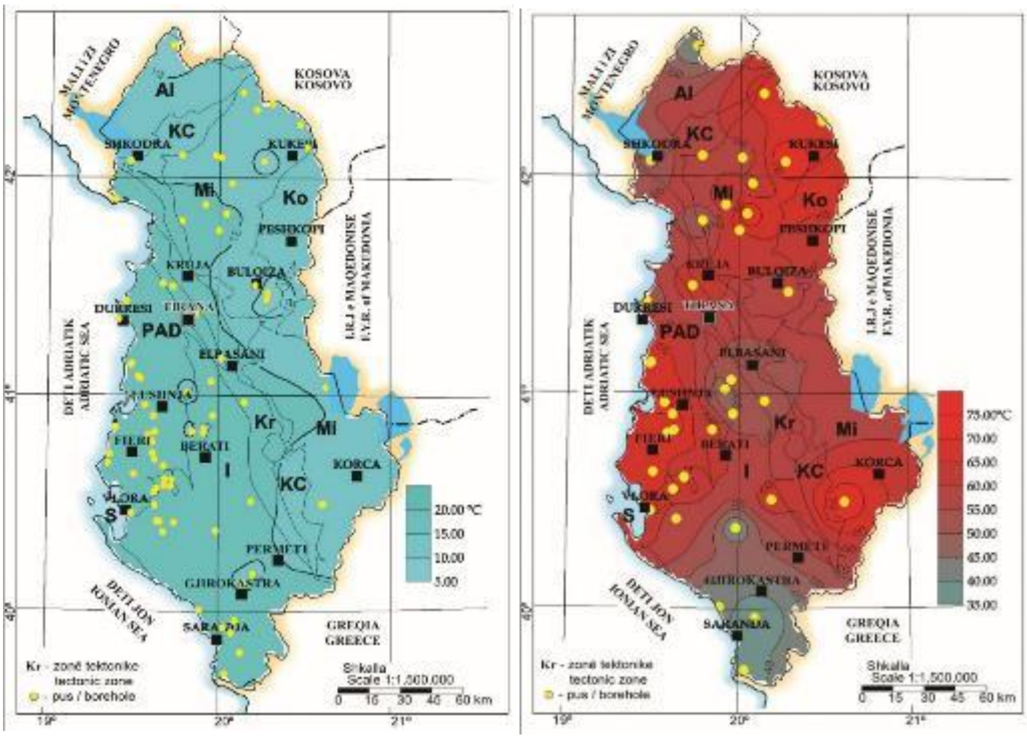


Figure 14: Temperatures at 100 m and 300 m depth

The geothermal gradient of Albania

In the External Albanides, the geothermal gradient is relatively higher (Figure 15). The geothermal gradient displays the highest value of about 21.3 m°K/m in the Pliocene clay section in the center of the Peri-Adriatic Depression. The largest gradients are detected in the anticline molasses structures of the center of Pre-Adriatic Depression. The gradient decreases about 10-29per cent, where the core of anticlines in the Ionic zone contains limestone. Elsewhere in the Ionian zone, the gradient is mostly 15 m°K/m. The modeling results show that deeper than 20 km is observed, decreasing the gradient. This change in the gradient coincides with the top of the crystal basement. The lowest values of 7-11 m°K/m of the gradient are observed in the deep synclinal belts of the Ionic and Kruja tectonic zones. Low gradient values (5 m°K/m) were also observed in the southern part of Albanides and in the Albanian Alps. In these cases, the gradient decreases toward zero or becomes negative. It decreases even more when the cold surface waters flow through a limestone anticline. In the Albanian Sedimentary Basin, the geothermal gradient changes from one formation to the others. The greatest geothermal gradient values were observed in the clay sections. At the same time, decreases in geothermal gradient are observed with increasing sand content at the geological section. In the conglomerate-sandstone part of the Rrogozhina suite of Pliocene, the geothermal gradient is almost two times lower than in the Helmësi

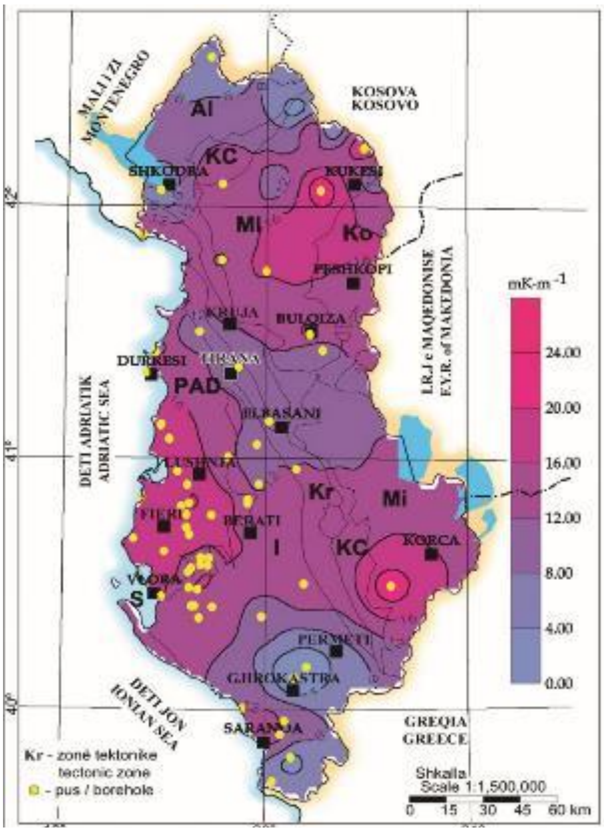


Figure 15: Geothermal gradient of Albania

clay suite of Pliocene. The sandstone reaches up to 65per cent of the section in the conglomerate-sandstone section. Local variations of the temperature and their geothermal gradient values are observed at a distance of 7-8km. For example, at a depth of 3000m on these distances, the temperature may vary from 8-9°C. The geothermal gradient values change from 10.5 to 17.5 m°K/m, even in the vertical direction, there occur deviations from the normal trend of the above-mentioned phenomenon in the case of lateral influences. Over-pressure in the molasses of the Albanian Sedimentary Basin has a great influence on the values of geothermal gradient13, 22, 24, 27, 29].

It is also obvious the influence of salt diapir in the gradient values. The rocks have a high thermal conductivity in the salt part of the geological section. These deposits explain why the geothermal gradient is lower than in other parts of the section. In the ophiolitic belt of the Mirdita tectonic zone, the geothermal gradient values increase up to 36 m°K/m in northeastern and southeastern parts of Albania. In this belt is also observed the existence of a lower gradient section, up to 10 m°K/m. This gradient decrease is explained by the convection influence that is related to cold underground water's circulation. In the mountainous area, this circulation is very intensive, especially in disjunctive tectonic zones. After the geothermal modeling, decreasing in the gradient is also observed deeper than 12 000 meters in this part of Albania, at the top of the Triassic salt deposits.

Heat Flow Density

The regional pattern of heat flow density in Albanian territory is presented in the Heat Flow Map (Figure 16). There are observed two particularities of the scattering of the thermal field in Albanides:

- The maximal value of the heat flow is equal to 42 mW/m^2 in the center of the Peri-Adriatic Depression of External Albanides. The 30 mW/m^2 value isotherm is open towards the Adriatic Sea Shelf. Heat flow density values are lower than 25-30 mW/m^2 in the Albanian Alps area. This phenomenon has taken place owing to the great thickness of sedimentary crust, mainly carbonate, in this zone;
- In the ophiolitic belt in the eastern part of Albania, the heat flow density values are up to 60 mW/m^2. The contours of Heat Flow Density give a clear configuration of the ophiolitic belt. The contours of 45 mW/m^2 in the Northeast and 40 mW/m^2 in South-East of Albania remain open toward the ophiolitic belt continuation beyond the Albanian border.

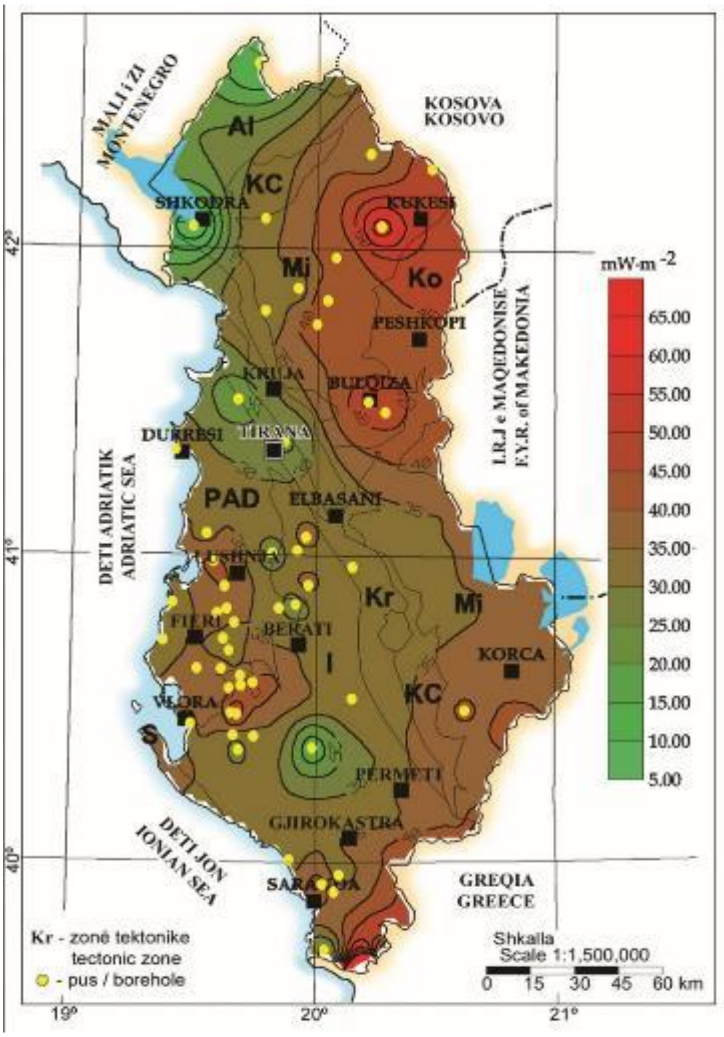


Figure 16: Heat flow density of Albania

Radiogenic heat generation of the ophiolites is very low. In these conditions, increasing the heat flow in the ophiolitic belt is linked with heat flow transmitting from the depth. The ophiolitic belt Heat Flow Density highest value can be explained by the small thickness of the geological section down to the top of the crystalline basement and MOHO discontinuity. The granites of the crystalline basement, with the radiogenic heat generation, represent the heat source. In the ophiolitic belt, there are some hearths observed of higher heat flow density. Heat flow anomalies are conditioned by intensive heat transmitting through deep and transversal fractures.

Country Update on the Energy Generation and Geothermal Use for Albania, 2015-2022

During this period, Albania approved several laws:

- Law No. 124/2015 “On Energy Efficiency,” whose aim is to: Compile regulatory and national policies on the promotion and improvement of energy efficiency with a primary focus on energy saving, supply reliability, and removal of barriers on the electrical energy market; Setting of National Target regarding the energy efficiency; Increase of competition between different operators.
- Law No.116/2016, “On the Energetic Performance of the Buildings,” whose aim is to: Establish the legal framework regarding the energetic performance of the new buildings, considering the local and climatic conditions, buildings' comfort as well as cost-effectiveness.
- Law No. 7/2017, “On Promotion of the Renewable Energy Resources usage,” whose aim is to: To promote the generation of electrical energy from renewable resources of energy; Decrease the import of organic fuels, greenhouse gases emissions & environmental protection; Promote the development of the electrical energy market, generated from the renewable resources as well as the regional integration; Support the diversification of the energy resources; Support the rural and remote areas development by improving their energy supply.
- DoCM No. 179, dated 28.3.2018, “On Approval of the National Action Plan on the Renewable Energy Resources, 2018-2020”.

In the frame of diversifying the energetic portfolio in Albania have taken place some important development in the sector of solar energy by issuing and having constructed and/or under construction a number of photovoltaic parks: Karavasta Photovoltaic Park – Voltalia (voltalia.com). The expected investment is above 100,000,000 Euros for an installed capacity of 140 MW. PPA is signed for 70 MW pricing 24.89 Euros/MW for a duration of 15 years; Spitalla Photovoltaic Park – Voltalia. The expected investment is around 80,000,000 Euros for an installed capacity of 100 MW. The PPA is signed for 70 MW pricing 29.89 Euros/MW for a duration of 15 years; Sheq Marinas, Topojë, Fieri Region: “LM Energy Corporate - installed capacity is 50 MW; Floating Photovoltaic Implant of Banja – Statkraft (www.stakraft.al): In the frame of the Devolli Cascade development, Statkraft made an investment of 2,000,000 Euros for an installed capacity of 2 MW (finalized on June 2021) nearby the Banja HPP damp. The implant is composed of 4 floating units (0.5 MW/unit). Each unit has a diameter of 70 m. Still, there is so much to do regarding the legal basis and, most importantly, to incentivize the development of the renewable energies sector and not remain focused on hydro and solar energies.

Table -4: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		**Total Electric Power in the country**		**Share of geothermal in total electric power generation**	
	Capacity (MW$_e$)	**Production (GWh$_e$/yr)**	**Capacity (MW$_e$)**	**Production (GWh$_e$/yr)**	**Capacity (per cent)**	**Production (per cent)**
In operation end of 2021	0	0	2,283	7,629	0	0
Under construction end of 2021	0	0	557.8	2,453	0	0
Total projected by 2023	0	0	1,204	5,391	0	0
Total expected by 2028	N/A	N/A	4494,8	15,573	N/A	N/A
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development:	
					Under investigation**:	

Table - 5: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		**Geothermal heat in agriculture and industry**		**Geothermal heat for buildings**		**Geothermal heat in balneology and other**	
	Capacity (MW$_{th}$)	**Production (GWh$_{th}$/yr)**	**Capacity (MW$_{th}$)**	**Production (GWh$_{th}$/yr)**	**Capacity (MW$_{th}$)**	**Production (GWh$_{th}$/yr)**	**Capacity (MW$_{th}$)**	**Production (GWh$_{th}$/yr)**
In operation end of 2021	1.907	1,902.7	0	0	1.907	1,902.7	N/A	N/A

Under constru-ction end of 2021	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total projected by 2023	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total expected by 2028	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table - 6: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commissioned	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 production (GWh_{th}/y)	Geoth. share in total prod. (per cent)	Operator
Tirana	Pallati i Kulturës	2001	Y	0.5	0.5	$2.4*10^{-3}$	$3.14*10^{-5}$	Ministry of Culture
Tirana	Twin Towers	2003	Y	1.2	1.2	$5.76*10^{-3}$	$7.536*10^{-5}$	Private
Shkodra	Peter Mahringer High School	2004	Y	0.18	0.18	$0.88*10^{-3}$	$1.04*10^{-5}$	Municipal
Korça	Kindergarten	2006	N	0.0227	0.0227	$0.108*10^{-3}$	$0.108*10^{-5}$	Municipal
total				1.9027	1.9027	$9.148*10^{-3}$	$11.72*10^{-5}$	

Table - 7: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (per cent)
In operation end of 2021	11	1.9027	$9.148*10^{-3}$	N/A	0	0
Of which networks	N/A	0	0	N/A	0	0
Projected total by 2023	N/A	N/A	N/A			

Geothermal direct use potential of Albania

UN on Resources Classification and Sustainable Development

The 2030 Agenda for Sustainable Development has inaugurated a new era of global development marked by an imperative to integrate social, environmental, and economic objectives. The multifaceted requirements of sustainable development depend on optimal and responsible production and use of natural resources. However, the sustainable use of resources faces a myriad of challenges today. These challenges include economic aspects like market volatilities, the need to pursue responsible investments, avoid windfalls, and guarantee no one is left behind. Social impacts need to be appropriately evaluated and explained to the satisfaction of society in line with all targets determined by the commitments from the UN Climate Change Conferences. This has to be done in an environment of geopolitical conflicts and many uncertainties. While recognizing that some of the challenges mentioned above are widespread in the general economy and industrial sectors, the governments guide sustainable resource management, together with the industry's efforts and responsibility from the financial sector. Resource production, transformation, and use, properly managed, can ensure beneficial social and environmental outcomes, inducing equitable distribution, reducing poverty, and eliminating conflicts.

The development of geothermal projects is a complex and time-consuming process that requires several experts' (developers, suppliers, and regulatory bodies) involvement in setting objectives to achieve project bankability and begin implementation. It encompasses several activities: Developing adequate geological knowledge, which requires an understanding of the geothermal reservoir conditions – temperature, permeability, flow rate, and fluid chemistry – and the associated uncertainties that affect confidence in future resource quantities. Knowledge concerning the resource will allow the developer to conduct extensive technical studies to evaluate the feasibility of extraction in the field. Establishing socio-economic viability, which requires conducting environmental, economic, and social impact assessment studies as per national laws and regulations. This entails extensive public consultations with residents, local government, and other stakeholders as part of the project approval process. It also seeks to guarantee economic viability (identification of potential consumer(s), projections of demand growth, and accessibility to infrastructure such as roads and grids); and determine financial feasibility by identifying the most cost-effective project design and securing a power purchase agreement as well as the requisite permits and licenses, and initial supplier contracts. Developing the project, which requires the commitment of funds and installation of all equipment, as per the established design, to begin plant operation and resource extraction. Although the above activities are well-defined and -intentioned, the lack of relevant worldwide standards and/or guidelines has hampered a consistent and comparable estimation and reporting of geothermal resource potential, thereby generating ambiguity and limiting understanding of the viability of geothermal projects among potential investors, which has undermined funding, including from capital markets. Many approaches have been proposed for classifying geothermal resources, including those based on accessibility/discovery, geological settings, temperature/use/status, potential, heat in-place, electric power generation potential, and energy or geological confidence.

The Llixha Elbasan hot springs in Albania, study of temperature conditions and utilization calculations

The following aims to do an estimation of the temperature conditions of the hot springs and at depth in the reservoir as well as a preliminary design of a district heating system utilizing the hot springs. Estimated temperature measurements based on different geothermometers indicate that the temperature of the waters in the formation of the Llixha reservoir may be above 220°C. The reservoir is believed to be in the depth interval of 4500-5000 m.

The following is addressed in the study:

- The general geological conditions in the area;
- A review of the theoretical basis of heat transfer;
- Three-dimensional modeling of variations in the temperature conditions in the surface region around the hot springs using the finite-element technique;

- Finite-volume modeling of the whole geothermal system down to 5000 m depth, incorporating both thermal convection and conduction, based on a simple boundary conceptual model;
- A study of the temperature conditions of the hot spring and their up-flow channels on the basis of simple dynamic modeling. Results are compared with the results of geothermometric water temperature estimates;
- A basic engineering design of a district heating network, including tanks and heat exchangers (radiators).

All this aims at demonstrating that the thermal water flowing from the Llixha springs is usable for direct utilization. This utilization would mitigate the electricity supply in the region and help improve living conditions for the local community.

Geological background of the Llixha Elbasan region

The geological structure of the Llixha region

The Llixha region is situated southwest of Elbasan. The region is well known for its thermal springs, appreciated since ancient times for their curative properties. A geological map of the region and a representative cross-section (I-I) are presented in Figure 17.

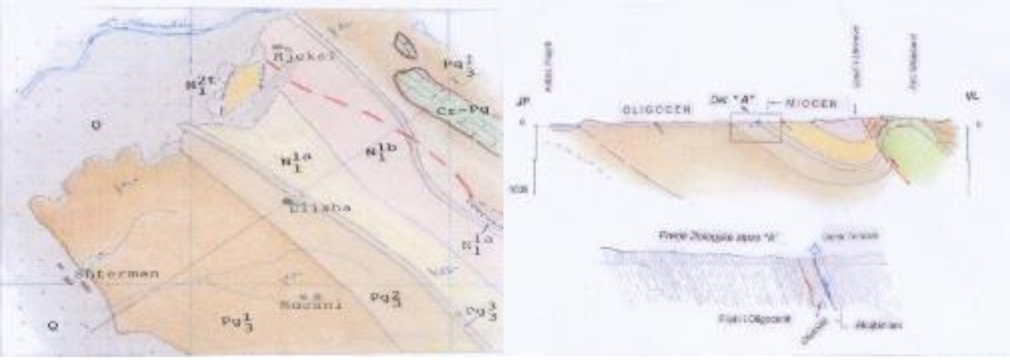


Figure 17: Geological map and cross-section of the Llixha Elbasan area

The region under study is south of the Shkumbini river valley. The surface relief increases rapidly up to intermediate elevation (300-500m). In the western part of the region, a system of hills declines gradually in the Cërriku field. The region has a rich hydro system of small streams and many underground water systems. The flow rate for the underground waters varies from 100-200 l/h in Thanë up to 5000 l/h in Tregan. Generally, the formations are composed of flysch with a diverse and chaotic morphology. This is an inhabited area, with small villages clustered around the thermal waters no more than 2-3 km from each other [22]. The region lies between two tectonic regions; the transversal Vlorë-Elbasan-Dibër and the longitudinal Leskovik-Drini river bay. Both of these connect the lower part in connection with the northern and western parts of the country. In the context of Albanian tectonics, the region represents the western part of the Kruja tectonic zone. The formation represents the Llixha synclinal structure limited by the anticline structures of Elbasan-Valeshit in the east and Papri in the west. The Elbasan-Valeshi structure rises at the surface through the calcareous formation of Creta-Paleogenic, while in Papri, the calcareous formations are at greater depth. The orientation of these structures is SW-NE, as is the rest of the Albanides structure [1, 13, 22, 26].

The formations in the region are mainly composed of flysch (three Oligocene and lower Miocene (fewer molasses) sections), while calcareous formations with a limited surface area are mainly composed of olistolith through the over-lined terigenic rocks. The biggest part is composed of lower Oligocene (Pg_3^1) rocks, consisting of 6 lithological units, as shown in Figure 17 [22]. The lowest part of the formation is composed of thinner flysch units intercalated by clays and sandstone, while the upper part is composed of thicker flysch with conglomerates. The lithology of the middle and upper Oligocene formation is mainly flysch with differently shaped packs. Interestingly the lithological evidence of the upper packs of the middle Oligocene where among the flysches are located with lengths up to 100 m. They are organized in a chain, preserving the general orientation of the other strata. Together with the conglomerate sandstone formation, they form a chain alternating in relief.

The lithology of the lower Miocene (Aquitanian-Burdigalian) deposits is characterized by Margoles alternating with the clays-sandstones as well as the presence of sandstone-conglomerates.

The Llixha syncline represents a depressed structure with eastern asymmetry filled in the central part with terigenic, flysch, and molasses deposits. The eastern part is distinguished by an easterly drop. The tectonics put the upper deposits in contact with the lower flysch Oligocene formation and has made the surface intrusion of the Eastern anticline calcareous formations possible. This tectonic layout is regional and includes the Western anticline chain of the Kruja tectonic zone [18, 19]. The Llixha system comprises a reservoir that feeds the southern part of the Shkumbini River. The main hydrological characteristic of the region is the presence of several hot springs. Their position is related to the Kruja geothermal zone, and they are connected with the calcareous olistoliths of the upper Oligocene conglomerate sandstones. The temperature of the hot springs varies, ranging from 50° to 68°C, while flow rates vary from one spring to another, without any seasonal characteristics.

Heat transfer theory

Thermal properties of rocks

The reservoir temperature field and the heat transfer between reservoir rocks and fluid, as well as between different reservoir layers, are highly dependent on the thermal properties of the rocks. In order to determine the equilibrium status (mechanic or thermal), knowledge of three macroscopic properties: pressure P, volume V, and temperature T, is needed. The relationship between these properties, f (P, V, T) = 0, is the so-called equation of state. Determination of the temperature as a qualitative property of the system, which determines the thermal equilibrium, only allows a qualitative appreciation of it. In order to determine the temperature in a quantitative way, we can use its relationship with the kinetic energy of atoms. It is generally accepted that [33]:

$$kT = \frac{2}{3}E_k = \frac{2}{3}\frac{\overline{mv^2}}{2} = \frac{\overline{mv^2}}{3} \tag{1}$$

Where k is the so-called Boltzmann constant, i.e., the energy contained in one degree Kelvin (k=1.380662*10-23 J/K).

Specific heat

Specific heat is defined as the energy needed to increase the temperature of a mass by a certain amount. Its SI units are J/kg·K. The specific heat can be measured at constant pressure (C_p) or constant volume (C_v). If the medium is considered to be incompressible, then they are equal [33]:

$$C_V = C_P = C(T) \tag{2}$$

In general, C (T) is a function of temperature so that in a given interval, the temperature dependence can be written as follows:

$$C(T) = C(T_i) + \beta(T - T_i) \tag{3}$$

For saturated rocks at high temperatures, their heat capacity may be calculated by [33]:

$$C_R = \frac{M_R}{\rho_m} \tag{4}$$

where:

$$M_r = (1-\phi)M_{r0} + \phi(S_0 M_0 + S_w M_w) + \phi S_g\left[f M_g + (1-f)\left(\frac{\rho_v L_{wv}}{T} + \rho_v C_w\right)\right] \tag{5}$$

and

$$\rho_m = \rho_{r0}(1-\Phi) + \Phi\left(S_o\rho_o + S_w\rho_w + S_g\rho_g\right) \tag{6}$$

Thermal conductivity

Thermal conductivity describes the ability of a material to conduct heat. Consider a wall with an infinite area of arbitrary material. Its width is one unit, and the boundaries of the wall are kept at constant temperatures. The temperature difference is assumed to be one degree. Let's assume that we are able to measure the amount of heat transferred through the wall in one unit of time. That value is the coefficient of thermal conductivity for that material, λ. The units are J/m·s·K. Via experimentation, it has been found that the amount of heat conducted into the wall (ρ_A) is proportional to the area (A), temperature change (ΔT), and the wall thickness (ΔX). This relation is known as Fourier's law:

$$q = -\lambda \frac{\partial T}{\partial x} \tag{7}$$

The negative sign is used because the heat flows from a higher temperature to a lower temperature. According to [7, 8], heat conductivity can be approximated by an inversely linear function of temperature:

$$\lambda^{-1} = a_0 + a_1 T \tag{8}$$

where a_0 and a_1 can be determined for each formation using exponential relations.

To determine the thermal conductivity of sedimentary rocks at temperatures above 300°C the Kutas and Gordienko [33] relation is used:

$$\lambda_T = \lambda_{20} - (\lambda_{20} - 3.3)\exp\left(0.725\frac{T-20}{T+130} - 1\right) \tag{9}$$

where: λ_{20} is the thermal conductivity at T=20°C.

Thermal diffusivity

The thermal diffusivity reflects the rate of the temperature change in the solid media [33]:

$$a = \frac{\lambda}{\rho c} \tag{10}$$

The geothermal gradient and heat flux

The temperature regime of sedimentary rocks is influenced by several factors: geological, topographical (sedimentary processes, erosion, groundwater movement, etc.), previous climatic changes, and the heat flux from depth to the surface. The time-dependent temperature field in 3-D space (*x, y,* and *z*) is written as follows:

$$T = T(x, y, z, t) \tag{11}$$

The time variations in temperature are because of climatic changes, which affect the mean annual temperature, and also because of changes in the Earth's heat flux (q).

Various model calculations have shown that the value of q hasn't changed in some millions of years. Climatic changes don't affect the temperature at depths greater than 300-500 m. So, in an undisturbed area, we can neglect time dependence and rewrite Equation 11 as follows:

$$T = T(x, y, z) \tag{12}$$

It is a well-known and accepted fact that the temperature increases with depth (except in some rare cases near the oceans or in glacial areas). Temperature conditions are controlled by the geothermal gradient (Γ). In the 3-D space, its value is calculated by [33]:

$$\Gamma = \sqrt{\Gamma_x^2 + \Gamma_y^2 + \Gamma_z^2} \tag{13}$$

where:

$$\Gamma_x = \frac{\partial T}{\partial x}; \qquad \Gamma_y = \frac{\partial T}{\partial y}; \qquad \Gamma_z = \frac{\partial T}{\partial z} \tag{14}$$

The heat flux density q specifies the amount of heat passing through a unit surface area in a one-time unit based on the subsurface temperature distribution. For homogenous and isotropic formations, the thermal conduction coefficient is constant. The heat flux density q can then be calculated through Fourier's law:

$$\vec{q} = -\lambda \operatorname{grad} T = -\lambda \nabla T \tag{15}$$

In anisotropic formations, this relation takes the form:

$$\vec{q} = (q_x, q_y, q_z); \qquad \nabla T = (T_x;\ T_y;\ T_z) \tag{16}$$

So, for homogenous and isotropic formations, the relation between gradient and heat flux is:

$$q = \lambda \Gamma \tag{17}$$

In order to calculate the heat flux density, it is enough to know the gradient (Γ) and the thermal conductivity of the formation. There are two methods commonly used for this purpose, the so-called intervals and the Bullardy methods. In the interval method, the climatic change effect is admitted, the underground change of the heat conductivity, relief change, underground water flows, and the temperature gradient (G) are evaluated, and the result was that both gradients are quite equal ($G \approx \Gamma$). In this method, the temperature gradient value is combined with the thermal conductivity of the value of the rock. Bullard's method [33] is used only for 1-D heat conduction in layered materials:

$$T(N) = T_0 + q_0 \sum_{i=0}^{N} \frac{\Delta Z_i}{\lambda_i} \tag{18}$$

Following measurements, experiments, and several model studies, it was generally accepted that for quite a long time, the mean values of q over the continents and oceans were unchanged.

The heat content of a geothermal reservoir at a certain moment in time can be determined using the volume model of the heat storage as follows [13]:

$$Q = [(1-\Phi)\rho_m C + \Phi \rho_w c_w](T_t - T_0) A \Delta Z \tag{19}$$

where:	C	the specific heat capacity of rock matrix (kJ/kg°K);
	T_t	the seal temperature of the aquifer (°C);
	T_0	is the surface temperature (°C);
	ΔZ	is the thickness of the aquifer (m);
	Φ	is the porosity

The heat production potential for a single well (with reinjection) is often calculated by the following equation [13]:

$$Q_p = Q R_0 \tag{20}$$

The extraction coefficient (R_o) can be calculated in several ways, also depending on whether reinjection is applied or not. In the case of reinjection, its value can be calculated by [13]:

$$R_0 = 0.33 \frac{T_t - T_r}{T_T - T_0} \tag{21}$$

The heat reserves for production wells can be calculated as follows:

$$Q_{p_2} = R_1 Q_p \tag{22}$$

where: R_1 is an extraction coefficient for production wells, which can be calculated by:

$$R_1 = \frac{E - I}{Q_p} \quad \text{with} \quad \begin{cases} E = Q_v (T_t - T_r) \rho_w C_w \Delta t \\ I = \frac{I_\$ C}{P} \end{cases} \tag{23}$$

In general, there are only small pressures and flow changes for many geothermal wells, and the dependence on rocks properties can be estimated by the relationship [13]:

$$Q_w = \frac{2\pi k_v S}{\ln\left(\frac{R}{r}\right)} \tag{24}$$

The vertical and horizontal permeability can be determined by the relation [13]:

$$k = \sum_{i=1}^{N} \frac{b_i^2 \Phi_i}{12}; \qquad \Phi_i = \sum_{i=1}^{N} b_i D_i \tag{25}$$

The thermal power, F_T (MW) from the well can also be calculated by [13]:

$$F_T = Q_{w_{max}} (T_{in} - T_{out}) 0.00184 \tag{26}$$

The annual energy production, E_{annual} (J/year), is calculated by [13]:

$$E_{annual} = \overline{Q_w} (T_{in} - T_{out}) 0.03154 \tag{27}$$

The thermal capacity is then calculated by:

$$K_{thermal} = 0.03171 \frac{E_{annual}}{F_T} \tag{28}$$

Temperature and lithological profiles

For *N* different layers, without heat exchange between them, the product of geothermal gradient and thermal conductivity is constant:

$$\lambda_1 \, \Gamma_1 = \quad \lambda_2 \quad \Gamma_2 = \text{.........} \quad = \lambda_N \, \Gamma_N \tag{29}$$

This shows that the higher the thermal conductivity of the rocks, the lower the geothermal gradient is. The conduction equation for steady vertical heat flow, which gives the relation between temperature, thermal conductivity $\lambda(T)$, and heat transfer as a function of depth, is [34]:

$$H(Z) + \frac{d}{dZ}\left[\lambda(T)\frac{dT}{dZ}\right] = 0 \tag{30}$$

The boundary conditions are:

$$T_0 = T(Z = 0); \qquad q_0 = \lambda\left(\frac{dT}{dZ}\right)_{Z=0} \tag{31}$$

If H = H_o and $\lambda(T) = {}^{\lambda_0}/_{(1 + Ct)}$, then the solution is:

$$T(Z) = \frac{1}{C}\left\{(1 + CT_0)\exp\left[\left(\frac{C}{\lambda_0}\right)(q_0 Z) - \frac{H_0 Z^2}{2}\right] - 1\right\} \tag{32}$$

If $H = H_0 \exp\left(-\frac{Z}{D}\right)$ with D ≈ 10 km then:

$$T(Z) = \left(\frac{1}{C}\right)\left\{(1 + CT_0)\left\langle \exp\left(\frac{C}{\lambda_0}\right)\left[H_0 D^2\left(1 - \exp\left(-\frac{Z}{D}\right)\right) - H_0 DZ + q_0 Z\right] - 1\right\rangle\right\} \tag{33}$$

The regional characteristics of the heat influx

The most important heat sources in the Earth's crust are the radioactive isotopes of Uranium, Thorium, and Potassium. So, the crustal thickness and the isotope distribution influence the heat flux from the interior of the Earth. An analytical relation between this flux and the radioactive heat is [33]:

$$q = q_r + DH_o \tag{34}$$

Three empirical equations are used to calculate the radioactive heat, *H* (μWm^{-3}) [33]:

$$H = 10^{-5}\rho(9.2C_U + 2.56C_{TH} + 3.48C_K) \tag{35}$$

$$\ln H = 16.5 - 2.74v_p \tag{36}$$

$$\ln H = 22.5 - 8.15\rho \tag{37}$$

where: C_U, C_{TH}, C_K	Uranium, Thorium, natural Potassium concentrations;
ρ	is the rock density; and
v_p	is the p-wave velocity (m/s)

The measured values of *H* help in the estimation of H_o by using the above relationships.

Annual temperature changes

The annual ground temperature change can be simplified by this periodic relation [18, 19]:

$$T(t) = T_0^a + A_0 \sin \omega t \tag{38}$$

whereas

$$\omega = \frac{2\pi}{P_d}$$

The temperature field *T (Z, t)* at depth in the area of the annual changes is obtained by solving the heat conduction equation for a homogenous semi-infinite medium, with the initial and boundary conditions:

$$\frac{1}{a}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2}; \qquad Z > 0 \tag{39}$$

$$T(Z,0) = T_0 + \Gamma_Z; \qquad T(0,t) = T(t); \qquad T(0,t) = T_0 + \Gamma_Z$$

The solution for this equation is known [9, 10, 11]:

$$T(Z,t) = T_0 + \Gamma_Z + A_0 \exp\left(-Z\sqrt{\frac{\omega}{2a}}\sin(\omega t) - Z\sqrt{\frac{\omega}{2a}}\right) \tag{40}$$

where the temperature amplitude A_z is given by:

$$\frac{A_Z}{A_0} = \exp\left(-Z\sqrt{\frac{\omega}{2a}}\right) \tag{41}$$

Therefore:

$$\frac{A_Z}{A_0} \longrightarrow o \qquad \text{for} \qquad Z \longrightarrow \infty \qquad\qquad \lim_{Z\longrightarrow\infty}\frac{A_Z}{A_0} = 0 \tag{42}$$

Heat transfer mechanisms

There are three heat transfer mechanisms; diffusion, convection, and radiation. If different parts of a “body” are in different temperatures, then there is a tendency to equal them. So, part of the energy from the “hot molecules” will be transferred to the “cold” ones. With time this causes the temperatures to equalize. This process is called diffusion. Convection is the process where the energy flows with moving fluid. There are two types of convection, Free, caused by a non-uniform distribution of density resulting in buoyant forces, and forced, caused by external factors. Usually, they can both occur at the same time but in different quantities. The relationship shows that the effect of thermal convection is a function of the diffusion/convection processes [33]:

$$\gamma_C = \frac{\lambda_e}{\lambda} = 1 + \frac{\lambda_c}{\lambda} \tag{43}$$

In the radiation processes, heat is released through electromagnetic waves. The amount of energy released per unit area is calculated by:

$$q = \sigma\varepsilon T^4 \tag{44}$$

where: σ =5.775 · 10^{-12} $Wm^{-2}K^{-4}$ and
ε is emissivity.

The differential equation for heat transfer

This equation is a mathematical expression of the first law of thermodynamics, the energy preservation low. The heat increases of an elementary volume ΔV is equal to the thermal energy which crosses the surface *S*. A solid medium is considered, which is not generating any energy (so the energy is only flowing through a surface *S*). The temperature *T* at point *P (x, y, z)* will be a continuous function of the position and time. For a homogenous solid medium, in which the thermal volume heat capacity is independent of temperature, the equation is [33]:

$$\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{a}\frac{\partial T}{\partial t} \tag{45}$$

with *a* thermal diffusivity of the solid medium.

In polar coordinates: $x = r\cos\alpha$; $y = r\sin\alpha$, hence:

$$\nabla^2 T = \frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{a}\frac{\partial T}{\partial t} \tag{46}$$

Let’s assume that in point *P (x, y, z),* the energy input per unit of time and unit of volume is *A (x, y, z, t)*, then Equation 45 is rewritten as:

$$\nabla^2 T + \frac{A(x,y,z,t)}{\lambda} = \frac{1}{a}\frac{\partial T}{\partial t} \tag{47}$$

If thermal conductivity depends on position and temperature, the equation can be written as follows:

$$\rho C\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda\frac{\partial T}{\partial z}\right) + A \tag{48}$$

Its solutions are often relatively simple and can be found for different functional forms of $\lambda(x, y, z)$. If the thermal properties are temperature dependent, the equation is non-linear and numerical methods can be used for its solution.

The basics hypothesis

Let's describe the heat exchange process between flowing fluids in a wellbore with appropriate boundary formations mathematically. Let's assume:

- The formation is homogenous and isotropic;
- The flow is in the axial direction only;
- The heat flow is only by conduction;
- There is no radial temperature gradient in the wellbore;
- In the boundary zone of the wellbore, the formation temperature is a known function of depth;
- The thermal properties of the fluid and formation are constant;
- The radial temperature in the wellbore is constant;
- The yield from the wells is constant;
- The flow in the wellbore is vertical (1D);
- The vertical heat conduction - is much less than the horizontal one, i.e., negligible.

[38] used a numerical model to verify the last hypothesis. In Figure 18 can be seen that the ratio between the vertical and horizontal temperature gradients, η, is less than 1per cent. To determine the value of η, the hypothesis that a constant linear source of heat could simulate the thermal effect of a drilling/production well is used:

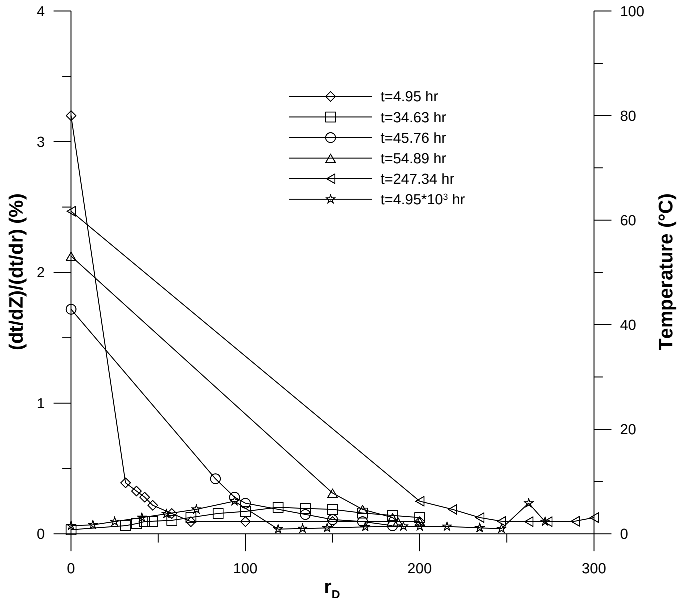


Figure 18: The gradient ratio

$$D = \frac{1}{2u}\int_0^u \left\{\sqrt{\pi\left[1-\Phi\left(\frac{1}{\sqrt{x}}\right)\right]} - \sqrt{x}\left[1-\exp\left(-\frac{1}{x^2}\right)\right]\right\}dx \qquad (49)$$

where: Φ	the errors' function;
$u = \frac{4at}{z^2}$	is dimensionless time;
a	thermal diffusivity;
z	depth of the well;
t	drilling (or production) time; and

$$\lim_{t\to\infty} D = \frac{\sqrt{\pi}}{2} \cong 0.886 \qquad (50)$$

The Laplace equation

For stable flow through a medium with constant thermal conductivity, without heat production, the form of the heat diffusion equation is:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \quad (51)$$

In polar coordinates with x = *rcosθ; y = rsinθ*:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} = 0 \quad (52)$$

And for 1-D radial flow:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = 0 \quad (53)$$

Using Equation 53, it is possible to calculate the temperature distribution through a cylindrical wall where the heat transfer is only radial direction. The solution is:

$$T = C_1 \ln r + C_2 \quad (54)$$

where the constants C_1 and C_2 depend on the initial and boundary conditions.

The Poisson equation

For a medium with constant conductivity and internal heat production, the following is used:

$$A(x, y, z) = \frac{H}{\lambda} \quad (55)$$

For stable heat-flow conditions, the diffusion equation is:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + A(x, y, z) = 0 \quad (56)$$

In polar coordinates, this becomes:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial^2 T}{\partial z^2} + A(x, y, z) = 0 \quad (57)$$

Initial and boundary conditions

In order to solve the thermal diffusion equation, let's assume that the formation temperature is the function of the position (*x, y, z*) and time (*t*) [33]. In addition, initial and boundary conditions must be specified.

A specific moment of time is chosen as the origin of the time coordinate. At that time, the temperature distribution is:

$$T(x, y, z, t = 0) = f(x, y, z) \quad \text{or} \quad T(r, \theta, z, t = 0) = f(r, \theta, z) \quad (58)$$

Suppose the radially symmetric case of a flowing wellbore is considered as an example. After a certain production time, the well is shut down. To determine the temperature distribution in the wellbore during the shutdown time, the end of production is considered as the origin of the time coordinate. In this case, the temperature *f (r, z)* must be known, i.e., the initial conditions.

To specify the temperature field of a medium, the boundary conditions must also be known beforehand. Different kinds of boundary conditions can be specified:

- Surface temperature is known. It can be a constant or function of position and time, T = *f (x, y, z, t).*
- The amount of energy flowing through the surface is known:

$$q_s(x, y, z, t) = -\lambda \frac{\partial T}{\partial n} \quad \left\{\frac{\partial}{\partial n} = \text{the derivation perpendicular to the surface}\right\} \quad (59)$$

- Linear surface heat flow. In such a case, the amount of energy transmitted through a given surface is proportional to the temperature difference between the surfaces and the surroundings.

$$q_s = \alpha(T_s - T_0) \quad (60)$$

where: T_s surface temperature;
T_0 the temperature of the surrounding;

α the heat transfer coefficient, and

$$\lim_{\alpha\to\infty} T_s = T_0 \tag{61}$$

- The connecting surface between two media with conductivity λ_1 and λ_2, respectively. If T_1 and T_2 are the temperatures of the media, then

$$T_1|_s = T_2|_s; \qquad -\lambda_1 \frac{\partial T_1}{\partial n}|_s = -\lambda_2 \frac{\partial T_2}{\partial n}|_s \tag{62}$$

Dimensionless parameters

In order to decrease the number of variables involved when solving heat conduction problems, a number of dimensionless parameters are used. Let's consider radial heat flow from a cylindrical source with radius r_c [33]:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{63}$$

With initial and boundary conditions:

$$T(r,0) = T_0; \qquad T(r_c,t) = T_c; \qquad T(\alpha,t) = T_0 \tag{64}$$

Let's introduce dimensionless parameters for the distance r_D, temperature T_D and time t_D can be introduced as:

$$r_D = \frac{r}{r_c}; \qquad T_D = \frac{T(r,t)}{T_c - T_0}; \qquad t_D = \frac{at}{r_c^2} \tag{65}$$

$$\frac{\partial^2 T_D}{\partial r_D^2} + \frac{1}{r_D}\frac{\partial T_D}{\partial r_D} = \frac{1}{a}a\frac{\partial T_D}{\partial t_D} = \frac{\partial T_D}{\partial t_D} \tag{66}$$

$$T(r_D,0) = \frac{T_0}{T_c - T_0}; \qquad T(1,\, t_D) = \frac{T_c}{T_c - T_0} \tag{67}$$

$$T(\alpha,t_D) = \frac{T_0}{T_c - T_0} \tag{68}$$

Thermodynamics of the hot springs

Temperature field modeling

In order to create a physical model to enable the stable state of heat flow through a formation to be studied, the analogy principle may be used. Let's assume that *n* dimensionless parameters *I₁, ... D*escribe the heat conditions in the formation and surroundings. In such a case, the model results should be expressed as *n* dimensionless parameters *I'₁, ... I'ₙ*. The conditions that must be fulfilled in order to use the model in a real reservoir are $I_1 = I'_1$, ... $I_1 = I'_n$. For stable heat transmission, the analogy with the electrostatic field can be used. For the 2D case and with the thermal conductivity is $\lambda = \lambda\ (x, y)$, the boundary conditions are:

$$T(z_{1,},x) = T_1; \qquad T(z_2,x) = T_2; \qquad -l \le x \le l; \qquad \frac{\partial T(z,x)}{\partial x}|_{-l} = \frac{\partial T(z,x)}{\partial x}|_{l} = 0 \tag{69}$$

In Table 1, a summary of the analogies between hydrodynamic, heat transfer, electrostatic, and electricity transmission fields is presented. As we can see from Table 8, the temperature change ΔT is analogous with the potential difference ΔU. Assuming the length unit, l_s, the dimensionless coordinates are:

$$x' = \frac{x}{l_s}; \quad z' = \frac{z}{l_s}; \quad z_1' = \frac{z_1}{l_s}; \quad z_2' = \frac{z_2}{l_s}; \quad l' = \frac{l}{l_s} \tag{70}$$

Table 8: The analogy between different physical fields (based on [33])

Hydrodynamics	**Heat transfer**	**Electrostatics**	**Electricity transmission**
Pressure P	Temperature T	Electrostatic potential Φ	Potential U
Pressure gradient $-\nabla P$	Temperature gradient $-\nabla T$	Field vector $E = -\nabla\Phi$	Potential gradient $-\nabla U$
Permeability/viscosity k/μ	Thermal conductivity	Dielectric constant $\varepsilon\ /\ 4\pi$	Specific resistance ρ

	λ		
Velocity vector $\vec{v} = -\frac{k}{\mu}\nabla p$	Heat amount transfer $\vec{q} = -\nabla T$	Dielectric displ. ${}^{\varepsilon}/_{4\pi}\vec{E} = -{}^{\varepsilon}/_{4\pi}\nabla\Phi$	Current $\vec{I} = -\nabla U$
Isobaric surface $\rho = C$	Isothermal surface *T=C*	Surface with electrostatic potential $\Phi = C$	Surface with potential $s = C$
Impermeable layer $\frac{\partial p}{\partial n} = 0$	Split surface $\frac{\partial T}{\partial n} = 0$	Force line $\frac{\partial \Phi}{\partial n} = 0$	Potential line $\frac{\partial U}{\partial n} = 0$

The relationship *λ = λ (x, z)* is analogous with ρ = *ρ (x, z).* Particular care should be used in unstable field modeling. Considering the hydrodynamics analogy with the thermal one, in particular the transitory flows of an incompressible fluid through a porous medium, then the main characteristics of this regime are the high value of the hydraulic diffusivity [1, 2]:

$$\eta = \frac{k}{\phi \mu c_t} \tag{71}$$

Its thermal field analogue is the thermal diffusion coefficient (*a*). The analogies principle can only be used in the case when the dimensionless times are equal. In thermal field modeling, the fact that the temperature is not affected by surface topography and groundwater flow is very important. To determine the boundary conditions, temperature maps at depth are widely used (Čermak and Haenel, 1988).

The unstable temperature fields

Before starting investment in a geothermal project, the stability of the temperature field involved, in space and time, needs to be confirmed, as well as the project's overall sustainability. The methods that can be used to answer such questions are numerous, but here we will apply the finite element method [30, 31, 32]. Considering the differential equation:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + q(x, y, z) - c\frac{\partial T}{\partial t} = 0 \tag{72}$$

The function of this equation is [30, 31, 32]:

$$X = X_v + X_r = \iiint_\Omega \left[\frac{k_x}{2}\left(\frac{\partial T}{\partial x}\right)^2 + \frac{k_y}{2}\left(\frac{\partial T}{\partial y}\right)^2 + \frac{k_z}{2}\left(\frac{\partial T}{\partial z}\right)^2\right] dxdydz + \iiint_\Omega \left(q - c\frac{\partial T}{\partial t}\right) dxdydz \tag{73}$$

Let's divide this function into two parts:

$$X_v = \iiint_\Omega \left[\frac{k_x}{2}\left(\frac{\partial T}{\partial x}\right)^2 + \frac{k_y}{2}\left(\frac{\partial T}{\partial y}\right)^2 + \frac{k_z}{2}\left(\frac{\partial T}{\partial z}\right)^2\right] dxdydz; \qquad X_r = \iiint_\Omega \left(q - c\frac{\partial T}{\partial t}\right) dxdydz \tag{74}$$

The initial conditions are *T (x, y, z, t=0) = f (x, y, z),* and the boundary conditions re [30, 31, 32]:

$$k_x \frac{\partial T}{\partial x} l + k_y \frac{\partial T}{\partial y} m + k_z \frac{\partial T}{\partial z} n + q + \alpha T = 0 \tag{75}$$

where *m,* n, and *l*	are the heading cosines of a vector perpendicular to the surface of the volume *Ω*;
q	heat flow density of surface hot springs;
α	convection heat transfer coefficient.

This is a 3-D temperature field problem. To integrate this equation, let's assume the time interval (*t, t+Δt*) through into *dT/dt = C*

T_i	temperature values in the nodes *I* = 1, 4

$$\frac{\partial X}{\partial T_i} = \frac{\partial X_v}{\partial T_i} + \frac{\partial X_r}{\partial T_i}; \qquad T = \frac{1}{6\Delta}\{N_1 \quad N_2 \quad N_3 \quad N_4\}\begin{Bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{Bmatrix} \quad \text{where} \quad N_i(x, y, z) = (a_i + b_i x + c_i y + d_i z); \quad i = \overline{1, 4} \tag{76}$$

The partial derivates of the function can be calculated as follows:

$$\frac{\partial X}{\partial T_i} = \begin{Bmatrix} \frac{\partial X}{\partial T_1} \\ \frac{\partial X}{\partial T_2} \\ \frac{\partial X}{\partial T_3} \\ \frac{\partial X}{\partial T_4} \end{Bmatrix} = \left\{ \frac{k_x}{36\Delta} \begin{vmatrix} b_1^2 & b_1 b_2 & b_1 b_3 & b_1 b_4 \\ b_2 b_1 & b_2^2 & b_2 b_3 & b_2 b_4 \\ b_3 b_1 & b_3 b_2 & b_3^2 & b_3 b_4 \\ b_4 b_1 & b_4 b_2 & b_4 b_3 & b_4^2 \end{vmatrix} + \frac{k_y}{36\Delta} \begin{vmatrix} c_1^2 & c_1 c_2 & c_1 c_3 & c_1 c_4 \\ c_2 c_1 & c_2^2 & c_2 c_3 & c_2 c_4 \\ c_3 c_1 & c_3 c_2 & c_3^2 & c_3 c_4 \\ c_4 c_1 & c_4 c_2 & c_4 c_3 & c_4^2 \end{vmatrix} + \frac{k_z}{36\Delta} \begin{vmatrix} d_1^2 & d_1 d_2 & d_1 d_3 & d_1 d_4 \\ d_2 d_1 & d_2^2 & d_2 d_3 & d_2 d_4 \\ d_3 d_1 & d_3 d_2 & d_3^2 & d_3 d_4 \\ d_4 d_1 & d_4 d_2 & d_4 d_3 & d_4^2 \end{vmatrix} \right\} \begin{vmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{vmatrix} -$$

$$\begin{vmatrix} \iiint_\Omega N_1^2 dxdydz & \iiint_\Omega N_1 N_2 dxdydz & \iiint_\Omega N_1 N_3 dxdydz & \iiint_\Omega N_1 N_4 dxdydz \\ \iiint_\Omega N_2 N_1 dxdydz & \iiint_\Omega N_2^2 dxdydz & \iiint_\Omega N_2 N_3 dxdydz & \iiint_\Omega N_2 N_4 dxdydz \\ \iiint_\Omega N_3 N_1 dxdydz & \iiint_\Omega N_3 N_2 dxdydz & \iiint_\Omega N_3^2 dxdydz & \iiint_\Omega N_3 N_4 dxdydz \\ \iiint_\Omega N_4 N_1 dxdydz & \iiint_\Omega N_4 N_2 dxdydz & \iiint_\Omega N_4 N_3 dxdydz & \iiint_\Omega N_4^2 dxdydz \end{vmatrix} \begin{vmatrix} \frac{\partial T_1}{\partial t} \\ \frac{\partial T_2}{\partial t} \\ \frac{\partial T_3}{\partial t} \\ \frac{\partial T_4}{\partial t} \end{vmatrix} - \frac{Q\Delta}{4} \begin{vmatrix} 1 \\ 1 \\ 1 \\ 1 \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \qquad (77)$$

Let’s make the following replacements:

$$\frac{k_x}{36\Delta} \begin{vmatrix} b_1^2 & b_1 b_2 & b_1 b_3 & b_1 b_4 \\ b_2 b_1 & b_2^2 & b_2 b_3 & b_2 b_4 \\ b_3 b_1 & b_3 b_2 & b_3^2 & b_3 b_4 \\ b_4 b_1 & b_4 b_2 & b_4 b_3 & b_4^2 \end{vmatrix} + \frac{k_y}{36\Delta} \begin{vmatrix} c_1^2 & c_1 c_2 & c_1 c_3 & c_1 c_4 \\ c_2 c_1 & c_2^2 & c_2 c_3 & c_2 c_4 \\ c_3 c_1 & c_3 c_2 & c_3^2 & c_3 c_4 \\ c_4 c_1 & c_4 c_2 & c_4 c_3 & c_4^2 \end{vmatrix} + \frac{k_z}{36\Delta} \begin{vmatrix} d_1^2 & d_1 d_2 & d_1 d_3 & d_1 d_4 \\ d_2 d_1 & d_2^2 & d_2 d_3 & d_2 d_4 \\ d_3 d_1 & d_3 d_2 & d_3^2 & d_3 d_4 \\ d_4 d_1 & d_4 d_2 & d_4 d_3 & d_4^2 \end{vmatrix} = [H] \qquad (78)$$

$$\begin{vmatrix} \iiint_\Omega N_1^2 dxdydz & \iiint_\Omega N_1 N_2 dxdydz & \iiint_\Omega N_1 N_3 dxdydz & \iiint_\Omega N_1 N_4 dxdydz \\ \iiint_\Omega N_2 N_1 dxdydz & \iiint_\Omega N_2^2 dxdydz & \iiint_\Omega N_2 N_3 dxdydz & \iiint_\Omega N_2 N_4 dxdydz \\ \iiint_\Omega N_3 N_1 dxdydz & \iiint_\Omega N_3 N_2 dxdydz & \iiint_\Omega N_3^2 dxdydz & \iiint_\Omega N_3 N_4 dxdydz \\ \iiint_\Omega N_4 N_1 dxdydz & \iiint_\Omega N_4 N_2 dxdydz & \iiint_\Omega N_4 N_3 dxdydz & \iiint_\Omega N_4^2 dxdydz \end{vmatrix} = [P] \qquad (79)$$

$$\frac{Q\Delta}{4} = [F] \qquad (80)$$

where: $[H]$ matrix of conductivity of the thermal field;
$[P]$ matrix of instability of the thermal field;
$[F]$ source vector.

After these replacements, the definitive form of Equation 77 becomes:

$$[H]|T| + [P]\frac{\partial T}{\partial t} - |F(t)| = 0 \qquad (81)$$

This matrix equation can be solved step by step. Expanding it as a Taylor series is obtained:

$$\begin{gathered} T(t+\Delta t) = T(t) + \frac{\Delta t}{1!}\frac{\partial T}{\partial t} + \frac{\Delta t^2}{2!}\frac{\partial^2 T}{\partial t^2} \\ \frac{\partial}{\partial t}T(t+\Delta t) = \frac{\partial T}{\partial t} + \frac{\Delta t}{1!}\frac{\partial^2 T}{\partial t^2} \\ \frac{\partial}{\partial t}T(t+\Delta t) = \frac{2}{\Delta t}[T(t+\Delta t) - T(t)] - \frac{\partial T(t)}{\partial t} \end{gathered} \qquad (82)$$

At times *t* and *t*+*Δt*, this equation is written:

$$[H]|T(t)| + [P]T(t) + [P]\frac{\partial T(t)}{\partial t} - |F(t)| = [0] \qquad (83)$$

$$[H]|T(t+\Delta t)| + [P]T(t+\Delta t) + [P]\frac{\partial T(t+\Delta t)}{\partial t} - |F(t+\Delta t)| = [0] \qquad (84)$$

$$\left\{[H] + \frac{2}{\Delta t}[P]\right\}\{T(t+\Delta t)\} + \left\{[H] - \frac{2}{\Delta t}[P]\right\}\{T(t)\} - |F(t+\Delta t) + F(t)| = [0] \qquad (85)$$

The temperature vector at time *t* will help to find the temperature at the time (*t*+*Δt*), which will help to find the temperature at the time (*t*+2*Δt*), and so on.

Pipe flow with heat addition

The flow to hot springs can often be modeled by the flow in a pipe surrounded by rock. If the heat balance in a thin cylindrical shell of fluid in the pipe is considered, as shown in Figure 19, the thickness of the shell is *δr* and the length *δx*.

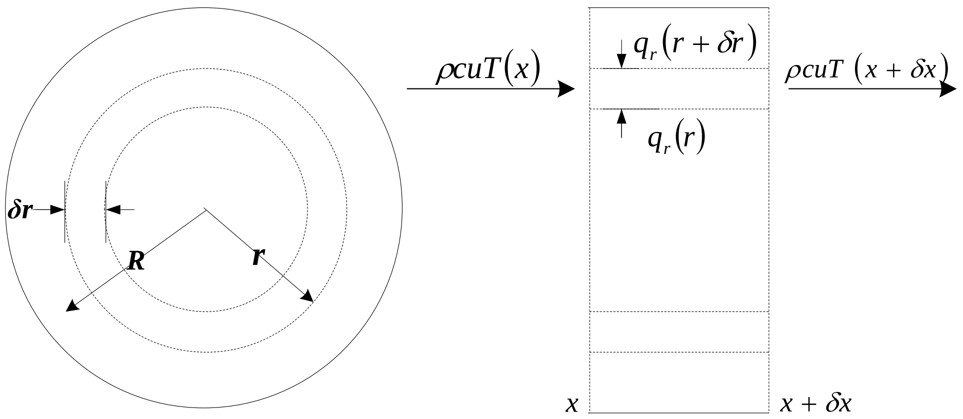


Figure 19: Heat balance in a small cylindrical wall (Turcotte and Schubert, 2003)

If the flow is steady, the temperature of the fluid does not change with time, and if axial heat conduction is unimportant compared with the advection of heat by the flow, the net effects of radial heat conduction and heat advection must balance each other [36]:

$$u\rho c\frac{\partial T}{\partial x} = k\left(\frac{\partial^2 T}{\partial r^2} + \frac{\partial T}{\partial r}\right) \tag{86}$$

The assumption of neglecting viscous dissipation, or frictional heating, is also made. In a laminar case, the velocity as a function of mean velocity $\bar{u}$ is calculated by [36]:

$$u = 2\bar{u}\left[1 - \left(\frac{r}{R}\right)^2\right] \tag{87}$$

The case in which the wall temperature of the pipe is T_w and the fluid temperature is changing linearly along the length as [36] gives:

$$T_w = c_1x + c_2; \qquad T = c_1x + c_2 + \theta(r) = T_w + \theta(r) \tag{88}$$

where: c_1 and c_2 are constants; and
$\theta(r)$ is the temperature difference between the fluid and the walls.

By inputting this in Equation 86, the following equation is obtained:

$$2\rho c\bar{u}\left[1 - \left(\frac{r}{R}\right)^2 c_1\right] = k\left(\frac{\partial^2\theta}{\partial r^2} + \frac{1}{r}\frac{\partial\theta}{\partial r}\right) \tag{89}$$

The boundary conditions are $T = T_w$ at $r = R$ and $q_r = 0$ at $r = 0$. The latter condition is required because there is no line source or sink along the axis of the pipe. The first condition is satisfied if $\theta_{r=R} = 0$ while the second one becomes $(d\theta/dr)_{r=0}=0$, with the aid of Fourier's law. The solution of Equation 89 with these boundary conditions is:

$$\theta = -\frac{\rho c\bar{u}c_1R^2}{8k}\left(3 - 4\frac{r^2}{R^2} + \frac{r^4}{R^4}\right) \tag{90}$$

Applying Fourier's law at r=R, the heat flux through the wall q_w is found to be as follows:

$$q_w = -\frac{1}{2}\rho c\bar{u}Rc_1 \tag{91}$$

This flux is constant and independent of the x. If c_1 is positive, the wall temperature increases in the direction of the flow, and heat flow through the wall of the pipe into the fluid. If its value is negative, the wall temperature decreases in the direction of flow, and heat flows out of the fluid into the wall of the pipe. The heat flux to the wall can be expressed through the coefficient of heat transfer h between the wall heat flux and the excess fluid temperature according to:

$$q_w = h(\bar{T} - T_w) = h\bar{\theta} \tag{92}$$

The average flow of the excess fluid temperature (for a unit of the area) is calculated by:

$$\bar{\theta} = \frac{2\pi \int_0^R (\theta u r) dr}{\pi R^2 \bar{u}} = -\frac{11 \rho c \bar{u} R^2 c_1}{48k} \tag{93}$$

In order to calculate the value of the coefficient *h*, Equations 92 and 93 are combined:

$$h = \frac{48k}{11D}; \qquad D = 2R \tag{94}$$

Equation 94 is valid only for $R_e < 2200$ (laminar flow). For pipe flow with heat addition, a dimensionless measure of the heat transfer coefficient is introduced, known as the Nusselt number, N_u, which is a measure of the efficiency of the process. This coefficient is calculated by [36]:

$$N_u = \frac{hD}{k} = \frac{\frac{48k}{11D} D}{k} = \frac{48}{11} \tag{95}$$

For the above difference in temperatures, fluid film thickness *D,* and conductivity *k*, the conductive heat flux would be:

$$q_c = \frac{k(\bar{T} - T_w)}{D} = \frac{q_w k}{Dh} \Longrightarrow N_u = \frac{q_w}{q_c} \tag{96}$$

Aquifer model for hot springs

The model of Figure 20 is considered. If the heat convected along the aquifer is balanced against the heat lost or gained by conduction to the walls, it leads to [36]:

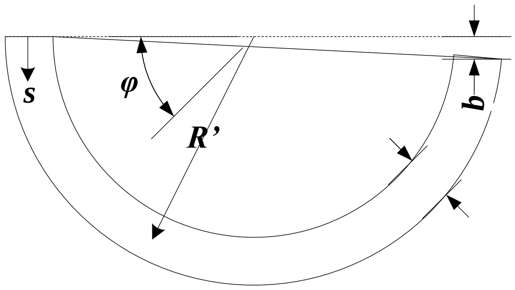


Figure 20: Model of a semi-circular pipe-like aquifer simulating a hot spring [36]

$$\pi R^2 \rho c \bar{u} \frac{d\bar{T}}{ds} = 2\pi R h (T_w - \bar{T}) \tag{97}$$

where s is the distance measured along the aquifer (*s=R'φ*).

We assume that the wall temperature of the aquifer depends on the local geothermal gradient *β* as follows:

$$T_w = R'\beta \sin\varphi + T_0 \Longrightarrow \frac{R^2 \rho c \bar{u}}{R'} \frac{d\bar{T}}{d\varphi} = \frac{48}{11} k (R'\beta \sin\varphi + T_0 - \bar{T}) \tag{98}$$

Equation 98 can be simplified through the introduction of the Pèclet number ($P_e = \rho c \bar{u} R/\kappa$) and the Prandtl number ($P_r = \rho c u/k$) and finally, the introduction of the dimensionless temperature as follows [36]:

$$\frac{11}{48} \frac{R}{R\prime} P_e \frac{\partial\theta}{\partial\varphi} + \theta = \sin\varphi \tag{99}$$

The solution of this linear first-order differential equation with appropriate boundary conditions is:

$$\bar{T} = T_0 \quad or \quad \theta = 0 \quad at \quad \varphi = 0$$

$$\theta = \left[\frac{48}{11} \frac{R\prime}{RP_e} \sin\varphi - \cos\varphi + \exp\left(-\frac{48}{11} \frac{R\prime}{RP_e} \varphi\right) * \left(\frac{48}{11} \frac{R\prime}{RP_e}\right)\right] * \left(\frac{48}{11} \frac{R\prime}{RP_e}\right) * \left[1 + \left(\frac{48}{11} \frac{R\prime}{RP_e}\right)\right]^{-1} \tag{100}$$

The dimensionless temperature θ_e at the exit of the aquifer, at $\varphi = \pi$, is given by [36]:

$$\theta_e = \frac{\left[\exp\left(-\frac{48R'\pi}{11RP_e}\varphi\right)+1\right]*\left(\frac{48\ R'}{11RP_e}\right)}{1+\left(\frac{48\ R'}{11RP_e}\right)^2} \qquad (101)$$

One-dimensional advection of heat in a porous medium

It is well known that geothermal systems develop above magma bodies, hot intrusions, and hot crustal regions, which induce large-scale motions of groundwater in the rocks above. A substantial fraction of hot springs with exit temperatures of about 50°C is believed to be the direct result of this type of hydrothermal circulation. The heat source heats the groundwater, which becomes less dense and rises. Near the Earth's surface, the water cools and becomes denser. It can then sink and recharge the aquifers and porous rock in the vicinity of the heat source. The water is then reheated, and the cycle repeats. An analysis of the complete hydrothermal convection system requires the solution of a coupled set of nonlinear differential equations in at least 2-D.

Here the upwelling flow above the heat source is studied. An incompressible fluid flows through the rock matrix (porous medium) with velocity components *u* (*x*-direction) and *v* (*y*-direction). In this case [36]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (102)$$

The energy conservation equation can be written [36]:

$$\rho_m c_{p_m} \frac{\partial T}{\partial t} + \rho_f c_{p_f}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \lambda_m\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \qquad (103)$$

For steady 1-D flow, ($dv/dy=0$) Equation 103 can be simplified as follows [36]:

$$\rho_f c_{p_f}\left(v\frac{\partial T}{\partial y}\right) = \lambda_m\left(\frac{\partial^2 T}{\partial y^2}\right) \qquad (104)$$

Integration of Equation 104 gives:

$$\rho_f c_{p_f} vt = \lambda_m \frac{\partial T}{\partial y} + c \qquad (105)$$

The value of the integration constant c_1 can be determined from the conditions at a great depth where upwelling fluid has a uniform reservoir temperature T_r therefore, as $y\rightarrow\infty$ leads to ($dT/dy\rightarrow 0$ and $T\rightarrow T_r$). This gives $c_1 = \rho_f c_{pf} v T_r$ and [36]:

$$\rho_f c_{p_f} v(T - T_r) = \lambda_m \frac{\partial (T-T_r)}{\partial y} \qquad (106)$$

This equation is rearranged as follows:

$$\frac{d(T-T_r)}{(T-T_r)} = \frac{\rho_f c_{p_f} v}{\lambda_m} dy \qquad (107)$$

The integration of Equation 107 gives:

$$\ln\frac{T-T_r}{c_2} = \frac{\rho_f c_{p_f} v}{\lambda_m} y \quad or \quad (T - T_r) = c_2 \exp\left(\frac{\rho_f c_{p_f} v}{\lambda_m} y\right) \qquad (108)$$

As ($y\rightarrow\infty$), the right side of Equation 108 approaches zero because $v < 0$. In order to evaluate the integration constant c_2, T is set to T_0 at the surface ($y=0$) and find $c_2 = T_0 - T_r$ and also:

$$T = T_r - (T - T_0)\exp\left(\frac{\rho_f c_{p_f} v}{\lambda_m} y\right) \qquad (109)$$

If the flow is driven by the buoyancy of the hot water, the Darcy velocity can be used to estimate the permeability of the system. Darcy's law can be written as:

$$v = -\frac{k}{\mu}\left(\frac{dp}{dy} - \rho g\right) \qquad (110)$$

Buoyancy forces are caused by a decrease in density (because of heating) described by [36] as:

$$\rho_f = \rho_{f_0} - \alpha_f \rho_{f_0}(T_r - T_0) \qquad (111)$$

where ρ_{f0} water density at T_0;

α_f the coefficient of thermal expansion.

Inserting Equation 111 into the Equation 110 gives:

$$v = -\frac{k}{\mu}\left(\frac{dp}{dy} - \rho_{f_0} g\right) - \frac{k}{\mu}\alpha_f \rho_{f_0} g (T_r - T_0) \tag{112}$$

By making the assumption that *dp/dy≈0*, Equation 112 can finally be written as [36]:

$$v = -\frac{k}{\mu}\alpha_f \rho_{f_0} g (T_r - T_0) \tag{113}$$

District heating system using the geothermal water

In general, the geothermal water for districts heating systems is taken directly from low-temperature reservoirs. Another way is the use the geothermal water through the heat exchangers to heat up the fresh water. The hot water can be stored in tanks if appropriate. This water is then transmitted to the buildings and can be used for heating and tap water. Heat flow to the buildings is controlled by the mass flow. A sketch of the geothermal district heating is given in Figure 21.

The following are given the basic calculations for geothermal district heating. The main elements of geothermal district heating are the radiators, and also this use is affected by the water thermal energy, building heat loss, pipe heat loss, and building energy storage. A short description of all of them is given below.

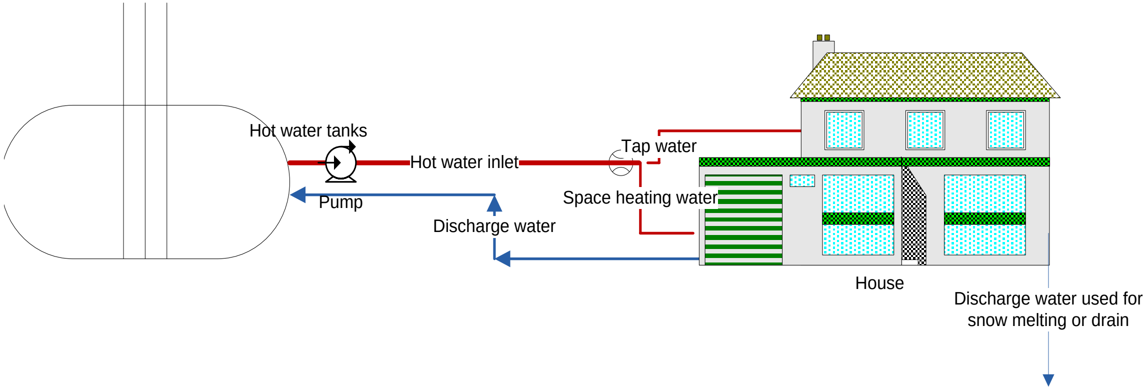


Figure 21: Geothermal district heating sketch

Radiators

Radiators are heat exchangers that make it possible to transfer heat from the geothermal water to indoors. The relative heat capacity of the radiator is given by the following relation:

$$\frac{Q^{rad}}{Q_0^{rad}} = \left(\frac{\Delta T_m}{\Delta T_{m0}}\right)^{4/3} \tag{114}$$

where the subscript 0 denotes the design conditions.

The temperature difference ΔT_m is calculated [29]:

$$\Delta T_m = \frac{(T_s - T_i) - (T_r - T_i)}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} = \frac{T_s - T_r}{\ln\left(\frac{T_s - T_i}{T_r - T_i}\right)} \tag{115}$$

The thermal energy of the water

The water thermal energy which the geothermal water will give to the indoors through the radiators is:

$$Q^{rad} = c_p m (T_s - T_r) \tag{116}$$

The relative thermal energy given by the geothermal water is [29]:

$$\frac{Q^{rad}}{Q_0^{rad}} = \frac{m(T_s - T_r)}{m_0(T_{s0} - T_{r0})} \tag{117}$$

The building's heat loss

The biggest part of the energy loss in such a system may come from the buildings. These losses can be calculated as [29]:

$$Q_{loss} = k_l(T_i - T_0) \tag{118}$$

Where building heat loss factor k_l is constant. The relative losses are [29]:

$$\frac{Q_{loss}}{Q_{loss\,0}} = \frac{T_i - T_0}{T_{i0} - T_{00}} \tag{119}$$

Pipe heat loss

The other losses in such a system are pipe heat loss. To determine the number of losses in the pipes is necessary to know the pipe transmission effectiveness parameter τ. Its value [37] is given by:

$$\tau = \frac{T_s - T_g}{T_1 - T_g} = \exp\left(-\frac{U_p}{mc_p}\right) \tag{120}$$

The reference value of τ can be calculated from the reference flow conditions as follow:

$$\tau_0 = \frac{T_{s0} - T_{g0}}{T_{10} - T_{g0}} = \exp\left(-\frac{U_p}{m_0 c_p}\right) \tag{121}$$

The values of U_p and c_p are assumed to be constant in the system. By combining Equations 120 and Equation 121, the transmission effectiveness can be calculated:

$$\tau = \tau_0^{\frac{m_0}{m}} \tag{122}$$

The supply temperature to the house can be calculated as follows:

$$T_s = T_g + (T_1 - T_g)\tau = T_g + (T_1 - T_g)\tau_0^{\frac{m_0}{m}} \tag{123}$$

and the return water temperature at the pumping station is calculated:

$$T_2 = T_g + (T_r - T_g)\tau = T_g + (T_r - T_g)\tau_0^{\frac{m_0}{m}} \tag{124}$$

Building heat storage

A building's heat storage (dependent on the amount of the thermo-insulation) can be very helpful for the heating system. Normally the builds are like a heat store. The building heat storage is calculated by [29]:

$$\frac{dT_i}{dt} = \frac{1}{C}Q_{net} = \frac{1}{C}\left(Q_{sup} - Q_{loss}\right) = \frac{1}{C}\left[mc_p(T_s - T_r) - k_l(T_i - T_0)\right] \tag{125}$$

Pipe and distribution network design

The network design is affected by a number of factors, the most important of which are; topology and route selection, pump station design and pipe system, tanks, and pressure vessels (structural design). After that, all the necessary calculations are made the costs evaluations process must be done in order to optimize all of them.

Pipe design

The pipe design is maybe the most important part and, at the same time, the costliest. The standard design process for the pipelines is as follows:

- Topology and route selection;
- Demand and flow analyses;
- Pipe diameter optimization;
- Thickness and pressure classes;
- Mechanical stress analysis (support, type, and distance between them);
- Thermal stress analysis (expansion loops, expansion units);
- Pump size and arrangement.

All this calculation is done with the purpose of minimizing the total cost (to optimize the calculations and selections).

Route selection

The route selection is the first step of these calculations, including the process of identifying constraints, avoiding undesirable areas, etc. In that phase, many factors are evaluated, such as the integrity of the pipeline, environmental impacts, public safety, land-use efficiency, proximity from the existing facilities, length of the path (attempting to select the shortest), and slopes. There are many ways to make this selection, including cost modeling comparison or transformation of the variable topography distance.

Pipe diameter and wall thickness

Deciding on the pipe diameter is another important step in the calculations. Here, the maximum allowable velocity and, of course, the minimization of the total cost (updated) are taken into account. Pressure is one of the most important design criteria. The design pressure value should be higher than the pressure at the most severe conditions. The pressure is calculated by taking into account the friction losses [21]:

$$H_f = f\,\frac{v_{hw}^{w}}{2}\frac{L_{pipe}}{d_i} \tag{126}$$

The friction factor depends on the flowing regime and can be calculated as follows:

$$\begin{cases} f = \frac{64}{R_e} \quad \text{for } R_e < 2100 \text{ (laminar flow)} \\ \begin{cases} f = \frac{0.361}{\sqrt[4]{R_e}} \\ \frac{1}{\sqrt{\mathrm{f}}} = 1.14 - 2\log\left(\frac{\mathrm{k}}{\mathrm{d_i}} + \frac{9.35}{\mathrm{R_e}\sqrt{\mathrm{f}}}\right) \end{cases} \text{for } R_e > 2100 \text{ (turbulent flow)} \end{cases} \tag{127}$$

Now it is possible to calculate the pressure for the pump and the power of the motor through the relationship:

$$P_{pump} = P_c + P_h + \frac{H_f \rho_w g}{10^5}; \qquad P_m = \frac{Q_w P_{pump}}{\eta_p \eta_m} \tag{128}$$

As we know all the prices, including electricity, pipes, junctions, bends, valves, and pumps, we are able to calculate the costs (operative and capital costs). The further design continues with the calculations of the thickness. The thickness based on the pumping pressure can be calculated [21]:

$$\delta = \frac{P_{pump} d_o}{2(S_a + P_{pump} y)} + \delta_a \tag{129}$$

Thermal stress analysis

The geothermal water pipeline is working at the conditions of the elevated values for pressure and temperature. Because of the elevated temperature, the pipe is constrained, and this movement should be controlled. This control is realized between the expansion loops, expansion units, or by using the pre-stressed pipes. The thermal expansion, the stress, and the force are calculated as follows:

$$\Delta L = \alpha L_{pipe} \Delta T; \qquad \sigma = E\,\frac{\Delta L}{L_{pipe}}; \qquad F = \frac{\pi d_i^2}{4} E \alpha \Delta T \tag{130}$$

And finally, the expansion arms [21]:

$$L_a = \frac{\sqrt{d_o \alpha \Delta T L_{anchor}}}{208.3\left(2-\sqrt{2}\right)^2} \tag{131}$$

The pressure vessels

During the design phase of the pressure vessels, there are several constraints, such as classification, diameter and thickness, form, supports (type), saddle (size), and openings (reinforcement). The classification of the pressure vessels is made on the base of the maximum allowable pressure, their volume, and the stored fluid. The thickness is calculated again in the base of the most severe conditions of the differential pressure and temperature. The first step in the calculations procedure for the tank consists of its optimization (minimizing the area). The function to be minimized is [21]:

$$A = \pi DH + 2\frac{\pi D^2}{4} \qquad (132)$$

The minimum could be reached for $D=|H|$.

The plate and roof thickness can be calculated as follows:

$$\delta_p = \frac{P_t D_{min}}{2 f_{tank} W_{factor}^{tank}} + \delta_{ad}^{tank}; \qquad \delta_r = \frac{40 D_{min}}{2 \sin \Theta \sqrt{20 P_{atm} \frac{100}{E_y}}} \qquad (133)$$

Results of simple hot spring modeling

The six hot water springs at Llixha in the Elbasan region have water temperature up to 65°C and flow rates up to 23 l/s. The estimated reservoir temperature at depth associated with the hot springs, based on the chemical composition using different geo-thermometers, is given in Table 3. These values show that the water is coming from great depth where the average temperature is over 200°C. The mineralization of the water is 7.2 g/l, the H_2S content 410 mg/l, and free CO_2 180 mg/l. The high content of CO_2 makes the Na+Ka+Ca geo-thermometer unreliable, so the reservoir temperature is likely to be in the range of 220-235°C (Arnòrsson, 2000; 2007; Arnòrsson and D'Amore, 2005). This is in agreement with calculations based on the geothermal gradient and a depth of 4500-5000 m. Its value for the region is of the order of 30°C/km, as is shown in Figure 16 (Frashëri et al., 2004). The water contains <1.2per cent tritium. The absence of tritium shows that this water originated as precipitation centuries ago. The water is chloro-magnesia and contains the cations Ca^+, $Mg^{+,}$ and Na^+ and the anions Cl^-, $SO^{4-,}$ and HCO^{3-}. The Ph is in the range of 6.8-7, and the density is 1000-1060 kg/m^3. As it is shown in Figure 11 [13, 24, 25, 26, 27, 28], the hot springs are situated in the middle of the village. The hot water has been used only for balneology for several centuries, possibly since the time of the Roman Empire. The first modern use dates back to 1937 with the building of the "Hotel Park" medical centre. The use of the water flowing from these springs can help to improve the economic effectiveness of district heating in the village. The realization of such a project will allow the utilization of geothermal water as an energy resource for the first time in Albania. The purpose of the calculations presented in this chapter is to show that the water of these hot springs can be used for the district heating of the village community.

The 3-D modelling of the temperature field of Llixha, Elbasan region

A finite volume model was set up for a crustal volume with an area of 10 x 10 km and 5 km thickness to model the temperature, density, and fluid velocity distribution in the Llixha region. The grid is shown in Figure 22. Here it is assumed that the medium is homogeneous and isotropic and that $k_x = k_y = k_z = 2$ W/m°K [30, 31, 32]. We also know that $Q = 20$ l/s (corresponding to $m_i = Q/6 = 3.3$ l/s or 3.224 kg/s for each of the hot springs), c_p =4180 J/kg°C [13]. The temperature at depth in the formation is set at 221°C while the temperature of the water at the surface is in the range of 60-65°C.

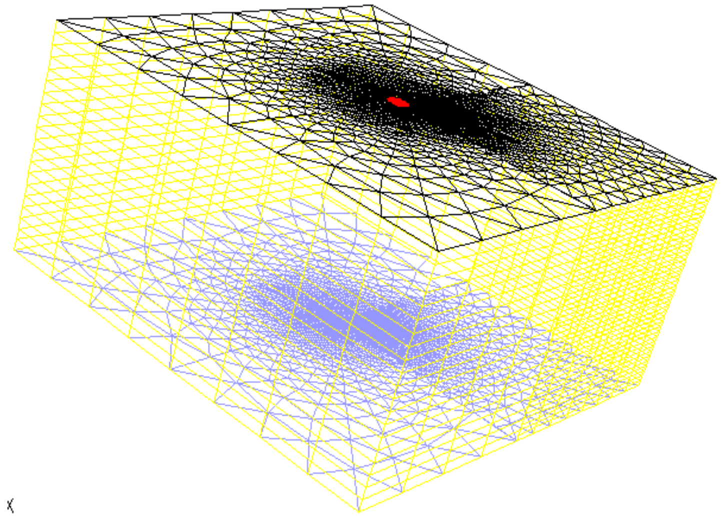


Figure 22: The finite volume grid used to model temperature and flow conditions in the Llixha region

The temperature gradient of the surroundings is assumed to be 12°C/km (see Figure 8). The modelling software FLUENT is used to solve the problem; it provides calculation results for temperature, density, and velocity for the volume modelled. In the model, water flows with a velocity of 1.25*10^{-7} m/s. The results for temperature, density, and velocity, as well as velocity vectors, are shown in Figures 23, 24, 25 & 26. More details on the modelling with FLUENT are presented in Appendix 1.

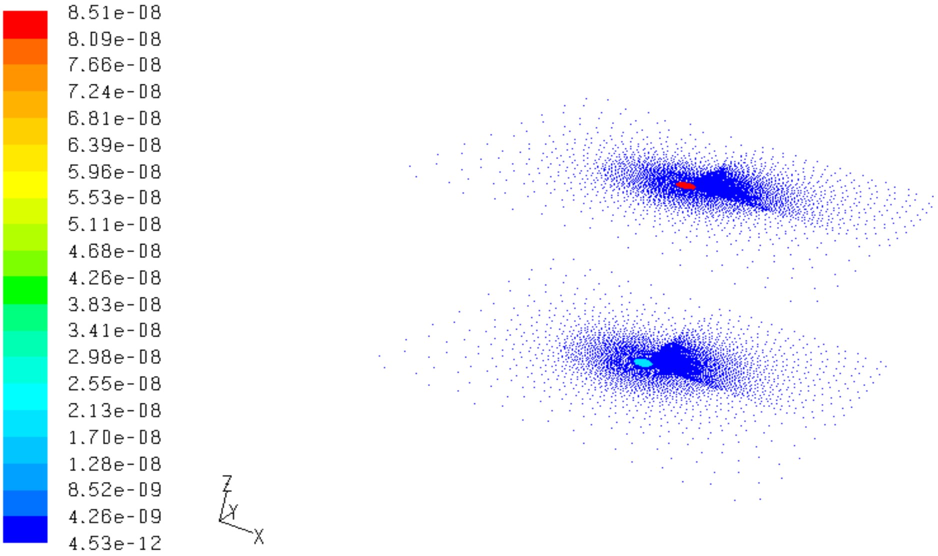


Figure 23: The temperature magnitude

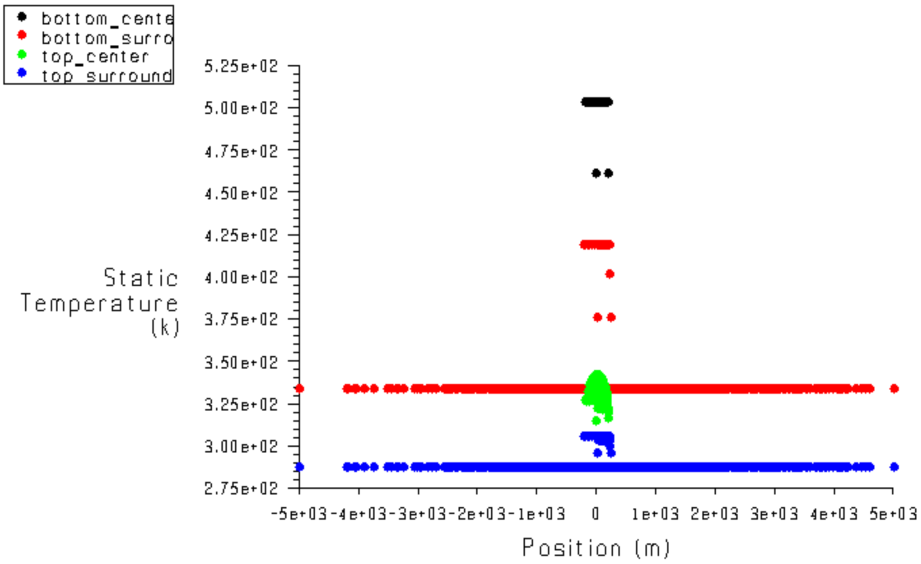


Figure 24: The fluid density magnitude

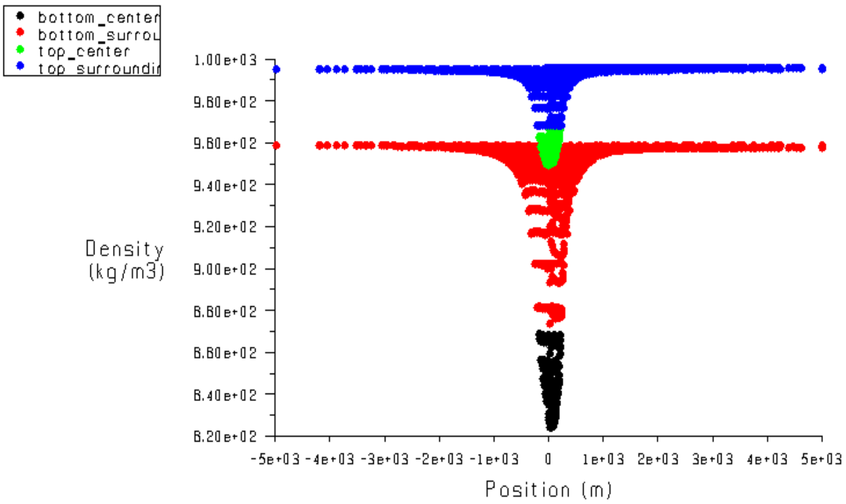


Figure 25: The velocity magnitude

In conclusion, we can say that the results of finite element calculations (section 7.1.3. and Appendix 1) and the FLUENT modelling allow us to predict the future temperature changes on the ground if it will change the flow from the hot springs.

Calculation results for the hot spring dynamics

The purpose of these calculations is to estimate the water temperature in the formation, to estimate formation properties, and to find how the temperature changes in the up-flow zone of the spring water. The water table was assumed to move at a velocity of 4 m/year. The temperature of the rocks was assumed to be about 230°C, the radius R' = 14.4 m, the geothermal gradient β = 30°C/km, the inflow 20 l/s, the value of the angle $\varphi = \pi/6$, the thermal diffusivity κ = $1.4*10^{-7}$ m^2*s^{-1} and the convection coefficient heat transfer α= $3*10^{-5}$ K^{-1} [36]. After solving the problem, we find that the water temperature in the reservoir is estimated to be about 221°C (quite the same as indicated by the geothermometers), the permeability of the formation is about 8,8 mD, the drainage area of the formation is about 0.1575 km^2 and the temperature of the up-flow water changes as shown in Figure 27.

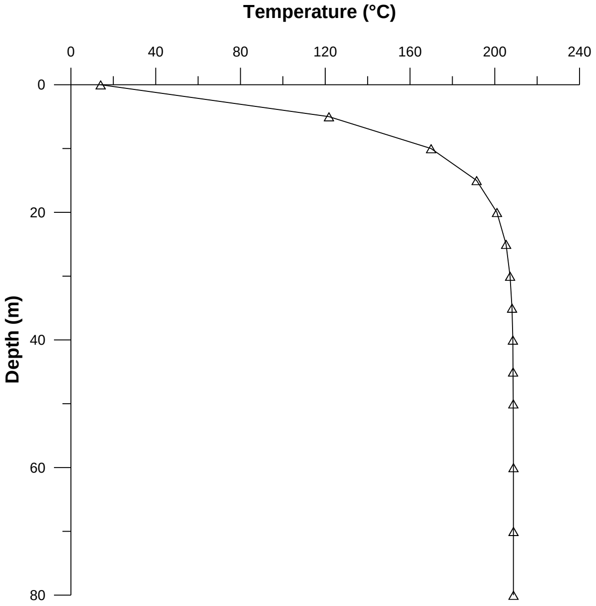


Figure 27: Temperature change on the water up flow

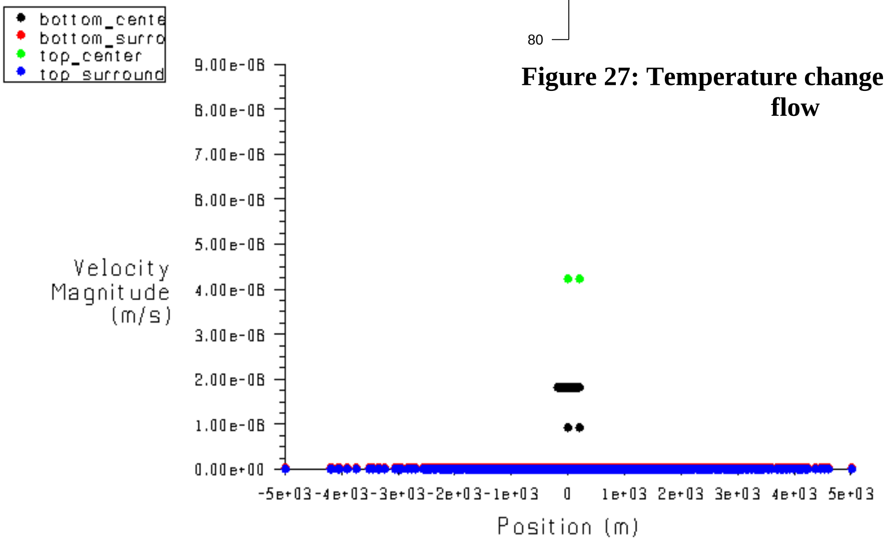


Figure 26: The velocity vectors

Results for the network system

The pipeline was assumed to be compounded from two parts, part one with a length of 2 km and part two with a length of 3 km. The flow baseline was assumed to be 20 l/s, and the temperature of the water was 65°C. The pressure at the consumer should be 2.31 bar. The calculations are made for 4 different diameters in the range of 0.07-0.111 m. The basic restriction was the water flow velocity. If this value is greater than 3 -4 m/s, the noise level and the corrosion and erosion ratio are higher. In these conditions, the pipeline optimization based on the total cost shows that the optimal diameter is 0.090 m (see Figure 28). The calculations for the tank are made for four different volumes in the range of 400-1000 m^3. The surface optimization of the tank shows that the optimal diameter is in the range of 7.986-10.84 m (Figure 28). All the calculations procedure is given in Appendix 3.

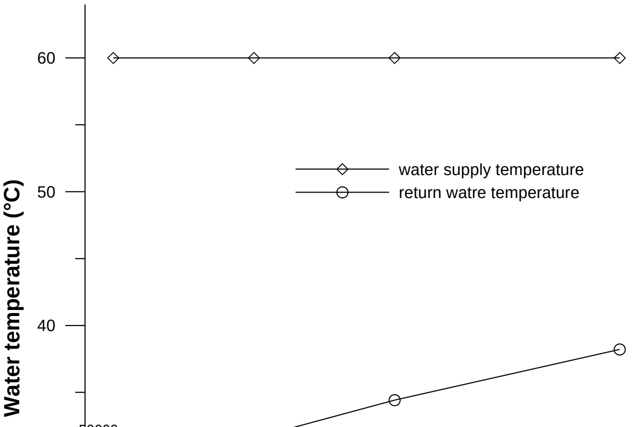


Figure 29: Results for the calculation of readiators

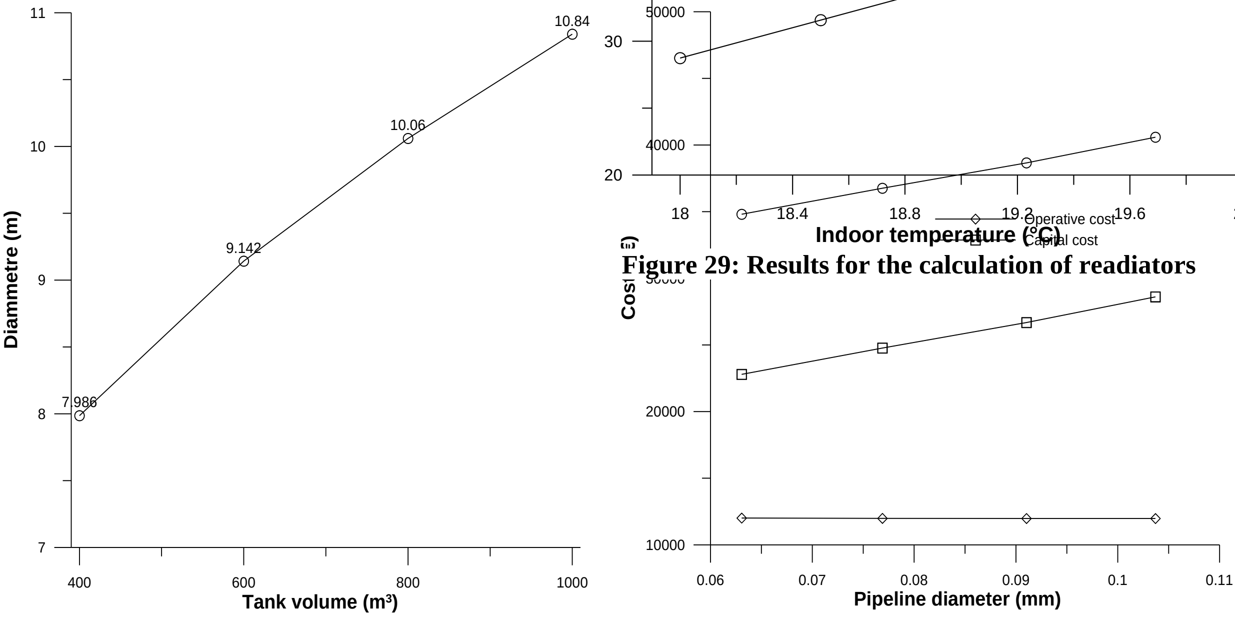


Figure 28: Tank and pipeline calculations results

The calculation for the radiators

The steps used to calculate the radiator's parameters are given above. In these calculations, it was assumed that the supply temperature of the water is 60°C, the reference temperature is 65°C, and the ground temperature is 6°C. The calculations were done for 4 different scenarios: The indoor temperature is assumed to change at the range of 18-20°C, the outdoor temperature in the range of -10 to -4°C, the return water temperature in the range of 33-40°C, the reference inflow in the range of 3.93-7 kg/s, the reference system inflow 18-24 kg/s. Based on these data, the relative heating of the radiators was calculated as 0.83-0.92, the relative heating of the building as 0.87-0.88, and the transmissivity coefficient τ=0.94. To be within these parameters, it is sufficient that the supply water temperature is 60°C and the inflow of the system 16-27 kg/s. Thus, the parameters for the Llixha thermal springs satisfy all these demands. Figure 29 shows the results of the calculations for the radiator's supply and return water temperatures vs. indoor temperature. The relevant calculations are done with EES, and the results are given in Appendix 3.

APPENDIX 1: Modelling of the Llixha Elbasan reservoir

Equation 74 in section 7.1.3.2. is solved for the volumes shown in Figure 30. In the figure, each node represents one of the hot springs. For each of them, we have all the data about coordinates and temperature, as given in Table 9.

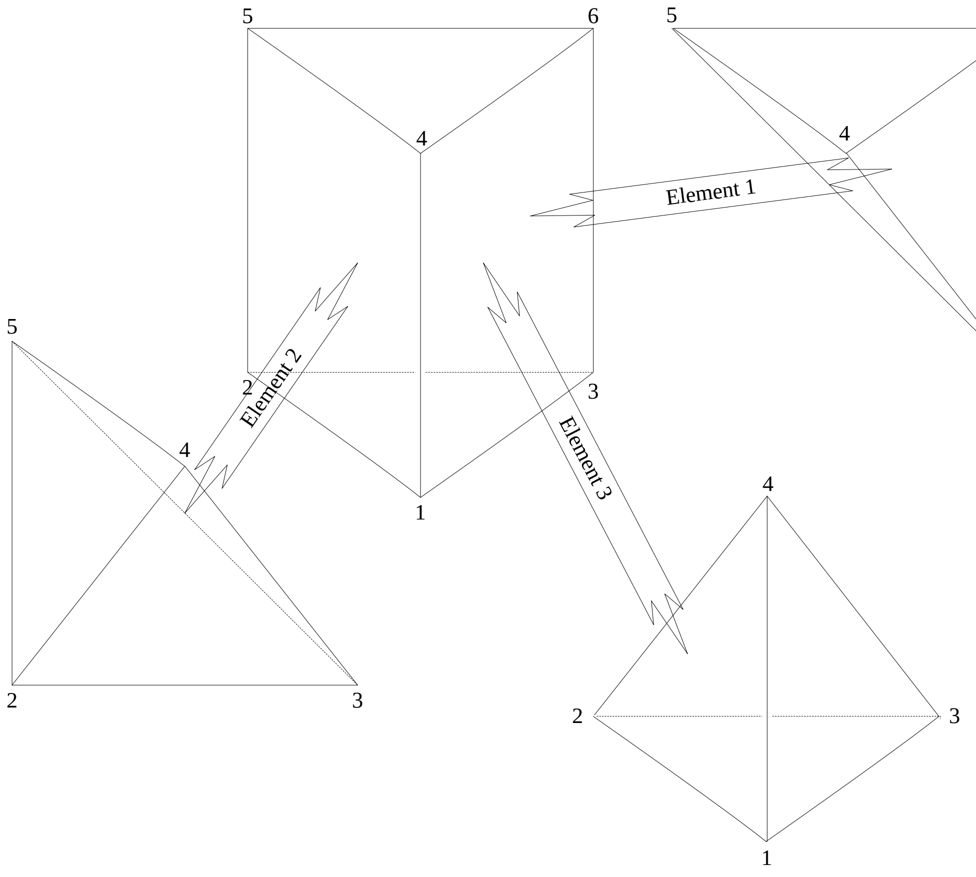


Figure 30: The finite volumes

Table 9: The coordinates and the temperatures of the hot springs

Spring (node)	X (m)	Y (m)	Z (m)	T (°C)
1 (1)	0	0	0	60
2 (3)	4	0	0.2	61
3 (2)	4	2	0.3	62.5
4 (4)	8	3	0.25	62
5 (5)	10	5	0.35	63
6 (6)	11	6	0.5	62

Using the relationships given below, the value of the coefficient and the value *Δ* for each volume. These values are given in Table 10.

Table 10: Values of the coefficients

Element 1																
a₁	**a₂**	**a₃**	**a₄**	**b₁**	**b₂**	**b₃**	**b₄**	**c₁**	**c₂**	**c₃**	**c₄**	**d₁**	**d₂**	**d₃**	**d₄**	**Δ₁**
-3.2	0.8	-5	-10	-0.8	-0.4	-0.5	0.05	2.2	1.15	-0.9	0	6	-9	3	0	21.1
Element 2																
a₁	**a₂**	**a₃**	**a₄**	**b₁**	**b₂**	**b₃**	**b₄**	**c₁**	**c₂**	**c₃**	**c₄**	**d₁**	**d₂**	**d₃**	**d₄**	**Δ₂**
5.85	-1.2	-3.2	2.4	-0.25	-0.15	0.2	-0.2	0.5	0.1	-1.4	0	-6	2	12	-8	5
Element 3																
a₁	**a₂**	**a₃**	**a₄**	**b₁**	**b₂**	**b₃**	**b₄**	**c₁**	**c₂**	**c₃**	**c₄**	**d₁**	**d₂**	**d₃**	**d₄**	**Δ₃**
0	0	0	-2.4	-0.4	0.6	-0.3	0.2	-0.4	-0.6	1.3	-0.4	8	-12	-4	8	4.8

The coefficients can be calculated using the following relations:

$$\begin{cases} a_1 = x_2y_3z_4 + x_4y_2z_3 + x_3y_4z_3 - x_4y_3z_2 - x_2y_4z_3 - x_3y_2z_4 \\ a_2 = z_1y_3x_4 + x_3y_1z_4 + x_1z_3y_4 - x_1y_3z_4 - y_1x_3z_4 - z_1x_3y_4 \\ a_3 = x_1y_2z_4 + x_4y_1z_2 + x_2y_4z_1 - x_4y_2z_1 - x_1y_4z_2 - x_2y_1z_4 \\ a_4 = x_3y_2z_1 + x_1y_3z_2 + x_2y_1z_3 - x_1y_2z_3 - x_2y_3z_1 - x_3y_1z_2 \\ b_1 = y_3z_2 + y_4z_3 + y_2z_4 - y_3z_4 - y_2z_3 - y_4z_2 \\ b_2 = y_3z_4 + y_1z_3 + y_4z_1 - y_3z_1 - y_1z_4 - y_4z_3 \\ b_3 = y_2z_1 + y_4z_2 + y_1z_4 - y_2z_4 - y_1z_1 - y_4z_1 \\ b_4 = y_2z_3 + y_1z_2 + y_3z_1 - y_2z_1 - y_1z_3 - y_3z_2 \\ c_1 = x_3z_4 + x_2z_3 + x_4z_2 - x_3z_2 - x_2z_4 - x_4z_3 \\ c_2 = x_3z_1 + x_4z_3 + x_1z_4 - x_3z_4 - x_1z_3 - x_4z_1 \\ c_3 = x_2z_4 + x_1z_2 + x_4z_1 - x_2z_1 - x_4z_2 - x_1z_4 \\ c_4 = x_2z_1 + x_1z_3 + x_3z_2 - x_2z_3 - x_1z_2 - x_3z_1 \\ d_1 = x_3y_2 + x_4y_3 + x_2y_4 - x_3y_4 - x_2y_3 - x_4y_2 \\ d_2 = x_3y_4 + x_1y_3 + x_4y_1 - x_3y_1 - x_1y_4 - x_4y_3 \\ d_3 = x_2y_1 + x_4y_2 + x_1y_4 - x_2y_4 - x_1y_2 - x_4y_1 \\ d_4 = x_2y_3 + x_1y_2 + x_3y_1 - x_2y_1 - x_3y_2 - x_1y_3 \end{cases}$$

$$\Delta = \pm \begin{vmatrix} 1 & x_1 & y_1 & z_1 \\ 1 & x_2 & y_2 & z_2 \\ 1 & x_3 & y_3 & z_3 \\ 1 & x_4 & y_4 & z_4 \end{vmatrix}$$

Replacing the above coefficient in Equation 77, we get:

$Element\ 1:$

$N_1 = -3.2 - 0.8x + 2.2y + 6z$

$N_2 = 0.8 - 0.4x + 1.15y - 9z$

$N_3 = -5 - 0.5x - 0.9y + 3z$

$N_4 = -10 + 0.05x$

$Element\ 2:$

$N_1 = 5.85 - 0.25x + 0.5x - 6z$

$N_2 = -1.2 - 0.15x + 0.1y + 2z$

$N_3 = -3.2 + 0.2x - 1.4y + 12z$

$N_4 = 2.4 - 0.2x - 8z$

$Element\ 3:$

$N_1 = -0.4x - 0.4y + 8z$

$N_2 = 0.6x - 0.6y - 12z$

$N_3 = -0.3x + 1.3y - 4z$

$N_4 = -2.4 + 0.2x - 0.4y + 8z$

The matrixes [P], [H] at [F] using the respective values and Equation 79. For element 1:

For element 2:

$$[H]_2 = \frac{1}{180}\left\{\begin{vmatrix} 0.063 & 0.037 & -0.05 & 0.05 \\ 0.037 & 0.023 & -0.03 & 0.03 \\ -0.05 & -0.03 & 0.04 & -0.04 \\ 0.05 & 0.03 & -0.04 & 0.04 \end{vmatrix} + \begin{vmatrix} 0.25 & 0.05 & -0.7 & 0 \\ 0.05 & 0.01 & -0.14 & 0 \\ -0.7 & -0.14 & 1.96 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix} + \begin{vmatrix} 36 & -12 & -72 & 48 \\ -12 & 4 & 24 & -16 \\ -72 & 24 & 144 & -96 \\ 48 & -16 & -96 & 64 \end{vmatrix}\right\} =$$

$$= \frac{1}{180}\begin{vmatrix} 36.313 & -11.913 & -72.75 & 48.05 \\ -11.913 & 4.033 & 23.83 & -15.97 \\ -72.75 & 23.83 & 146 & -96.04 \\ 48.05 & -15.97 & -96.04 & 64.04 \end{vmatrix} = \begin{vmatrix} 0.2 & -0.06 & -0.4 & 0.26 \\ -0.06 & 0.02 & 0.13 & -0.089 \\ -0.4 & 0.13 & 0.81 & -0.53 \\ 0.26 & -0.089 & -0.53 & 0.35 \end{vmatrix}$$

$$[P]_2 = \begin{vmatrix} 48.48 & 3.21 & 185.8 & -23.62 \\ 3.21 & 4.727 & 1.19 & 8.1 \\ 185.8 & 1.19 & -12.27 & 211.7 \\ -23.62 & 8.1 & 211.7 & 0 \end{vmatrix}$$

$$[F]_2 = \frac{m_2 c_p \Delta T_2 \Delta_2}{4} = \begin{bmatrix} 754.67 \\ 754.67 \\ 754.67 \\ 754.67 \end{bmatrix}$$

$$[H]_1 = \frac{1}{759.6}\left\{\begin{vmatrix} 0.64 & 0.32 & 0.4 & -0.04 \\ 0.32 & 0.16 & 0.2 & -0.02 \\ 0.4 & 0.2 & 0.25 & -0.025 \\ -0.04 & -0.02 & -0.025 & 0.0025 \end{vmatrix} + \begin{vmatrix} 4.84 & 2.53 & -1.98 & 0 \\ 2.53 & 1.3225 & -1.035 & 0 \\ -1.98 & -1.035 & 0.81 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix} + \begin{vmatrix} 36 & -54 & 18 & 0 \\ -54 & 81 & -27 & 0 \\ 18 & -27 & 9 & 0 \\ 0 & 0 & 0 & 0 \end{vmatrix}\right\} =$$

$$= \frac{1}{759.6}\begin{vmatrix} 41.48 & -51.15 & 16.42 & -0.04 \\ -51.15 & 82.4825 & -27.835 & -0.02 \\ 16.42 & -27.835 & 10.06 & -0.025 \\ -0.04 & -0.02 & -0.025 & 0.0025 \end{vmatrix} = \begin{vmatrix} 0.054 & -0.067 & 0.02 & -5.26e-5 \\ -0.067 & 0.11 & 0.036 & -2.63e-5 \\ 0.02 & 0.036 & 0.013 & -3.29e-5 \\ -5.26e-5 & -2.63e-5 & -3.29e-5 & 3.29e-6 \end{vmatrix}$$

$$[P]_1 = \begin{vmatrix} 195.4 & -1741 & -568.4 & -146.7 \\ -1741 & 26.42 & -1059 & 65.5 \\ -568.4 & -1059 & 913.7 & 279.3 \\ -146.7 & 65.5 & 279.3 & 674.5 \end{vmatrix}$$

$$[F]_1 = \frac{m_1 c_p \Delta T_1 \Delta_1}{4} = \begin{bmatrix} 768.15 \\ 768.15 \\ 768.15 \\ 768.15 \end{bmatrix}$$

And for element 3:

$$[H]_3 = \frac{1}{172.8}\left\{\begin{vmatrix} 0.16 & -0.24 & 0.12 & 0.05 \\ -0.24 & 0.36 & -0.18 & 0.12 \\ 0.12 & -0.18 & 0.09 & -0.06 \\ 0.05 & 0.12 & -0.06 & 0.04 \end{vmatrix} + \begin{vmatrix} 0.16 & 0.24 & -0.52 & 0.16 \\ 0.24 & 0.36 & -0.78 & 0.24 \\ -0.52 & -0.78 & 1.69 & -0.52 \\ 0.16 & 0.24 & -0.52 & 0.16 \end{vmatrix} + \begin{vmatrix} 64 & -96 & -32 & 64 \\ -96 & 144 & 48 & -96 \\ -32 & 48 & 16 & -32 \\ 64 & -96 & -32 & 64 \end{vmatrix}\right\} =$$

$$= \frac{1}{172.8}\begin{vmatrix} 64.32 & -96 & -32.4 & 64.21 \\ -96 & 144.72 & 47.14 & -95.64 \\ -32.4 & 47.14 & 17.78 & -32.58 \\ 64.21 & -95.64 & -32.58 & 64.2 \end{vmatrix} = \begin{vmatrix} 0.37 & -0.55 & -0.18 & 0.37 \\ -0.55 & 0.84 & 0.27 & -0.55 \\ -0.18 & 0.27 & 0.1 & 0.19 \\ 0.37 & -0.55 & 0.19 & 0.37 \end{vmatrix}$$

$$[P]_3 = \begin{vmatrix} 16.48 & -10.75 & -1.464 & 7.17 \\ -10.75 & 22.51 & -8.85 & 24.47 \\ -1.464 & -8.85 & -137.3 & 1.014 \\ 7.17 & 24.47 & 1.014 & 2.624 \end{vmatrix}$$

$$[F]_3 = \frac{m_3 c_p \Delta T_3 \Delta_3}{4} = \begin{bmatrix} 741.19 \\ 741.19 \\ 741.19 \\ 741.19 \end{bmatrix}$$

The generalized matrixes are:

$$[H]_g = \begin{vmatrix} 0.054 & -0.06 & -0.4 & 5.26e-5 & 0 & 0 \\ -0.06 & 0.22 & 0.07 & -4e-1 & 0.26 & 0 \\ -0.4 & 0.07 & 1.2 & -4.2e-1 & -0.269 & 0.37 \\ 5.26e-5 & -4e-1 & -4.2e-1 & 1.65 & -0.26 & -0.55 \\ 0 & 0.26 & -0.269 & -0.26 & 0.45 & 0.19 \\ 0 & 0 & 0.37 & -0.55 & 0.19 & 0.37 \end{vmatrix} [P]_g = \begin{vmatrix} 195.4 & -1741 & -568.4 & -1.47e2 & 0 & 0 \\ -1741 & 74.9 & -1055.79 & 2.51e2 & -26.32 & 0 \\ -568.4 & -1055.79 & 934.907 & 2.7e2 & 6.636 & 7.17 \\ -1.47e2 & 2.51e2 & 2.7e2 & 6.85e2 & 202.85 & 24.47 \\ 0 & -26.32 & 6.636 & 202.85 & -137.3 & 1.014 \\ 0 & 0 & 7.17 & 24.47 & 1.014 & 2.624 \end{vmatrix}$$

$$[F]_f = \begin{Bmatrix} 768.15 \\ 1522.82 \\ 2264.01 \\ 2264.01 \\ 1495.86 \\ 741.19 \end{Bmatrix}$$

The problem consists of modelling one element with the dimensions 10x10x5 km. The grid shown in Figure 31 will be used.

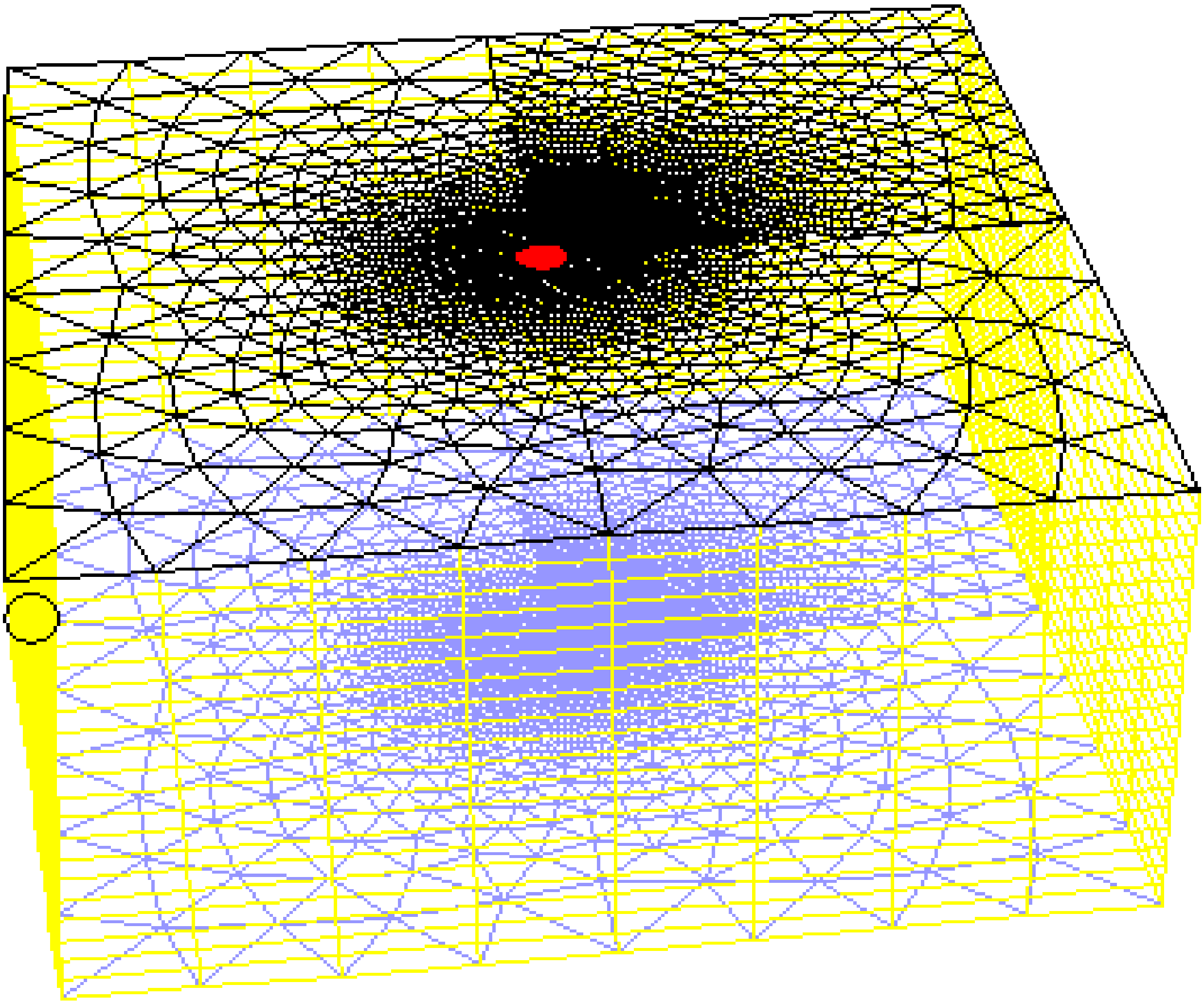
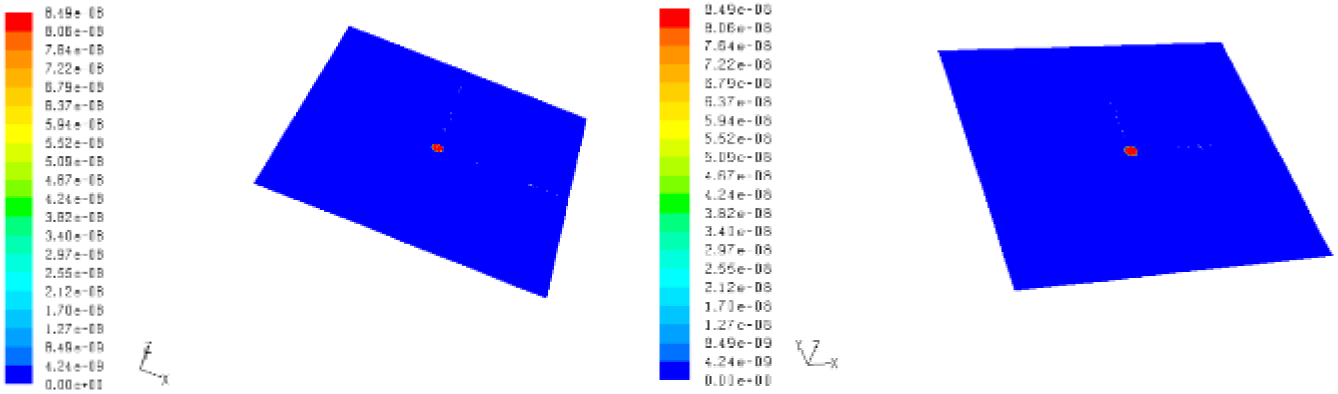


Figure 31: The grid

Now it will be shown how to practically solve the equation for the unstable temperature field using the finite volumes:

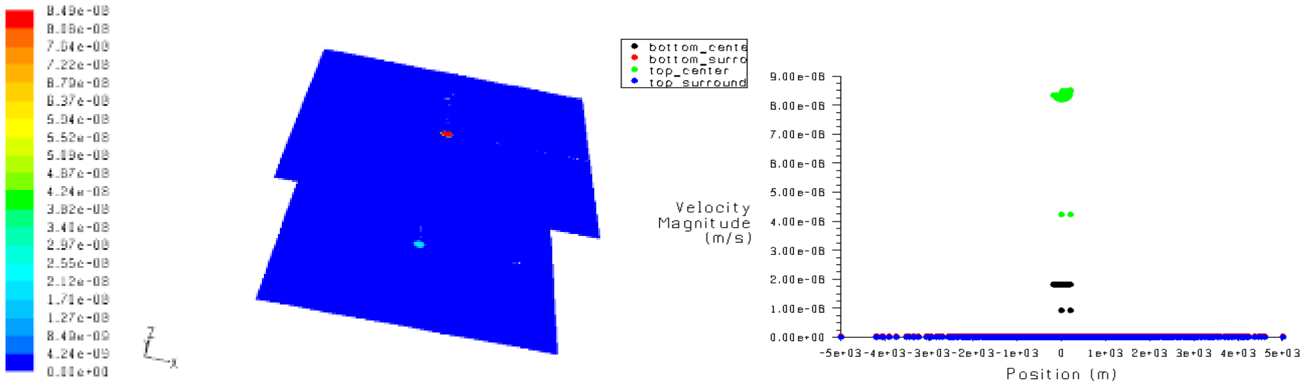
$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) + q(x,y,z) - c\frac{\partial T}{\partial t} = 0$$

The software FLUENT was used to obtain the results. The results for the temperature, density, and velocity distributions are shown in the Figures below.



Fluid velocity at the reservoir

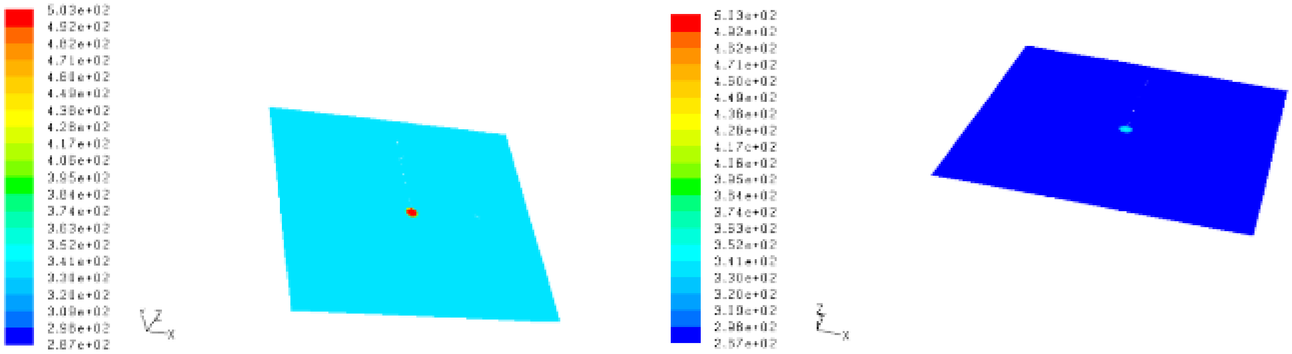
Fluid velocity at the surface



Fluid velocity distribution

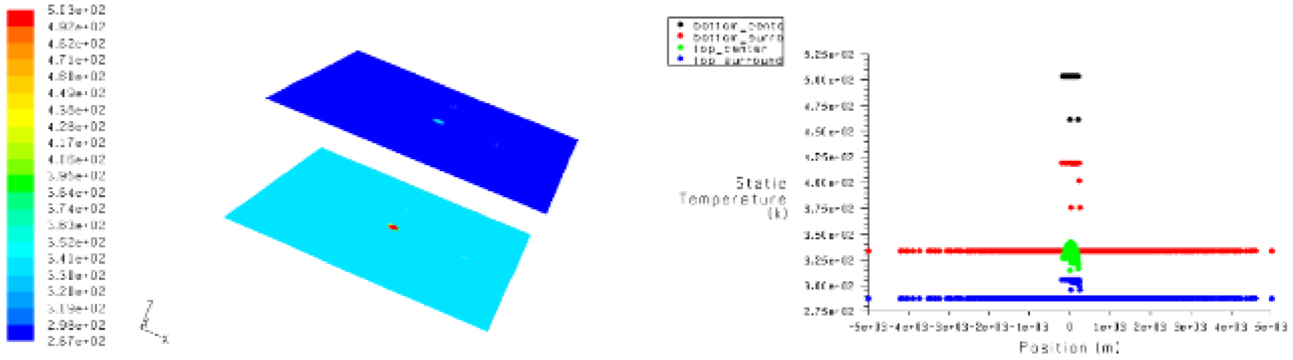
Fluid velocity magnitude

Figure 32: Fludi flow velocity modelling results



Reservoir temperature

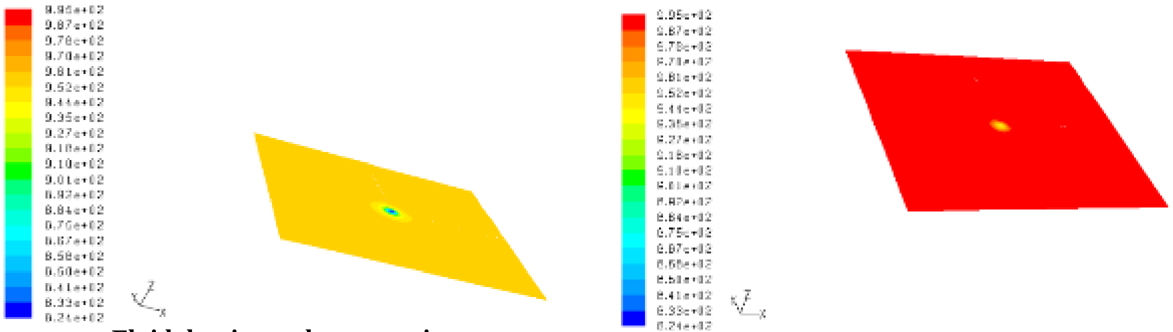
Surface temperature



Temperature distribution

Temperature magnitude

Figure 33: Temperature modelling results



Fluid density at the reservoir **Fluid density at the surface**

Fluid density distribution **Fluid density magnitude**

Figure 34: Fluid density modelling results

APPENDIX 2: Calculations for the Llixha-Elbasan-Albania network system

d_o_1	d_o_2	l_bend_1	l_bend_2	l_v_1	l_v_2	L_equivalent_1	L_equivalent_2	L_equivalent
0.073	0.02667	1.46	0.5334	0.73	0.2667	2079	3549	5628
0.0889	0.0733	1.778	1.466	0.889	0.733	2096	3634	5730
0.1016	0.0889	2.032	1.778	1.016	0.889	2110	3663	5772
0.1143	0.1016	2.286	2.032	1.143	1.016	2123	3686	5809

delta_1	delta_2	d_i_1	d_i_2	A_1	A_2	v_hotwater_1	v_hotwater_2	R_e_1
0.002108	0.001651	0.06878	0.02337	0.003716	0.000429	5.382	46.63	841395
0.002108	0.002108	0.08468	0.06908	0.005632	0.003748	3.551	5.336	683417
0.002108	0.002108	0.09738	0.08468	0.007448	0.005632	2.685	3.551	594292
0.002108	0.002108	0.1101	0.09738	0.009518	0.007448	2.101	2.685	525732

R_e_2	f_1	f_2	H_f_1	H_f_2	P_hidrostatic	p_consumer	P_pumping	DELTAh_pump
2.48E+06	0.01192	0.0091	0.05117	14.74	4.808	2.31	8.54	88.81
837741	0.01256	0.01193	0.01921	0.08763	4.808	2.31	7.128	74.13
683417	0.013	0.01256	0.009958	0.03357	4.808	2.31	7.122	74.07
594292	0.01341	0.013	0.005599	0.0174	4.808	2.31	7.12	74.05

P_motor	price_electricity	C_electricity	C_electricity_annual	price_pipes_1	price_pipes_2	C_pipes_1	C_pipes_2	C_pipes
22326	0.07	1.563	13691	4.2	3.9	8400	13650	22050
18636	0.07	1.304	11427	4.5	4.2	9000	14700	23700
18620	0.07	1.303	11418	4.8	4.5	9600	15750	25350
18615	0.07	1.303	11414	5	4.8	10000	16800	26800

pr_bend_1	pr_bend_2	C_bends_1	C_bends_2	C_bends	pr_junc_1	pr_junc_2	C_junctions_1	C_junctions_2
2.45	1.89	61.25	82.69	143.9	1.8	1.38	48.6	63.14
2.9	2.15	72.5	94.06	166.6	2.1	1.59	56.7	72.74
3.54	2.45	88.5	107.2	195.7	2.34	1.8	63.18	82.35
3.82	2.9	95.5	126.9	222.4	2.52	2.1	68.04	96.08

C_junctions	C_valves_1	C_valves_2	C_valves	pr_pump	C_pump	C_capital	C_operativ	C_total
111.7	158	129	287	1250	1250	22593	14367	36960
129.4	174	136	310	1500	1500	24306	11992	36298

145.5	202	158	360	1670	1670	26051	11982	38033
164.1	230	174	404	2010	2010	27590	11979	39569

R_m	R_p_c	R_p_h	S	Sc	Sh	f_c	S_allowabl	y
340	235	140	93.33	113.3	93.33	1	165	0.4
410	275	165	110	136.7	110	0.9	178.5	0.5
490	355	195	130	163.3	130	0.8	189.3	0.7
540	405	215	143.3	180	143.3	0.7	182.6	0.7

th_presclass_1	th_presclass_2	d_i_1_c	d_i_2_c	d_average	Z_1	Z_2	q_pipe_1	q_pipe_2
2.901	1.726	0.0672	0.02322	0.04521	1.08E-05	7.93E-07	49180	10414
2.79	2.485	0.08332	0.06833	0.07582	1.58E-05	9.47E-06	58111	42559
2.912	2.679	0.09578	0.08354	0.08966	2.17E-05	1.52E-05	69502	55868
3.219	2.978	0.1079	0.09564	0.1018	3.04E-05	2.21E-05	86491	71041

q_pipe_total	d_ins_1	d_ins_2	q_insulation_1	q_insulation_2	q_ins_total	q_sust_vertical	v_win	q_wind_1
59593	0.083	0.03667	9973	4049	14022	73616	4	498
100670	0.0989	0.0833	12006	10011	22017	122688	5	927.2
125370	0.1116	0.0989	13630	12006	25636	151006	6	1507
157532	0.1243	0.1116	15254	13630	28884	186416	7	2284

q_wind_2	q_wind_total	q_water_1	q_water_2	q_water_total	q_0	q_seismic	q_d_h	q_medium_1
220	718	70894	14447	85342	158958	38150	38150	34781
780.9	1708	109890	128145	238035	360723	86573	86573	53471
1335	2842	146156	193054	339210	490216	117652	117652	70655
2051	4335	186571	254641	441213	627628	150631	150631	89610

q_medium_2	q_medium_total	q_snow_1	q_snow_2	q_snow_total	q_seismic_vertical	q_d_v	M_A	M_B
4152	38933	19.92	8.801	28.72	19075	58037	2.91E+11	2.75E+11
35963	89434	23.74	19.99	43.73	43287	132764	5.04E+11	6.51E+11
53757	124411	26.78	23.74	50.52	58826	183288	6.29E+11	9.07E+11
70459	160069	29.83	26.78	56.62	75315	235441	7.86E+11	1.18E+12

L_supports_1	L_supports_2	DELTAL_1	DELTAL_2	DELTAL	sigma_x_1	sigma_x_2	Force_1	Force_2
49.93	3.676	1.621	2.768	4.39	1.56E+08	1.56E+08	652920	87149
43.81	26.32	1.635	2.835	4.47	1.56E+08	1.56E+08	968318	658298
54.25	38.05	1.646	2.857	4.502	1.56E+08	1.56E+08	1.27E+06	968318
66.36	48.34	1.656	2.875	4.531	1.56E+08	1.56E+08	1.60E+06	1.27E+06

L_arm_1	L_arm_2	H_tank	V_tank	D_tank	A_tank	H_tank_rm	D_tank_rm	A_tank_rm
2.986	1.805	4	400	11.28	341.8	7.986	7.986	300.5
3.295	2.992	6	600	11.28	412.7	9.142	9.142	393.8
3.523	3.295	8	800	11.28	483.6	10.06	10.06	477.1
3.736	3.523	9	1000	11.89	558.5	10.84	10.84	553.6

P_tank_abs	e_tank_min	e_a	sigma_b_c	sigma_b_a	e_roof
1.643	7.298	6.248	1.85E+08	1.54E+07	5.087
1.754	8.685	7.635	1.97E+08	1.64E+07	5.823
1.842	9.878	8.828	2.07E+08	1.72E+07	6.409
1.917	10.95	9.895	2.15E+08	1.79E+07	6.904

APPENDIX 3: Calculations for the heat exchangers

m	T_r	Q_hotwater	m_o	T_r_o	Q_hotwater_o	eta_hotwater	T_i	T_i_o
3.92	30	491.6	17.64	33	2360	0.2083	18	18.5
4.9	33	553	19.6	35	2458	0.225	18.5	19
5.88	36	589.9	21.56	38	2433	0.2424	19	19.4
6.86	40	573.5	23.52	40	2458	0.2333	19.8	20

eta_radiator	T_o	T_o_0	k_l	Q_loss_building	eta_building	tau	U_p	tau_o
0.8331	-4	-6.7	93.63	2060	0.873	0.9474	0.8859	0.9881
0.8739	-5	-8	91.03	2139	0.8704	0.9474	1.107	0.9866
0.8759	-6	-9	85.68	2142	0.8803	0.9474	1.329	0.9854
0.9243	-10	-13.5	73.37	2186	0.8896	0.9474	1.55	0.9844

T_s_h	T_s_h_r	T_rwater	T_rwater_r	Q_building_capacity	m_o_r
60	60	28.74	28.74	6.137	16.43
60	60	31.58	31.58	6.905	18.95
60	60	34.42	34.42	7.366	21.35
60	60	38.21	38.21	7.161	26.15

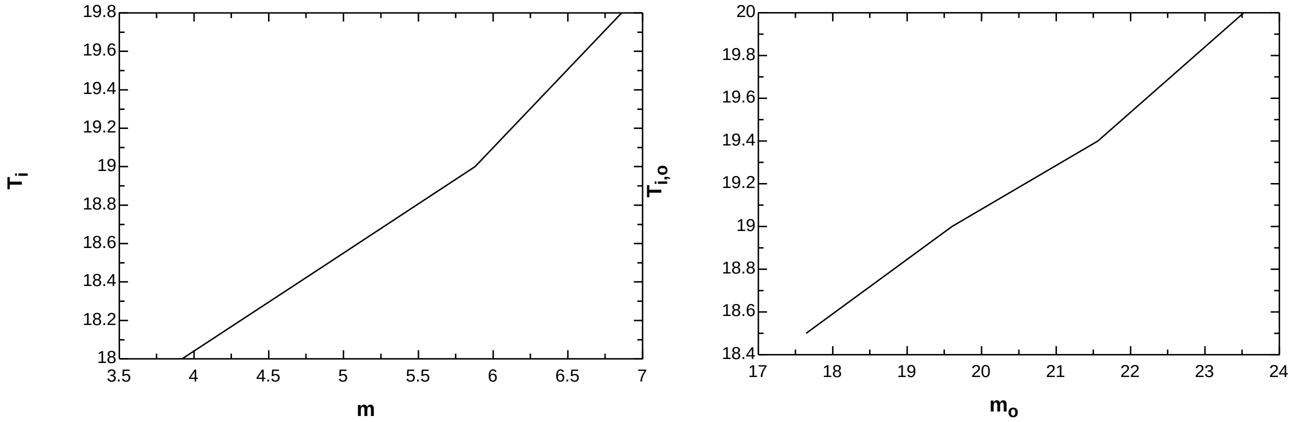


Figure 35: Indoor & indoor reference temperatures

Kozani-8 Low Enthalpy Geothermal Water Use Through a Cascade and Hybrid System

The temperature of the water blowing out of the wells (see Table 4) varies from 34°C up to 65.5°C to Kozani -8, the most important among the Albanian geothermal wells. It had been drilled in 1989. The finding of the hot brine was considered an “accident” at that time, as the well had been designed and drilled to search for oil & gas. The well is located on the hills, 26km SE of Tirana. It encounters limestone strata at 1819m, penetrating over 10m into this section. The yield of the well is 10.3 l/s and is presented as stable for more than 23 years. The geographical position of the well, placed in the middle of a village, very close to corridor 8, is some of the most important parameters for choosing these waters for our designs and the related calculations. The recreational centre provides the cascade and integral use of the Kozani-8 geothermal water, but not only. It also provides electricity generation through a hybrid system. The centre will also be equipped with SPA, open and closed pools, fitness, massages, a greenhouse & also aquaculture pools. The economic analyses, based on the NPV calculations, show that this resource is completely competitive and unjustified. It’s further “waste.” Despite the fact that the investment is too high (over 5.5 million Euro), it is completely feasible, and this is also proven by the risk analyses. It will also help to improve the living standards of the local community. The Albanian geothermal springs and wells are located in three different areas: Ishmi-Kruja, Ardenica, and Peshkopia. They differ from each other in geological and thermo-hydrogeological features and characteristics. Each one of them is the result of regional tectonics and seismic activity. The Ishmi-Kruja geothermal zone, Figure 11, is close to the “Mother Teresa” international airport. It is also next to the Kruja historical city, the wonderful Adriatic Sea beaches & Lake of Ohrid. The demonstrative geothermal centre, with the cascade and integral use, but also combined with the solar panels (hybrid system), is designed for the Kozani-8 well waters. The choice had been made because of its temperature, the value of 65.5°C, and yield of 10 l/s. In the aquifer top of the good trunk, the water is 80°C. Hot water has a salinity of (4.6-19.3) g/l. Actually, all these waters are “wasted”: they flow directly to a creek, meaning high economic losses. Among different processes of the cascade will be released CO_2 and H_2S, which will be used for food products (conservation) and medical purposes. The hybrid system, combing the middle enthalpy geothermal waters, with the solar panels, based on the fact that the Albanian climate allows such a thing (there are more than 280 sunny days in the area), will improve the economic efficiency of the project.

The Geological Structure of the Region

The main crease of the area became in the middle Oligocene and in the lower and middle Miocene. Therefore, there are some transgressed sedimentary sections of the upper Oligocene, and especially of the Miocene above the older ones, Figure 36.

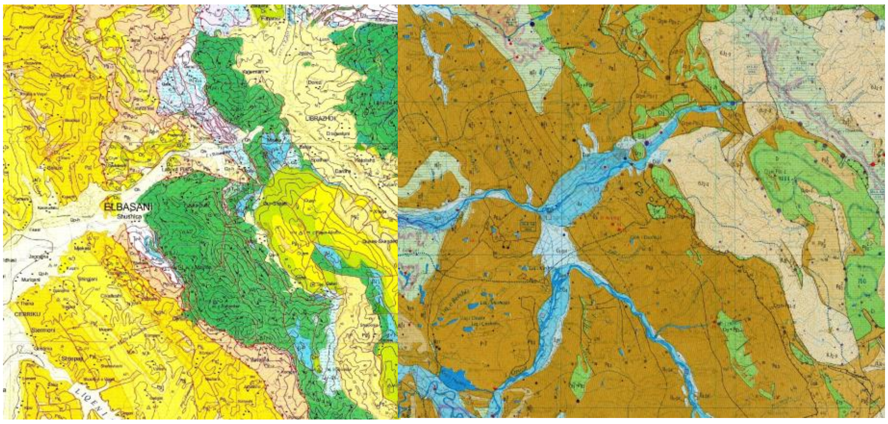


Figure 36: Geological and hydrogeological map of the Kozani 8 (Kruja) area

The geothermal aquifer is represented by a carstified neritic carbonate formation with numerous fissures and micro-fissures. Three boreholes produce hot and mineralized water: Ishmi-1/b, Kozani-8, and Galigati-2. The specific electric resistance varies in the levels of 20÷50 Ohm, a feature that promises good formation properties. In fact, the effective porosity is 1per cent, and the permeability varies from 0.05÷3.5 mD. The hydraulic conductivity of the limestone section varies between 8.6 * 10^{-10}÷8.8 *9 10^{-8} m/s, and the transmissivity ranges from 8.6 * 10^{-7}÷8.5 * 10^{-5} m^2/s. Kozani-8 well was drilled in 1989. Borehole is located on hills 26km SE of Tirana. It encounters limestone strata at 1816 m, penetrating over 10 m into the section. The temperature at the top of the aquifer reaches 80°C in the Kozani-8 borehole. Kruja stratigraphic break exists at the level of the Palaeocene-Eocene, which varies from one anticline string to another. This area was built by some anticline and synclinal lines descending westward. These are linear structures with tens of kilometers in length. Anticline generally has broken in their western side by overlying tectonic, so they are often observed only as monocline with eastern decreases, such as the Dajti-Kruja lines along the overlying limestone and dolomites of the Cretaceous tectonically contact with the Oligocene flysch of the western syncline west, Figure 37.

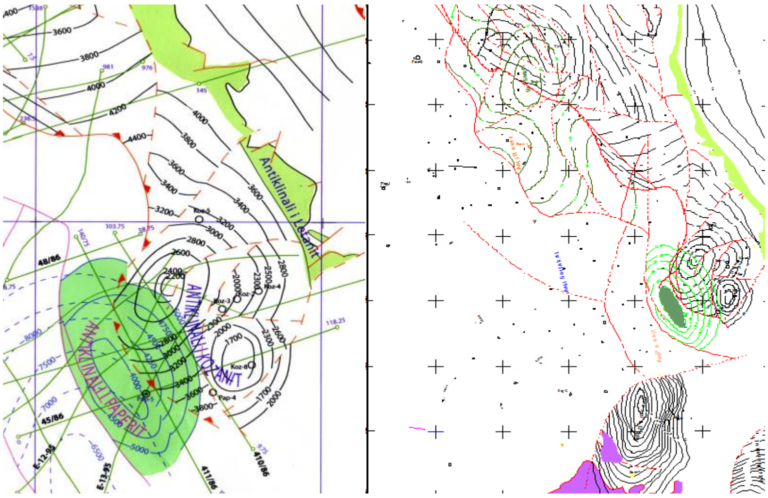


Figure 37: Structural map of the Kozani limestone formation and their sealing layers

In this area, there are three wells that produce hot water (geothermal wells): Ishmi-1/b, Kozani-8, and Galigati-2, Table 4. From the regional point of view, they extend up to a depth of 10 km; above evaporate, which is related to regional tectonics [1]. At this depth, the temperature reaches values of 120÷150°C. Water comes from the interval 1816÷1837 m [13]. The temperature at this depth is 80°C while the pressure is about 191 bars. The wellhead pressure is 12 bars, while the temperature is 65.5°C. The total dissolved solids are 4.6 g/l [2], pH= 7.5; the cations Ca_2^+=27.62 mg/l, Mg^{2+}=20.4 mg/l, Na^+= 268.5 mg/l, NH_4^+=47.5 mg/l; the anions Cl^-=270.2 mg/l, SO_4^{2-}=46.2 mg/l and HCO_3^{2-}=10 mg/l; the microelements B=0.00067 µg/l.

Energetic Reserves Evaluation of the Kozani Limestone Structure

The formation heat is calculated through the relation [13] (Table 11):

$$Q_0 = \left[(1-\Phi)\cdot\rho_m\cdot c_m + P\cdot\rho_w\cdot c_w\right](t_1 - t_0)\cdot A\cdot\Delta z \tag{133}$$

where: Φ	the effective porosity of the limestone (P=5.8x10^{-3});
ρ_m	mean density of the matrix (ρ_m= 2640 kg/m^3);
c_m	specific heat capacity of the formation (c_m=1.1 kJ/kgK);
ρ_w	water density (ρ_w= 980.37 kg/m^3);
c_w	water specific heat (c_w=4.1893 kJ/kgK);
t_1	formation temperature (t_1=85°C);
t_0	ground temperature (t_0=16.5°C).

The geothermal energy reserves are calculated through the relation (Table 11):

$$Q_1 = R_0 \cdot Q_0 \tag{134}$$

where: R_0=0.1 because Kozani-8 is the only well erupting hot water.

The recoverable geothermal energy is (Table 11):

$$E = Q_v \cdot (t_t - t_r)\cdot \rho_w \cdot c_w \cdot \Delta t \tag{135}$$

The specific reserves are (Table 11):

$$q = \frac{Q_1}{A} \tag{136}$$

The energetic capacity is (Table 11):

$$Q_e = P_{max} \cdot (t_w - t_g) \cdot 0.004184 \tag{137}$$

where: P_{max} the maximal yield of the well [l/s];
t_w water temperature [°C];
t_g ground temperature [°C].

The annual energy use is [TJ/y] (Table 11):

$$S_e = P_{av.} \cdot (t_w - t_g) \cdot 0.1319 \tag{138}$$

where $P_{av.}$ the average yields of the well [kg/s].

The capacity factor is (Table 11):

$$K = 0.03171 \cdot \frac{S_e}{Q_e} \tag{139}$$

Table 11: Energetic reserves of Kozani – 8 geothermal well

Parameter	Value
Formation Heat	$1.0712 \cdot 10^{10}$ [GJ]
Energy Reserves	$1.0712 \cdot 10^{9}$ [GJ]
Recoverable Energy	$2.401 \cdot 10^{6}$ [GJ]
Specific Reserves	39.63 [GJ/m^2]
Energetic Capacity	2.05 [MWh]
Energy Use	0.39 [TJ/year]
Capacity Factor	0.006

The Scheme for the Integral, Cascade, and Hybrid Use of the Kozani-8 Geothermal Waters

It looks that the best and more efficient way to use the geothermal waters of the Kozani-8 well is the construction of a multicentre [14, 15, 16]. The centre will include the SPA, massage, and fitness centre, outdoor and indoor pools (with different sizes and temperatures), a greenhouse, aquaculture cultivation pools, conference rooms, etc. The centre will be heated through direct geothermal use (through the installation of the heat exchangers) [20], while for the cooling will be installed a geothermal heat pump [17]. The roof, covered with solar panels, whose combination can provide sanitary water and also a part of them, will circulate the geothermal water and increase its temperature, allowing so electricity production (the hybrid system). This electricity will serve the lighting system of the centre (green energy). Figure 38 shows the frontal and lateral view of the centre, Figure 39 the principal sketch of the integral, cascade, and hybrid system, while figure 42 shows the aquaculture cultivation principal sketch.

Figure 38: Recreational/balneological centre Kozani-8, Shijon

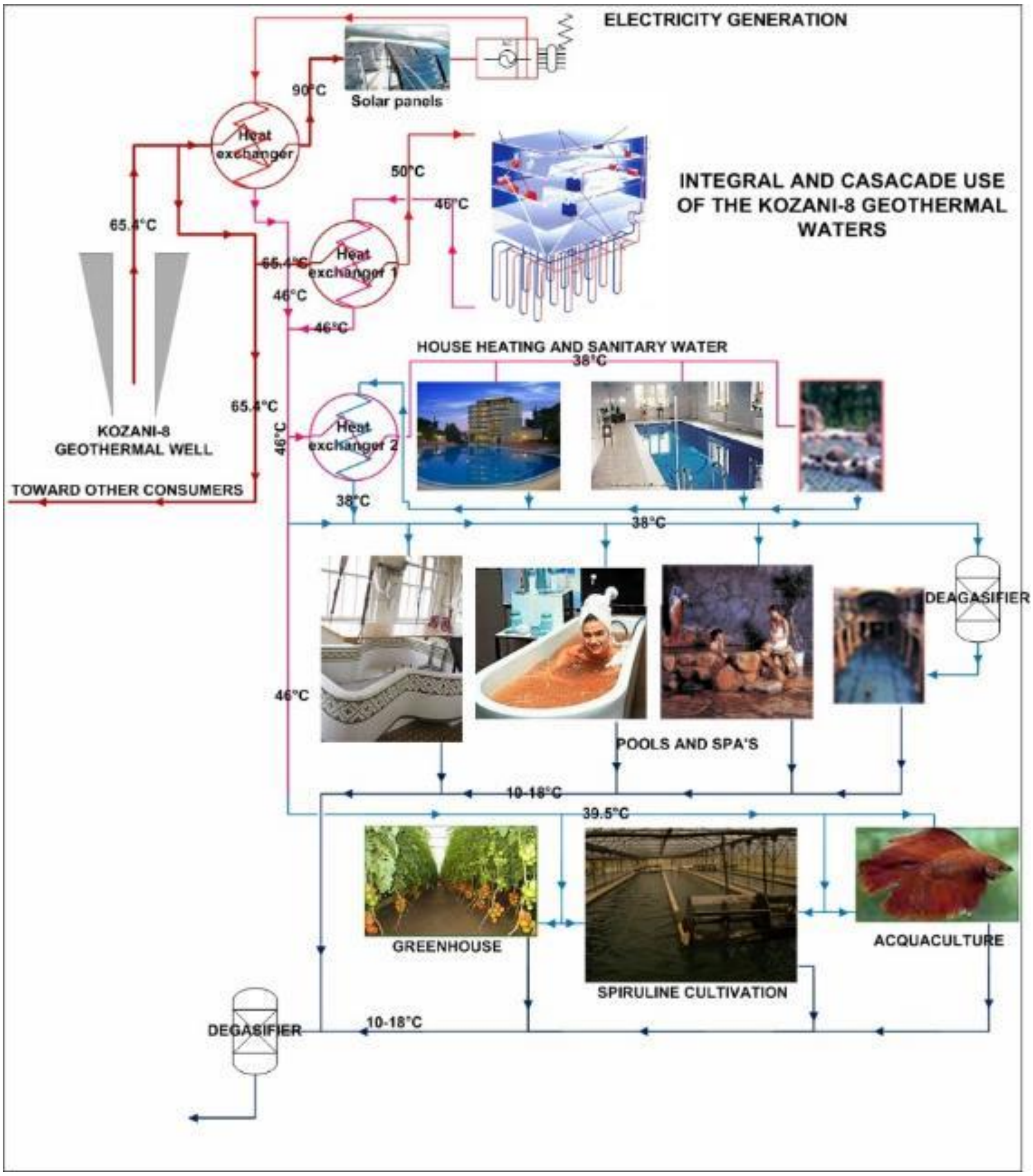


Figure 39: Principal sketch of the integral, cascade and hybrid use of the Kozani – 8 geothermal water use

Heat Losses

The proposed centre will have several pools: 1 geothermal pool (designed as a natural pond, sized 10*8*0.5 m, water temperature 38°C-regasified); 1 outdoor Olympic pool (sized 50*23*3 m, water temperature 30°C); 1 sweet water pool (sized 10*5*1.5 m-escalate, water temperature 38°C-degasified, lightly closed); 1 kid sweet water pool (sized 5*3*0.5 m-escalate, water temperature 30°C). The criteria for pool designing are psychological and physiological comfort, road width of 1-3 m, the height of the indoor pools of 4 m, temperature & humidity level, easy maintenance, and a noise level below 60 db. The thermal loads, based on their nature and effect on the thermal balance, can be calculated as losses or thermal increments. The heat losses of the system are influenced by a number of factors, including the number of guests, their physical activity, the electrical equipment, solar radiation, natural ventilation, thermal insulation, etc. The calculation for the electrical equipment is made based on the assumption that the maximum load varies during the day to avoid their supersizing. Figure 40, is shown the water circulation scheme for the pools. On the first cascade, the water will be used for house heating and also for pools. The water discharged by the geothermal and hot water pool (38°C) will be used for spirulina cultivation. On the first heat exchanger, the water supply should be 22.69 t/h of water for an installed capacity of 512 kW [23, 24, 25, 26, 27]. This amount of energy will be transmitted through the sweet water, heated at the level of 45-50°C. On the second heat exchanger are needed 15 [t/h of water] is for an installed capacity of 480 kW. The water temperature in this heat exchanger should be in the range of 40-50°C [7], Figure 41. Table 12 are presented the thermal loads for the center for both seasons: winter and summer, while Table 13 the parameters of the indoor pool’s environment [25].

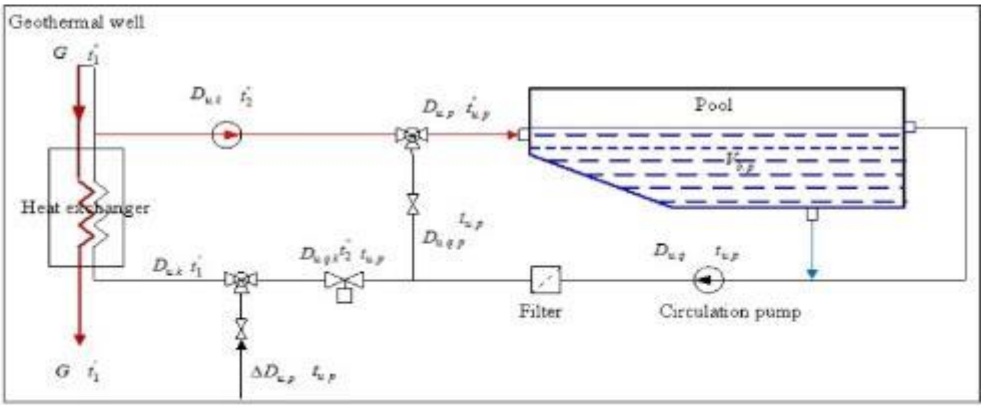


Figure 40: The geothermal/fresh water pools circulation scheme

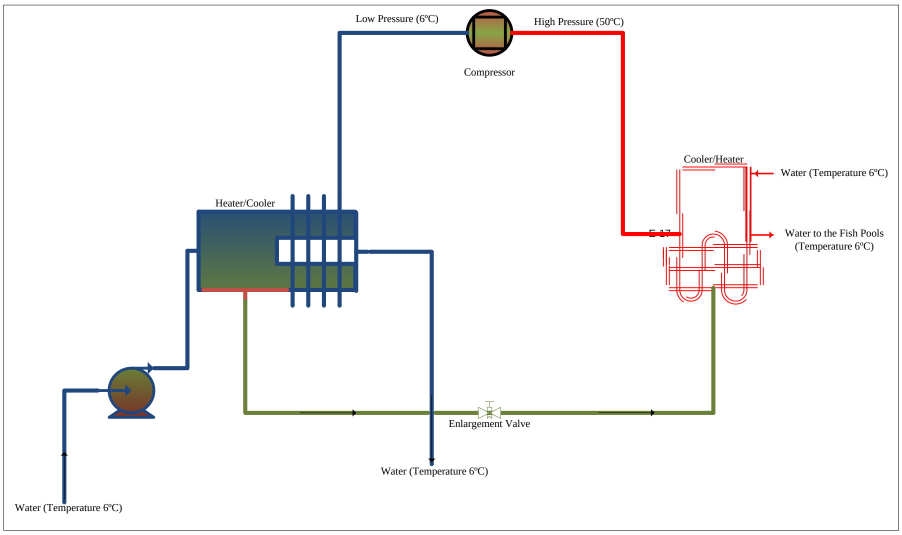


Figure 41: Heat exchanger and heat pump functional sketch

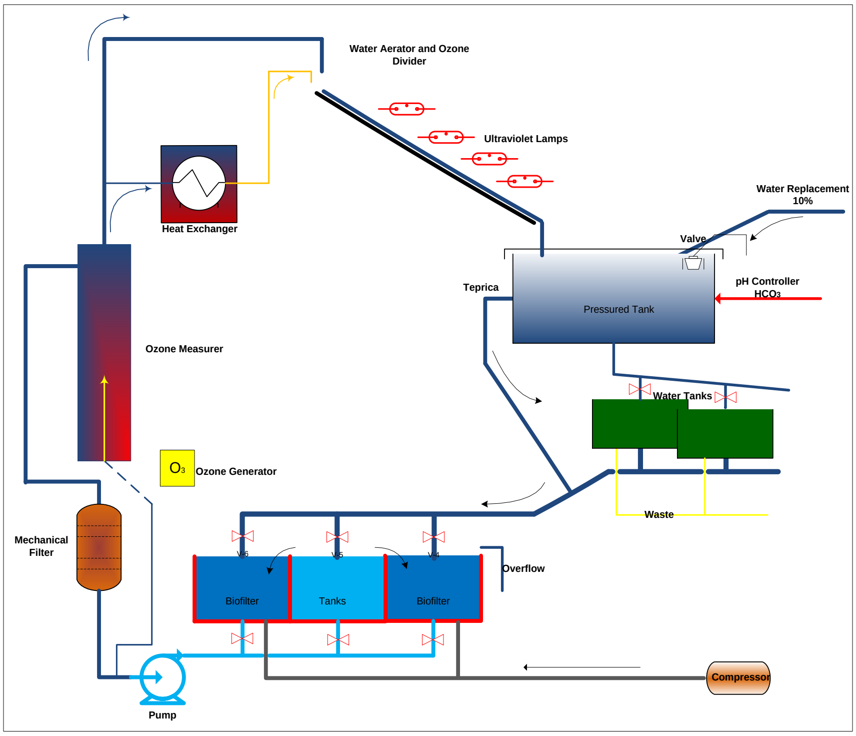


Figure 42: Acquaculture cultivation principal sketch

Table 12: Thermal loads of the proposed recreational/balneological centre

Room/environment	SUMMER			
	Thermal load [kW]	**Air [kW]**	**Sanitary water [kW]**	**Total [kW]**
Main Building	100	130	53	283
Indoor Pools				130.5
Geothermal Pool (10x 8) m				72
Sweet Water Pool (10x5m)				45
Kids Pool (5x3m)				13.5
Subtotal				**413.5**
Indoor Pool (Water)				
Geothermal Pool (Water)				
Sweet Water Wool				
Olympic Pool (Water)				
Total				**413.5**

Room/environment	WINTER			
	Thermal load [kW]	**Air [kW]**	**Sanitary water [kW]**	**Total [kW]**
Main Building	512	420	80	1012
Indoor Pools	32.3	63.6	130.5	226.4
Geothermal Pool (10x 8) m	18	35	72	125
Sweet Water Pool (10x5m)	11	22	45	78
Kids Pool (5x3m)	3.3	6.6	13.5	23.4
Subtotal				**1236.4**
Indoor Pool (Water)				68
Geothermal Pool (Water)				48
Sweet Water Wool				20
Olympic Pool (Water)				1300
Total				**2674.4**

Table 13: Indoor pool parameters

Environment	**Parameter**
Indoor Pools	V_{air}=45 [m^3/hm^2]
	Q_{floor}=220 [W/m^2]
	$Q_{sanitary\ water}$=0.90 [kW/m^2]

Environmental Analyses and Positive Impact of the Scheme

The environmental effects of the Kozani-8 geothermal well come because of two main reasons:

- A high content of gases;
- The high content of mineral salts.

The chemical analyses of the water show that the H_2S content is 410.07 mg/l, H_2SO_4 43.1 mg/l, HBO_2 25.4 mg/l, and free CO_2 184.7 mg/l. Other free elements of the water at 60°C are Cl, F, Br, J, and NO_2 [16]. These entire chemicals are not dissolved in the geothermal water, so it's enough for a small perturbation, and they can be released into the atmosphere. Most of them are poisoning to the people, except that they are extremely harmful to the equipment. Their actual effect on the environment is high, and also the health problem to the community caused by them is relevant. So, it is necessary that all these gases should be removed through and degassing process, Figure 43. The quantitative evaluations show that the total amount of the gases that should be removed is 5.12 kg/h for a total mass of geothermal water of 12.04 t/h with a mean temperature of 40.68°C. The mineral saline content of the Kozani-8 water is 4.6 g/l, while the pH is 7.5. In big amounts are the cations Na^+ 1.19 g/l, Ca^{2+} 0.79 g/l, Mg^{2+} 0.2 g/l, K^+ 0.17 g/l, NH_4^+ 0.02 g/l, traces of Fe^{2+}, As and Cu^{2+}, Al^{3+} 0.2 g/l, traces of heavy metals as Fe, Cu, Al and the anions Cl^- 2.36 g/l, SO_4^{2-} 1.78 g/l, HCO_3^- 0.43 g/l, F^{1-} 0.8 g/l, Br^{1-} 2.4 g/l, J^{1-} 1.1 g/l, HS^{1-} 95.3 g/l, $S_2O_3^{2-}$ 1.5 g/l, SO_3^{2-} 0.1 g/l, HPO_4^{2-} 0.4 g/l, traces of NO_2^{1-}. The water also contains dry residue (at 180°C) at the level of 6808 mg/l. Their effect extends to pollution of the surface and underground waters, soil pollution, and corrosion and depositions problems, while the most important is the human and animal health issues, Figure 43. That's why the proposed scheme predicts treating this water in order to remove all the pollutants. The purification process will involve total desalination and, as the second step, selective desalination in order to get the valuable compounds. This scheme will be economically feasible, as part of them have market values, so they will be sold to the national market.

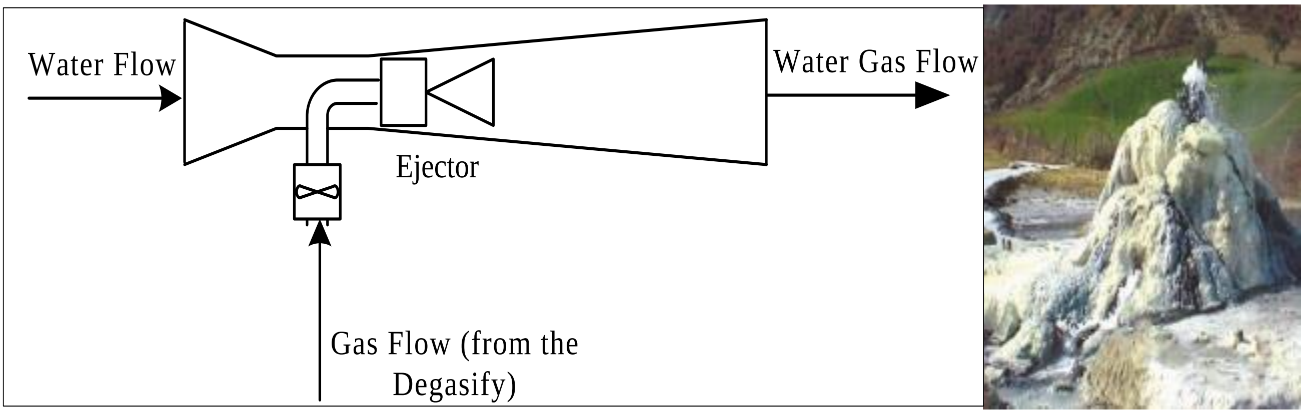


Figure 43: Degassify sketch of the Kozani -8 fluids/silica & calcite depositions at the welhead

Economic Analyses

Table 14 shows some cost data related to the construction cost for the Recreational Geothermal Centre & SPA, Shijon, and Elbasan. There can be clearly seen that the biggest investment should be made for the building (66.7per cent), while the total investment is calculated to be 5 708 285 Euro [16].

Table 14: Costs calculations for the Shijoni Recreative Geothermal Centre & SPA

Constituent	The investment [€]
Property (land)	440 880
Hotel-Clinic - Building - Acclimatize System - Furniture	 3 808 280 654 560 229 670
Greenhouse	186 710
Spirulina Cultivation Centre	252 085
Aquaculture Installations	136 100
Total [€]	**5 708 285**

The economic analyses are done based on the Net Present Value (NPV) Calculations. The center will be constructed through a banking loan. Underlined this fact because the Albanian banking system does not give loans in such cases if the Rate of Return (ROR) is lower than 0.1 (10per cent). Table 15 shows the NPV values for different scenarios based on different Cash Flow (CF). From this table can be seen that the NPV becomes positive for CF greater than 350 000 €/y. Figure 44 shows the chart of PV/time, while Figure 45 is the chart of (NPV/CF). The analytical analyses (and also graphical) show that the NPV is equalized to zero only if the CF is 382 949 €/y. For lower CF, the NPV result is negative, and of course, for greater CF, it will be positive. The business plan predicts a CF of about 445 000 €/y, based on the Albanian touristic market and its prices.

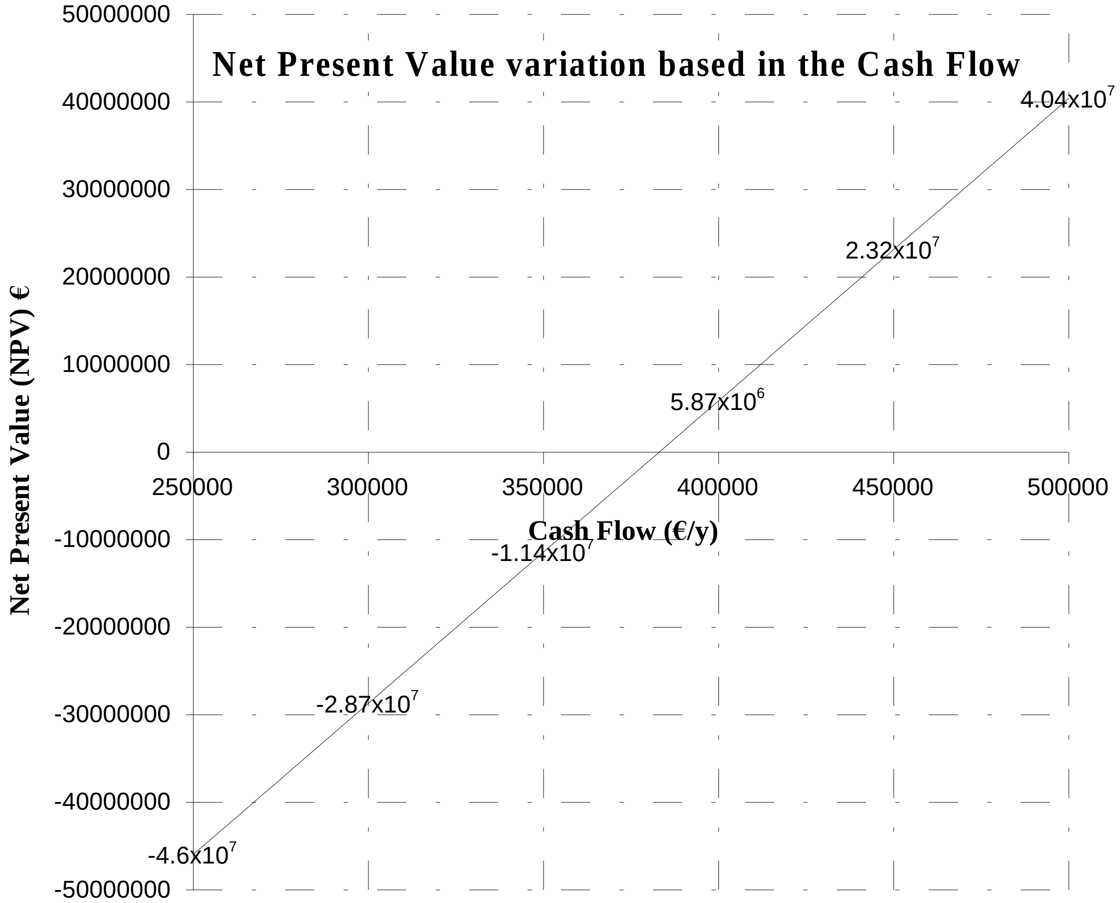


Figure 44: Net present value calculation chart

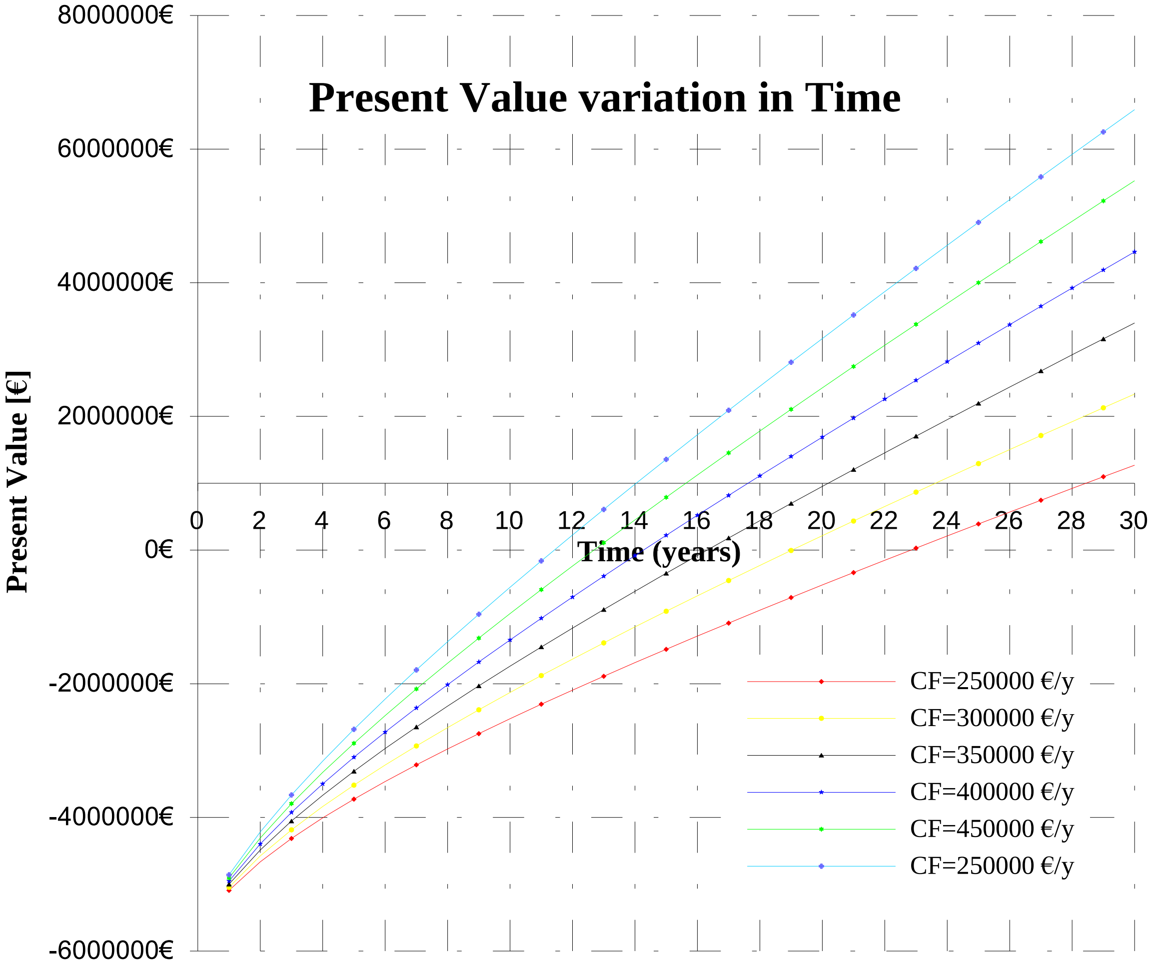


Figure 45: Present value calculation chart

Table 15: The NPV calculations for different scenarios (based in the CF)

Time [years]	Present Value for Different Cash Flow					
	250000 [€/y]	300000 [€/y]	350000 [€/y]	400000 [€/y]	450000 [€/y]	500000 [€/y]
1	-5.09E+06	-5.05E+06	-5.00E+06	-4.95E+06	-4.91E+06	-4.86E+06
2	-4.67E+06	-4.58E+06	-4.49E+06	-4.40E+06	-4.31E+06	-4.22E+06
3	-4.32E+06	-4.19E+06	-4.06E+06	-3.93E+06	-3.79E+06	-3.66E+06
4	-4.01E+06	-3.84E+06	-3.67E+06	-3.50E+06	-3.33E+06	-3.16E+06
5	-3.73E+06	-3.52E+06	-3.31E+06	-3.10E+06	-2.89E+06	-2.68E+06
6	-3.46E+06	-3.22E+06	-2.97E+06	-2.72E+06	-2.48E+06	-2.23E+06
7	-3.22E+06	-2.93E+06	-2.65E+06	-2.36E+06	-2.08E+06	-1.79E+06
8	-2.98E+06	-2.66E+06	-2.34E+06	-2.01E+06	-1.69E+06	-1.37E+06
9	-2.75E+06	-2.39E+06	-2.03E+06	-1.68E+06	-1.32E+06	-959775
10	-2.52E+06	-2.13E+06	-1.74E+06	-1.34E+06	-950671	-557274
11	-2.31E+06	-1.88E+06	-1.45E+06	-1.02E+06	-591445	-162458
12	-2.10E+06	-1.63E+06	-1.17E+06	-702794	-238538	225717
13	-1.89E+06	-1.39E+06	-889616	-390386	108844	608073
14	-1.68E+06	-1.15E+06	-616532	-82596	451340	985275
15	-1.48E+06	-915709	-347315	221079	789472	1.36E+06
16	-1.29E+06	-684191	-81569	521053	1.12E+06	1.73E+06
17	-1.09E+06	-455596	181041	817677	1.45E+06	2.09E+06
18	-900107	-229656	440796	1.11E+06	1.78E+06	2.45E+06
19	-710218	-6140	697937	1.40E+06	2.11E+06	2.81E+06
20	-522379	215148	952675	1.69E+06	2.43E+06	3.17E+06
21	-336429	434380	1.21E+06	1.98E+06	2.75E+06	3.52E+06
22	-152225	651708	1.46E+06	2.26E+06	3.06E+06	3.87E+06
23	30358	867264	1.70E+06	2.54E+06	3.38E+06	4.22E+06
24	211429	1.08E+06	1.95E+06	2.82E+06	3.69E+06	4.56E+06
25	391087	1.29E+06	2.20E+06	3.10E+06	4.00E+06	4.90E+06
26	569420	1.50E+06	2.44E+06	3.37E+06	4.31E+06	5.24E+06
27	746506	1.71E+06	2.68E+06	3.65E+06	4.62E+06	5.58E+06
28	922416	1.92E+06	2.92E+06	3.92E+06	4.92E+06	5.92E+06
29	1.10E+06	2.13E+06	3.16E+06	4.19E+06	5.23E+06	6.26E+06
30	1.27E+06	2.34E+06	3.40E+06	4.46E+06	5.53E+06	6.59E+06
N.P. V	**-4.60E+07**	**-2.87E+07**	**-1.14E+07**	**5.87E+06**	**2.32E+07**	**4.04E+07**

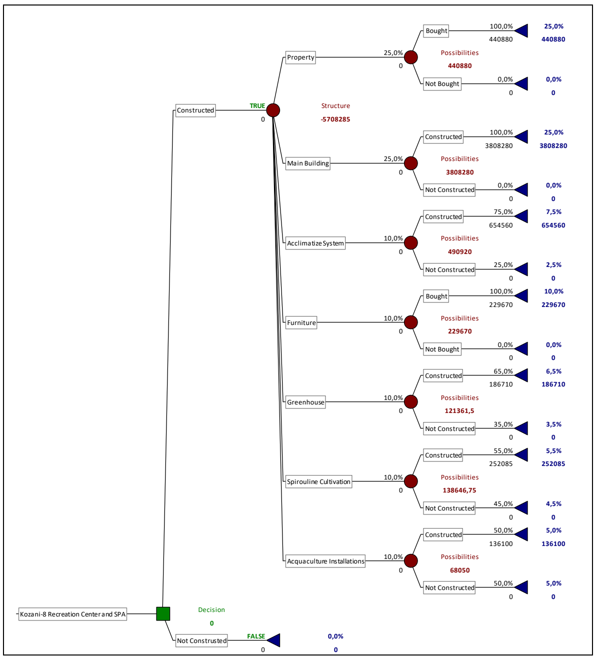


Figure 46: Risk analysis chart for the Kozani-8 recreation centre construction

Figure 46 shows the chart of Risk Analyses. There can be seen even better that the risk is minimal, so the investment is totally efficient. In the following charts, Figure 47 is possible to see the risk for each value of NPV. So once more, the risk is minimal, and the investment is very profitable.

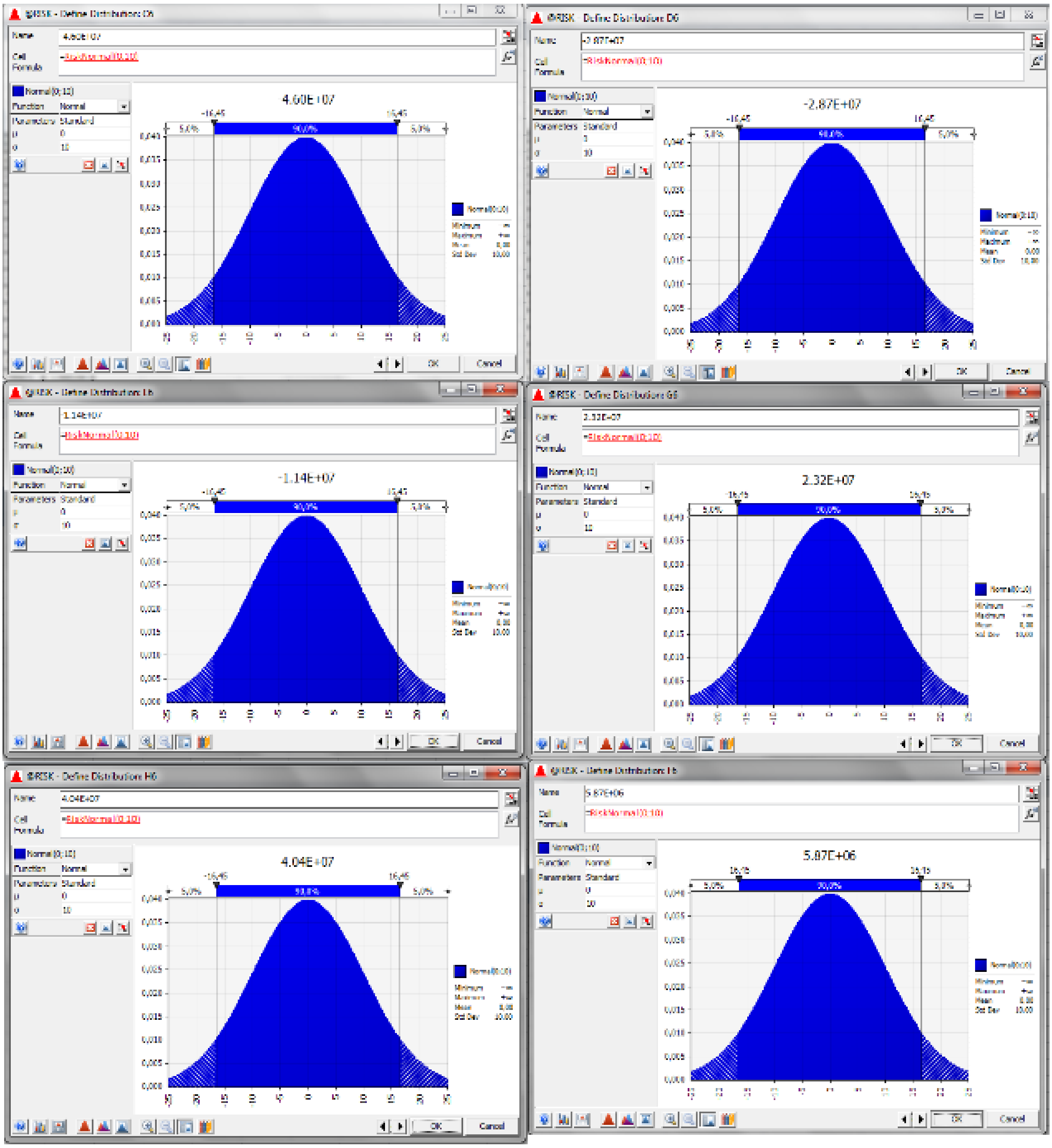


Figure 47: Risk analysis charts based on the NPV

The potential of Bënja Geothermal Springs for Direct Utilization

In the Bënja of Përmeti village, in the Lëngarica creek, are found eight springs known and used for their curative values since the time of the Roman Empire. The eight springs blow out mineral water with temperatures in the range of 23÷30 °C and yields in the range of 8 up to more than 40 l/s. These waters, even though with relatively low temperatures, represent a competitive energy resource. Their flows directly to the river of Lëngarica, similar to the other geothermal resources of Albania, can be "translated" as "throwing in the creek" of considerable monetary value, delay in the economic development, infrastructure, and also social of the area. Below will be shown that these waters are not only a competitive energy resource by using a combined and cascade system, but they can be efficiently used for greenhouses, aquaculture, and mineral salts extraction [25-28]. The following aims to give some calculations that show that these resources not only fulfill all the requirements for direct utilization but, if combined through hybrid systems are fully competitive compared with conventional resources.

Katiut Bridge (Ura e Katiut), Lëngarica-Përmet Geothermal Springs

In the village of Bënja, there are 8 springs linked with the regional dissociative tectonic of the Bodar-Postenan anticlines chain. The limestone's layers sink toward the west with an angle of nearly 20°C and azimuth of 210÷215°C. These limestone layers are karstified, especially on the right bank of the river, where some caves or cavities can be found. In a 500 m long belt, on both sides of the river are found the geothermal springs: 4 on the left side and 4 on the right side. The water generally blows out at the water level, below or even 1÷2.5 m above it. Their location is [23, 25, 28]:

- Spring 1 is 25÷30 m further down the bridge, 20 m far from the riverbed. Its temperature is 26°C;
- Spring 2 is 8 m beyond the bridge and blows out below the water level. It can be seen by its blue with some white tint color on the limestone's surface, by whose fractures the waters blow out;
- Spring 3 is 25 m beyond the bridge, in the water table but 15 m far from the river shore. They blow out as three very potent griffons. The water temperature is 26°C and the yield about 8 l/s;
- Spring 4 is 150÷200 m beyond the bridge, where the canyon width is over 20 m. they blow out as two griffons. The most important is about 15÷20 cm in height, blow 0.5 m above the water level, has a yield of 8÷9 l/s, and a temperature of 23°C. Approx. 30 m beyond is the second griffon with a yield of 4 l/s and the same temperature.

The other four springs are placed on the left bank of the river. Their main characteristics are given below:

- Spring 5 is 300÷400 m beyond the bridge before the canyon, which is 10-12 m wide and 40÷50 m height. Some powerful water blow out by the limestone fractures have yields of 30÷40 l/s and temperature of 30°C;
- Spring 6 is at the bridge pier, 0.81 m above the water level and 4 m away from the river. Its yield is 30 l/s and the temperature 30°C;
- Spring 7 is 7 m further down the bridge, in the water level, and 2÷3 m away. The yield is 30÷40 l/s and the temperature 30°C;
- Spring 8 is the biggest one. This spring is 20÷25m further down the bridge, 1÷1.5 m above the water level, and 8÷10 m away from the river. The yield is over 40 l/s, and the temperature is 30°C.

The temperature of the geothermal water is low. Thus their direct utilization, according to the Lindale diagram, Figure 3, is more suitable and efficient. Despite this, their combination with solar power increases the possibility of improving the efficiency of the system so as to successfully apply the cascade schemes.

The springs belong to the Kruja geothermal area, the biggest and the most important geothermal field in Albania. Kruja geothermal zone represents a zone with large geothermal resources. The Kruja zone has a length of 180km, Figures 9 & 10. The Kruja Geothermal zone extends from the Adriatic Sea in the North and continues down to the South-Eastern area of Albania and to the Konitza area in Greece [13, 23, 25]. The geothermal aquifer is represented by a carstified neritic carbonates formation with numerous fissures and micro-fissures. The most important natural springs are presented by the Llixha Elbasan springs, Hydraj Elbasan, and the springs of Lëngarica, Përmet. Three boreholes blow out high-temperature and mineralization water: Ishmi-1/b, Kozani-8, and Galigati-2. The chemical analyses of the geothermal fluid's composition are presented in Table 16.

Table 16: Chemical composition of the geothermal springs of Lëngarica

Iones	Unit	Spring (Lëngarica river)	Spring 5	Spring 6
PH		7.4	7.4	7.4
Mineralisation	G/l	1.6562	1.6394	1.6528
Cations				
Ca^{2+}	G/l	0.1273	0.1283	0.1273
Mg^{2+}	g/l	0.0347	0.0343	0.0330
Na^{1+}	g/l	0.3786		
K^{1+}	g/l	0.0019		
$(Na^{1+})+(K^{1+})$	g/l		0.3949	0.4025
NH_4^{1+}	g/l	0.0004	0.0004	0.0004
Fe^{2+}	g/l	0.0004	-	-
Al^{3+}	g/l	Traces		
Mn^{2+}	g/l	0.00001		
As	g/l	-		
Cu^{2+}	g/l	0.00001		
Anions				
Cl^{1-}	g/l	0.7017	0.69	0.7056
F^{1-}	g/l	0.0007		
Br^{1-}	g/l	0.0006		
J^{1-}	g/l	Traces		
SO_4^{2-}	g/l	0.1614	0.1601	0.1551
HCO_3^{1-}	g/l	0.2098	0.2123	0.2105
CO_3^{2-}	g/l			
HS^{1-}	g/l			
$S_2O_3^{2-}$	g/l			
SO_3^{2-}	g/l			
HPO_4^{2-}	g/l	0.0004		
NO_3^{1-}	g/l	Traces		
NO_2^{1-}	g/l	0.0012		
Total solid (180°C)	g/l	1.568	1.5600	1.5640
H_2S (total)	g/l	-	0.0042	-
H_2SiO_3	g/l	0.0163	0.0141	0.0182
HBO_2	g/l	-		
CO_2 (free)	g/l	0.0384		

The Geothermal Complex- Katiut Bridge (Ura e Katiut), Lëngarica, Përmet

The demonstrative geothermal complex for the integral and cascade use of Katiut Bridge, Lëngarica, Përmet assumes that the construction will be completed step by step in order to decrease the value of the initial investments [23-25]. In the design phase of the center should be considered several factors and parameters should be, such as orientation, approach with different environments, thermo insulation of the walls, floor, windows, sealing, etc. Based on the yield of the geothermal spring is possible to be installed at a capacity of 10 040 kW. Due to the fact that their temperature is low for optimizing their utilization should be used the complex cascade scheme that includes the hybrid system through combining geothermal with solar panels and water-water geothermal heat pumps and heat exchangers, as it is shown in Figure 48 [13, 23].

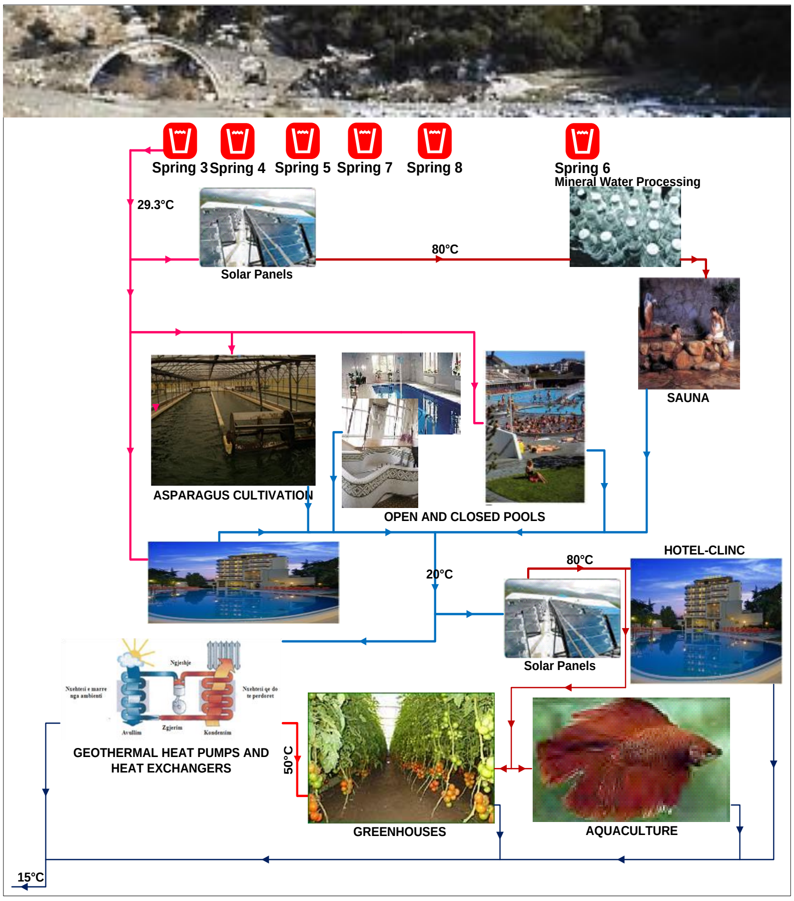


Figure 48: Bënja geothermal springs utilization sketch

Cost calculation and economic analysis of the proposed center

Table 17 is presented the detailed cost for the construction of the proposed center. There is clearly seen that the main investment goes for the main building (40.27per cent) while the total investment goes about 3 024 645 Euro [13, 23].

Table 17: Cost analysis of the proposed center based on the constituent

Constituent	***The investment [€]***
Property (land)	*370 980*
Hotel-Clinic	
Building	1 812 280
Acclimatize system	354 560
Furniture	129 670
Greenhouse	*86 710*
Spirouline cultivation center	*154 085*
Aquaculture installations	*116 900*
Total [€]	*3 024 645*

Due to the fact that for the proposed area, there are some WB programmers, the construction will be released through a bank loan with an interest of only 2 per cent/year. This is underlined as the Albanian Banking system does not supply projects with ROR lower than 0.1 (10 per cent). Based on this information, the ROR results:

$$ROR = \ln\left(\frac{Final\ Value}{Investment}\right) = \ln\left(\frac{4051504.93}{3024645}\right) = 0.2923 = 29.23\%$$

A detailed economic analysis is completed to find out the viability of the installation. This analysis was based on the Present and Net Present Values Calculation Table 18. The results showed that NPV becomes positive for income not lower than 250,000 €/y [13, 23].

Table 18: Economic analyses results

Time (years)	Present Value (PV) for different income (CF) calculated (€/year)						
	50000	**100000**	**150000**	**200000**	**250000**	**300000**	**350000**
1	-2429000	-2388000	-2347000	-2307000	-2266000	-2225000	-2184000
2	-2121000	-2049000	-1976000	-1904000	-1831000	-1759000	-1686000
3	-1917000	-1817000	-1717000	-1617000	-1517000	-1417000	-1317000
4	-1765000	-1640000	-1515000	-1390000	-1265000	-1140000	-1015000
5	-1643000	-1495000	-1347000	-1199000	-1051000	-903057	-754980
6	-1543000	-1373000	-1203000	-1033000	-863270	-693407	-523544
7	-1456000	-1266000	-1075000	-884678	-694090	-503503	-312915
8	-1381000	-1170000	-959960	-749517	-539074	-328631	-118188
9	-1313000	-1084000	-854324	-624756	-395187	-165618	63950
10	-1253000	-1004000	-756432	-508363	-260295	-12227	235841
11	-1197000	-930906	-664884	-398862	-132839	133183	399205
12	-1146000	-862130	-578635	-295140	-11645	271851	555346
13	-1098000	-797419	-496880	-196342	104197	404735	705274
14	-1053000	-736185	-418990	-101795	215400	532596	849791
15	-1011000	-677961	-344460	-10959	322542	656043	989544
16	-971853	-622367	-272881	76605	426091	775577	1125000
17	-934270	-569093	-203917	161260	526436	891613	1257000
18	-898476	-517882	-137287	243308	623903	1004000	1385000
19	-864277	-468516	-72755	323005	718766	1115000	1510000
20	-831504	-420813	-10121	400570	811261	1222000	1633000
21	-800016	-374615	50787	476189	901590	1327000	1752000
22	-769693	-329787	110118	550024	989930	1430000	1870000
23	-740429	-286213	168003	622218	1076000	1531000	1985000
24	-712132	-243790	224553	692895	1161000	1630000	2098000
25	-684723	-202427	279868	762164	1244000	1727000	2209000
26	-658131	-162046	334039	830123	1326000	1822000	2318000
27	-632293	-122576	387142	896859	1407000	1916000	2426000
28	-607155	-83953	439248	962450	1486000	2009000	2532000
29	-582667	-46122	490422	1027000	1564000	2100000	2637000
30	-558784	-9032	540719	1090000	1640000	2190000	2740000
NPV	-33572403	-23749833	-13926627	-4105742	5717716	15541155	25364324

Results and Discussion

By the economic analysis, it can be clearly seen that NPV becomes positive for income not lower than 250 000 €/y [13, 23, 24, 25]. To go a little bit deeper into this analysis, the PV and NPV graphs were designed, as shown in Figure 49.

Their analytic processing proves that the NPV is equalized to zero for a yearly income of 220,893 €/y. The business plan is based in the Albanian touristic market, and its prices evaluate that the yearly CF will be around 237,000 €/y, so 7.29per cent higher than the minimal calculated value [4, 5, 7]. Impressive results are obtained in the risk evaluation process of the proposed project. The Monte Carlo simulator (Precision tree), Figure 50 clearly shows that even if the financing will be through mixed sources (soft loan, private and commercial loan), there isn't any risk that can jeopardize the future of the investment. This risk evaluation process was decided to be followed, as the geothermal energy direct utilization in Albanian is only in its first steeps, so it is important to evaluate form the desk study all possible hazards and find their mitigation ways.

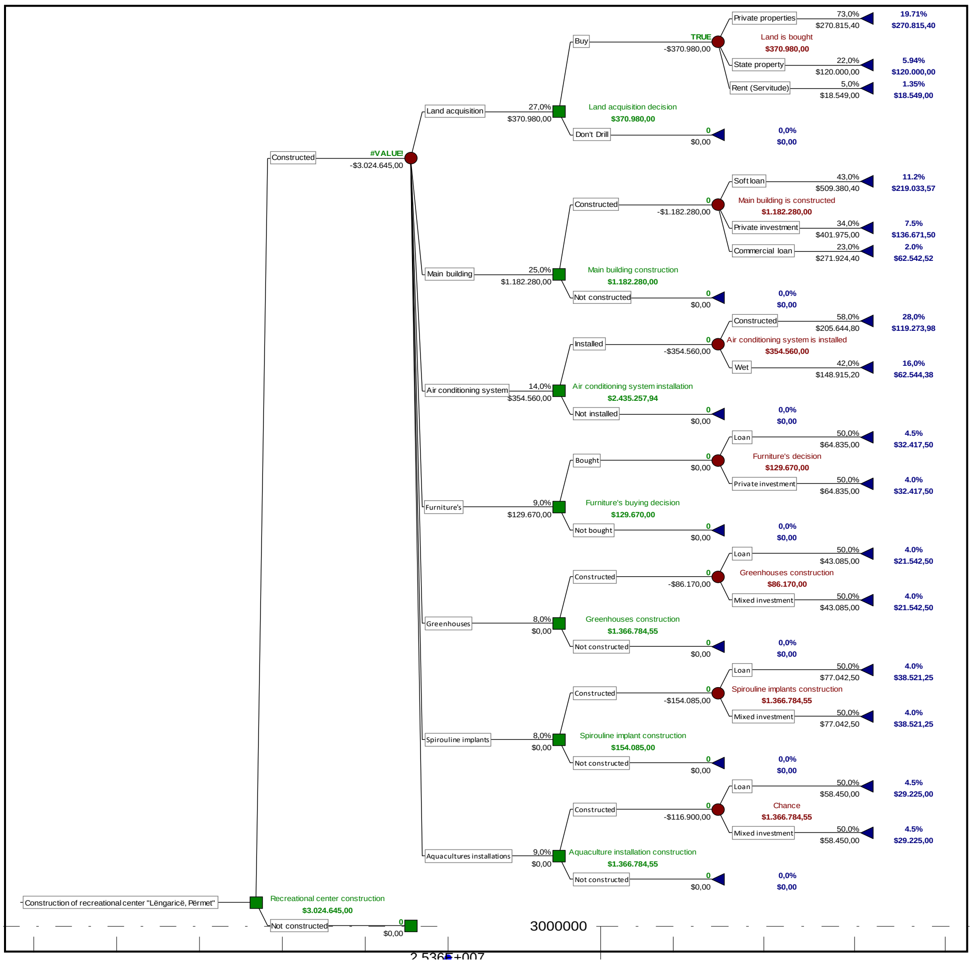


Figure 50: Precision tree of the Bënja-Përmet recreational geothermal center

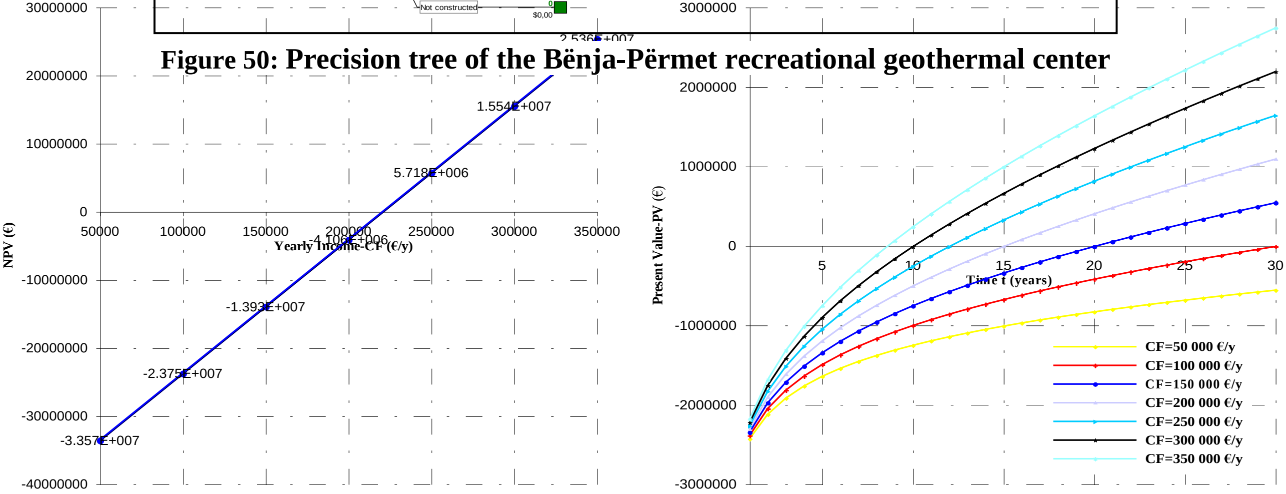


Figure 49: Economical analysis of the Bënja-Përmet recreational geothermal center

District heating options using underground hot rock temperatures

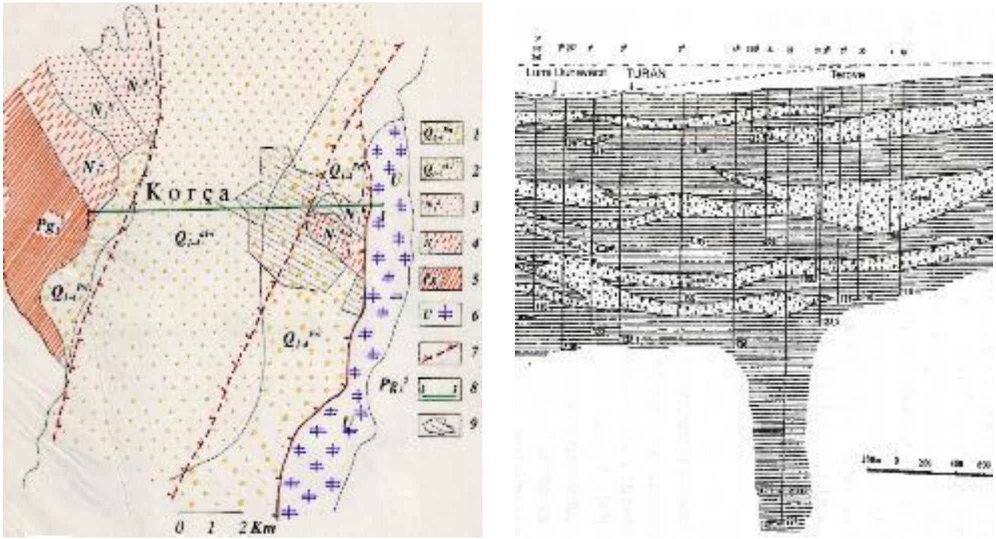
“FAN S. NOLI” university campus geothermal heating design and viability

The following gives the basic calculation for the heating system of the “Fan. S. Noli” University campus building. The choice of this building is made based on its importance and the climatic regime of Korça that makes necessary the heating for more than 5 months per year. Actually, in Albania, geothermal energy is not yet considered to be an important source, so we are allowing its “spread.” In Korça, there is no evidence of hot waters or steam sources, but the geothermal regime of the region allows the use of both systems: Water-Water and Earth-Water. Despite the fact that the initial investment is larger for the geothermal systems, the NPV calculations and the risk analysis show very clearly that they are much more viable. Without mentioning another fact, they are environmentally friendly.

Due to the Albania geothermal regime, the cooling/heating systems of the buildings seem to be the best way to start their direct utilization. Albania is relatively rich with low up to the middle enthalpy geothermal resources, which had not been used until now for their energetic values. The temperatures in the depth of 100 m (Figure 14) are within limits for heat exchanger utilization in both ways: water-water systems or even through heat extraction. The climate of Korça, especially the winter season, enforces the use of the heating system for more than 4 months/per year. The university campus had been chosen not only for its characteristic but also because this is the biggest public building in the region, so the economic profit can be significant. Some important problems as energetic calculations, including heat loss, setting off the geothermal heating system based on their viability, Vertical heat exchanger capacity evaluation and their design, economic analyses, and related calculations as the preliminary installation costs, water production, and injection wells costs, the comparison with the coal heater and air conditioners are part of the viability study.

The geological structure of Korça and its geothermal region

The region of Korça is part of the flysch depositions of the lower Neogene (N_1), Paleogene (Pg_3), and the ultrabasic massive of Morava Mountain (Figure 51). The youngest depositions of Quaternary cover the oldest in the field of Korça. This field is 800-850 m a.s.l. and is confined by the Morava Mountain (E) and the Dried Mountain (N-E) by an active tectonic fracture. The quaternary formations study is done by a large number of wells, by the geophysical SP & DCR & IP, and by the high-frequency seismic methods. The hydrogeological survey shows that the Korça aquifer (Figure 51) is composed of 7 gravel layers. The 4 upper layers are the most important. Their width is about 2-22 m. The transmissivity coefficient is 1500-2000 m2/ d., the hydraulic conductivity is 60-150 mD., the porosity is 0.0004, and the specific capacity of the wells is 6-10 l/s/m [1].



The city of Korça is in the S-E of Albania, and its climatic regime is Mediterranean highlands and peri-highlands. The “Fan S. Noli” University campus is in the third climatic region of Albania. The low temperatures during the winter make necessary the heating for the period October-May. The general area to heat is 1260 m^2 and has three floors.

The elements of this system will be The heater, the oil deposit, the burner, the chimney, the circulation pump, and the control panel. The energy of this system is calculated at 178 kW, with an increase of 15per cent to cover loses. The calculation for the VHE shows that their length should be 1257 m for the water-water pump and 1500 m for the soil heat extraction. To achieve this length will be drilled 13 wells 100m deep/each for the water-water pump and 15 wells 100 m deep/each for the soil extraction system [13]. Based on the energetic calculations and the market options, the system will be

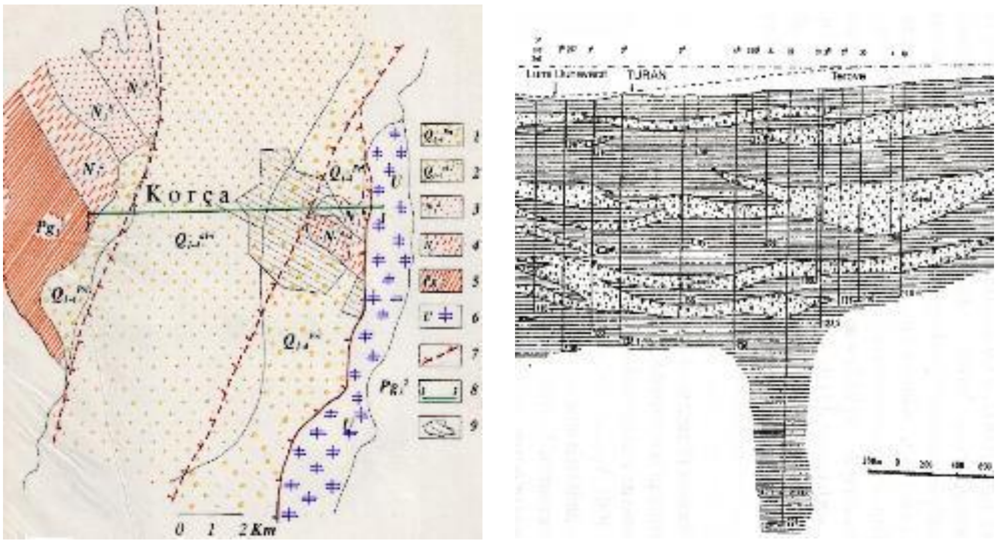


Figure 51: Korça geological map and the Korça acquifer profile

composed of two geothermal heating pumps of 87.7 kW each. Two options were considered: Water-Water pumps and soil heating extraction through vertical heat exchanger (VHE) use. The soil temperatures in the Korça region make more viable soil heat extraction through VHE use [16].

The climatic regime of Korça

The "Fan S. Noli" University campus is in the third climatic region of Albania. The low temperatures during the winter (Table 19) make necessary the heating for the period October-May. The general area to heat is 1260 m^2 and has three floors.

Table 19: The climatic parameters of the Korça region and their monthly fluctuation

Parameter	Month												Mean
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.	
Solar [kWh/m^2]	52	63	88	124	159	180	199	182	145	90	71	60	118
Sunny hours	102	122	155	187	239	279	332	307	230	185	122	95	2355 h/y
Mean temp. [^{o}C]	0.4	2.4	4.8	9.4	14.5	17.6	19.7	19.8	16.3	11.0	6.6	2.0	10.4
Wind [m/s]	2.1	2.5	2.7	2.7	2.2	1.8	1.6	1.6	1.7	2.2	2.2	2.2	2.1
Humid. [per cent]	79	76	69	64	64	61	55	55	63	70	76	80	64

The energy needed for its heating is given in (Table 20) [3].

Table 20: Energetic calculation results for the campus heating

Environment	Energy [W]
First floor	35366
Second floor	35366
Third floor	59763

The temperature fluctuation and other climatic data of Korça are presented in (Figure 52). One of the most important factors that will make this project viable is the ground temperature. That's why some surveys were implemented regarding the measurement of ground temperatures in different depths. These values are presented in (Table 21 & Figure 53) and were measured in the depths: 5 cm, 10 cm, 15 cm, and 160 cm [13].

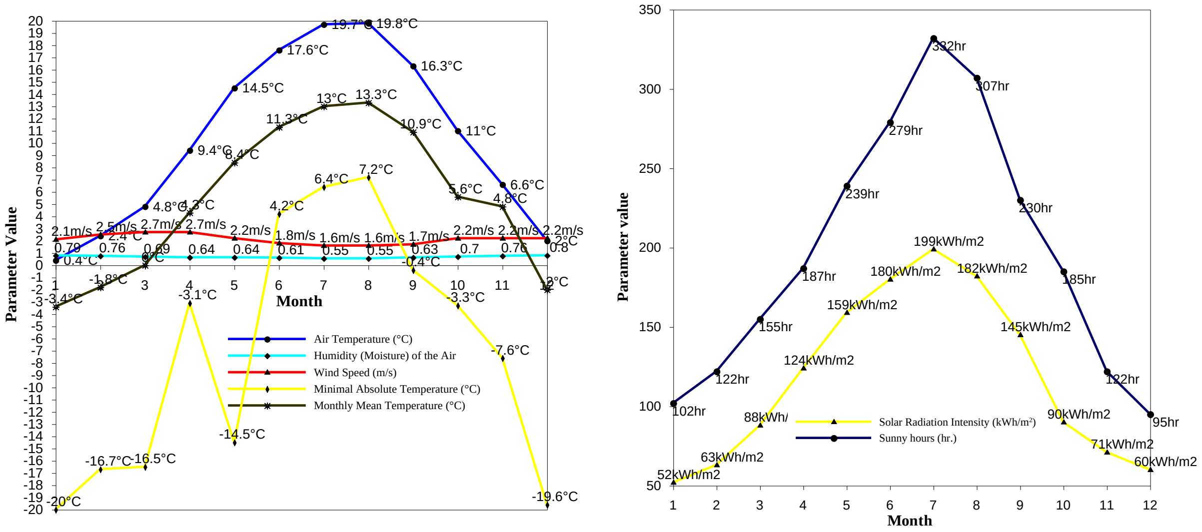


Figure 52: Annual fluctuation of different climatic parameters in Korça

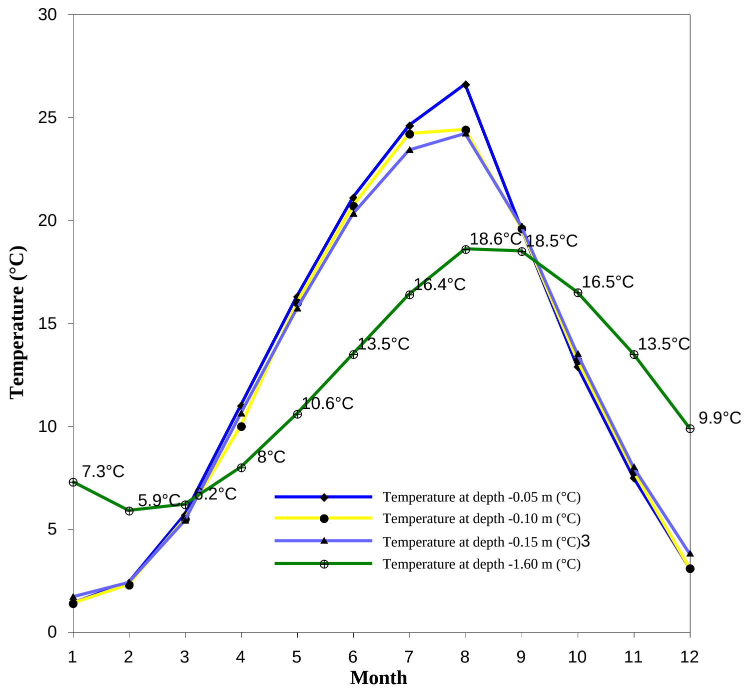


Figure 53: Underground temperature fluctuations

Table 21: Soil temperatures in different depth

Depth [cm]	Monthly temperature [°C]												
	I	II	III	IV	V	VI	VII	VII	VIII	IX	X	XI	XII
-0.05	1.4	2.4	5.7	11	16.3	21.1	24.6	26.6	19.6	12.9	7.5	3.1	1.4
-0.10	1.4	2.3	5.5	10	16.0	20.7	24.2	24.4	19.6	13.2	7.8	3.1	1.4
-0.15	1.7	2.4	5.4	10.6	15.7	20.3	23.4	24.2	19.7	13.5	8.0	3.8	1.7
-160	7.3	5.9	6.2	8.0	10.6	13.5	16.4	18.6	18.5	16.5	13.5	9.9	7.3

The heating scenarios

The oil heater scenario

The elements of this system will be The heater, the oil deposit, the burner, the chimney, the circulation pump, and the control panel. The energy of this system is calculated at 178 kW (Table 20), with an increase of 15per cent to cover loses.

The geothermal heating scenario

Based on the energetic calculations (Table 20) and the market options, the system will be composed of two geothermal heating pumps with 87.7 kW each. The calculation for the VHE shows that their length should be 1257 m for the water-water pump and 1500 m for the soil heat extraction. To achieve this length will be drilled 13 wells 100m deep/each for the water-water pump and 15 wells 100 m deep/each for the soil extraction system (Figure 54).

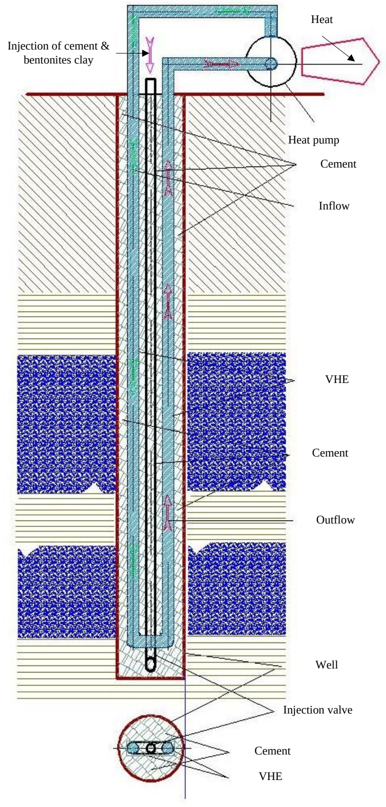


Figure 54: VHE installation

Economic analysis

Cost calculation for the heating systems

Due to the fact that the author considered three different scenarios, the cost is calculated for all of them. The results based on the international market (Table 22) show that the oil heating system is the cheapest one [25].

Table 22: Cost calculations for all the heating systems implants

The elements	**Costs for each element according to the system [€]**		
		Geothermal heating systems	
	Oil heater system	**Water-water geothermal pump**	**Soil heat extraction**
Radiators	7.667	15.334	15.334
Pipes	2.144	5.424	5.424
Switching relays	727	1.157	1.157
Valves	2.566	2.893	2.893
Pumps	475	950	950
Boilers	3.000	22.100	33.500

The total cost, including the other elements, is shown in (Table 23).

Table 23: Total cost for the heating systems

Heating system	**Element**	**Cost/Element [€]**	**Total [€]**
Oil Heating system	Implant installation	16579	16579
Geothermal water-water system	Implant	47888	74680
	Geothermal node	19959	
VHE (earth-water system)	Implant	59288	137712
	Geothermal node	78424	

Cost analyses for the heating systems

The cost analysis for the different scenarios is done by NPV calculations. This calculation is made based on the yearly expenditures of 25780 € (oil price 75¢/l), 39960 € (oil price 1.16 €/l) for the oil heating system, 13290 € for the water-water pump, and 15146 € for the VHE soil heat extraction system [6]. The ROR was taken as 10per cent as the Albanian banking system work only under these conditions. The results are really impressive (Figure 55).

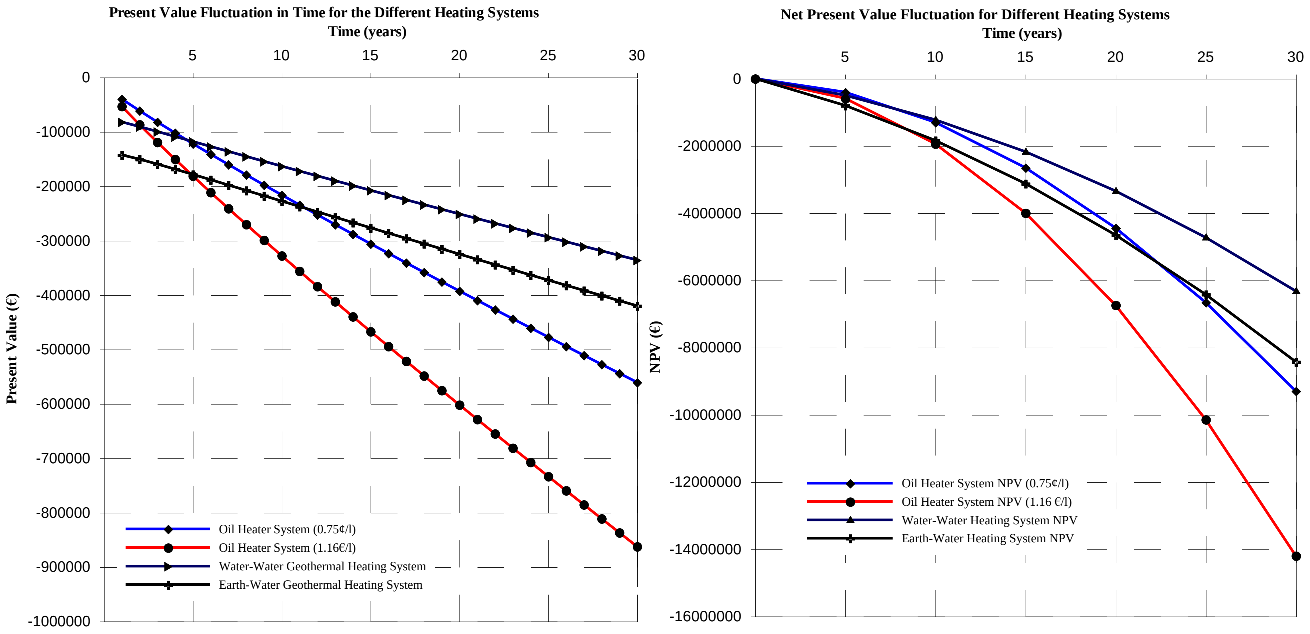


Figure 55. Present Value and Net Present Value calculations for all the heating systems

By analyzing the calculations result that by comparing the Oil Heating System (oil price 75/l) with the Water-Water Geothermal Heating System, the NPV are equalized after 4.367 years. After this time, the geothermal system is more viable, while with the second scenario (oil price 1.16 €/l), it becomes more viable only after 2.172 years. In the second geothermal scenario (Earth-Water System), the times are respectively 11.37 & 4.874 years. If we add to this, even the positive impact on environmental protection is out of any reasonable doubt that the geothermal systems are much more viable, as they are considered to be environmentally friendly.

Risk analysis of the proposed heating system

The risk is evaluated through the Palisade Decision Tool (Monte Carlo Simulation). The results are presented in (Figure 56). There can be clearly seen that the risk is minimal for the water-water geothermal system. It goes up while going to the earth-water geothermal system and rich the maximal value at the oil heating system (oil price 1.16 €/l). So combined with the NPV analyses, the decision is even easier to install the geothermal heating system [27].

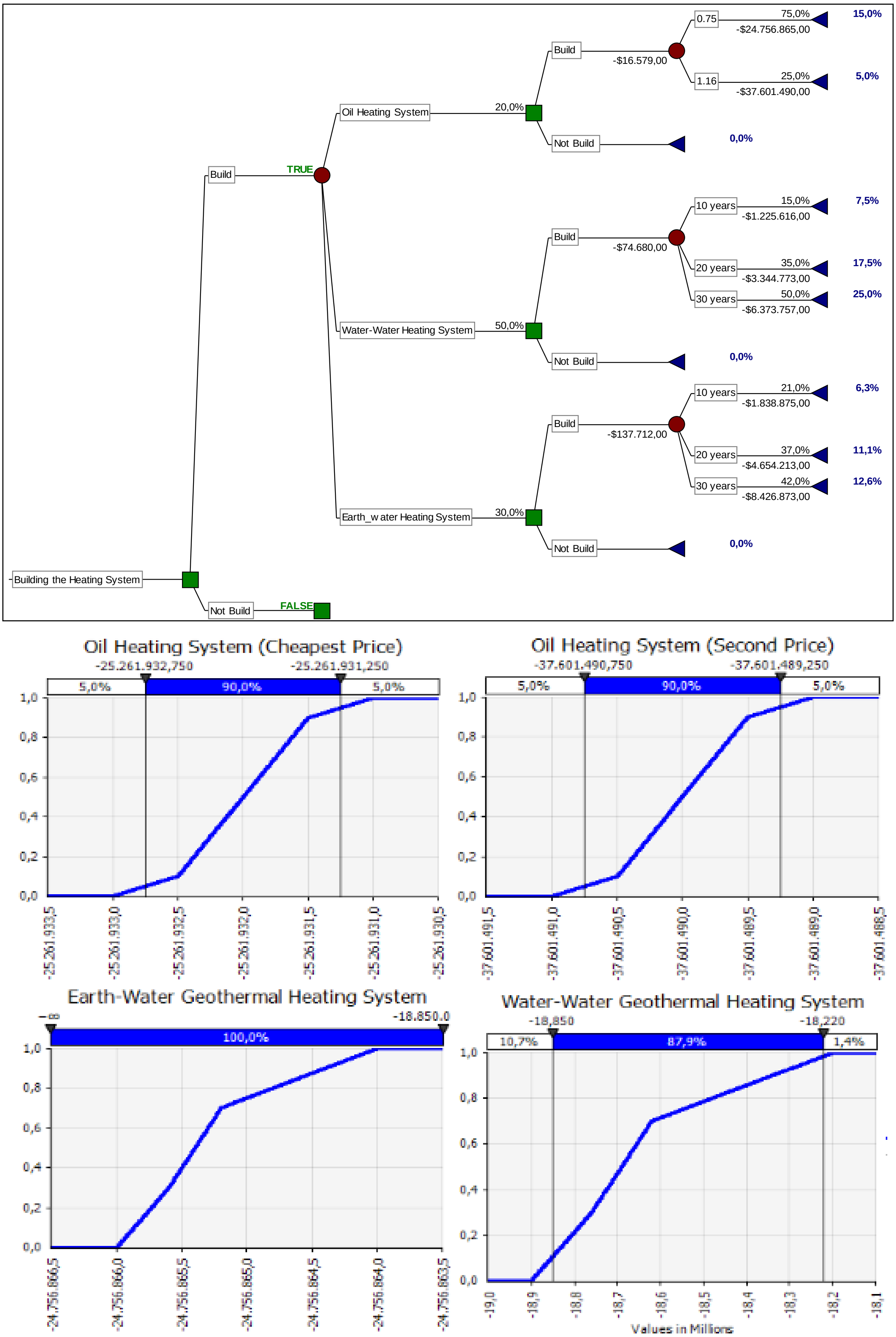


Figure 56: Precision tree and risk analysis charts

Tirana university campus geothermal heating design and viability

The University's Campus of Tirana is composed of 29 buildings, which are partially heated through a coal heater. The installed capacity is 2558kW, while the coal consumption is about 920 kg/h. The University's Campus in Tirana is one of the most important areas and with the highest density of population in Tirana, so it is the best area to show the heat exchanger efficiency. The economic analyses prove that borehole heat exchangers are more convenient than coal heating systems. Tirana's geothermal heat sources are:

- Underground waters of the Tirana quaternary depression;
- Underground waters of the tortonian's sandstones;
- The heat of the peri-superficial quaternary or tortonian layers;
- Limestones and dolomites saturated with artesian waters.

The geological structure of the Tirana region

Tirana aquifer is related to the syncline deposits of Tirana (Figure 57), whose morphology represents a depression of 10-12 km in width and 70-80 km in length. Wells yield in the region varies between 7-10 l/s, while for the Tortonians molasses, the yield of the well is about 3-4 l/s.

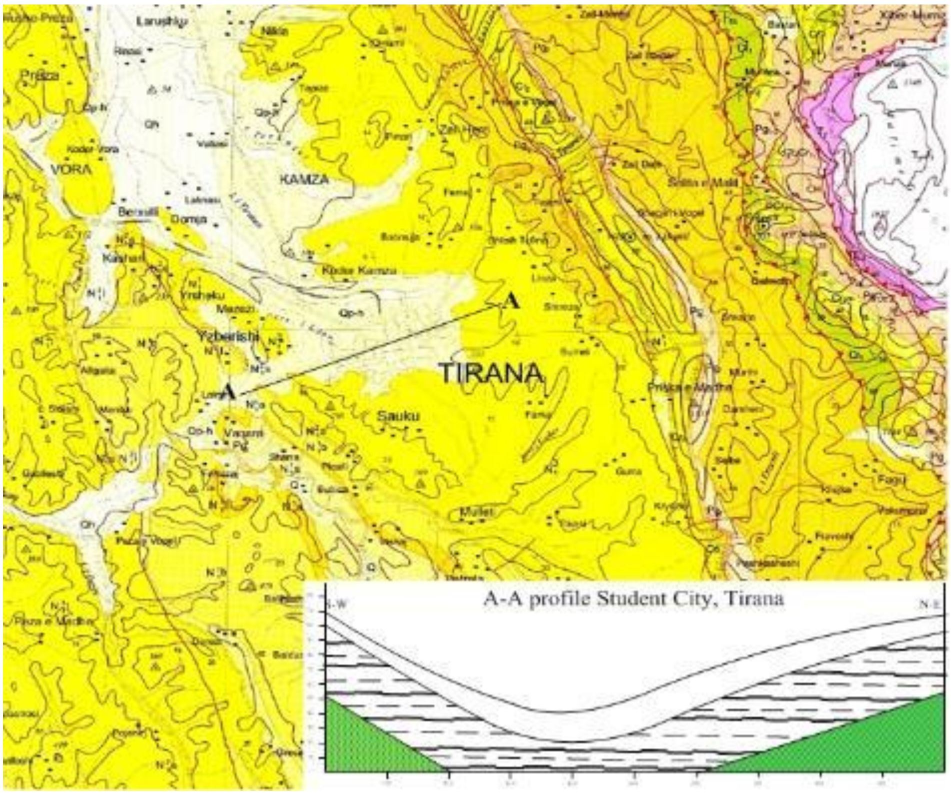


Figure 57: Geological Map of Tirana aquifer

Borehole heat exchangers calculations

The thermal characteristics of the rocks drilled by the well of Figure 58 are given in Table 24, while the physical characteristics of Tirana tortonian sandstones are given in Table 25.

Table 24: Thermal characteristics of the rocks

Age	Lithology	Thermal conductivity (W/m°C)	Thermal resistance (m°C/W)
Tortonian	Sandstone	1,6	0,625
−	Clay	1,5	0,666

Table 25: Thermal characteristics of the rocks

Layer	Filtration coefficient	Water conductivity (m/day)	Specific yields (lm/s)
Tortonian sandstone, upper part	0.08	3.2	0.038
Tortonian sandstone, lower part	0.08	5.3	0.038

For this well is known:

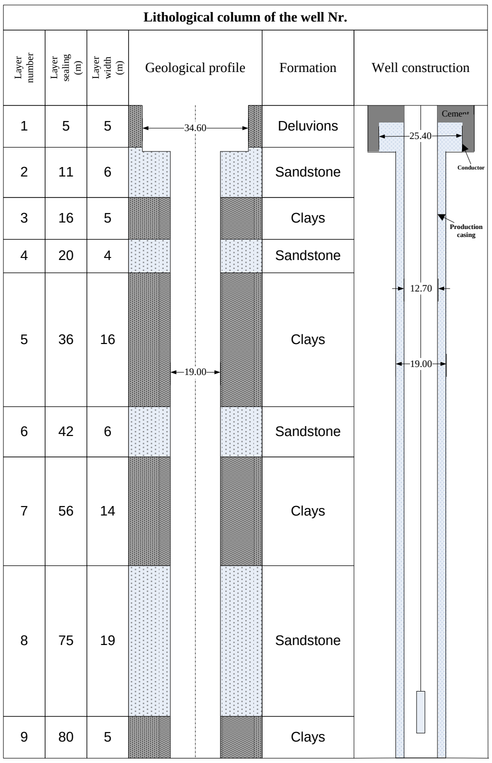
– Dynamic level	100 m;
– Static level	50 m;
– Level falls	40 m;
– Pump depth	108 m;
– Average yield	1 l/s;
– Ph	7.5-8;
– Water temperature	13-15°C;
– General strength	10-15°Gj;
– Mineralization	250-350 mg/l;
– Formula	HCO_3-Ca-Mg.

The thermal resistance for the formations R_p, drilled by the well, is calculated as follows:

$$R_p = \frac{(40 * 0.666 + 34 * 0.625)}{(40 + 35)} = 0.647 \frac{m * °C}{W}$$

The conductance rate U is calculated:

$$U = \frac{2\pi}{R_p} = \frac{2\pi}{0.647} = 9.711 \ \frac{W}{m * °C}$$



Lithological column of the well Nr.

Layer number	Layer sealing (m)	Layer width (m)	Formation
1	5	5	Deluvions
2	11	6	Sandstone
3	16	5	Clays
4	20	4	Sandstone
5	36	16	Clays
6	42	6	Sandstone
7	56	14	Clays
8	75	19	Sandstone
9	80	5	Clays

Figure 58: Lithological column of a well drilled in Tirana

According to the measurements, the earth's temperature in 100 m depth in Tirana is T_0=18°C. The fluid exit temperature is 3.5°C lower than the fluid entry temperature. The difference temperature of the system is calculated:

$$\Delta T = T_0 - \frac{T_1 + T_2}{2} = 6.75° \, C$$

For these parameters, the heat exchangers, for the installed capacity of 100 kW, result:

$$L = \frac{Q}{U * \Delta T} = \frac{100 * 10^3}{9.711 * 6.75} = 1525 \, m$$

So the problem is solved through a drilling process of 15 wells 100 m depth each. The economic analyses (profit-expenditure) of three systems: Water-Water geothermal pumps, Earth-Water geothermal pump, and the existing coal heater are presented in Figure 59. So it can clearly be seen that the maximal profit is for the Water-Water system than for the Earth-Water and finally for the coal heater. The payback period for the geothermal heating pumps varies from 2.8 to 10.75 years.

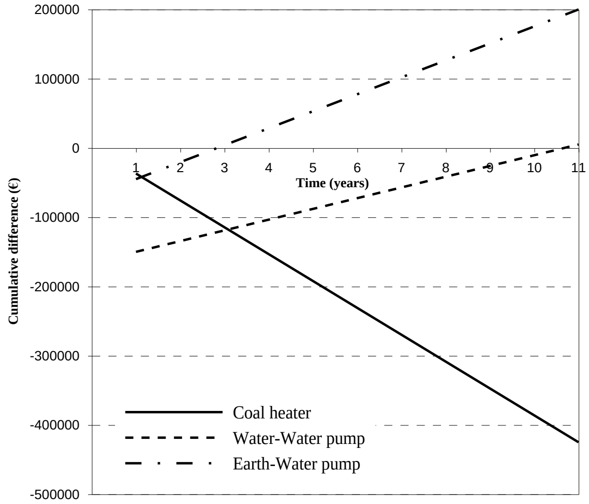


Figure 59: The economic analyses of three different systems

Nomenclature

A_o	T-change amplitude of the ground
b_i	Fractures mean width [m]
C_t	Total compression of the system
C	Heat capacity of the house [J/kg°K]
c_p	Fluid-specific heat
c	Constant which takes into account the properties of the fluid and the rock
C_u	Isobaric capacity of specific heat of the water
D	Effective thickness
Di	Fractures mean diameter.
DH_o	Radioactive heat on the upper part of the crust
d_i	Inner diameter of the pipeline
d_o	the Outer diameter of the pipeline
f	Volume of incondensable gas (gaseous phase)
f_f	Friction factor
H_o	Constant
H_f	Friction losses
k_v	Permeability
k_x, k_y, k_z	Thermal conductivity in ox, oy, oz
L_{anchor}	Anchor length
L	Amount of energy for a unit of mass
L_{pipe}	Length of the pipeline
L_w^v	Heat needed for the water evaporation
m	Mass of particles (g)
M	Isobaric volume heat capacity for the phases (ro - rock, o- oil, w - water, g - gas)
M_R	Effective volume capacity
m	Water mass flow (kg/s)
m_0	Reference water mass flow
N	Number of fractures
I	Installation costs for a single well
$I_\$$	Maintenance cost for a single well
p	Pressure
P	Price
P_c	Pressure on the consumer
P_d	Periods

P_h	Hydrostatic pressure
$Q=Q\ (x, y, z)$	Volume density of the source
Q_{rad}	Heat capacity of the hot water
Q_0^{rad}	Heat capacity of the hot water at the reference conditions
Q_{loss}^0	Heat losses at the reference conditions
Q_{loss}	Heat losses
Q_{net}	Net heat
Q_w	Flow rate
q_o	Heat flow density
q_r	Radioactive heat on the upper mantle
R	Drainage radius of the well
r	Well radius
R_e	Reynolds number
R_o	Exertion coefficient for the reinjection well
S	Saturation of the formation
S_a	Allowable stress
t	Time
$T=T\ (x, y, z)$	Temperature
T_f, T_d	Transitory temperatures (frost, dried)
T_i	Initial temperature
T_o^a	Air temperature in a given time
T_o	Ground extrapolated temperature
T_r	Reinjection water temperature
T_s	Water supply temperature (primary network)
T_i	Indoor temperature
T_r	Return water temperature
T_s^0	Reference water supply
T_r^0	Reference returns water temperature
T_g	Ground temperature
U_p	Pipe heat loss factor
v	Velocity of particles (m/s)
w	Ice amount for the dried zones
y	Resultant movement
α	Coefficient of thermal expansion
β	Coefficient which takes into account the formation composition (Btu/lb.*0F)
δ	Pressure coefficient of the thermal conductivity
Δt	Duration of the installations
ε	Surface radiation coefficient
ω	Angular frequency
Φ	Porosity
Θ	Angle of the roof of the tank
λ_o	Conductivity in normal pressure
λ_e	Thermal diffusion coefficient
λ_c	Thermal convection coefficient
γ_c	Effect of the heat convection in its transfer
λ_f, λ_d	Thermal conductivity (frost, dried)
λ_i	Thermal conductivity on the depth, ΔZi
μ	Viscosity (dynamic)
η_p	Pump efficiency
η_m	Motor efficiency
ρ_m	Average density
ρ_v	Vapor density
$\rho(r_o,{}_{o,\,w,\,g})$	Density of the (rock, oil, water, gas)
ρ_w	Water density
τ_0	Pipe transmission effectiveness at reference conditions

Integration with all UNFC and UNRMS principles and requirements

Scope and context

Integrated management of resources is the key to overcoming the aforementioned challenges. UNRMS embraces the critical concept of integrated resource management that considers complexity, multiple scales, and competing interests and brings these together to make informed decisions. Sustainable resource management starts with understanding the world's natural capital and natural resources, including the efforts required to refine and use them and how these resources relate to societal needs. Given that the natural capital is the world's stock of natural assets, it includes various components such as water, geology, energy, biodiversity, soil, and the ozone layer, and properties like ecological resilience, ecosystem health, and integrity.

According to the UNFC & ENRMS, natural resources are parts of the natural capital used to produce goods and services in economic activities. Material resources such as minerals, petroleum, nuclear fuels, injection projects, anthropogenic resources, and renewable energy resources such as geothermal, solar, wind, biofuels, and water resources could be considered natural resources. While utilizing natural resources for society's benefit, the net natural capital could be enhanced rather than depleted.

Justification

Pursuant to the UN provisions, sustainable resource management is defined as the total of policies, strategies, regulations, investments, operations, and capabilities within the framework of public, public-private, and civil society partnerships, and based on environmental-socio-economic viability and technical feasibility, which determine what, when and how resources are developed, produced, consumed, reused and recycled by the society, therefore it is intended for optimizing sustainable benefits to stakeholders within the people-planet-prosperity triad. The approach emphasizes cross-sectoral nexus linkages and minimization of potential adverse impacts. The fundamental UNFC & UNRMS principles of sustainable resource management are as follows:

- State rights and responsibilities in the management of resources;
- Responsibility to the planet;
- Integrated management of resources;
- Social contract on natural resources;
- Service orientation;
- Comprehensive resource recovery;
- Value addition;
- Circularity;
- Health and safety;
- Innovation;
- Transparency;
- Continuous strengthening of core competencies and capabilities.

Optimization

These (12) principles are the basements for the 54 requirements on the screening of the geothermal resource's potential in Albania. Based on Annex 1, "Definition of Categories and Supporting Explanations," this report comes to the conclusion that they are part of the **E2** Axis given that: on the basis of realistic assumptions of future conditions, the development and operation are expected to become environmentally socially economically viable in the foreseeable future. Given that their technical feasibility for more extensive project development is subject to further evaluation because the existing preliminary studies presented in this report provide sufficient evidence of the potential for development and that further study is required. We are confident that further studies shall confirm the feasibility of development. These are the reasons why all proposed potential projects are classified as **F2**. The studies presented in the report are the result of extensive research work done in the past 20 years in Albania regarding the assessment of the geothermal potential of the country. The lack of financing and reliable data generate a moderate level of confidence regarding the resource & reserves uncertainty, geologic uncertainty, and facility uncertainty; therefore, they are classified as **G2**. Summarized all this is presented in the following table.

Table 26: The UNFC & UNRMS Classification results

Country	Main product	Other products	Main commodity for map display
Albania	Geothermal natural springs	Recreational	Google Earth
Albania	Geothermal Well	Recreational	Google Earth
Albania	Geothermal natural springs	Recreational	Google Earth
Albania	Geothermal natural springs	Recreational	Google Earth
Albania	Hot rocks	District Heating	Google Earth
Property	**Latitude**	**Longitude**	**Owner**
Public	41° 2'2.22"N	20° 4'22.53"E	Elbasani Municipality
Public	41°06'	20°01'6"	Elbasani Municipality
Public	40°14'37.84"N	20°25'56.90"E	Përmeti Municipality
Public	41°41'8.52"N	20°26'57.39"E	Peshkopia Municipality
Public	40°37'39.08"N	20°47'7.50"E	Korça Municipality
Webpage	**Country owner**	**Development Stage**	**State of activity**
elbasani.gov.al	Albania	Preliminary Economic Assessment	Active
elbasani.gov.al	Albania	Preliminary Economic assessment	Active
bashkiapermet.gov.al	Albania	Preliminary Economic Assessment	Inactive
bashkiapeshkopi.gov.al	Albania	Preliminary Economic Assessment	Active
bashkiakorce.gov.al	Albania	Preliminary Economic assessment	Inactive
UNFC most mature status	**UNFC E1F1.1G1 (quantity units)**	**UNFC E1F1.1G2 (quantity units)**	**UNFC E1F1.2G1 (quantity units)**
E2F2G2	N/A	N/A	N/A
E2F2G2	N/A	N/A	N/A
E2F2G2	N/A	N/A	N/A
E2F2G2	N/A	N/A	N/A
E2F2G2	N/A	N/A	N/A
UNFC E1F1.2G2 (quantity units)	**UNFC E2F2.1G1 (quantity units)**	**UNFC E2F2.1G2 (quantity units)**	**UNFC E2F2.2G3 (quantity units)**
N/A	N/A	2760KW	N/A
N/A	N/A	2070KW	N/A
N/A	N/A	10040 kW	N/A
N/A	N/A	1610 kW	N/A
N/A	N/A	130 kW	N/A
UNFC E2F2.2G1 (quantity units)	**UNFC E2F2.2G2 (quantity units)**	**UNFC E2F2.2G3 (quantity units)**	**UNFC E3.2F2.2G1 (quantity units)**
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
UNFC E3.2F2.2G2 (quantity units)	**UNFC E3.2F2.2G3 (quantity units)**	**UNFC E3.3F2.3G1 (quantity units)**	**UNFC E3.3F2.3G2 (quantity units)**
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
UNFC E3.3F2.3G3 (quantity units)	**UNFC E3F4G1 (quantity units)**	**UNFC G3F4G2 (quantity units)**	**UNFC E3F4G2 (quantity units)**
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
N/A	N/A	N/A	N/A
UNFC E3F3G4 (quantity units): PROSPECTIVE PROJECT	**E1F1G1,2 (Reserves) (quantity units)**	**E2F2G1,2,3 (Resource) (quantity units)**	**Original classification scheme**
N/A	N/A	2760kW	Development Pending
N/A	N/A	2070kW	Development Pending
N/A	N/A	10 040 kW	Justified for Development

N/A	N/A	1610 kW	Development Pending
N/A	N/A	130 kW	Development Pending

Comments	Availability of the production data	Contact person for production data	Email of the contact person for production data
First use dates back centuries, but the first modern use started in 1937. Unfortunately, this water hasn’t been used for its energetic values yet. The temperature of the water is above 60°C, and the flow is above 16 l/s, thus direct utilization is possible, in particular for (space heating. Estimated temperature measurements based on different geothermometers indicates that the temperature of the waters in the formation of the Llixha reservoir may be above 220°C. The reservoir is believed to be in the depth interval of 4500-5000 m. Three-dimensional temperature field calculations, a simple study of the dynamics of the hot springs, and engineering calculations on a heating system with heat exchangers shows that the water temperature is expected to be stable and considerably higher temperature are expected through well drilling. The main purpose should be the evaluation of the temperature conditions of the hot springs and at depth in the reservoir as well as a preliminary design of a district heating system utilizing the hot springs by addressing: – The general geological conditions in the area; A review of the theoretical basis of heat transfer; Three-dimensional modelling of variations in the temperature conditions in the surface region around the hot-springs, using the finite-element technique; Finite-volume modelling of the whole geothermal system down to 5000 m depth, incorporating both thermal convection and conduction, based on a simple boundary conceptual model; – Study of the temperature conditions of the hot spring and in their up-flow channels on the basis of simple dynamic modelling. Results are compared with the results of geothermometric water temperature estimates; – A basic engineering design of a district heating network, including tanks and heat exchangers (radiators). All this aims at demonstrating that the thermal water flowing from the Llixha springs is usable for direct utilization. This utilization would mitigate the electricity supply the region and help improve living conditions for the local community. The environmental and social criteria are also very important, and due to all these this area is proposed to be subject of more in-depth studies to “Justify its Development”. The reason for not being classified as F2.2 is related with the total lack of investments in the past, to make possible at the development of the pre-feasibility study regarding the direct use of this important energy resource.	Yes	N/A	N/A
The Ishmi-Kruja geothermal zone is close to the “Mother Teresa” international airport. It is also next to the Kruja historical city, the wonderful Adriatic Sea beaches & Lake of Ohrid. The demonstrative geothermal center, with the cascade and integral use, but also combined with the solar panels (hybrid system), is designed for the Kozani-8 well waters. This well has been drilled in early '80 of the past century as an oil & gas exploration well. The blowing of hot brine was considered as a "terrible accident" at the time. The choice had been made because of its temperature, on the value of 65.5°C, and yield 10 l/s. In the aquifer top of the well trunk the water is 80°C. Hot water has salinity of (4.6-19.3) g/l. actually all these waters are “wasted”: they flow directly to a creek, meaning high economical loses. Among different processes of the cascade, will be released CO_2 and H_2S, which will be used for food products (conservation) and medical purposes. The hybrid system, combing of the middle enthalpy geothermal waters, with the solar panels, based on the fact that the Albanian climate allow such a thing (there are more than 280 sunny days on the area), will improve the economic efficiency of the project. All this aims at demonstrating that the thermal water flowing from the Kozani 8 well is usable for direct utilization. This utilization would mitigate the electricity supply for the region and help improve living conditions for the local community. The environmental and social criteria are also very important, and due to all these this area is proposed to be subject of more in-depth studies to “Justify its Development”. The reason for not being classified as F2.2 is related with the total lack of investments in the past, to make possible at the development of the pre-feasibility study regarding the direct use of this important energy resource.	Yes	N/A	N/A
In the village of Bënja, there are 8 springs with temperatures 23÷30 °C and yields in between 8÷40 l/s each. The springs belong to the Kruja geothermal area, the biggest and the most important geothermal filed of Albania. Geothermal aquifer is represented by a carstified neritic carbonates formation with numerous fissures and micro fissures. They are linked with the regional dissociative tectonic of the Bodar-Postenan anticlines chain. The limestone’s layers sink toward west with an angle of nearly 20 °C and azimuth of 210÷215	Yes	N/A	N/A

°C. These limestone's layers are carstified, especially in the right bank of the river where some caves or cavities can be found. In a 500 m long belt, in both sides of the river are found the geothermal springs: 4 in the left side and 4 in the right side. The water generally blows out in the water level, below or even 1÷2.5 m above it. Their location is: – Spring 1 is 25÷30 m further down the bridge, 20 m far from the riverbed. Its temperature is 26 °C; Spring 2 is 8 m beyond the bridge and blow out below the water level. It can be seen by its blue with some white tint color on the limestone's surface, by whose fractures the waters blow out; Spring 3 is 25 m beyond the bridge, in the water table but 15 m far from the river shore. They blow out as three very potent griffons. The water temperature is 26°C and the yield about 8 l/s; – Spring 4 is 150÷200 m beyond the bridge, where the canyon width is over 20 m. they blow out as two griffons. The most important about 15÷20 cm height, blow 0.5 m above the water level, have a yield 8÷9 l/s and temperature 23 °C. Approx. 30 m beyond is the second griffon with yield of 4 l/s and the same temperature. The other four springs are placed in the left bank of the river. Their main characteristics are given below: – Spring 5 is 300÷400 m beyond the bridge, before the canyon whose is 10-12 m wide and 40÷50 m height. Some powerful water blow out by the limestone fractures have yields of 30÷40 l/s and temperature 30°C; – Spring 6 is at the bridge pier, 0.81 m above the water level and 4 m away from the river. Its yield is 30 l/s and the temperature 30°C; Spring 7 is 7 m further down the bridge, in the water level and 2÷3 m away. The yield is 30÷40 l/s and the temperature 30°C; – Spring 8 is the biggest one. This spring is 20÷25m further down the bridge, 1÷1.5 m above the water level and 8÷10 m away from the river. The yield is over 40 l/s and the temperature is 30°C. The temperature of the geothermal water is low; thus, their direct utilization is more suitable and efficient if combined and hybrid. It results that their combination with the solar power increases the possibility to improve the efficiency of the system, so as to apply successfully the cascade schemes. All this aims at demonstrating that the thermal water flowing from the Bënja springs is usable for direct utilization. This utilization would mitigate the electricity supply the region and help improve living conditions for the local community. The environmental and social criteria are also very important, given that they located in the Lëngarica river canyon, one of the most astonishing natural landscapes of Albania, and due to all these this area is proposed to be subject of more in-depth studies to "Justify its Development". The reason for not being classified as F2.2 is related with the total lack of investments in the past, to make possible at the development of the pre-feasibility study regarding the direct use of this important energy resource.			
Peshkopia geothermal zone is located in the Northeast of Albania, in the Korabi hydrogeologic zone. At distance of two kilometers east of Peshkopia, water at 43.5°C flows out of a group of thermal springs on a river slope composed of flysch deposits. Some of the springs yield flow rates up to 14 l/s. The occurrence of these springs is associated with a deep fault at the periphery of a gypsum diapir of Triassic age that has penetrated Eocene flysch, which surround it like a ring. These springs are linked with the disjunctive tectonic of seismic-active belt Ohrid Lake-Dibër, at periphery of the gypsum diapir. With this tectonic belt are linked the Banjishte and Kosovrasti thermal springs, which are located at Macedonian territory, close to the Albanian-North Macedonian border. Evaporite diapir extends vertically over (3-4) km and comprises the main aquifer of this geothermal system. The occurrence of thermal waters is connected with the low circulation zone always under water pressure. Where gypsum plunges, under the level of free circulation zone, the presence of H_2S can be detected in the water. The thermal waters are of sulphate-calcium type, with a mineralization of up to 4.4g/l, containing 50mg/l H_2S. On riverbed, outcrops of anhydrides and gypsum are located also, with big yield of cold mineralized water springs, of sulphate-calcium type. Their water temperature is 12°C. Different geothermometers indicate the reservoir temperatures are (140-270)°C. Considering the regional geothermal gradient, temperatures of 220°C would be found at depth of (8-12) km. However, the gypsum diapir represents e high thermal conductivity body focusing heat from its surroundings. Therefore, water could become warmer at shallow depths that suggested by the geothermal gradient. Water temperature and big yield, stability, and also aquifer temperature of Peshkopia Geothermal Area is similar with those of Kruja	Yes	N/A	N/A

Geothermal Area. For this reason, the geothermal resources of Peshkopia Area have been estimated to be similar to those of Tirana-Elbasani area. All this aims at demonstrating that the thermal water flowing from the Peshkopia springs is usable for direct utilization. This utilization would improve living conditions for the local community. The environmental and social criteria are also very important, given that they located in the Lëngarica river canyon, one of the most astonishing natural landscapes of Albania, and due to all these this area is proposed to be subject of more in-depth studies to "Justify its Development". The reason for not being classified as F2.2 is related with the total lack of investments in the past, to make possible at the development of the pre-feasibility study regarding the direct use of this important energy resource.			
Due to the Albania geothermal regime the cooling/heating systems of the buildings seems to be the best way to start its direct utilization. Albania is relatively rich with low up to the middle enthalpy geothermal resources whose had not been used until now for their energetic values. The temperatures in the depth of 100 m are within the limits for heat exchangers utilization in both ways: water-water systems or even through the heat extraction. The climate of Korça, especially the winter season, enforces uses of the heating system for more than 4 months/year. The university campus had been proposed not only for its characteristic but also because this is the biggest public building of the region, so the economical profit can be significant. The region of Korça is part of the flysch depositions of the lower Neogene (N1), Paleogene (Pg3) and the ultrabasic massive of the Morava Mountain. The youngest depositions of Quaternary cover the oldest in the field of Korça. This field is 800-850 m a.s.l. and is confined by the Morava Mountain (E) and the Dried Mountain (N-E) by an active tectonic fracture. The quaternary formations study is done by a large number of wells, by the geophysical SP & DCR & IP and the high frequency seismic methods. The hydrogeological survey shows that the Korça aquifer is composed by 7 gravel layers. The 4 upper layers are the most important. Their width is about 2-22 m. The transmissivity coefficient is 1500-2000 m^2/ d., the hydraulic conductivity is 60-150 mD., the porosity is 0.0004 and the specific capacity of the wells is 6-10 l/s/m. The city of Korça is in the S-E of Albania and is climatic regime is Mediterranean highlands and peri-highlands. The "Fan S. Noli" University campus is in third climatic region of Albania. The low temperatures during the winter make necessary the heating for the period October-May. The general area to heat is 1260 m^2 and has three floors, 420 m^2 each. The elements of this system will be: The heater, the oil deposit, the burner, the chimney, the circulation pump and control panel. The energy of this system is calculated 178 kW, with an increase of 15per cent to cover loses. The calculation for the VHE shows that their length should be 1257 m for the water-water pump and 1500 m for the soil heat extraction. To achieve this length will be drilled 13 wells 100m deep/each for the water-water pump and 15 wells 100 m deep/each for the soil extraction system. Based in the energetic calculations and the market options the system will be composed by two geothermal heating pumps by 87.7 kW each. Two options were considered: Water-Water pumps and the soil heating extraction through the vertical heat exchanger (VHE) use. The soil temperatures in the Korça region make more viable the soil heat extraction through the VHE use. One of the most important factors that will make this project viable is the ground temperature, and have been measured in the depths: 5 cm, 10 cm, 15 cm and 160 cm. The geothermal pumps can be used as the ground temperature in depth more than 1 meter tent to remain stable during the year, leading to the conclusion that the air temperature fluctuations don't affect the underground. All this aims at demonstrating that the geothermal regime of Albania, specifically the temperature gradient, allows also the use of the ground temperature for district heating. This utilization would improve living conditions for the students of the "Fan S. Noli" University, whose are facing tough winter days. Actually, they are using Oil Electrically Heated Radiators. These investments shall be the best proof the hot rocks temperature can be an efficient and cheap energy resources for the district heating, and could be the start to expand the model to the entire region (Korça region). The reason for not being classified as F2.2 is related with the total lack of investments in the past, to make possible at the development of the pre-feasibility study regarding the direct use of this important energy resource.	Yes	N/A	N/A

E Category for POLICY	**Comments POLICY**	**E Category for REGULATORY APPOVAL**	**Comments REGULATORY APPOVAL**
2	The reason for proposing this project is due to the favorable location of the natural (six) geothermal springs. For the moment these springs are simply used for balneological purposes, allowing in this way not only to waste their energy, but also due to the calcite, silica and H2S gas in the water they are causing very serious environmental and health issues to the local community.	2	Law No. 124/2015 "On Energy Efficiency" whose aim is to: Compile regulatory and national policies on promotion and improvement of the energy efficiency with primary focus on energy saving, supply reliability and removal of barriers on the electrical energy market; Setting of National Target regarding the energy efficiency; Increase of competition between different operators.
2	This reason for proposing this project is due to the favorable location of the geothermal well. For the moment these springs are simply used for balneological purposes, allowing in this way not only to waste their energy, but also due to	2	Law No. 124/2015 "On Energy Efficiency" whose aim is to: Compile regulatory and national policies on promotion and improvement of the energy efficiency with primary focus on energy saving, supply reliability and removal of barriers on the electrical energy market; Setting of

	the calcite, silica and H2S gas in the water they are causing very serious environmental and health issues to the local community.		National Target regarding the energy efficiency; Increase of competition between different operators.
2	The reason for proposing this project is due to the favorable location of the natural (eight) geothermal springs. For the moment these springs are simply used for mostly natural (is not established any SPA center in the region and peoples are bathing in natural ponds along the river) balneological purposes, allowing in this way not only to waste their energy, but also due to the calcite, silica and H2S gas in the water they are causing very serious environmental and health issues to the local community.	2	Law No.116/2016 “On the Energetic Performance of the Buildings” whose aim is to: Establish the legal framework regarding the energetic performance of the new buildings, considering the local and climatic conditions, buildings comfort as well as cost effectiveness.
2	The reason for proposing this project is due to the favorable location of the natural) geothermal springs. For the moment these springs are simply used for balneological purposes (is one of the most frequented centers in Albania - basically by the third generations ages), allowing in this way not only to waste their energy, but also due to the calcite, silica and H2S gas in the water they are causing very serious environmental and health issues to the local community.	2	Law No. 7/2017 “On Promotion of the Renewable Energy Resources usage” whose aim is to: To promote the generation of the electrical energy from the renewable resources of energy; Decrease the import of the organic fuels, greenhouses gases emissions & environmental protection; Promote the development of the electrical energy market, generated from the renewable resources as well as the regional integration; Support the diversification of the energy resources; Support the rural and remote areas development by improving their energy supply.
2	The reason for proposing this is because we wish to demonstrate that the geothermal regime of Albania, specifically the temperature gradient, allows also the use of the ground temperature for district heating. This utilization would improve living conditions for the students of the “Fan S. Noli” University, whose are facing tough winter days. Actually, they are using Oil Electrically Heated Radiators. These investments shall be the best proof the hot rocks temperature can be an efficient and cheap energy resources for the district heating, and could be the start to expand the model to the entire region (Korça region).	2	Law No. 7/2017 “On Promotion of the Renewable Energy Resources usage” whose aim is to: To promote the generation of the electrical energy from the renewable resources of energy; Decrease the import of the organic fuels, greenhouses gases emissions & environmental protection; Promote the development of the electrical energy market, generated from the renewable resources as well as the regional integration; Support the diversification of the energy resources; Support the rural and remote areas development by improving their energy supply. DoCM No. 179, dated 28.3.2018 “On Approval of the National Action Plan on the Renewable Energy Resources, 2018-2020”.

E Category for FISCAL/CONTRACTUAL	**Comments FISCAL/CONTRACTUAL**	**E Category for SOCIAL CONSIDERATIONS**	**Comments SOCIAL CONSIDERATIONS**
2	To be finalized after the prefeasibility study	2	The full study, aiming the construction of a modern balneological center, using the combined and hybrid scheme, as well the district heating shall create some hundreds of jobs along the different stages of the project development. Given that this represent one of the poorest areas of Albania, the social impacts are expected to be strongly positive and significant for the local community.
N/A	To be finalized after the prefeasibility study	2	The full study, aiming the construction of a modern balneological center, using the combined and hybrid scheme, shall create some tenth of jobs along the different stages of the project development. Given that this represent one of the poorest areas of Albania, the social impacts are expected to be strongly positive and significant for the local community.
N/A	To be finalized after the prefeasibility study	2	The full study, aiming the construction of a modern balneological center, using the combined and hybrid scheme, shall create some tenth of jobs along the different stages of the project development. Given that this represent one of the poorest areas of Albania, the social impacts are expected to be strongly positive and significant for the local community.
2	To be finalized after the prefeasibility study	2	The full study, aiming the construction of a modern balneological center, using the combined and hybrid scheme, shall create some tenth of jobs along the different stages of the project development. Given that this represent one of the poorest areas of Albania, the social impacts are expected to be strongly positive and significant for the local community.
2	To be finalized after the prefeasibility study	2	The full study, aiming the construction of first "large scale" district heating system in Albania using the ground (hot rocks) temperature. Given that the project shall be implemented to the University Campus, one of the mos sensitive institutions of the entire -south-east Albania, the social impacts are expected to be strongly positive and significant for the local community.

E Category for Economic Considerations	**Comments Economic Considerations**
2	The expected investment value to develop the: Prefeasibility and feasibility study as well as the construction of the modern balneological center and the district heating infrastructure is in the range of 7-8 million Euros (considering the significant price increase of the last year). The payback time is calculated to be in the range of 7-8 years
2	The full study, aiming the construction of a modern balneological center, using the combined and hybrid scheme, shall create some tenth of jobs along the different stages of the project development. The payback time is calculated to be in the range of 10-12 years
2	The expected investment value to develop the: Prefeasibility and feasibility study as well as the construction of the modern balneological center is in the range of 3-4 million Euros (considering the significant price increase of the last year). The payback time is calculated to be in the range of 7-10 years
2	No estimations have been done so far.
2	The expected investments shall have an approximate cost of 200.000 Euros. The payback period is estimated to be in the range of 3-4 years

Sustainable Development Goals Alignment

UNFC reflects conditions in the markets and government framework conditions, social and environmental considerations, technological and industrial maturity of the projects, and the ever-present uncertainties and is aligned with the requirements of the 2030 Agenda. A key benefit of the UNFC is its flexibility and ability to be adapted to diverse national and regional requirements. The European Union, African Union, and countries such as the Russian Federation, Ukraine, China, India, and Mexico have national initiatives for the use of UNFC. The use of UNFC is mandatory in the United Nations System of Environmental-Economic Accounting (SEEA) Central Framework for energy accounts, which is applied globally.

UNFC is developed and maintained by the United Nations Economic Commission for Europe (UNECE), under the global mandate given by the United Nations Economic and Social Council (ECOSOC), and through the cooperation and collaboration of both UNECE and non-UNECE member countries, UN Regional Commissions, other United Nations bodies and specialized agencies, international organizations, intergovernmental bodies, professional associations, the private sector, and many individual experts.

The Albanian government has ratified the Resolution adopted by the General Assembly on 25 September 2015, being committed to the following:

1. We recognize that social and economic development depends on the sustainable management of our planet's natural resources. We are therefore determined to conserve and sustainably use oceans and seas, freshwater resources, as well as forests, mountains, and drylands, and to protect biodiversity, ecosystems, and wildlife. We are also determined to promote sustainable tourism, tackle water scarcity and water pollution, strengthen cooperation on desertification, dust storms, land degradation, and drought, and promote resilience and disaster risk reduction. In this regard, we look forward to the thirteenth meeting of the Conference of the Parties to the Convention on Biological Diversity to be held in Mexico;
2. We recognize that sustainable urban development and management are crucial to the quality of life of our people. We will work with local authorities and communities to renew and plan our cities and human settlements so as to foster community cohesion and personal security and to stimulate innovation and employment. We will reduce the negative impacts of urban activities and of chemicals that are hazardous for human health and the environment, including through the environmentally sound management and safe use of chemicals, the reduction and recycling of waste, and the more efficient use of water and energy. And we will work to minimize the impact of cities on the global climate system. We will also take account of population trends and projections in our national rural and urban development strategies and policies. We look forward to the upcoming United Nations Conference on Housing and Sustainable Urban Development to be held in Quito;
3. Sustainable development cannot be realized without peace and security, and peace and security will be at risk without sustainable development. The new Agenda recognizes the need to build peaceful, just, and inclusive societies that provide equal access to justice and that are based on respect for human rights (including the right to development), the effective rule of law, and good governance at all levels and on transparent, effective and accountable institutions. Factors that give rise to violence, insecurity, and injustice, such as inequality, corruption, poor governance, and illicit financial and arms flows, are addressed in the agenda. We must redouble our efforts to resolve or prevent conflict and to support post-conflict countries, including ensuring that women have a role in peacebuilding and State building. We call for further effective measures and actions to be taken, in conformity with international law, to remove the obstacles to the full realization of the right of self-determination of people living under colonial and foreign occupation, which continue to adversely affect their economic and social development as well as their environment;
4. We pledged to foster intercultural understanding, tolerance, mutual respect, and an ethic of global citizenship and shared responsibility. We acknowledge the natural and cultural diversity of the world and recognize that all cultures and civilizations can contribute to and are crucial enablers of sustainable development;

5. Sport is also an important enabler of sustainable development. We recognize the growing contribution of sport to the realization of development and peace in its promotion of tolerance and respect and the contributions it makes to the empowerment of women and of young people, individuals, and communities, as well as health, education, and social inclusion objects.

The energy balance of the country is presented in Figure 60.

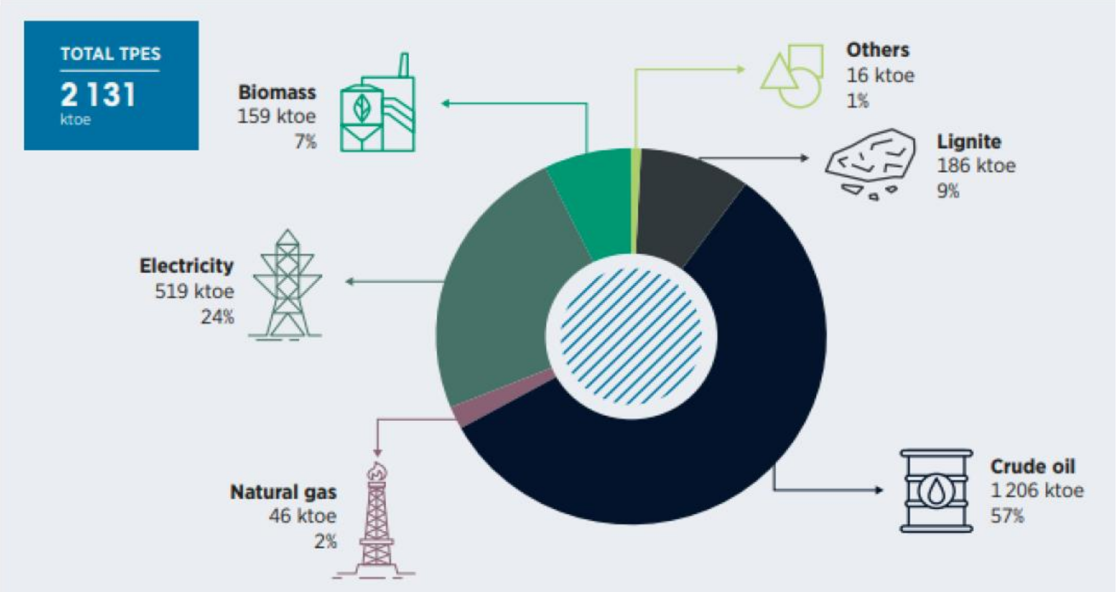


Figure 60: Energetic Balance of Albania (2021)

As explained above, the Albanian authorities are focusing on extending the portfolio by diversifying the energy resources, primarily solar energy. The private investment has made it possible to have some generations, as presented in Figure 61.

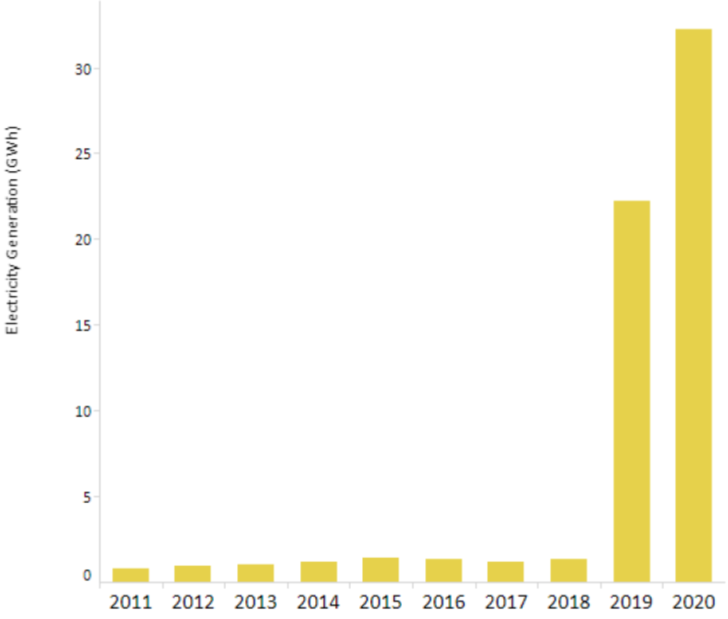


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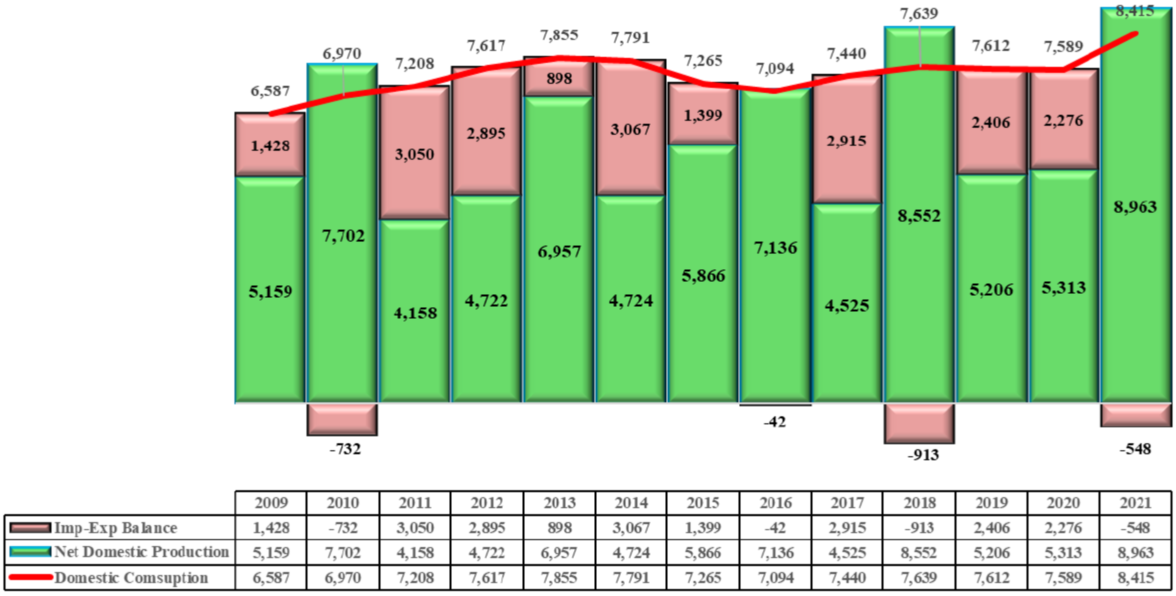
Figure 61: Solar energy generated in Albania

Despite these efforts, Albania still remains a net importer country for electrical energy (Figure 62). Domestic generation is mostly related to hydropower, which is positive from the environmental point of view but leaves the system fully exposed to the climate. The last two years have been atypically dried, and combined with the Ukrainian war, created serious difficulties in supplying the total demand, therefore ins some areas of the country implemented moderate black-out. Energy purchasing with abnormal prices (here should be mentioned that Albania doesn't yet have a functional Energy Stock Market) caused very serious difficulties for the public operators and the state budget.



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
🟥 Imp-Exp Balance	1,428	-732	3,050	2,895	898	3,067	1,399	-42	2,915	-913	2,406	2,276	-548
🟩 Net Domestic Production	5,159	7,702	4,158	4,722	6,957	4,724	5,866	7,136	4,525	8,552	5,206	5,313	8,963
━ Domestic Comsuption	6,587	6,970	7,208	7,617	7,855	7,791	7,265	7,094	7,440	7,639	7,612	7,589	8,415

Figure 62: Power consumption, net domestic generation and import-export energetic balance 2009-2021

Clearly is seen that in some years, Albania needs to import a significant amount of energy to supply all demand. This is the primary reason why the geothermal potential of the country, although limited, could be an important tool to mitigate some problems, at least in the vicinities of the already-known resources. This shall mark an important step forward to the Sustainability of the Energetic System, but most of all to the Sustainability of the Development of Albania.

Conclusions and recommendations

Conclusions

The study's conclusions suggest that the utilization of geothermal resources in Albania is economically viable and can help diversify the country's energy resources, improve living standards, and mitigate environmental problems. The study recommends following UNFC and UNRMS guidelines to develop adequate geological models of the geothermal aquifers and conducting extensive studies to evaluate their possible further development. Additionally, conducting ESIA studies and extensive public consultations with stakeholders are crucial for the socio-economic viability of the project. To further advance geothermal utilization in Albania, continued efforts towards capacity building, technology transfer, and knowledge dissemination could be implemented.

Summarized the conclusions for all geothermal resources, the subject of this report is:

Based on the calculations presented in this report, the following can be concluded regarding the utilization of the hot springs of the **LLIXHA-ELBASAN** hot-spring area in Albania:

- The water temperature is expected to be stable in the future;
- The geothermal reservoir temperature at 4500-5000 m depth is thought to be about 220°C;
- The water starts to cool down when it reaches 160 m depth;
- The geothermal water from the Llixha hot springs fulfills all requirements for district heating in the region;
- Considerably higher temperatures are expected through further well drilling.

KOZANI 8

- The Kozani-8 water temperature is suitable for the supply of a recreational center, including geothermal indoor and outdoor pools;
- The water temperature is suitable for feeding two cascades;
- The hybrid system will improve the economic efficiency of the project;
- The construction of the center will improve the energetic balance of the region;
- The construction of the center will help diversify the energy resources in Albania;
- The degasified and desalination line will improve the environmental status of the area, as it is actually highly polluted;
- It will improve the living standards of the community;
- The economic analyses show that it is feasible.
- The risk analysis shows very optimistic data for the future of the investment.

BËNJA GEOTHERMAL SPRINGS

- Based on the calculations presented in this report, the following can be concluded regarding the utilization of hot springs in Albania:
- Albanian geothermal regime allows different scale borehole heat exchangers applications;
- Use of the low and middle enthalpy geothermal waters is economically viable in Albania, and they can be successfully used;
- The use of the low enthalpy geothermal waters in Albania can mitigate economic problems, improve the living standards of the communities and diversify the energy resources;
- The Bënja springs, water temperature, is suitable for the supply of a recreational center, including geothermal indoor and outdoor pools;
- The water temperature is suitable for feeding two cascades;
- The hybrid system will improve the economic efficiency of the project;
- The construction of the center will improve the energetic balance of the region;
- The construction of the center will help diversify the energy resources in Albania;
- The degasified and desalination line will improve the environmental status of the area, as it is actually highly polluted;
- It will improve the living standards of the community of the Bënja village;
- The economic analyses show that it is feasible;
- The electricity generated by the combined scheme will improve its efficiency;

- The geothermal systems are environmentally friendly;
- Risk analysis shows that there is not any added risk for the proposed investment;
- Direct utilization of the low enthalpy geothermal resources of Albania will help in diversifying the energetic resources mitigating the supply problems faced in the near past.

KORÇA & TIRANA DISTRICT HEATING

- Albanian geothermal regime allows different scale borehole heat exchangers applications;
- The heating system of the “Fan S. Noli” University campus was discussed between the oil and geothermal systems;
- The geothermal regime of Korça allows the use of both geothermal systems: Water-Water and Earth-Water;
- The Water-Water system is the most viable;
- The Oil Heating systems are the less viable, despite the oil price;
- The geothermal system also has a very good environmental impact;
- This project application will help the diversification of the energetic Albanian system;
- Demographic and geological features of the student’s city (Tirana) allow, and furthermore are feasible, the borehole heat exchanger’s utilization.

Pursuant to the UNFC & UNRMS criteria and requirements, all proposed geothermal projects of Albania are classified as **E2** Axis given that: development and operation are expected to become environmentally-socially economically viable in the foreseeable future.

Given that their technical feasibility for more extensive project development is subject to further evaluation because the existing preliminary studies presented in this report provide sufficient evidence of the potential for development and that further study is required. We are confident that further studies shall confirm the feasibility of development. These are the reasons why all proposed potential projects are classified as **F2**.

The studies presented in the report are the result of extensive research work done in the past 20 years in Albania regarding the assessment of the geothermal potential of the country. The lack of financing and reliable data generate a moderate level of confidence regarding the resource & reserves uncertainty, geologic uncertainty, and facility uncertainty. Therefore they are classified as **G2.**

Recommendations

Obviously, the development of geothermal projects is a complex and time-consuming process that requires several experts’ (developers, suppliers, and regulatory bodies) involvement in setting objectives to achieve project bankability and begin implementation. It is known that UNFC emphasizes the creation of resource inventories based on separate categorizations for environmental–socio-economic viability, technical project feasibility, and confidence levels based on geological knowledge and future resource availability. This provides useful classifications for assessing recent, current or potential resource development projects. It also helps with analyzing all phases of project development, with the aim of determining viability or the need for further analysis and improvement.

The following activities should be considered:

- Conducting more detailed geological studies to understand the geothermal aquifers, including the reservoir conditions, temperature, permeability, porosity, and flow rate.
- Developing adequate geological models of the geothermal resources to enable realistic evaluations of their potential further development.
- Conducting extensive environmental and social impact assessments (ESIA) studies, including public hearings and consultations with residents, local and central governments, and other stakeholders as per international and national laws and regulations.
- Develop Albanian UNFC and UNRMS guidelines and standards for resource classification, reporting, and management.
- Improving the capacity building of local experts and stakeholders in geothermal resource management and development.

- Establishing a regulatory framework for geothermal resource management and development to ensure sustainable development and protection of the environment.
- Encouraging investment in geothermal projects by providing incentives, including tax breaks, subsidies, and favorable policies.
- Strengthening the partnership between the public and private sectors to facilitate geothermal development in the country.

More angles that may be considered based on environmental-social-economic viability and technical feasibility include:

- The potential to use geothermal energy for other purposes beyond district heating and recreational centers, such as agriculture, aquaculture, or industrial processes.
- Investigate the possibility of using geothermal energy for electric power vehicles or public transportation in the region, which could reduce air pollution and promote sustainable mobility.
- Explore the potential of using geothermal energy for carbon capture and storage, which could help mitigate greenhouse gas emissions from industries and power plants. (Through a process called geothermal energy with carbon capture and storage (GECO), carbon dioxide (CO2) is captured from industrial processes or directly from geothermal fluid and then injected into geothermal reservoirs. The CO_2 is stored in the reservoirs, and the geothermal heat helps accelerate the mineralization rate, which converts the CO_2 into stable mineral carbonates over time. This process allows for the permanent storage of CO_2 and helps mitigate climate change's impacts. Additionally, the injection of CO_2 into geothermal reservoirs can enhance geothermal energy production by increasing the pressure and temperature of the reservoir.)
- Partnering with neighboring countries with advanced geothermal industries, such as Iceland or Italy, to exchange knowledge and expertise and to facilitate technology transfer and investment in the Albanian geothermal sector.
- Using blockchain technology to create a transparent and secure platform for geothermal resource management, trading, and financing could attract more private investment and promote sustainable development.

The following next steps are recommended to benefit from the study:

- Dissemination of the findings: The results of the assessment and case study should be widely disseminated to key stakeholders, including government officials, policymakers, energy companies, and the general public, to raise awareness of the potential of geothermal energy in Albania.
- Capacity building: Capacity building is crucial to exploit geothermal energy's potential fully. Training and education programs should be established to educate professionals and technicians on geothermal energy development and to ensure that the necessary skills and knowledge are available to develop and operate geothermal power plants.
- Exploration and development of geothermal resources: The study recommended that further research and development be conducted to explore the potential of geothermal energy in Albania fully. This includes drilling exploration wells, geophysical and geothermal measurements, drilling production wells, and constructing power plants.
- Policy and regulation development: The government should develop favorable policies and regulations for geothermal energy development. This includes tax incentives, feed-in tariffs, and other financial mechanisms to encourage private sector investment in geothermal energy.

The location, stakeholders' engagement, technical data, land properties rights and issues, proximity with the capital of Albania (Tirana), and economics shows that the best location to start with the completion of the pre-feasibility and feasibility study is KOZANI – 8 GEOTHERMAL WELL. These studies shall prove that also in Albania, despite the unfavorable geothermal

regime, under the latest development of the energy sector, these immense resources are fully competitive and shall support the entire country's sustainable development.

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