

Angola's Geothermal Potential: characterizing resources for sustainable management in the energy transition

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Abstract

The aim of this paper is to provide an overview of Angola's geothermal potential and its determinants with a view to boosting the country's energy sector. It focuses on analyzing the potential of geothermal energy in Angola and its role in the transition to a greener energy matrix. This dissertation begins with a brief introduction to the energy panorama in Angola, followed by the topic of geothermal energy as a whole and its low and high enthalpy aspects, as well as the case of Enhanced Geothermal Systems (EGS). Throughout the work, special attention is put on the geothermal potential in Africa, mentioning some countries where the use of geothermal energy is already a reality. The geology of Angola, the Lucapa corridor and the Kwanza Basin is briefly presented. Finally, the case study of Tocota thermal spring water is presented, where the aim is to build a spa to make use of this low enthalpy geothermal resource. To this end, an economic evaluation of the development of this geothermal project was carried out, which proved the effectiveness and economic viability of this project. In the future, it is hoped that the government will invest in the requalification and construction of these infrastructures for the development of thermal tourism and make geothermal energy in Angola one of the sources used in a sustainable way.

Keywords: Geothermal energy, Low enthalpy, Geothermal potential in Angola, Thermalism, Economic Evaluation.

1. Introduction

The energy landscape in the world and specifically in Africa is being transformed by political and social changes so that we don't have to rely solely on fossil fuels. Africa has been strengthening its work so that its contribution to this range of changes is significant with the implementation of primary sources and alternative sources such as solar energy, wind energy, wave energy, hydrogen and geothermal energy have been the sources on which current investments are focused to urgently develop cleaner technologies for the environment that reduce greenhouse gas (GHG) emissions[1]. According to the report published by the Lusophone Renewable Energy Association [2], Angola's work on renewable energy involves the following statistics: solar energy with an installed capacity of 100 MW, with the implementation of photovoltaic panel production units. In the same trend, wind power could reach an installed capacity of 100 MW, taking advantage of existing infrastructures as well as the great natural potential. Biomass will also be a renewable source, with 500 MW of installed capac-

ity due to the expansion of agriculture and livestock farming, as well as the country's abundant forest resources. In recent years, Angola has realized the importance of diversifying its energy matrix as part of a broader strategy to promote sustainable economic development. With this goal in mind, the government drew up the Angola Energy Vision 2025, a strategic plan that encourages the use of renewable sources, such as solar, wind and geothermal, to strengthen energy security and reduce greenhouse gas emissions[3]. Angola has great potential for the development of renewable energy, especially hydroelectric and solar energy, and the government seeks to increase the share of these sources in the national electricity grid, thus reducing dependence on oil and diesel[4]. In addition, the country has attracted international investment in renewable energy projects and has established partnerships with global organizations, such as the International Renewable Energy Agency (IRENA), to improve its regulations, attract new investment and develop the technical capacity needed for these projects [4]. Among the renewable energies cur-

rently being developed and used, Geothermal Energy (meaning: GEOTHERMAL GEO - Earth; THERMAL - Heat), is the Earth's natural heat, the energy derived from the heat coming from inside the Earth [5]. Geothermal energy offers a notable potential as a stable, low-emission renewable energy source, with applications in both electricity generation and direct-use that contribute to sustainable energy solutions. Geothermal energy's flexibility extends beyond electricity generation, especially in direct-use applications that can make use of low- to moderate-temperature geothermal resources. Such applications can reduce the energy footprint of industries and communities by using geothermal heat directly for agriculture, heating and cooling, industries processes[6] According to [4], the countries of the East African Rift region are endowed with significant geothermal potential for electricity production as well as for direct use. Regions in Africa, such as the East African Rift System (EARS) and the Comoros Islands, have temperatures reaching up to 400°C at depths of approximately 2.3 km with a high geothermal gradient. In these areas, as groundwater circulates through permeable rocks, geothermal reservoirs are created, where deep circulating groundwater is heated by conduction and circulates by convection (from recharge to discharge). The world has supported the development of this clean energy, and Africa has followed suit by discovering its geothermal resources. Countries located near the East African Rift System, such as Kenya and Ethiopia, have already been using this energy source to produce electricity because the area has very high geothermal potential. Although Angola does not belong to the African rift system, studies have shown that Angola's geothermal gradient is reasonable at around 30°C/km. Solar energy projects are being prioritized in the country's arid regions, particularly in the southern provinces, while geothermal potential in areas with hot springs is being assessed and also petroleum resources such as abandoned wells are being assessed for future development of geothermal energy. The scope of this report focus on the geothermal potential of Angola, where few studies have so far been carried out in this area. It should be stated that the implementation of geothermal energy and its utilisation according to the resources classification, as well as the development of an economic assessment for this project will contribute to harness the use of the country's geothermal resources. Carrying out an economic analysis, taking into account initial investments, operating costs and possible returns on investment, in order to determine the viability of a future geothermal project in Angola (construction of a thermal spa for the development of tourism and its sustainable management), based on the case study of the

Tocota thermal spring, in Kwanza-Sul province in Angola.

2. Background

According to the classification of geothermal resources, they are categorized into high enthalpy systems (reservoir temperature above 150°C), low enthalpy systems (reservoir temperature between 20°C and 150°C) and very low enthalpy fields (reservoir temperature below 20°C)[7], as can be seen in the Table 1.

Table 1: Geothermal Energy / Reservoir Temperature [14]

Geothermal Energy	Temperature (°C)
High Enthalpy	> 150°
Low Enthalpy	20° – 150°
Very Low Enthalpy	< 20°

As quoted in the report by the [8], geothermal energy (energy stored inside the Earth in the form of heat) results from the fact that geothermal systems can be found in areas with normal or slightly above normal geothermal gradients (on average, the Earth's temperature increases with depth by around 25 – 30°C/km above the ambient temperature at the surface - the so-called normal geothermal gradient), in regions far from the contact zones of tectonic plates, without the presence of an active heat source (magma close to the surface - stable zones of the globe), or in areas close to the edges of tectonic plates (unstable zones of the globe), where geothermal gradients can be much higher. In the stable zones of the globe (low enthalpy) the geothermal gradient varies between 25 – 40°C/km, maximum so that at depths of 1.5 - 2.0 km temperatures of 40-80 °C can occur [5]. On the other hand, in unstable areas of the globe, the geothermal gradient can vary between 130 – 150°C/km, which makes it possible for temperatures of 200 to 300 °C to occur at a depth of 1.5 - 2.0 km. However, most geothermal exploration and use takes place where the gradient is higher and therefore where drilling is shallower and less expensive. Sub-Saharan Africa's geothermal potential is linked to recent volcanism and magmatic activity, according to [9]. The continent's main geothermal resources are concentrated along the East African Rift System (EARS) and manifest on the surface through earthquakes and the release of heat, either through hot springs or volcanic eruptions [10]. The geothermal narrative also extends to West African countries, including Chad, Cameroon, Nigeria, Ghana, Ivory Coast, Liberia, Sierra Leone, Guinea, Senegal, Mauritania and Algeria. Further south, the Western Congolese belt in

Gabon and Congo, as well as the orogenic belts of southern Africa also have geothermal potential, not forgetting Angola, which has granitoid rocks with thermal anomalies indicative of geothermal potential. Angola, a country far from the unstable zones of the tectonic plates, has a normal gradient of 30°C/km, and there is evidence of low enthalpy hot springs with temperature variations between 20-50 °C.

2.1. Geothermal Energy Potential in Angola

The Republic of Angola, as illustrated in Figure 1, has an area of 1,246,700 km², located on the west coast of the African continent, in the South Atlantic, with its boundaries delimited: to the north and northeast by the Republic of Congo, Namibia to the south, to the east by the Republic of Zambia, and finally to the west by the Atlantic Ocean. The country lies between latitudes 4°–18°S and longitudes 11°–24°E, and has a land border of 4,837 km and a sea coast of 1,650 km ([1].



Figure 1: Map of Angola. Taken from [1].

Angola is a country with geological conditions that allow geothermal resources to occur. Despite the existence of some springs that have already been categorized, there are still others throughout the country of which there are not many historical records, although local populations have been using these waters and have observed that they have medicinal characteristics, even without exhaustive studies on the physical and chemical characterization of these waters. Most of these geothermal occurrences have an emergence temperature of over 20°C and can even reach 50°C. The study of Angola's geothermal potential requires knowledge of its geological structures and occurrences in its sedimentary basins and also in other geological struc-

tures in the country, such as the Lucapa structure or corridor, as shown in Figure 2.



Figure 2: Map showing the Lucapa corridor. Taken from [9].

The Lucapa Corridor or Graben shown in Figure 2 dates back to the Cretaceous period and represents a sequence of faults that runs through the central corridor of the country in a southwest-northeast direction. The Lucapa corridor has an extensional tectonic structure that crosses the country from NE (Lundas) to SW (Namibe), for more than 2000 km [12], covering the entire provinces of Lunda, Huambo, Bié, Lubango, Benguela and part of the province of Kwanza-Sul [13]. This Lucapa corridor or graben, a lineament of tectonic weakness 50-90 km wide, lies along a set of discontinuous faults around 400 km long in southwest and central Angola and eventually connects to a transform fault in the South Atlantic Ocean during its opening and during the formation of the Walvis Ridge related to a possible rupture induced by hot mantle plumes.

Most of Angola's springs are concentrated in this Lucapa corridor, where faults and geological conditions favor their appearance. In this corridor we can find 10 of the country's hot springs (Figure 3). At the Conda spring, the thermal anomaly is linked to igneous intrusions, below the metaquartzites and migmatites. In Catanda, the heat source is associated with volcanism with carbonate breccias and fractures with quartz veins, which allow the release of gases and the formation of travertines, typical of hydrothermal fields. In Ndolondolo, the heat is associated with an alkaline-carbonate complex in an intracontinental hot-spot, with various intrusions and fractures that control the thermal emergences. In short, the degree of exhumation of the

heat-generating complexes tends to increase from northeast to southwest [14].

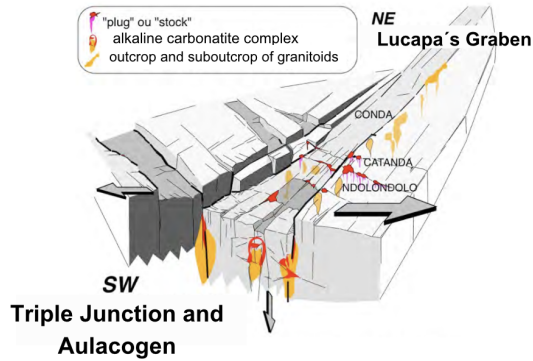


Figure 3: Representation of the faults in the Luçapa structure showing the thermal anomalies that could potentially generate hydrothermal convective circuits. Taken from [13].

The Kwanza Interior Basin, initially located on the seabed during the deposition process, stands out for its relatively high geothermal gradients [15]. These gradients are associated with the underlying rift systems and intrusive/eruptive volcanic activity. This context has led to the induction of hydrothermal processes in the area [15]. This Basin extends offshore and is known for its important hydrocarbon resources [16], presenting significant potential for oil exploration. In addition to the Kwanza Basin, the Lower Congo Basin, where the country's oil exploration is also underway, are areas of high interest for abandoned oil wells to be repurposed for high enthalpy geothermal exploitation, which is the production of electricity through geothermal gradients and high well temperatures at depth.

3. Characterization of Thermal Occurrences in Angolan Territory

So far, 10 hot springs have been identified in Angola, in the provinces of Kwanza-Sul, Uíge, Namibe, Huambo, Bié and Lubango. In Namibe, we can find the thermal springs of Montipa, Pediva and Ndolondolo. Montipa is a spa that was built many years ago, but is in a very poor state of repair and use. In Kwanza-Sul we can find the thermal springs of Tocota, Conda 1, Conda 2 and the Catanda springs. In Bié, in the municipality of Chilessó, we find the Chitocota spring and in Huambo we can find the thermal waters of Alto-Hama. Balombo hot springs in Benguela. There is not much information on the hot springs of Uíge and Lubango. Table 2 shows the characteristics of these hydrothermal occurrences in the country. The hot springs distributed throughout the country have varied miner-

alization, shows the values of all the springs in the country, with more emphasis on those that have documented data. Below I will characterize the physical and chemical composition of the waters of Montipa in Namibe, Tocota, Conda 1 and 2 in Kwanza Sul.

Table 2: Thermal Springs Properties. Retirado de [14] e [17]

Thermal Spring	Max Temperature (°C)	Mineralization (mg/L)	pH	Water Chemistry
Tocota	45.8	49.3	5.66	Sodium bicarbonate, siliceous
Conda 1	33	26.9	5.06	Sodium bicarbonate, siliceous
Conda 2	27.9	22.4	4.56	Bicarbonate, sodium, siliceous
Catanda	32	530	n.d.	Bicarbonate
Pediva	20	n.d.	n.d.	n.d.
Ndolondolo	10–15	n.d.	n.d.	n.d.
Montipa	49	400	9.1	Sulfated
Chitocota	50	n.d.	n.d.	Sulfurous
Alto-Hama	n.d.	n.d.	n.d.	Sulfurous
Balombo	50	n.d.	n.d.	Silico-fluorinated

Note: n.d stands for not determined.

3.1. Namibe Springs

Namibe province has several thermal springs that have already been identified and can be used for various purposes such as balneotherapy, thermal health and wellness, among others. The thermal springs are distributed throughout the municipalities of Virei, Camacuio, and Bibala, namely Montipa, Pediva, and Ndolondolo.

The thermal waters of Montipa have Total Dissolved Solids (TDS) values between 300 and 450 mg/L and are considered weakly mineralized waters with $\text{SO}_4^{2-} > 400$ mg/L. They are alkaline waters with a $\text{pH} > 9.1$. The geological formations through which these waters circulate are mostly granitic, but there are also limestone/dolomite rocks, giving these waters interesting characteristics for therapeutic purposes, as they can be used as a sedative and to combat muscle contractions and hypertonia. In the same region as Montipa, there are also other

waters with lower temperatures that can be used as a stimulant to improve circulation, for dermatological purposes, and as a vasoconstrictor [17]. Table 3 shows the properties of Montipa’s thermal waters.

Table 3: Montipa’s water Parameters [2]

Parameter	Value	Unit
pH	8.2	Sorenson Scale
Fe	0.2	mg/L Fe
Al	0.01	mg/L Al
Mn	0.0	mg/L Mn
NO ₃ ⁻	6.5	mg/L NO ₃ ⁻
NH ₄ ⁺	0.01	mg/L NH ₄ ⁺
SO ₄ ²⁻	> 400	mg/L SO ₄ ²⁻
Total Hardness	80	mg/L CaCO ₃
Residual Chlorine	0.0	mg/L Cl ₂

3.2. Kwanza-Sul springs

The thermal springs of Conda and Tocota are located in Kwanza-Sul, about 4 km away, and are considered to be hyposaline waters, their circulation being associated with quartzite and granitoid rocks (see Figure [14]). In the same province, there are other hot springs in the Catanda region (32 °C), known as Catanda hot springs, which are bicarbonated due to the volcanic-carbonate structure that occurs in the region. These waters are highly mineralized, reaching free CO₂, levels of around 530 mg/L [14]. The waters of Tocota and Conda (1 and 2) differ in terms of emergence temperature: 45.8 °C, in Tocota, Conda 1 with a temperature of 33 °C) and Conda 2 with an emergence temperature of 27.9 °C. The three springs show very low mineralization, dominated by silica which accounts for 65 % of the total mineralization for Tocota and Conda 1 and around 54 % in the Conda 2 spring. These geochemical signatures are associated with the meta-quartz formations of the region in which these waters circulate. The Total Dissolved Solids (TDS) of Tocota, Conda 1 and Conda 2 are 49.3 mg/L, 26.9 mg/L, 22.4 mg/L, respectively. The majority component of these waters is dominated by bicarbonate and silica, representing more than 87 % of the total mineralization of these waters. All this parameters are shown in Table 4.

All these springs characterized in Angola have characteristics suitable for their direct use, and their properties allow them to be used for thermalism and balneotherapy. Following this presentation and characterization of the springs, the case study of the Tocota spring will be presented in order to present the economic project for implementing a spa

Table 4: Water Quality Parameters of Thermal Springs[13]

Parameter	Unit	Conda 1	Conda 2	Tocota
Temperature	°C	33.0	27.9	45.8
Electrical Conductivity	μS/cm at 25 °C	15.9	16.3	25.1
pH	Sorenson Scale	5.06	4.56	5.66
Alkalinity	mg/L CaCO ₃	4.38	5.05	8.68
Bicarbonate	mg/L HCO ₃ ⁻	5.34	6.16	10.60
Nitrate	mg/L NO ₃ ⁻	0.94	0.39	1.18
Nitrite	mg/L NO ₂ ⁻	0.27	0.35	0.24
Sulfate	mg/L SO ₄ ²⁻	0.42	0.24	0.36
Phosphate	mg/L PO ₄ ³⁻	0.04	<0.01	0.06
Chloride	mg/L Cl ⁻	0.77	0.84	1.18
Sodium	mg/L Na ⁺	0.636	0.926	1.590
Magnesium	mg/L Mg ²⁺	0.307	0.229	0.434
Aluminum	μg/L Al ³⁺	11	26	18
Silica	mg/L SiO ₂	17.1	12.2	32.5
Potassium	mg/L K ⁺	0.570	0.590	0.200
Calcium	mg/L Ca ²⁺	0.430	0.470	0.900

on the site of this spring.

4. Case Study: Tocota Thermal Spring - Construction of a Thermal Resort for the development of Thermal Tourism

This chapter discusses, in general terms, the potential for commercial use of Angola’s geothermal potential in the province of Kwanza-Sul. This province is important for local tourism, with a diverse landscape and environmental beauty due to its mountains and plateaus. It is a province well irrigated by the Kwanza, Longa, Queve, Cubal and Cuvo rivers, making it a province with fertile soil, high agricultural potential, fishing activity and other tourist resources, gasocarbon waters and thermal groundwaters).

Thermal tourism is already a reality in many European countries such as Portugal, Italy, Hungary and others. The practice of health and well-

ness tourism has helped to treat various illnesses in which these thermal waters have a positive effect. According to [18], health tourism covers three main aspects: therapeutic or curative, preventive and recovery or rehabilitation. The author also states that thermalism is the oldest tourism product in the world.

According to [19], spa services can encompass the following forms of operation:

- spas with incorporated hotel services.
- urban spas.
- Spa resorts

4.1. Selection of Tocota Spring

Tocota has a considerable temperature of 45.8 (°C), and the water flows from the spring at a rate of 7.1 m³/hour [14], which corresponds to approximately 2 L/s. Water collection wells could be drilled to feed the resort and thus increase the number of people who can come and benefit from the same services. Tocota has a productivity of around 215 m³/day, the amount of water filled the tanks per day. Using the silica (quartz) geothermometer we can calculate a temperature of 83 (°C) at a depth of 1980 m, considering the average annual temperature of the region of 23.6 (°C) and a geothermal gradient of 30 °C/km according to the study presented by [14]. The equation used to calculate the reservoir temperature is presented below (Truesdell, 1975)[20]:

$$T(^{\circ}\text{C}) = \frac{1315}{5.205 - \log(\text{SiO}_2)} - 273.15 \quad (1)$$

Where:

- T: Reservoir temperature (°C)

The depth of the reservoir was calculated using the following equation:

$$D = \frac{T_r - T_a}{gg} \quad (2)$$

Where:

- D: Reservoir Depth
- Tr: Reservoir temperature (°C),
- Ta: Average annual temperature of the region (°C),
- gg: Average geothermal gradient (°C/km)

With these calculated values we can see that by drilling about 2 km deep we can obtain higher temperatures and probably a greater flow rate.

The Tocota spring was chosen because of its location and also because of its physical and chemical

characteristics, as well as its flow rate and temperature. These are hyposaline waters, circulating in quartzite, similar to other hot springs in mainland Portugal.

The aim of the project is to refurbish the existing hot water pool in Tocota, which was once used by the local population, and to build from scratch infrastructures such as accommodation and catering services and the construction of a spa for health and wellness tourism. In order to boost local tourism, accommodation and breakfast services will also be developed. The need for investment arises because the site does not meet the minimum conditions required by the quality control authorities, especially with regard to the minimum areas established for accommodation establishments, the requirements for sanitary facilities, which establish one sanitary facility for every four rooms, and the need to prioritize the implementation of practices that promote efficient water and energy consumption.

4.2. Techno-economic analysis

For the development of a project, the decision to implement it is based on an economic analysis directly connected to the useful life of the project, based on economic data from the Cabeço de Vide spa in Portugal, and translated into the Angolan reality. This chapter is based on the economic and financial feasibility analysis of an investment project which aims to answer whether (or under what circumstances) an investment project to build a spa in Tocota is financially viable. Economic indicators were calculated such as the Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period.

4.3. Data and Assumptions for Economic Analysis

The initial investment was presented by the head of the Cabeço de Vide thermal spa project, who presented the financial plan for the spa and, based on these figures, the feasibility study for the Tocota thermal spa for the Angolan reality is presented. Table 5 shows the initial investment data.

In order to analyze the investment, we must take into account the employees to be hired and the expenses and salaries allocated according to the salary market. It is planned to hire 5 employees specialized in medical spa services, 5 maintenance staff, receptionists and administration staff for a total of 4 people, catering staff for a total of 10 people, 4 security guards, 4 cleaning workers, making the monthly total salary 4 075 kAOA. The monthly operating costs involve: Raw materials (food, spa products, etc.) amounting to 3,000 kAOA, Utilities (electricity, water, gas, internet, telephone), 2,000 kAOA, Maintenance and Cleaning 1,000 kAOA, Continuous Advertising and Marketing 1,000 kAOA, Other Operating Costs 1,000 kAOA, totaling 8,000 kAOA.

Table 5: Initial Investment in Fixed Assets

Item	kAOA
Land Purchase and Legalization	20,000
Licensing and Legalization	5,000
Construction and Infrastructure (includes construction of buildings, thermal pools, spa, restaurants, recreational areas, internal roads, etc.)	145,000
Equipment and Furniture	100,000
Landscaping and Development of External Areas	20,000
Initial Advertising and Marketing	10,000
IT Equipment	10,000
Project Studies	10,000
Total Investment in Fixed Assets, FA	600,000

The total annual costs plus the 75% seasonality factor gives us a figure of 108.674 kAOA. The data assumptions for this project are shown in the Table 6.

Table 6: Assumptions for economic analysis

Description	Values
Social Capital (kAOA)	600,000
Useful Life of Fixed Assets (years)	20
Residual Value of Fixed Assets	25%
Investment in Current Assets	5%
Cost of Capital	25%
Corporate Tax	25.0%
Annual Sales Growth Rate	10%
Annual Cost Growth Rate	7%
Revenue (kAOA/year)	319,500
Costs (kAOA/year)	108,675

Revenues will be driven by local and international tourism, with an expected annual growth rate of 10% per year and an annual cost growth rate of 7% per year. This fees carried out by analogy with the Portuguese tourism sector, due to the lack of Angolan data. The development of this resort will have 20 rooms and an estimated occupancy rate of 50-70% in high season, at 40,000 AOA/room, and a spa service in which 75% occupancy is estimated, at a price of 10,000 AOA/person. The resort will also have a restaurant service and recreational activities at a unit cost of 5,000 AOA/person, in order to make use of the thermal pool and other recreational activities, with a total revenue of 319,500 kAOA with a seasonality factor of 75%. The capital update rate of 25% was obtained at starting

from the basic interest rate in Angola (BNA Rate) of 19.50% in 2023, plus a “spread” risk of 5% and being in line with the discount rates used by Portuguese companies to investments in Angola.

4.4. Estimating Cash Flows

The economic analysis presents the results over the 20 years, showing the company’s growth. There has been a considerable increase in sales and revenues from 319,500 AOA in Year 1 to 1,954,033 AOA in Year 20, indicating that the company has higher sales, a great indication of market expansion. The increase in costs, from 108,675 AOA to 393,026 AOA, was smaller compared to sales, thus helping to increase the profit margin. On the other hand, there has been a significant increase in operating profit from 180,825 AOA to 1,531,007 AOA in 20 years. This growth is a reflection of higher revenue and effective cost control. The amount to be paid in taxes rose sharply from 45,206 AOA to 382,752 AOA, and likewise profits increased, as higher profits mean higher taxes to be paid. The company’s net profit increased over time, thus showing efficiency, after paying taxes the net operating result, the final profit, rose from 135,619 AOA to 1,148,255 AOA. It should be noted that these values may be subject to inflation and price variations, making them not directly comparable as they occur in different years.

4.5. Economic Results

The analysis was carried out over a 20-year period, using cash flows discounted at an annual rate of 25%, as presented in the assumptions. The NPV obtained of 459,586 AOA allows us to conclude that this is a profitable project, giving us a payback Period of around 11.23 years and providing a return higher than the discount rate used to calculate the NPV, meaning that the project manages to generate a rate of return higher than the opportunity cost of capital, making it an economically viable project. The criteria for economic evaluation such as the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Investment Payback Period, were calculated and evaluated from Liquidation perspective and continuity of operation perspective and the results are presented in Table 7 and 8. From the perspective of “continuity”, the perpetuity of the business which, with the perpetuity of Cash Flows overlapping the value of the liquidation of assets, you in the 20 year, generates higher minimum results than from the perspective of the “Settlement”.

4.6. Sensitivity Analysis

According to [21], the aim of carrying out a sensitivity analysis is to understand how changes in the variables involved in the cash flow calculation will

Table 7: Evaluation from the Liquidation Perspective

Evaluation from the Liquidation Perspective	Values
Net Present Value (NPV)	459,586
Internal Rate of Return (IRR)	37.71%
Accumulated Present Value of Project Cash Flows	1,059,586
Payback Period (years)	11.23

Table 8: Evaluation from the Continuity of Operation Perspective

Evaluation from the Continuity of Operation Perspective	
Net Present Value (NPV)	512,194
Internal Rate of Return (IRR)	38.04%
Accumulated Present Value of Project Cash Flows	1,112,194
Payback Period (years)	10.79

influence the economic analysis. Sensitivity analysis aims to assess how sensitive viability indicators such as NPV, IRR and Payback Period will behave. Sensitivity analysis is a valuable tool for identifying and understanding how different variables affect the economic, financial and operational performance of any company wishing to invest in a spa or business plan. This analysis allows managers to make more informed decisions about the viability of the business and the areas that require greater attention or adjustment. A variation in internal variables such as the price of the services offered as well as a variation in the percentage of occupancy, or in operating costs can have a positive or negative impact on the economic indicators. Variations such as:

- Occupancy rate: Changes in the occupancy rate directly affect revenue.
- Growth in expenses: Inflation and input costs can grow more than expected.
- Average price per customer: Fluctuations in purchasing power and willingness to pay can have an impact.

We can present the following scenarios for sensitivity analysis, with 3 scenarios: one optimistic (1) and two pessimistic (2 and 3):

1. Optimistic Scenario (15% increase in demand for Spa).
2. Pessimistic Scenario (15% drop in demand for the Spa) does not produce a variation that is too far from reality.
3. Pessimistic Scenario (15% drop in demand for Spa and 30% drop in demand for Accommodation).

To anticipate possible unexpected situations that might be beyond the company's control, a risk analysis was carried out based on sensitivity analysis. In this context, Scenario 1 - Optimistic - was considered, in which an increase of 15% in demand for spa services is projected. The results of this projection indicated a NPV (Net Present Value) of 706,484 AOA and an IRR (Internal Rate of Return) of 44.26%, demonstrating the viability and attractiveness of the project under favourable conditions.

In pessimistic scenario 2, with only a 15% reduction in demand for the spa compared to the initial forecast presented values of NPV of 274,413 AOA with an IRR of 32.71%. However if there is a 15% reduction in demand for the spa and a 30% reduction in demand for the accommodation shown in scenario 3, result in a negative NPV of - 71.244 AOA and a lower than expected IRR of 22.89%, making the project unviable.

The global trend in the sector is a reflection of the marked seasonality of classic thermal spas. The Factor of seasonality as previously mentioned translates the percentage of the year in which the activity economic-financial life in full, with the complement of the seasonality factor being the period of inactivity. Simulating a decrease in the seasonality factor from 75% to 50%, it showed a variation in economic indicators, a reduction in their values, obtaining a positive NPV of 116 852 AOA and an IRR of 28%, and a Payback Period of 16 years, which does not make the project unfeasible, but will lead to more time to recover the investment. These values may reduce according to the reduction in demand for these services, due to factors such as the seasons, but also for thermal spa services health care does not apply, due to the search for these alternative health therapies. The development of new well-being experiences and the creation of well-being products (activities aimed at for well-being, nature, "spa"/well-being services), making the resort more attractive both for the younger age group and Adults alike, will positively impact the seasons and the demand for services.

5. Conclusions

Africa has been accelerating the process of energy transition, as a result of many political, economic and environmental challenges, towards the goal of

reaching Net Zero by 2050. A large part of this process is related to technologies aimed at a cleaner energy footprint, thus reducing the damaging impact that fossil fuels have had on the environment. This study focused on contextualizing geothermal energy in the context of Angola's energy transition. After a brief introduction to the energy market and concepts of geothermal energy, the potential of geothermal energy in Africa was presented, with special emphasis on the study of the potential of geothermal energy in Angola. In the case of Angola, special emphasis was placed on the current geothermal resources available for geothermal energy to become a future reality in Angola, with a view to characterizing these resources and their contribution to the country's economy. It should be noted that low enthalpy geothermal energy is viable on a global scale and is not restricted to regions located close to the contact of tectonic plates. It can be emphasized that Angola has superficial evidence of the existence of low enthalpy geothermal resources, with the identification of several hot springs throughout the country and others yet to be discovered. Angola's hot springs have temperatures ranging from 20°C-50°C and are characterized as low enthalpy, which can be used directly for various purposes. On the other hand, there are many oil wells in the region of the Kwanza sedimentary basin, which will make it easier (in the future) to bring them back (once they have been abandoned) for the use of geothermal energy in Angola, which could give rise to high enthalpy geothermal energy used for electricity production, making a major contribution to the country's energy transition, which so far has been developing solar energy projects with more emphasis, but which intends to extend the range of renewable energies to be developed. In this context, the concept of Enhanced Geothermal Systems (EGS) could be implemented in abandoned oil wells, where a thorough study will be carried out in the future to create conditions for the extraction of geothermal fluids for electricity generation. Angola has a high geothermal potential, largely due to the hot springs it has and the large collection of oil wells that can generate geothermal energy. The dissertation presented positive results with regard to the potential and ways of using these geothermal resources. As the country's thermal springs are low enthalpy resources, they can be used for the direct application of these resources and the form chosen in this dissertation is their application for thermalism and balneotherapy. This project has proved to be of great interest to the country, and the viability of this project points us towards future success. Economic viability was demonstrated by analyzing the economic indicators calculated for the implementation of this project in Kwanza-Sul, Tocota.

Using an Excel tool to calculate these values such as cash flow, Net Present Value (NPV) of 459 586 AOA, Internal Rate of Return (IRR) of 37.71%, and Payback Period of 11.23 years, which makes an profitable investment. Angola's energy transition is already a reality. The current objective is to diversify the country's energy matrix by implementing other energy sources such as geothermal energy. In the future, efforts must be made to implement the project presented here in the dissertation, continuing to carry out a study in order to locate all the springs in the country that have yet to be discovered and to characterize all the oil wells that have the conditions for being converted to geothermal energy. Likewise, the public-private investment sector will need to outline clear objectives for the implementation of these projects that will generate great benefit in this area of energy sustainability, bringing benefits not only to Angolan tourism, but also to the diversification of the country's energy sources.

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References

- [1] International Energy Agency (IEA). Africa Energy Outlook 2019, 2019. Licence: CC BY 4.0.
- [2] Associação Lusófona de Energia Renováveis ALER. Relatório nacional do ponto de situação de energias renováveis em angola. Relatório, 2022.
- [3] Ministério da Energia e Águas de Angola (MINEA). Projeto de elaboração do plano diretor de desenvolvimento do sector elétrico na república de angola, 2018. Accessed: 2022-02-28.
- [4] International Renewable Energy Agency (IRENA), German Development Bank (KfW), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). *The Renewable Energy Transition in Africa*. International Renewable Energy Agency, German Devel-

- opment Bank, and Deutsche Gesellschaft für Internationale Zusammenarbeit, Abu Dhabi, Frankfurt, and Bonn, 2021.
- [5] M.J. Dickson and M. Fanelli. *What is Geothermal Energy?* Istituto di Geoscienze e Georisorse, CNR, Pisa, Italy, 2004.
- [6] John W. Lund and Aniko N. Toth. Direct utilization of geothermal energy 2020 worldwide review. *Geothermics*, 90:101915, 2021.
- [7] J. A. M. M. Leitão. Study of the potential for low-enthalpy geothermal energy use in mainland portugal. Master’s thesis, University of Coimbra, 2014.
- [8] World Energy Council (WEC). World energy resources: Geothermal, 2013.
- [9] D. Chandrasekharam, A. Lashin, N. Al Arifi, A.M. Al-Bassam, and C. Varun. Geochemical evolution of geothermal fluids around the western red sea and east african rift geothermal provinces. *Journal of Asian Earth Sciences*, 164:292–306, 2018.
- [10] Peter Omenda and Meseret Teklemariam. Overview of geothermal resource utilization in the east african rift system. *Short Course V on exploration for geothermal resources*, 2010.
- [11] Governo de Angola. O perfil de angola, 2022. Accessed: December 2023.
- [12] K. N. Egorov, E. F. Roman’ko, V. T. Podvysotsky, S. M. Sablukov, V. K. Garanin, and D. B. D’yakonov. New data on kimberlite magmatism in southwestern angola. *Russian Geology and Geophysics*, 48(4):323–336, 2007.
- [13] M. Castillo-Oliver, S. Gali, A.O. Gonçalves, and J.C. Melgarejo. Use of indicator minerals in diamond exploration: A comparison between barren and fertile kimberlites in angola. In *10th International Kimberlite Conference*, 2012.
- [14] A. Lima, C. Gomes, and L. Sabalo. Ocorrências hidrominerais do sw de angola: Proposta de um modelo hidrogeológico conceptual. *APRH*, 2009.
- [15] Stellae Energy. Geothermal energy in angola, 2021.
- [16] L. V. Duarte. De regresso à geologia de angola: I. a zona costeira de luanda ao cuanza sul. *Revista Ciência Elementar*, 7(04):078, 2019.
- [17] A. F. Cachapa, M. K. Abel, L. N. De Oliveira, and J. K. Mestre. Avaliação da qualidade das águas termais de montipa, município de bibala-namibe. *Sociedade Tecnologia*, 5(1):43–56, 2022.
- [18] L. Cunha. *A procura turística*. Editorial Verbo, Lisboa, 2006.
- [19] R. J. D. C. Guerra. *Turismo de saúde e bem-estar: Estratégia de desenvolvimento local para as Caldas da Cavaca*. Doctoral dissertation, Universidade de Coimbra, 2016.
- [20] A. H. Truesdell. Summary of section iii. geochemical techniques in exploration. In Lawrence Berkeley Laboratory, University of California, editor, *Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources*, pages 53–79, San Francisco, California, 1975.
- [21] I. Soares, J. Moreira, C. Pinho, and J. Couto. *Decisões de Investimento - Análise Financeira de Projetos*. Edições Sílabo, Lda., Lisboa, 2008.