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Jack Kiruja

THE VIABILITY OF SUPPLYING AN INDUSTRIAL PARK WITH THERMAL ENERGY FROM MENENGAI GEOTHERMAL FIELD, KENYA

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THE VIABILITY OF SUPPLYING AN INDUSTRIAL PARK WITH THERMAL ENERGY FROM MENENGAI GEOTHERMAL FIELD, KENYA

MSc thesis
Iceland School of Energy
School of Science and Engineering
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INTRODUCTION

The Geothermal Training Programme of the United Nations University (UNU) has operated in Iceland since 1979 with six-month annual courses for professionals from developing countries. The aim is to assist developing countries with significant geothermal potential to build up groups of specialists that cover most aspects of geothermal exploration and development. During 1979-2016, 647 scientists and engineers from 60 developing countries have completed the six month courses, or similar. They have come from Africa (38%), Asia (36%), Latin America (14%), Europe (12%), and Oceania (1%). There is a steady flow of requests from all over the world for the six-month training and we can only meet a portion of the requests. Most of the trainees are awarded UNU Fellowships financed by the Government of Iceland.

Candidates for the six-month specialized training must have at least a BSc degree and a minimum of one-year practical experience in geothermal work in their home countries prior to the training. Many of our trainees have already completed their MSc or PhD degrees when they come to Iceland, but many excellent students with only BSc degrees have made requests to come again to Iceland for a higher academic degree. From 1999 UNU Fellows have also been given the chance to continue their studies and study for MSc degrees in geothermal science or engineering in co-operation with the University of Iceland. An agreement to this effect was signed with the University of Iceland. A similar agreement was also signed with Reykjavik University in 2013. The six-month studies at the UNU Geothermal Training Programme form a part of the graduate programme.

It is a pleasure to introduce the 52nd UNU Fellow to complete the MSc studies under a UNU-GTP Fellowship and the second to do his studies at Reykjavik University. Philip Jack Muthomi Kiruja, BSc in Biomechanical and Processing Engineering from Geothermal Development Company – GDC in Kenya, completed the six-month specialized training in Geothermal Utilization at UNU Geothermal Training Programme in October 2011. His research report was entitled: *Use of geothermal energy in dairy processing.* After three and a half year of geothermal energy work in Kenya, he came back to Iceland for MSc studies at Iceland School of Energy – School of Science and Engineering, Reykjavik University in July 2015. In December 2016, he defended his MSc thesis presented here, entitled: *The viability of supplying an industrial park with thermal energy from Menengai geothermal field, Kenya.* His studies in Iceland were financed by the Government of Iceland through a UNU-GTP Fellowship from the UNU Geothermal Training Programme. We congratulate Jack on his achievements and wish him all the best for the future. We thank Iceland School of Energy – School of Science and Engineering, Reykjavik University for the co-operation, and his supervisors for the dedication.

Finally, I would like to mention that Jack's MSc thesis with the figures in colour is available for downloading on our website *www.unugtp.is*, under publications.

With warmest greetings from Iceland,

Lúdvík S. Georgsson, Director
United Nations University
Geothermal Training Programme

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I appreciate the gesture by the UNU-GTP under the leadership of its director, Lúdvik S. Georgsson, for giving me the opportunity to do my Master of Science degree at Reykjavik University. I appreciate the efforts of the staff both at the UNU-GTP and Reykjavik University in ensuring that my stay in Iceland was comfortable. My employer, the Geothermal Development Company, was very gracious to grant me time off from my work so that I could concentrate on my studies. Working with the Iceland Geothermal Cluster during my internship introduced me to the geothermal actors in Iceland courtesy of Vidar Helgason. My colleagues and classmates, thank you for your friendship, support and encouragement.

Finally, I thank my family for their support and encouragement during my studies, especially my wife for enduring my absence. To my four year old daughter, who could not understand why I was still in school despite being a “big boy”, thank you for always checking on

ABSTRACT

Kenya has an installed geothermal capacity of more than 600 MWe, and more geothermal energy projects are under development (Matek, 2016). One of the fields under development is Menengai, which is owned by the Geothermal Development Company (GDC). Besides developing the Menengai field for electricity generation, GDC intends to establish and industrial park which will be powered using geothermal energy in the same field. The industries located in the park will not only benefit from green electricity but they will also utilise the other by-products of electricity generation such as excess heat in separated brine and/or low pressure wells, dissolved substances in the geothermal brine, non-condensable gases such as carbon dioxide and hydrogen sulphide among other by-products. Analysis of the demand for industrial process heat in the park resulted in the creation of three scenarios with a demand of between 6 MWt and 22 MWt. This energy would be obtained from hot geothermal brine produced in the Menengai field. Five possible options for supplying this energy to the industries were analysed. The options considered for energy supply were separated brine from power generation, brine from low pressure wells or a combination of both. This energy would be extracted through heat exchangers and delivered to the industries through pipes, a distance of 6 km. The energy was cascaded among different thermal processes in order to achieve a high degree of energy utilisation. This resulted in a 60% reduction in the amount of water required to transport thermal energy to the industrial park. Since water is the energy carrying medium, a suitable tariff for the hot water was determined to have a floor of 2.39 $/m3 and a ceiling of 7 $/m3. The floor price was determined using the operating costs as the basis while the ceiling price was determined using the price of alternative sources of fuel for industrial applications. All the analysed scenarios and options proved to be profitable after 25 years of operation with a payback period of between 6 and10 years and an Internal Rate of Return of between 20% and 30%. The most suitable option for supplying thermal energy to the industrial park for each of the scenarios was then determined by considering a number of criteria.

Key words: *Geothermal, industrial park, energy, viability, Menengai*

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

Page

1. INTRODUCTION

The project to be discussed in this thesis is about supplying thermal energy from Menengai geothermal field in Kenya to an industrial park located within the same field. The thermal energy which will be used within the park will be obtained from separated geothermal brine or from low-pressure geothermal wells which cannot be connected to flash steam power plants for electricity generation.

The project will be implemented by Geothermal Development Company (GDC). This is a Kenyan state owned corporation created to accelerate the development of geothermal resources in the country – for electricity generation and promotion of direct use of geothermal energy.

Geothermal development activities in the Menengai geothermal field began in 2011, and this has culminated in the realization of 135 MWe worth of steam. The steam will be used by three independent power producers; each with a capacity of 35 MWe; to generate a total of 105 MWe (Geothermal Development Company, 2016).

A concept paper by GDC on how to facilitate the development of geothermal direct use has proposed the development of industrial parks in the geothermal field in order to attract investors. In this regard, GDC has already made initiatives towards the development of an industrial park in Menengai by identifying a piece of land within the geothermal field, on which the industrial park will be established.

In addition, GDC has developed a geothermal direct use demonstration centre in Menengai geothermal field using energy from MW03, a low-pressure well. The centre has four projects: a heated greenhouse unit, a heated aquaculture unit, a geothermal Laundromat and a geothermal milk pasteurization unit (Mburu, 2015).

The area surrounding Menengai geothermal field is of great agricultural potential with the farmers practicing dairy farming, horticulture, aquaculture, cereal farming and livestock rearing (VEGA, 2014a). According to the roadmap to Kenya's industrialization by the ministry of industrialization and enterprise development, the country needs to increase its manufacturing base from 11% to 20% of GDP by the year 2030 in order to achieve middle income status. One of the strategies of achieving this will be to leverage on the country's natural advantages to create competitive sectors such as textile and cotton, leather, agro-processing, beef and fishing (MIED, 2015a).

It is the industries in these sectors that GDC will be targeting to attract to the industrial park. Furthermore, the Kenyan constitution which was promulgated in 2010 established county governments which have been creating incentives to attract industries to their areas of jurisdiction to spur economic development. Some of activities by the county governments include improving road networks to make transportation easier, supply of clean water for domestic and industrial use, expanding health services, etc. They have also been hosting investment conferences to sensitize the public of the available investment opportunities within their areas of jurisdiction.

One of the impediments to industrial development in Kenya has been the high cost of energy and its unreliability. Electricity from the grid costs about USD 0.15/kWh (Regulus, 2016). Power outage is a common occurrence in Kenya due to routine rationing and unstable grid which forces most industries to incur an extra cost of installing and running standby diesel generators for several hours every month (VEGA, 2014a).

In addition, industries which require steam for their operations normally use industrial diesel oil or furnace oil to fire boilers. These produce pollutants and greenhouse gases. Besides, their prices are usually volatile and in most cases high, which eats into the manufacturers' margins and makes it difficult to predict profits accurately. Geothermal energy on the other hand is cheaper, cleaner and more reliable than the other sources of energy currently being used. In addition, direct use of geothermal energy presents an opportunity to eliminate the use of fossil fuels to generate thermal energy for industries.

Kenyan farmers suffer huge postharvest losses due to spoilage of their produce caused by lack of timely processing such as drying, pasteurization or cooling. This is partly because the processing industries are located in major town away from the agricultural zones. Middlemen take advantage of the ensuing desperation by farmers; buying the produce at a throw away price as the farmers sell their harvest to avoid further losses.

The establishment of agro-processing industries in geothermal fields which are close to agricultural lands will provide farmers with a ready market for their produce; which in turn will reduce postharvest losses occurring when the produce is awaiting processing. Furthermore, the middlemen will be eliminated since the farmers can choose to deliver their produce directly at the factory or alternatively, the factories can make arrangements to collect the produce at the farm gate.

Finally, geothermal energy in Kenya has primarily been used for electricity generation while the separated brine is normally reinjected back into the ground while still containing huge amounts of energy. In addition, no other by-products of geothermal energy such as chemical elements or gases are extracted for useful purposes. As a result, there is inefficient utilization of the geothermal resource.

It is expected that the establishment of a geothermal industrial park will address some of these problems to a large extent. In addition, thousands of jobs will be created for the local population and businesses through employment and provision of services to the industries in the park.

1.1 Industrial park

An industrial park is a production zone or production cluster reserved for industrial development. Specialized infrastructure required by the industries such as access roads, water supply, energy supply systems, waste management systems, etc. are provided at a central place where they can be shared by all the industries. This has the effect of reducing the unit cost of building these infrastructure as well as attracting investment and minimising the spread of ecological/environmental impacts in built-up areas (Vidova, 2010).

Sometimes, industrial parks develop into more advanced industrial infrastructure such as the following (Falcke, 1999):

- Export Processing Zones – they produce goods with a focus on the export market.
- Science and Technology parks – they emphasis the use of shared infrastructure for high level support services such as research and development, consultancy and experiments and use venture capital to meet their objectives.
- Eco-industrial park – they emerged in the 1990 based on the concept of industrial ecology which entails collaboration in the use of resources and environmental management for sustainable economic, environmental and social development. Implementation of eco-industrial parks is challenging because it requires a lot of stakeholder management (Hein et al., 2015). The focus here is cleaner production, green designs of infrastructure, pollution prevention, energy efficiency and inter-company partnering (GeKon, 2011).

A simplified version of the eco-industrial park is referred to as "industrial symbiosis." The institutions in this arrangement collaborate mainly in exchange of by-products, energy and water; resulting in better utilisation of resources (GeKon, 2011)

The most successful example of industrial symbiosis is in Kalundborg in Denmark. Eleven industries are part of this eco-industrial park. The waste by-product from one industry is used as the raw material for another industry. At the centre of the park is the 1,500 MWe Asnaes coal fired power station, Statoil oil refinery, Novo Nordisk who manufacture pharmaceuticals and enzymes and Gyproc who manufacture plasterboard. These industries came together seeking to give value to their by-products and as well as to comply with stringent environmental regulations (Ehrenfeld and Gertler, 1997).

A geothermal resource park is an example of industrial symbiosis; where the by-products of geothermal power generation i.e. excess thermal energy, non-condensable gas such as carbon dioxide and hydrogen sulphide, geothermal brine and dissolved substances are utilised by different industries located in the same area (GeKon, 2011). If these other industries also exchange their by-products, then it can be defined as an eco-industrial park.

1.2 Geothermal resource parks

Countries with geothermal resources such as Kenya and Iceland have over the years been developing and utilising these resources to meet their energy needs. Whereas Kenya has been using its geothermal resources mainly for electricity generation, Iceland has used its resource for both electricity generation and direct uses such as district heating and fish farming. In recent years, there has been a growing tendency by industries to use geothermal waste heat to meet their thermal energy needs especially in aquaculture and greenhouse production.

It is more economical to utilise the geothermal resource close to its source because of the high cost involved in transporting the energy. For this reason, geothermal developers are establishing geothermal resource parks near the geothermal fields. Besides economic considerations, the geothermal resource parks are based on the concept of waste reduction due to sharing of by-products.

Iceland is leading the way in the development of geothermal resource parks. Two of these establishments, Svartsengi and Reykjanes geothermal resource parks are located in the Reykjanes peninsula close to Svartsengi and Reykjanes geothermal power plants, which are owned and operated by HS Orka hf (Albertsson and Jónsson, 2010). Orka Náttúrunnar, a subsidiary of Reykjavik Energy, is in the process of developing a geothermal resource park at Hellisheidi.

Svartsengi geothermal resource park hosts the world famous Blue Lagoon, which besides offering spa services, has evolved into a leader in innovation by growing algae for production of cosmetics. Carbon Recycling International, also located in Svartsengi, uses carbon dioxide from the geothermal resource to produce methanol, which is used as an additive to petrol.

Reykjanes Geo-Park hosts Stolt fish farm, which is utilising warm sea water, a by-product of the Reykjanes power plant cooling tower to rear fish. The power plant also supplies Haustak, a fish processing factory, with thermal energy which it uses to dry fish.

Orka Náttúrunnar Resource Park in Hellisheidi hosts GeoSilica, a health products company which extracts silica from geothermal brine and markets it as a dietary supplement (Libdeh, 2016).

Geothermal power plants in Iceland are the nucleus upon which geothermal resource parks are built. The geothermal resource parks are based on the following principles (Albertsson, 2013).

- Integrated use of a variety of resources – utilisation of the various resources available from geothermal energy.
- Sustainable development – this results in ecological balance due to minimizing of waste through by-product sharing; economic prosperity due to creation of jobs in various disciplines; and social progress due to development of innovation, new job opportunities and environmental awareness.
- Bridge to technical and cultural barriers – different professions and companies get to collaborate more resulting in sharing of equipment, machinery and manpower.
- Longevity in utilisation of resources – this is the direct result of more efficiency in the utilisation of resources.

The concept of geothermal resource parks which is being implement in Iceland can be applied in any country with a geothermal resource. Kenya's geothermal potential is estimated to be more than 10,000 MWe (Omenda, 2015). There are 14 high temperature geothermal areas in Kenya located along the

Kenyan section of the Great Rift Valley which are to be developed for power generation as shown in Figure 1

Currently, only Olkaria and Eburru have operational geothermal power plants while Menengai is at an advanced stage in development.

Kenya's long-term development blueprint, "The vision 2030'', aspires to transform Kenya into a newly industrialised middle income economy by the year 2030. Under the economic pillar of the blueprint, development of industrial parks has been identified as one of the strategies aimed at boosting the manufacturing sector (Government of Kenya, 2007).

The other strategy that was identified was to leverage on the country's natural competitive advantages in selected sectors and establish flagship projects in these sectors. Some of the identified sectors are as follows:

- Agro-processing;
- Fisheries;
- Leather;
- Textile and apparel.

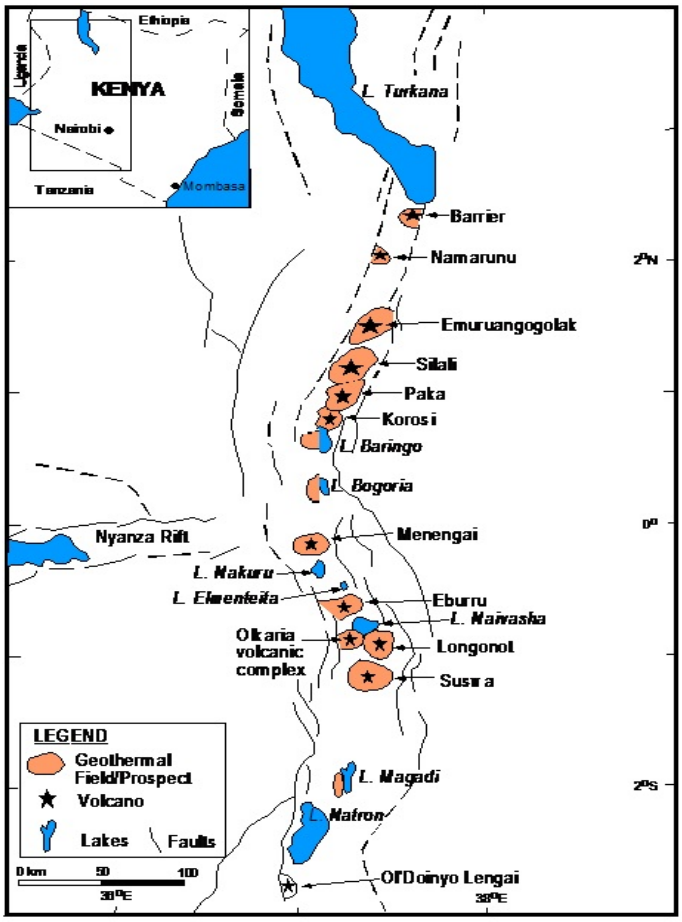


FIGURE 1: Kenya's geothermal fields and prospects (Omenda, 2015)

Availability of affordable energy was also identified as a key driver towards the realisation if the goals of the vision 2030. In this regard, the government established the Geothermal Development Company (GDC) in 2008, to accelerate the development of geothermal resources in the country under the following mandate:

a) To undertake surface exploration and drilling for steam;
b) To avail steam to power plant developers for electricity generation;
c) To manage the geothermal reservoirs to ensure constant supply of steam for power generation;
d) To promoting alternative uses of geothermal resources other than electricity generation (direct uses of geothermal energy).

GDC began its operations in Menengai geothermal field in 2011 and to date has realized 135 MWe of steam at the well head. This steam will be used by 3 independent power producers to generate 105 MWe of electricity in the first phase of development of Menengai geothermal field (Geothermal Development Company, 2016).

In order to realise its fourth mandate, "To promote alternative uses of geothermal resources other than electricity generation,'' GDC proposes to establish a geo-industrial park in Menengai geothermal field. Industries will utilise the excess energy from separated brine and low-pressure wells to meet their thermal energy needs. In addition, the industries will be able to use the other by-products of electricity generation such as non-condensable gases, water and dissolved mineral elements in an industrial symbiotic relationship. Infrastructure which supports industrial development will be built to attract industries to the park.

1.2.1 The proposed Menengai geo-industrial park

As the drilling for geothermal energy continues in Menengai, more energy will become available for electricity generation. As a result, the production of separated geothermal brine, which is a by-product of geothermal electricity generation will also increase. The separated brine is normally reinjected back into the ground to replenish the geothermal reservoir. However, at the separation pressure of 7 bar absolute, the brine is at a temperature of around 165°C. The energy in the brine could be harnessed before reinjection. In addition, geothermal power generation produces other by-products such as non-condensable gases and water; as well as dissolved substances, which can be extracted and turned into useful products.

The proposed geo-industrial park in Menengai is where the utilisation of these by-products of geothermal electricity generation will take place. GDC has identified a suitable location for the park on the south-western part of the Menengai geothermal field as shown in Figure 2. The location is relatively free of lava terrain and is a short distance from the geothermal wells. Furthermore, the area is at a lower elevation relative to the geothermal wells, which means that the need to pump the energy bearing water to the park will be minimal.

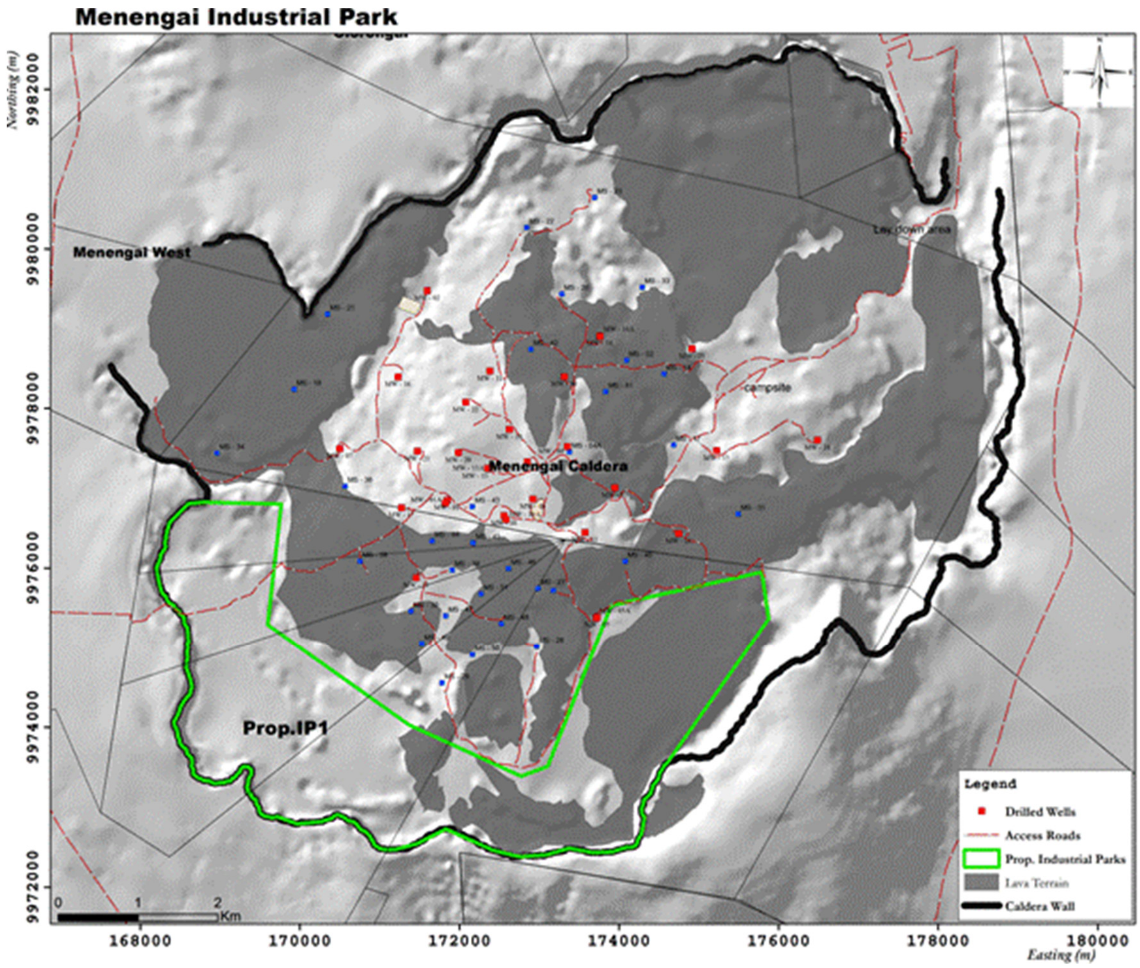


FIGURE 2: The proposed Menengai geo-industrial park
(Geothermal Development Company, 2016)

On this land, the energy will be provided centrally for utilization by the industries. Besides energy supply, the industrial park will also be served with fresh water supply, access roads and telecommunication equipment. Furthermore, availability of raw materials for use by industries in production and the availability of ready markets for the industrial goods will make the park more attractive to the industries (GeKon, 2011).

2. SUITABILITY OF MENENGAI FOR INDUSTRIAL DEVELOPMENT

Menengai geothermal field is surrounded by an agriculturally rich area. GDC will be targeting to attract agro-processing industries to the park so that they can use the energy in the geothermal brine to add value to the agricultural produce from Menengai. This is in line with the government's industrial transformation programme, which has identified agro-processing as one of the sectors where Kenya has a natural competitive advantage.

The farmers residing around Menengai practice dairy farming, horticulture, aquaculture, cereal farming and livestock rearing; and they are expected to provide the industries with raw materials for production. In addition, Menengai is located within a short distance of Nakuru town, one of the fastest growing urban centres in Kenya with a population of 310,000 people within the municipality. The municipality is within the larger county of Nakuru, which has a population of 1.7 million people (Nakuru County, 2013). This population will consume a substantial amount of goods produced from the Geo-Industrial Park.

The success of an industrial development project depends on several industrial enablers. Some of the enablers, which have been identified around Menengai, are as follows:

Availability of land
Large tracts of undeveloped land are available inside the Menengai caldera. GDC is drilling for geothermal steam on gazetted forest land. Besides the forest land there is privately owned land inside the caldera, which is considered suitable for industrial development. This land is relatively flat, free of lava and has minimal vegetation; mainly shrubs as shown in Figure 3.

FIGURE 3: Identified land for the proposed Menengai geo-industrial park

Availability of energy
Drilling for geothermal energy in Menengai is expected to generate large amounts of thermal and electrical energy, which can be obtained cheaply for utilisation by industries. The close proximity of the industrial park to the Menengai geothermal field means that energy will be transported for a short distance to the industries that need it.

Availability of raw materials
Menengai is surrounded by an area of rich agricultural potential. This area, which includes Bahati, Kuresoi, Njoro, Molo, Naivasha, Rongai, Subukia and Kabarak produces a number of agricultural products which are raw material for industries. These include milk, livestock, poultry, fish, cereals, sisal, oil seeds, fruits and vegetables among others.

Availability of labour
Industries require well-trained personnel who should be capable of carrying out administrative as well as industrial production functions competently. Most of the major universities in Kenya have campuses in Nakuru and offer courses that cover engineering, scientific and arts disciplines. The students graduating from these universities will present the industries with a pool of professional to recruit from. In addition, there exists an industrial zone in Nakuru town from which industries in Menengai can access experienced labour force. In the districts of Nakuru North and Menengai west, both of which surround Menengai geothermal field, the youths have formed savings and credit cooperative organisations (SACCOs) for purposes of employment; from which GDC hires skilled and non-skilled casual labour. The same SACCOs could also provide labour to the industries in Menengai.

Availability of housing
The growth of property market in Nakuru has been high in the past couple of years. Houses for high, medium and low income earners have been built within Nakuru town and its environs and are available for purchase and/or rent.

Market for industrial products
The Menengai geo-industrial Park will be located approximately 30km from Nakuru town by road. Nakuru is one of the fastest growing towns in Kenya with a population of around 310,000 people. Nakuru town is located within the larger Nakuru County, which has a population of 1.7 million people, who are potential consumers of the processed goods from the industries (Nakuru County, 2013). In addition, Nakuru is situated within 200 km of both Eldoret and Nairobi, which also have a high population of people with the purchasing power for industrial goods.

Education
Nakuru is home to some of the best schools in the country. The schools include primary schools, secondary schools, midlevel colleges and universities. Nakuru has public, private as well as international schools.

Hospitals
Hospitals to provide health care to the industrial workers are situated mostly in Nakuru town. The hospitals are both public and private. A number of clinics, which specialise in different health aspects are also found in Nakuru.

Recreation
A number of social and night clubs are located in Nakuru town for people to relax and socialise. Many eateries, hotels and resort are also found in Nakuru. The Nakuru national park is yet another facility available in Nakuru for visitors to see wild life and relax.

Transport services
The Nairobi-Nakuru-Eldoret highway, which is part of the northern transport corridor passes through Nakuru town and is a major transport route for industrial goods. Menengai is accessible by road through Nakuru-Kabarak road to the south and Nakuru-Nyahururu road to the East; both of which are paved roads. The caldera is accessible through all-weather dirt roads, which are maintained by GDC. A railway line offering freight services passes through Nakuru town and can be used to transport bulky industrial goods as well as raw materials. In addition, a standard gauge railway is being constructed to pass through Naivasha, a sub county of Nakuru county. Eldoret and Jomo Kenyatta International airports are also situated within 200 km of the Menengai geo-industrial park.

Banking services
Credit and banking facilities are very critical for industrial development. To this effect, all the major banks in the country have established branches in Nakuru to tap into the rapidly expanding population and economy of the town. These financial institutions will be of great value to the industries, which will set up at the industrial park in Menengai.

Communication
The services of all the major telecommunication companies in Kenya are available in Menengai. GDC has installed equipment for data communication in Menengai. Postal and courier services are available in Nakuru town.

Water quality and supply
Menengai is a water scarce area. The permanent rivers in the area are Molo and Rongai in the North Western part. The perennial rivers are the Crater and Olbanita streams in the eastern parts. Productive boreholes in the area are characterized by very shallow, low-yield aquifers that get depleted fast since the deeper formations are impervious (African Development Bank, 2011). However, GDC has drilled 5 boreholes in the caldera which supply the water needs for the drilling operations. The Nakuru water and Sanitation Company (NAWASCO) supplies water to the drilling camp for domestic use. Rain water harvesting is a critical source of water for most households in Menengai, where about 80% of the population depends on harvested rain for their daily water needs (Nakuru County, 2013).

3. PROPOSED INDUSTRIES FOR THE MENENGAI GEO-INDUSTRIAL PARK

The prevalence of agricultural based activities in Menengai means that the core industries expected to drive the development of an industrial park in Menengai will be agro-processing based. However, other non-agricultural based industries whose energy requirements can be met using geothermal energy will also be part of the park. Previous work done by GDC and USAID identified some key industries which could be potential customers for geothermal energy in Menengai (VEGA, 2014a). Some of the identified industries are discussed below.

Horticulture

Horticulture entails the production of fruits, vegetables and flowers (floriculture). The Kenyan horticulture subsector contribute about 3% to the country's GDP. Floriculture alone employs over 500,000 people in Kenya and covers an area of 4,000 hectares (VEGA, 2014b). While most farmers practice open field horticulture, there is a growing trend in Kenya for farmers to invest in greenhouse farming. This is evidenced by the numerous greenhouse suppliers in the market today such as: Amiran, Elgon Kenya, Hortipro, Nguzo international, etc. The use of greenhouses has been necessitated by unpredictable weather patterns, which have affected open field horticulture negatively and the need for better environment control, which results in a good harvest (The Organic Farmer, 2011). The crops that the small scale farmers are growing in these greenhouses are high value crops such as tomatoes, cucumbers, pepper and capsicum for the domestic market; mainly for hotels, supermarkets and open air markets. Medium and large scale farmers are using greenhouses to grow flowers, fruits and vegetables for export.

The trend in the production of horticultural crops in Kenya is as shown in Table 1.

TABLE 1: Horticultural productivity

	2010			2011			2012			
	Area (Ha)	**Quantity (Ton)**	**Value (KSh. Million)**	**Area (Ha)**	**Quantity (Tons)**	**Value (KSh. Million)**	**Area (Ha)**	**Quantity (Tons)**	**Value (KSh. Million)**	**Share by value**
Vegetables	277,284	4,600,000	85,736	277,578	4,642,522	95,564	336,517	6,084,341	104,920	48%
Flower	3,419	133,736	44,964	3,213	123,270	41,608	4,039	878,067	39,685	18%
Fruits	158,291	2,768,435	50,578	177,715	2,848,028	60,645	166,915	5,236,365	61,524	28%
Nuts	94,838	123,221	3,796	99,576	147,583	5,876	98,063	226,785	6,900	3%
Maps	4,173	2,673	44	7,004	15,034	429	17,301	152,430	4,940	2%
Total	**538,055**	**7,628,065**	**185,118**	**565,086**	**7,776,437**	**204,122**	**622,835**	**12,577,988**	**217,969**	**100%**

Generally, there has been a sustained growth of horticulture in Kenya. The total acreage, the quantity produced and the value of the produce has been consistently increasing over the years (VEGA, 2014b). Greenhouse heating is being practiced in Kenya by Oserian Development Company, a floriculture firm, which exports cut flowers to Europe. The main reason for heating greenhouses in Kenya is to lower the humidity of air below 85% especially during the early morning hours when the air temperature approaches the dew point. This prevents condensation of water on the leaves of the crop hence reducing incidences of fungal diseases. Furthermore, greenhouse heating maintains the temperature at an optimal level for the growth of the crop resulting in improved productivity of 15-25% and early maturity of the crop. Greenhouse heating is done for a period of between 6 and 8 hours per day. The amount of energy required to regulate relative humidity is about 300 kWh/ha. (VEGA, 2014c). Greenhouse used for intensive floriculture propagation should be heated to at least 20°C at all times and their energy requirement is approximately 1,000 kWth/ha (VEGA, 2014b). This is shown in Table 2.

Geothermal water at 55°C, can be used to provide thermal energy to heat the greenhouses. Hot water at 100°C can provide energy for cold storage using Lithium Bromide vapour absorption refrigeration systems (VEGA, 2014b).

A greenhouse consumes around 0.6 kg/s of water per hectare for irrigation. However, through the use of hydroponics which allow for irrigation water recycling by as much as 30%, the water consumption for irrigation can come down to about 0.44 kg/s (VEGA, 2014b).

TABLE 2: Energy requirement for greenhouse heating

Facility	Process	Energy usage (kWth/ha)	Temp. (°C)
Fruit/vegetable greenhouse	Temperature & humidity control	300	55
Floriculture propagation greenhouse	Temperature & humidity control	1,000	
Cold store	Temperature control		100

Aquaculture

Traditionally, Kenya has relied on wild catch fisheries to supply its market with fish but a decline in the wild fish stocks led to a decline in per capita supply of fish from 6.1 to 2.8 kg/year between 1999 and 2005. This resulted in a change of policy in the fisheries sector, which put emphasis on the development of aquaculture (VEGA, 2013a). The poverty reduction strategy paper of the year 2000 identified aquaculture as one of the strategies of empowering rural communities. This resulted in the growth of aquaculture to about 4,500 MT in 2007 from 1000 MT in the 1990s. After the economic slowdown of 2008, the government of Kenya initiated an economic stimulus programme in 2009 to spar economic recovery and regional development; which lead to the development and stocking of 52,100 aquaculture ponds in Kenya. This paid dividends as aquaculture production rose to 12,000 MT in 2010. This grew further to 22,000 MT in the year 2012 and as more farmers got involved in aquaculture production (Munguti et al., 2014) as shown in Figure 4.

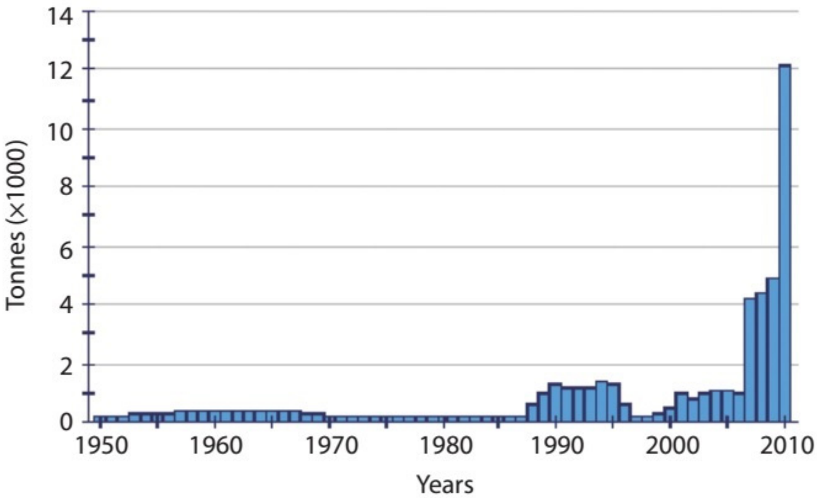


FIGURE 4: Aquaculture production in Kenya (Munguti et al., 2014)

The main species of fish farmed in Kenya are Tilapia and Catfish. Most of the fish from aquaculture farms is sold to the surrounding locality while the urban wholesale and retail markets are served mainly by wild catch from Lake Victoria. It is important to note that aquaculture in Kenya is practised mainly by small scale farmers, who happen to inhabit Menengai.

Tilapia and catfish, the main fish grown in Kenya require 29°C water for optimal growth. This is because at that temperature, the metabolism of the fish is at its peak. Experiments have shown that for every one-degree rise in temperature above 20°C, the metabolism of fish rises by about 3%. By heating the water for aquaculture production in Menengai, which has an average water temperature of 22°C, the growth of fish will improve by approximately 20%. This will require about 1,260 kWth of energy per hectare of aquatic ponds (VEGA, 2014c). The energy required for various processes in aquaculture production is shown in Table 3.

TABLE 3: Energy requirement for aquaculture (VEGA, 2013a)

Facility	Process	Energy usage	Temp. (°C)
Aquaculture unit	Temperature control	1,260 kWth/ha	40
Cold store	Temperature control		>140
Water treatment	Water heating	180 kWth/kg	80

Fish is a highly perishable product, which requires immediate cold storage after harvesting to prolong its shelf life. It is common to park fish in ice to keep it cold during storage and transportation (Odoli, 2009). The production of ice to store fish requires the use of water/ammonia vapour absorption equipment, which should be supplied with hot water at a temperature above 140°C.

The water used for aquaculture operations in Kenya is obtained mainly from rivers and may contain pathogens such as salmonella, which may infect the fish. Heating this water to about 60°C is sufficient to kill these pathogens.

Maintaining an aquaculture unit at a constant temperature requires supply of heated water on a flow through basis throughout the day. Approximately 0.95 kg/s of heated water will be required to maintain a hectare of aquatic pond at 29°C (VEGA, 2014c). The water that flows out of the aquaculture unit should be used as irrigation water for the greenhouses to minimise wastage of the scarce commodity. In addition, this water contains nitrogenous waste from fish excrement, which is a valuable nutrient for plants. It is therefore important to match the irrigation needs of the greenhouse to the flow rate of heated water into the aquaculture unit so that all the water that flows out of the aquaculture unit is used for irrigation. This means that for every hectare of greenhouses constructed, 0.47 hectares of aquaculture should also be constructed.

Milk processing

Kenya produces about 5 billion litres of milk annually, over 85% of which is produced by small scale farmers. The per capita consumption of milk in Kenya was 115 litres in 2012 and the dairy industry growth was 3.5% from the previous year. The dairy subsector contributes about 4% to the GDP of Kenya. According to the Kenya dairy master plan, the per capita milk consumption in the country is set to grow to 220 kg by the year 2030. Several initiatives are being implemented to achieve this such as improving the quality of animals through the use of superior genes, encouraging the use of artificial insemination, improving the quality of feeds and educating farmers on better animal management techniques (VEGA, 2013b).

Only 30% of the milk produced currently goes through the formal markets. 40% is consumed on the farm while 30% is sold to the informal market as raw milk (Ettema, 2015). All the milk produced in Kenya is consumed locally as fresh milk, cultured milk, cheese and butter or processed into powder milk (VEGA, 2013b).

Milk processing by pasteurisation in Kenya is a regulatory requirement by the Kenya Dairy Board. The main products marketed by the milk processors are pasteurised skimmed milk (short and long life), cultured milk (yoghurt and sour milk) and to a lesser extent powder milk. The thermal energy requirements for producing these products are as shown in Table 4.

TABLE 4: Thermal energy requirement for milk processing (Kiruja, 2011a)

Process	Energy usage (kWth/litre)	Temperature (°C)
Low temperature short time pasteurisation	0.056	100
Milk cultures processing Milk sterilisation (UHT)	0.35	130
Powder milk, cheese making	0.5	200
Cold storage		100

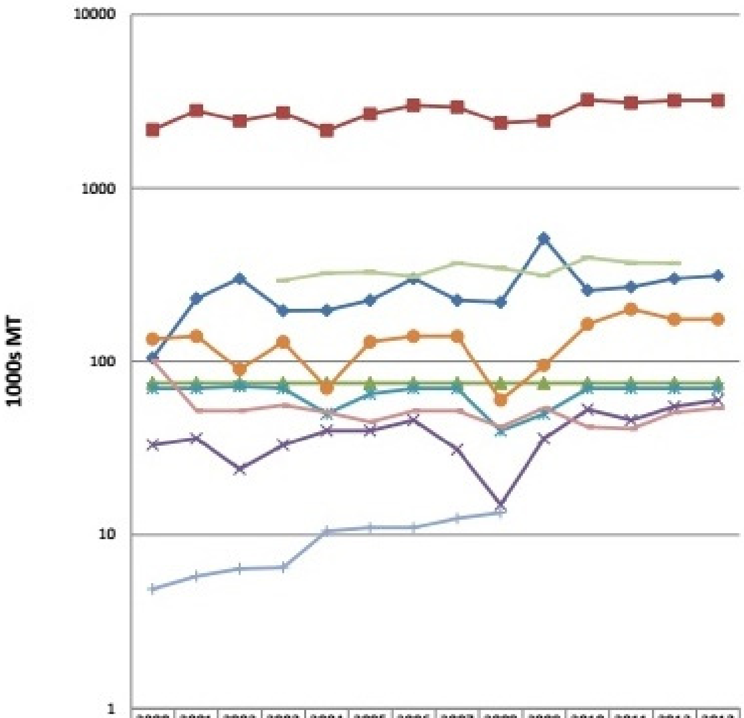
Besides powder milk, which requires very high temperature, the other products can be readily processed using thermal energy from geothermal brine. Production of powder milk would require the use of geothermal steam as the source of energy.

Milk processors consume huge amounts of water for cleaning to meet the high standards of hygiene required in milk factories. At least 0.6 litre of water are required for every litre of milk processed (Kiruja, 2011a). The waste water from milk processors, mostly from cleaning operations, is rich in nutrients. Disposal of this water poses challenges, but it is possible to recycle the nutrients by using the water for irrigation (VEGA, 2013b)

Crop drying
Drying of crops after harvesting is done to reduce the moisture content in order to improve the shelf life. This is because drying considerably slows down the microbial and chemical reactions that take place after harvesting leading to spoilage. Some of the crops produced around Menengai which require drying for preservation include the following:

1. Cereals – maize, wheat, sorghum;
2. Vegetables – kales, onions, amaranth;
3. Fruits – tomatoes, pepper, legumes.

Cereals are the most important crop for drying in Kenya, especially maize. Small-scale farmers form the majority of maize producers in Kenya, producing about 75% of the crop. All the maize is consumed locally, and supplemented with imports, which account for about 10% of the local demand (VEGA, 2014d). The production of various crops in Kenya which require drying is shown in Figure 5.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Wheat	105	230	300	196	197	225	300	225	219	512	256	268	300	312
Barley	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Rice	33	36	24	33	40	40	46	31	15	36	53	46	55	60
Millet	70	70	72	70	50	65	70	70	40	50	70	70	70	70
Sorghum	135	140	90	130	70	130	140	140	60	95	164	200	175	175
Macadamia	4.9	5.8	6.4	6.5	10.5	11	11	12.5	13.5					
Coffee	101	52	52	56	51	45	52	52	42	54	42	41	51	54
Tea				293	324	328	310	369	346	314	398	371	369	
Maize	2160	2792	2430	2710	2140	2670	3000	2930	2367	2439	3222	3100	3200	3200

FIGURE 5: Crop production in Kenya (VEGA, 2014d)

Vegetables are dried mainly to be used as additives in soups and to preserve the excess harvest when a market glut occurs (Basak et al., 2014). In Kenya, however, fruits and vegetables are mostly sold fresh, for local or export markets.

The main sources of energy used to dry crops in Kenya are solar, wood fuel and heavy fuel oils depending on the scale of drying involved. Industrial drying is achieved using hot air at a temperature of 50-100°C. The crops with potential to benefit from geothermal drying around Menengai are maize and onions. Onion dehydration requires 55 MJ/kg of dried produce to reduce the moisture from 80% to 4% (Lund and Lienau, 2003). Maize requires 350 kJ/kg to dry from 27% to 13% moisture content while sliced fruits require 900 kJ/kg to dry from 80% to 20% moisture content (Kinyanjui, 2013). Drying can be done using batch or continuous dryers. In batch drying the produce is exposed to elevated temperature for 2-24 hours to achieve the desired moisture content; therefore, the maximum drying temperature should not exceed 75°C, to avoid compromising the quality after drying (Basak et al., 2014). However, for continuous drying, elevated temperature does not have adverse effects on the produce because the exposure is for a short period. Table 5 shows the energy requirements for drying different crops.

Whereas the energy needs for drying operations are high, the dryers are expected to operate at full capacity only during the harvesting season. However, they will still be operating at a lower capacity during off season period to maintain the desired moisture contents in the stored crops.

TABLE 5: Energy requirement for crop drying (Basak et al., 2014)

Crop	Energy consumption (kJ/kg of dried produce)	Final moisture content (%)	Temp. (°C)
Onion	35,000	4	50-120
Grain	350	13	55-90
Fruit	900	20	50-60

Abattoir operations
Livestock sub-sector accounts for about 50% of the agricultural GDP and 12.5% of the national GDP. The livestock for meat production are reared mainly in the Northern and North Eastern regions of the country by pastoral communities. These animals find their way into the abattoir of the major cities and towns in Kenya such as Nakuru, where they are slaughtered for meat. The slaughter figures for Nakuru are shown in Table 6.

TABLE 6: Slaughter figures for Nakuru in 2012 (Chabari, 2014)

District	Bovine	Ovine	Cap.	Porc.	Chicken	Turkey	Ducks	Rabbits
Naivasha	12,293	13,002	3,587	28	12,167	32,314	20,254	-
Rongai	1,833	3,232	4,382	50	4,890	-	-	-
Molo	1,616	7,295	274	0	1,590	-	-	-
Gilgil	1,993	6,133	1,814	158	30	-	-	95
Njoro	2,698	11,272	1,660	8	259	-	-	-
Nakuru North	2,795	10,512	2,670	524	27,718	-	-	-
Kuresoi	2,973	2,465	563	0	0	-	-	-
Subukia	763	3,055	1,361	13	65	-	-	-
Nakuru	4,682	15,212	4,488	615	33,554	-	-	20
Total	**31,646**	**72,178**	**20,790**	**1,396**	**80,273**	**32,314**	**20,254**	**115**

Abattoirs are categorised depending on their throughput. Category A abattoirs are those with a minimum throughput of 200 heads of cattle and a similar number of goats and sheep per day. Export level abattoir require chilling capability to achieve at least -10°C for 24 hours in addition to having all category A requirements (Chabari, 2014).

Nakuru municipality is served by six abattoirs, five privately owned and one owned by the municipality. The county government of Nakuru has indicated the need to replace the dilapidated municipal abattoir, which was constructed in 1943. The alternative is to establish a new abattoir in Menengai and benefit from the use of geothermal energy.

Hygienic conditions in an abattoir must be maintained at very high standards to avoid accumulation of microbial, which could cause diseases to humans. This requires hot water to melt away the animal fats, which stick on surfaces and create breeding ground for the germs. Other operations requiring thermal energy include freezing of the meat, precooking of meat for canning and sterilising the canning containers. The energy needs of an abattoir are as shown in Table 7.

TABLE 7: Energy requirement for abattoir operations (Kiruja, 2011b)

Process	Temp (°C)
Cleaning	80
Freezing	>140
precooking & canning	120
Sterilisation of containers	110

Precooking operation is performed before canning by boiling or steaming the meat. The containers used for canning should be sterilized using heat before the meat is canned. Within the first 24 hours after slaughtering, meat should be chilled to prevent it from developing a sour taste (Kiruja, 2011b).

Hides and skins treatment
Kenya's leather industry has a good support in terms of the source for the raw material and the market for the finished products. The industry is made up of four main sub-sectors; raw material base (hides and skins), tanneries, footwear, and leather goods manufacturing.

Kenya currently exports leather and leather products worth $140 million as semi processed ''wet blue'' leather (89%), finished leather (2%), leather products (4%) and raw hides and skins (5%) (Ministry of Industrialisation and Enterprise Development, 2015). In return, the country imports shoes worth $86 million annually. On the contrary, the local manufacture of shoes would create about 35,000 jobs and contribute $200 million to the country's GDP (MIED, 2015b). The leather industry has grown consistently over the years as shown in Figure 6.

FIGURE 6: Growth of the Kenya leather industry (MIED, 2015b)

If an abattoir is located in Menengai, a tannery would be located next to it, so that it could use the hides and skins from the slaughtered animals as its raw materials. Nakuru currently has only one operational tannery, which processes 200 tons of salted cow hides and 150,000 pieces of goats and sheep skins monthly.

A tannery requires thermal energy for drying of the processed leather and to heat water to the temperatures needed for chemical processes. Water at a temperature of 35°C – 65°C is required mainly during the tanning process. In addition, hot air of up to 80°C will be required to dry the treated leather. On average, 25 MWh/1,000 m^2 of leather is required in a tannery, of which 50% is consumed by thermal processes (Cotance and IndustriAll, 2012).

Water consumption in leather treatment averages 11.3 litres/sq. foot of finished leather (ShoeBAT, 2014). However, it is possible to recycle about 70% of the water used in leather processing as reported by Alpharama Ltd, the biggest tannery by output operating in Kenya.

Edible oils and soaps processing

Kenya imports crude palm oil from Malaysia to process into refined edible oils in addition to using pressed oils from locally growth oilseeds such as sunflower, Canola, rapeseed, soy and maize germ. Most of the processed oil is consumed within the country, though a small amount is exported regionally as shown in Figure 7.

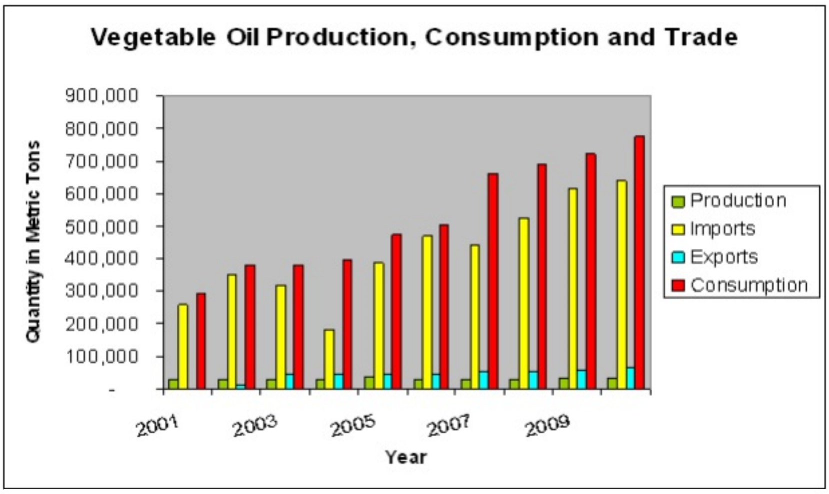


FIGURE 7: Kenya's edible oil industry (Schatz, 2009)

The refining process is energy intensive and involves the application of thermal energy to catalyse some processes or to evaporate impurities. The thermal energy processes together with their energy needs are summarised in Table 8.

TABLE 8: Energy requirement for edible oils refinery (Sulaiman et al., 2012)

Process	Energy usage (kWth/kg)	Temp. (°C)
Degumming & Neutralisation	121	90
Bleaching	40	110
Deodorizing	317	200
Storage	0.004	70

Most of these processes can be achieved by using hot geothermal water except deodorizing, which requires the crude palm oil to be heated to over 200°C using steam to evaporate the volatile impurities. The bleaching operation gets rid of chlorophyll from the oil while neutralising removes the acids, which are present. The refined oil is stored at 70°C so that it does not solidify.

Textile manufacture

The Kenyan textile and clothing industry is dominated by export oriented apparel companies who manufacture and sell clothes for the United States market duty-free, courtesy of the African Growth and Opportunities Act which was enacted in 2001. The apparel companies depend largely on imported fabric for their operations. However, the textile industry was included in Kenya's vision 2030 as a target sector to drive the country's industrialisation plan (McKinsey and Co., 2015). There is renewed focus on the upstream of the textile value chain with the revival of ginneries and garment manufacturers such as Rivatex be targeted; in addition to incentivising the cotton farmer through competitive pricing for their produce (Ministry of Industrialisation, 2010).

The presence of a well-established apparel industry in Kenya which is estimated to have generated over $415 million in exports to the US alone will be of great benefit to the recovering textile industry (MIED, 2015a). In addition, many of the international apparel companies such as H&M are starting to turn to African countries to source for fabrics because the demands for higher wages in China, which is the main source of fabric, has driven up the cost of doing business. A survey by McKinsey and Co. on the preferred source of fabric by the apparel manufacturers showed that Kenya was rated highly as shown in Figure 8.

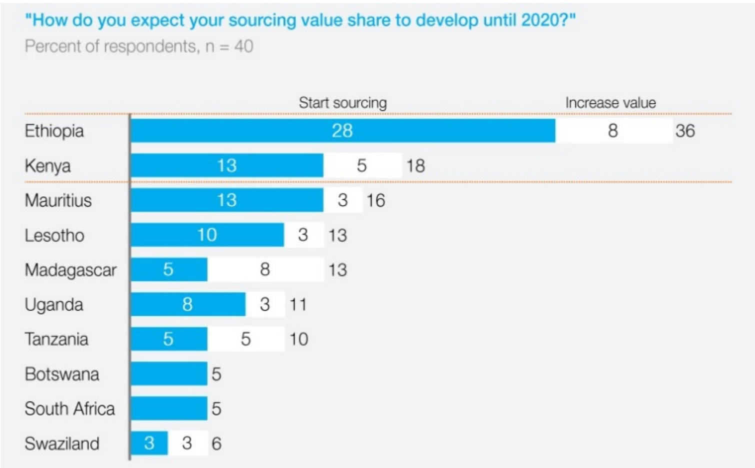


FIGURE 8: Preferred sourcing of textile fabric by apparel companies (McKinsey and Co., 2015)

The processes involved in textile manufacture require electrical energy, thermal energy and fresh water. In total, seven (7) processes require water usage at a temperature of 60-100°C. Drying of the fabric in tumble dryers requires hot air at a temperature of 80°C. These requirements are summarised in Table 9.

TABLE 9: Thermal energy requirements for textile manufacture processes (Mwaura, 2015)

Process	Temp. (°C)
Chemical processes	60 - 100
Drying	100

The chemical processes in textile manufacture are water intensive. The water to fabric ratio for these processes is 10:1. After the chemical processing, the fabric is dried in tumble driers.

Most of these potential customers of thermal energy at Menengai industrial park were identified through a study conducted by GDC and USAID based on the following criteria (VEGA, 2014a):

a. The energy requirements of the industry must be within a range that can be supplied using geothermal energy;
b. The availability of a market for the processed industrial goods, either local or export;
c. The potential of the industry to attract investors based on return on invest of the venture, availability of raw materials, capacity of the industry among others;
d. The potential of the industry to create jobs for the communities living close to the geothermal field;
e. Socio-cultural acceptability of the industry within the locality where it will be established;
f. The potential of the industry to generate positive environmental impacts such as displacing the use of fossil fuels;
g. The potential of the project to be replicated in other regions.

4. ENERGY SUPPLY IN THE MENENGAI GEO-INDUSTRIAL PARK

Petroleum products, mainly furnace oil and industrial diesel oil are the most common fuels for powering industrial activities in Kenya. Though commercially viable petroleum reserves have been discovered in Kenya, exploitation has not begun. This means that the country has to rely on imported fuels to keep the industries running. About 500,000 metric tonnes of diesel oil is consumed by Kenyan industries annually as shown in Figure 9 (Kenya National Bureau of Statistics, 2016).

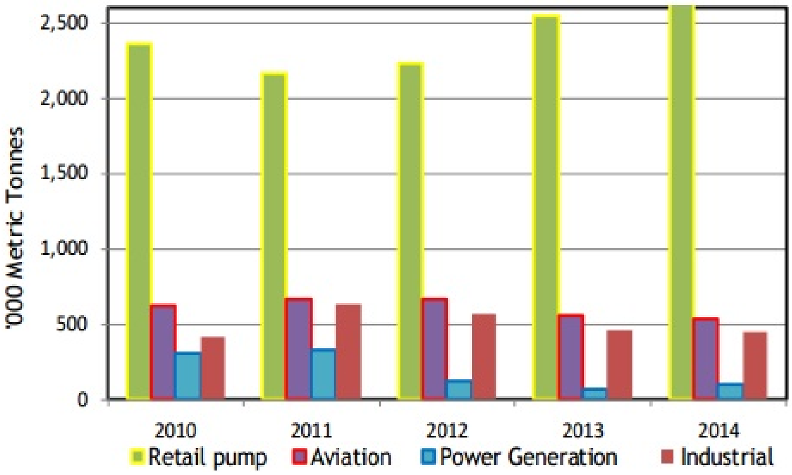


FIGURE 9: Fossil fuel consumption in Kenya (Kenya National Bureau of Statistics, 2016)

Firewood as a source of industrial energy is utilised mainly by tea factories and tobacco factories. Other industrial users of firewood include vegetable oil refineries, milk processors, fish smoking, brick making, bakeries and jaggeries (Nyambane et al., 2014). Most of these industries are located in the rural areas, with tea factories being the major consumer of firewood. The use of firewood by tea factories instead of furnace oil results in energy cost savings of about 60%. The consumption of firewood by industries in the year 2000 was estimated at 500,000 tonnes (Githiomi and Oduor, 2012).

The use of fossil fuels and firewood as sources of industrial energy is associated with negative environmental impacts such as air pollution due to the release of particulate matter into the atmosphere, global warming due to the release of greenhouse gases and deforestation due to the cutting down of trees among others.

The proposed Menengai geo-industrial park seeks to address some of these negative aspects of conventional fuels. The thermal energy, which will be used by the industries in the Menengai geo-industrial park will be obtained from the geothermal well drilled in Menengai geothermal field. Though these wells have been drilled primarily for electricity generation, the fluids whose energy will not be used for electricity generation will supply thermal energy to the park. The following sources of thermal energy were considered:

a. Brine from low enthalpy and low-pressure geothermal wells which cannot be connected to the power plant;
b. Separated brine, which is a by-product of electricity generation.

The amount of energy, which can be obtained from the brine will depend on the enthalpy of the geothermal brine, the flow rate of the brine as well as its chemistry. A high enthalpy, high flow rate and low chemical concentration means more energy is available from the brine.

4.1 Sources of thermal energy in Menengai

In Menengai geothermal field, steam for electricity generation will be obtained from separator stations at a pressure of 7 bar absolute. Therefore, any well that discharges geothermal fluid at a pressure less than 7 bar is considered unsuitable for electricity generation. The geothermal wells are drilled on different well pads, with each well pad accommodating at least one well. A geothermal steam gathering system has already been built to collect energy from the wells. The design of the Menengai steam gathering system consists of six separator stations (SS) as shown in Figure 10. Each of these stations will be connected to one or more well pads. The separated steam from all the separator stations will be collected into the main steam pipeline and directed to the power plant for electricity generation.

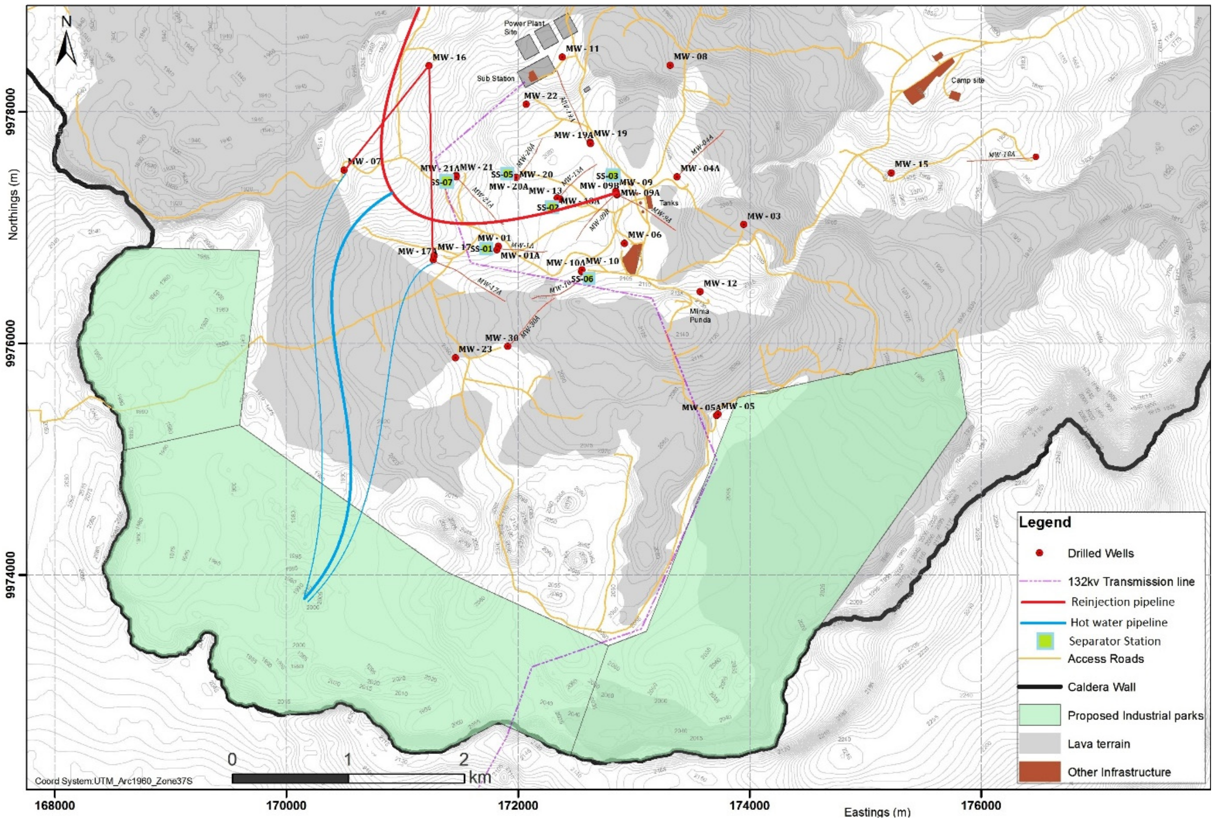


FIGURE 10: Sources of thermal energy in Menengai

All the separator stations will be connected to the brine reinjection pipeline, which will collect the separated brine and transports it to the reinjection wells. The separated brine will be at a pressure of 7 bar absolute and its enthalpy will be 697 kJ/kg and a temperature of 165°C.

An analysis of the discharge data for 11 wells, which have a high likelihood of being connected to the power plant shows that 370 ton/h of separated brine will be generated. The wells under consideration are MW-01, MW-01A, MW-09, MW-09B, MW-10A, MW-13, MW-19, MW-19A, MW-20, MW-20A and MW-21A. The amount of separated brine is likely to increase as more wells are being drilled in Menengai. It is this brine, which will be considered as a source of thermal energy for the Menengai geo-industrial park.

In addition, three low-pressure wells were also analysed as possible sources of thermal energy to the park. These are MW-07, MW-17 and MW-17A. These wells were selected because they are located close to the identified site of the park. The data used to determine the thermodynamic properties of the brine from these wells is based on discharge through a lip pressure pipe of 8" diameter. The thermodynamic properties of the brine from the various source is shown in Table 10.

TABLE 10: Thermodynamic properties of brine from different sources in Menengai

Source of thermal energy	Discharge pressure (bar)	Flow rate (Ton/h)	Enthalpy (kJ/kg)	Brine temp. (°C)
Separated brine	7	370	697	165
MW-07	2.6	160	504	130
MW-17	2	85	483	120
MW-17A	5	150	568	150

Since the low-pressure wells discharge at a pressure less than 7 bar absolute, they are considered unsuitable for electricity generation and therefore; they can supply heat energy to the geo-industrial park. These wells generate between 85 and 160 ton/h of geothermal fluid at a discharge temperature is at least 120°C, hence they contain a lot of energy, which can serve the various thermal energy needs of industries.

4.2 Geothermal brine chemistry

Geothermal fluids contain several dissolved substances, which might not be desirable to the operations of the industries. In addition, these substances present challenges during the utilisation of geothermal energy such as scaling on the surfaces of equipment. Of great concern in this respect is silica, whose solubility in water is dependent on its concentration and the temperature of the water. At a given concentration, silica remains in solution until the amorphous silica saturation temperature is reached. Below the saturation temperature, silica begins to precipitate from the solution and could form scales on equipment such as pipes and heat exchangers. This is shown in Figure 11.

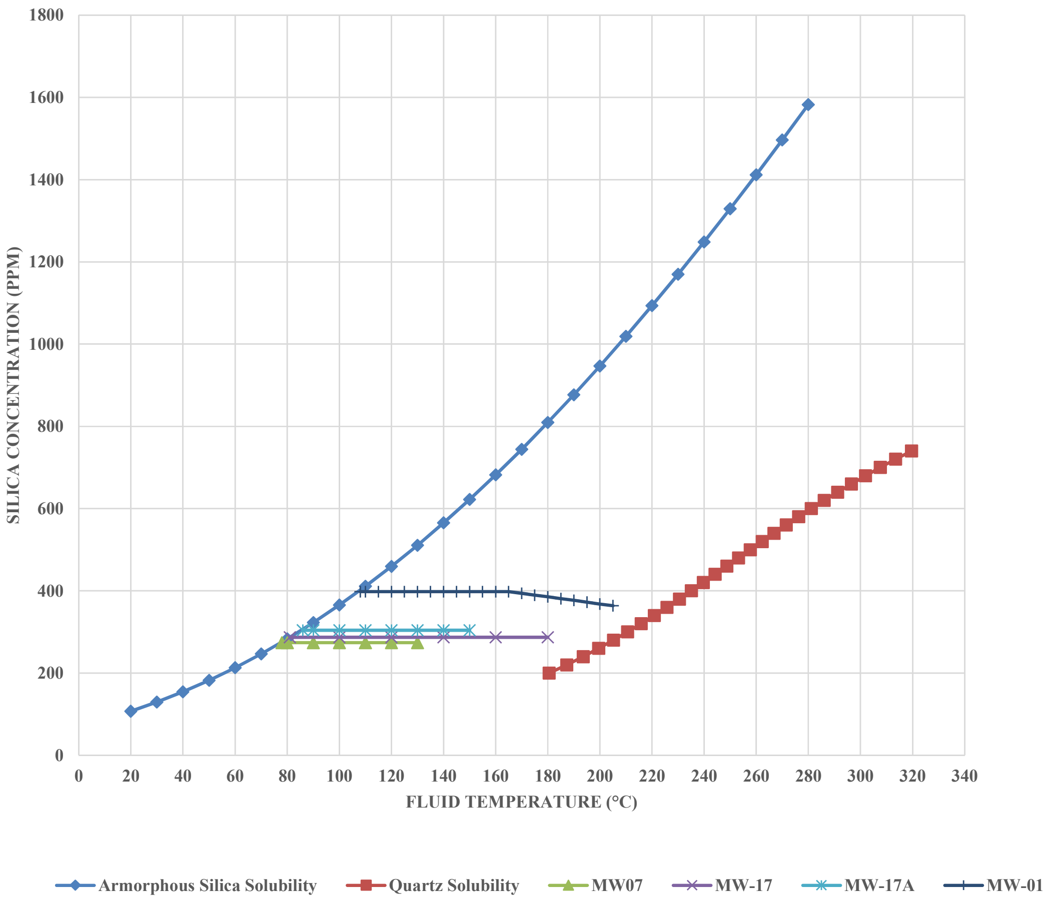


FIGURE 11: Silica solubility curves for fluids from selected wells in Menengai

The behaviour of silica in the brine from the three low-pressure wells and the separated brine was analysed and presented in Figure 6. One of the wells, which will be connected to the power plant, MW-01, was assumed to be representative of the conditions of the separated brine in the brine reinjection pipeline. As steam gets separated from the brine in MW-01, the concentration of silica in solution increases until separator condition of 7 bar absolute and 165°C is attained. Below this temperature, the concentration of silica remains constant while the brine is being cooled, until the silica saturation temperature is attained. For the low-pressure wells, steam and brine are not separated and therefore, the concentration of silica remains constant during cooling until precipitation begins.

To avoid downstream challenges such as scaling during the utilisation of geothermal energy, it is important to use heat exchangers to extract the heat from the brine. In this regard, only fresh water is used to transport the energy for utilisation to the industries as shown in Figure 10. Care should be taken during the extraction of heat from brine to ensure that the temperature of the brine does not drop below the silica saturation temperature for the given concentration of silica. The silica saturation temperature for each of the four sources of thermal energy under consideration is shown in Table 11.

TABLE 11: Silica concentration and saturation temperature for some wells in Menengai

Source of thermal energy	Silica concentration (ppm)	Silica saturation temp. (°C)
Separated brine	398	108
MW-07	274	78
MW-17	287	81
MW-17A	304	86

The silica saturation temperature for a given concentration is determines by the silica geothermometer shown in Equation 1, which describes the solubility of silica as a function of temperature and concentration (Fournier and Potter, 1982).

$$t = \frac{731}{4.52 - log10(C_{SiO2})} - 273.15 \quad (1)$$

where, t - Silica saturation temperature (°C);
C_{SiO2} - Concentration of silica in geothermal brine (ppm).

4.3 Energy extraction

Heat exchange involves the extraction of thermal energy from one fluid into another while keeping the two fluids separated (Haslego and Polley, 2002). This separation of the fluids is achieved using a heat exchanger. The most important properties that a heat exchanger should have are high thermal conductivity and high heat transfer coefficient between it and the fluid. In addition, the heat exchanger should be constructed from a material that can withstand corrosion and fouling caused by the fluids exchanging heat. Furthermore, the walls of the heat exchanger should be thin to facilitate quick flow of heat between the fluids.

There are two types of heat exchangers to choose from based on the application under consideration: shell and tube and plate type heat exchanger. For applications involving geothermal fluids, plate type exchangers are preferred because they can be cleaned easily when fouling occurs. Plates can also be added or removed to match the energy demand to the energy supply.

4.3.1 Heat exchange

In order to achieve greater heat recovery through heat exchange, a counter current flow of the fluids is preferred to a parallel flow. This is because the outlet temperature of the cold stream ($T_{c, out}$) greater than the outlet temperature of the hot stream ($T_{h, out}$) can be achieved with a counter current flow. In addition, the temperature difference between the hot and cold streams remains relatively constant at any point in the heat exchanger, hence, the rate of heat exchange remains relatively constant as the fluids move through the entire length of the heat exchanger. This is shown in Figure 12.

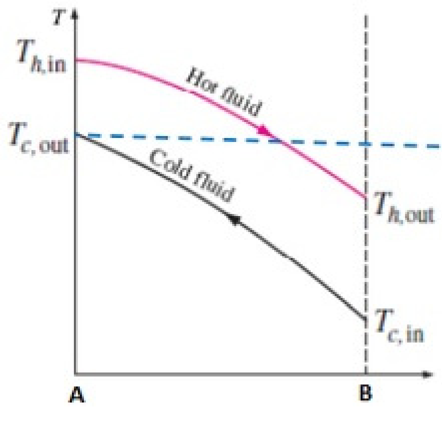


FIGURE 12: Counter current flow temperature profile (Haslego and Polley, 2002)

The amount of energy, which can be extracted through a heat exchanger is determined by the available area of the heat exchanger, physical and thermal properties of the heat exchanger material and the temperature difference between the hot and cold fluid streams. This relationship is represented by Equation 2 (Haslego and Polley, 2002):

$$\dot{Q} = A_{hex} * U * LMTD \quad (2)$$

where A_{hex} - Surface area of the heat exchanger (m^2);
U - Overall heat transfer coefficient (W/m^2 °C);
$LMTD$ - Logarithmic temperature difference (°C).

During the heat exchange process, fresh water should be heated to the highest possible temperature. However, since most of the thermal industrial processes under consideration require at most 130°C, this temperature was selected as the heat exchange temperature. It was assumed that the fresh water enters the heat exchanger at 22°C and that the brine should exit the heat exchanger at least 5°C above the silica saturation temperature. The resultant heat exchange parameters are shown in in Table 12.

TABLE 12: Heat exchanger design parameters

Source of thermal energy	Brine outlet temp. (°C)	Cold outlet temp. (°C)	LMTD	Effectiveness
Separated brine	113	135	55	0.79
MW-07	83	120	28	0.91
MW-17	86	110	29	0.90
MW-17A	91	135	35	0.88

The rate of energy extraction from the brine is determine using Equation 3. Using the energy balance between the hot and cold streams, the flow rate of the cold stream was determined using the same equation (Lienhard IV and Lienhard V, 2016):

$$\dot{Q} = \dot{m} * C_p * \Delta T \quad (3)$$

where $\dot{m}$ - Mass flow rate (brine, fresh water) (kg/s);
C_p - Specific heat capacity (brine, fresh water) (kJ/kg °C);
ΔT - Temperature difference (brine, fresh water) (°C).

Table 13 shows the amount of energy that can be extracted from the brine considering the previously assumed brine and fresh water conditions.

TABLE 13: Energy extracted from different sources of brine

Source of thermal energy	Energy available (MWt)	Fresh water mass flow rate (kg/s)
Separated brine	22.6	47.8
MW-07	8.8	21.4
MW-17	3.3	9.0
MW-17A	10.4	21.9

5. ENERGY DEMAND IN THE MENENGAI GEO-INDUSTRIAL PARK

In order to estimate the energy demand in the geo-industrial park, the energy needs for each of the industries discussed in the markets section (Chapter 2) were estimated. This estimate was based on an assumed size for each of the industries and an estimate of the thermal energy consumed by the industrial processes in those industries. The size of the industries was based on the recommendation of studies that have been conducted by GDC in collaboration with its partners as well as the size of similar industries in Kenya. The thermal energy, which is to be used in these industries will be transported using hot fresh water and therefore, the flow rate of this water into each thermal process was analysed. This flow rate depends on the temperature required by the thermal processes as well as the per unit energy requirement for each of those processes.

5.1 Cascading of energy

The industries which are to be located within the geo-industrial park have different energy needs. Some processes have high temperature requirements while others have lower temperature requirements. Exchange of energy among these processes results in better energy utilisation because a single stream of hot water can meet the energy needs of several processes as shown in Figure 13.

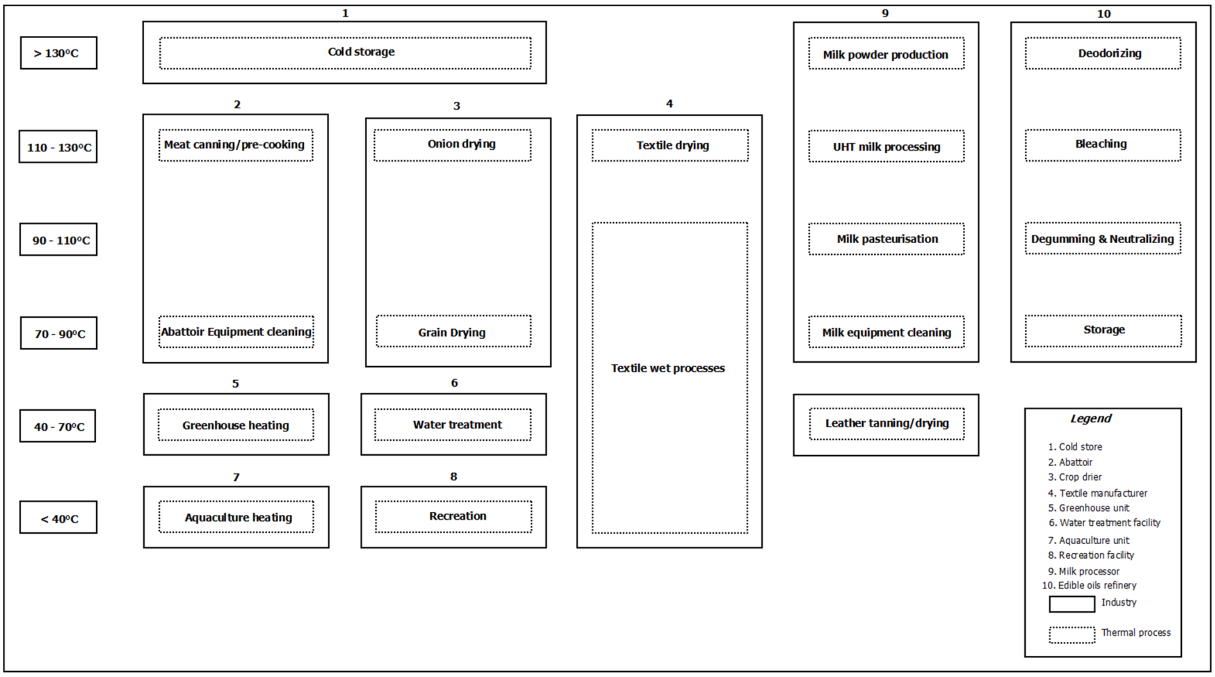


FIGURE 13: Cascading of energy

The thermal processes in the industries were categorised into six temperature bands with each band having a temperature range of 20°C. The highest temperature band comprises of processes, which require more than 130°C while the lowest temperature band processes require less than 40°C. Cold storage, milk powder processing and deodorizing have the highest temperature requirement while aquaculture heating, some wet processes in textile manufacture and recreation facility water heating have the lowest temperature requirements. A stream of hot water can be utilised by as many processes as possible of subsequently lower temperature requirements, where each process extracts some energy from the stream. In case the hot water stream gets into direct contact with a product that is being processed or it is used in cleaning of equipment, then that stream cannot be cascaded down to any other process but is discarded.

The industries requiring temperature above what can be obtained from geothermal sources, i.e. above 130°C are considered unfeasible. Cold storage requires at least 140°C to operate at a reasonable coefficient of performance when using water/ammonia refrigeration equipment in order to achieve freezing conditions. Therefore, the use of vapour absorption refrigeration equipment is considered unfeasible since the hot water is not heated beyond 130°C. The production of powder milk requires 200°C to dry the milk to the required moisture content. Edible oils processing requires at least 200°C for the deodorizing process in order to evaporate the volatile impurities from crude palm oil. Due to the lack of sufficient energy to produce powder milk and undertake deodorizing process, powder milk production and edible oil processing are considered unfeasible. It is important to note that if steam is availed to the geo-industrial park at 15 bars or more, then cold storage, powder milk production and edible oils refining processes would become feasible.

5.2 Energy demand scenarios

Since the energy demand was based on estimates of the thermal requirements for each process as well as an estimate of the capacity of the industries, scenarios were created to analyse the effect of any variations from the base case scenario. These variations in demand are expected to dictate how much energy would be required in the park and which sources of brine would be considered suitable to supply this energy. The sources of energy under consideration are the separated brine and the low-pressure wells. In scenarios where the energy available from a single source was not sufficient, then a combination of sources was considered. When more than one source of brine was used to provide the energy, it was assumed the hot fresh water carrying the energy extracted from those brines would be combined and transported using a single pipeline to the industrial park.

5.2.1 Scenario 1

This is the base case scenario and the most likely scenario. The energy requirements for the industries considered in scenario 1 are shown in Table 14.

TABLE 14: Scenario 1 energy requirements

Industry	Process	Thermal energy requirement	Inlet temp. (°C)	Outlet temp. (°C)	Thermal energy consumption (kJ/s)
Greenhouse	Greenhouse heating	300/1000 kWth/ha	55	40	467
Aquaculture	Aquaculture heating	1,260 kWth/ha	40	-	245
Drying	Onion drying	35,000 kJ/kg	120	80	1,458
	Grain drying	350 kJ/kg	90	75	486
Milk processing	Cleaning		80		1,751
	UHT milk processing	0.35 kWth/litre	130	100	2,370
	Milk pasteurisation	0.056 kWth/litre	100	90	788
Abattoir	Cleaning		90		1,134
	Precooking and canning	1.5 m3/bovine carcass	120	-	1,556
	Equipment sterilisation		120	-	
Tannery	Chemical processes	12 kWth/m2 of leather	65	-	306
	Drying		100	55	
Textile	Chemical processes	10 kg of hot water/kg of fabric	100	-	38
	Drying		110	90	
Recreation	Water heating	180 kWth/kg of water	40		833
Water Treatment	Water heating		80	65	616
Total					**12,047**

Ten hectares of greenhouse were considered, where 2 hectares were for floriculture propagation while 8 hectares were for various fruits and vegetables. Hot water - 7.41 kg/s at 55°C - would supply the greenhouses with sufficient energy.

Aquaculture production would require 4.44 kg/s of hot water at 40°C to maintain 4.7 hectares of aquaculture ponds at 29°C. The constant temperature of 29°C can only be maintained if the heated water is allowed to flow through the aquaculture unit. This size of the aquaculture unit was selected by matching the flow from the aquaculture unit to the irrigation needs of the greenhouse. The water flowing from the aquaculture unit was used for irrigation in the greenhouse to prevent wastage of water.

An onion dryer with a capacity to produce 150 kg of dry onion per hour and a grain dryer with a capacity to dry 5 tons/h of maize were considered. The onion dryer would require 8.1 kg/s of 120°C water to dry onions to 4% moisture content while the grain dryer would require 5.4 kg/s of 90°C hot water to achieve a moisture content of 13% in maize.

A milk processing facility with a capacity of 250,000 litres of milk per day was considered. Between 20-30% of the milk would undergo high temperature short time pasteurisation and be marketed either as ultra-heat treated (UHT) fresh milk or cultured milk. The remaining 70-80% of the milk would undergo low temperature long time pasteurisation and be marketed as pasteurised fresh milk. These processed milk products are popular in the Kenyan market (VEGA, 2013b). 18.81 kg/s of 130°C water and 18.75 kg/s of 100°C water would be required to process both milk products respectively. Since hygiene is critical in a milk processing facility, 5.21 kg/s of hot water at 80°C would be required to clean the equipment and the space used for milk processing.

An export level abattoir with a capacity to slaughter 200 heads of cattle and an equal number of goats and sheep was considered. The abattoir should have refrigeration equipment, which can keep the meat refrigerated for at least 24 hours at a temperature of minus 10°C. In addition, equipment for meat canning should be installed in the abattoir. In order to maintain the required hygienic standards and meet the thermal energy requirements of meat canning, 9.26 kg/s of water at 80-120°C will be required. This is based on the assumption that 1.5m^3 of water is required per a bovine carcass and that 3 ovine carcass are equivalent to one bovine.

If all the hides and skins produced in the abattoir are treated into leather in a tannery located at the geo-industrial park, then 631 m^2 of hides and skins would be processed daily assuming that a bovine hide is 2.3 m^2 and an ovine skin is 0.8 m^2. Hot water at 65-100°C with a flow rate of 2.92 kg/s would be required to meet the thermal energy needs of such a tannery.

A textile manufacturer with a capacity to make 1 ton of fabric daily would require 10 m^3 of water daily to accomplish the wet textile processes. This water at a temperature range of 60-100°C would be required at a flow rate of 0.12 kg/s assuming the factory will operate for 24 hours every day.

A recreational facility consisting of a swimming pool, hot tabs and steam bath and occupying an area of 2,000 m^2 with the average water depth of 1m was considered. The water in this facility would be treated using chemicals, heated to achieve the required temperature and recirculated during cleaning to reduce wastage. However, about 10% of the water will be lost daily through evaporation and cleaning operations and should be replaced. About 4.63 kg/s of water at 50-70°C would be required for this purpose.

The water used in the aquaculture unit and for irrigating crops many contain harmful micro-organisms. It is important to sterilise this water in order to get rid any microorganisms which might be harmful to the fish and the crops. 7.99 kg/s of water at 80°C would be required to heat the aquaculture and irrigation water to a temperature of 60°C in order to kill any disease causing micro-organisms.

Cleaning of equipment and working areas is important for hygiene in the factories. Washing off the fats from foods such as milk, meat and fish requires hot water at 80°C.

In total, 12 MWt would be required to meet the energy requirements of the discussed thermal processes. This would require 93 kg/s of 130°C water. However, none of the analysed sources of brine could generate enough hot water flow rate to meet this demand.

A cascaded model of the thermal processes revealed that the same amount of energy could be supplied using 36 kg/s of 130°C water. This is because a stream of hot water can be used to supply energy to more than one process, provided that the temperature requirement of the downstream process is lower than that of the preceding processes.

Two sources of brine were found to contain sufficient energy and hot water flow rate to satisfy the demand of the industries as shown in Table 15

TABLE 15: Proposed sources of energy for Scenario 1

Source of thermal energy	Energy available (MWt)	Hot water temp. Delivered at the park (°C)	Available fresh water flow rate (kg/s)	Required fresh water flow rate (kg/s)	Proportion of un-utilised hot water
Separated brine	22.6	131	47.8	36.17	24%
Combined MW-07 & MW-17A	19.2	123	43.2	41.89	4%

Whereas both sources of brine have sufficient energy and flow rate to supply the needs of the industries, Combined MW-07 and MW-17A (option 2) has a temperature of 123°C which is less that what is required for UHT milk processing. This can however be addressed by supplying more flow rate of 123°C water to that process. When option 2 was considered as the source of energy, UHT milk processing would require 24.53 kg/s instead of 18.81 kg/s. The needs for the other processes remained unchanged. Both options had some unutilised energy left over which could be used to meet future demand.

In this scenario, cascading reduced the demand for hot water by 61% when the energy is supplied from Separated brine (option 1) and by 58% in the case of option 2.

5.2.2 Scenario 2

In this scenario, the capacity of the industries was reduced by half in comparison to the base case scenario. This was a pessimistic scenario and is shown in Table 16

TABLE 16: Scenario 2 energy requirements

Industry	Process	Thermal energy requirement	Inlet temp (°C)	Outlet temp. (°C)	Thermal energy consumption (kJ/s)
Greenhouse	Greenhouse heating	300/1000 kWth/ha	55	40	233
Aquaculture	Aquaculture heating	1,260 kWth/ha	40	-	123
Drying	Onion drying	35,000 kJ/kg	120	80	729
	Grain drying	350 kJ/kg	90	75	243
Milk processing	Cleaning		80		699
	UHT milk processing	0.35 kWth/litre	130	100	583
	Milk pasteurisation	0.056 kWth/litre	100	90	373
Abattoir	Cleaning		90		756
	Precooking and canning	1.5 m3/bovine carcass	120	-	812
	Equipment sterilisation		120	-	
Tannery	Chemical processes	12 kWth/m^2 of leather	65	-	153
	Drying		100	55	
Textile	Chemical processes	10 kg of hot water/kg of fabric	100	-	19
	Drying		110	90	
Recreation	Water heating	180 kWth/kg of water	40		833
Water treatm.	Water heating		80	65	308
Total					**5,865**

This resulted in about 50% reduction in the amount of energy required by the industries to 5.9 MWt. When the hot water carrying this energy is cascaded through the thermal processes, only about 20 kg/s of hot water would be required. The sources of brine which would supply this energy are shown in Table 17.

TABLE 17: Proposed sources of energy for scenario 2

Source of thermal energy	Energy available (MWt)	Hot water temp. delivered at the park (°C)	Available hot water flow rate (kg/s)	Required hot water flow rate (kg/s)	Proportion of un-utilised hot water
MW-07	8.8	115	21.4	19.93	7%
MW-17A	10.4	129	21.9	19.56	11%

Again, the temperature of the water in MW-07 (option 1) is less than what is required for processing UHT milk. However, with increased flow rate to the process, sufficient energy was supplied.

When the source of energy for scenario 2 is option 1, only 39% of flow rate would be required when compared to the case without cascading. MW-17A (Option 2) would require 42% of the water demanded in the absence of cascading.

5.2.3 Scenario 3

In this scenario, the capacity of the industries under consideration was doubled in comparison to the base case scenario. This was an optimistic scenario as shown in Table 18.

TABLE 18: Scenario 3 energy requirements

Industry	Process	Thermal energy requirement	Inlet Temp (°C)	Outlet Temp (°C)	Thermal energy consumption (kJ/s)
Greenhouse	Greenhouse heating	300/1000 kWth/ha	55	40	933
Aquaculture	Aquaculture heating	1,260 kWth/ha	40	-	490
Drying	Onion drying	35,000 kJ/kg	120	80	2,917
	Grain drying	350 kJ/kg	90	75	972
Milk processing	Cleaning		80		3,501
	UHT milk processing	0.35 kWth/litre	130	100	4,740
	Milk pasteurisation	0.056 kWth/litre	100	90	1,575
Abattoir	Cleaning		90		2,268
	Precooking and canning	1.5 m3/bovine carcass	120	-	3,111
	Equipment sterilisation		120	-	
Tannery	Chemical processes	12 kWth/m2 of leather	65	-	612
	Drying		100	55	
Textile	Chemical processes	10 kg of hot water/kg of fabric	100	-	76
	Drying		110	90	
Recreation	Water heating	180 kWth/kg of water	40		833
Water Treatment	Water heating		80	65	616
Total					**22,644**

This scenario requires 22.6 MWt to meet the thermal energy demand for the industries. A flow rate of 170 kg/s of water at 130°C would be required to supply each of the processes with adequate energy but after cascading, only 72.34 kg/s would be required. Since no single source of energy considered can generate this energy, a combination of separated brine, MW-17 and MW-17A was proposed to supply the energy as shown in Table 19.

Due to cascading of energy, the need for hot water in the industrial park is reduced by 58% in this scenario

TABLE 19: Proposed sources of energy for scenario 3

Source of thermal energy	Energy available (MWt)	Hot water temp. delivered at the park (°C)	Available hot water flow rate (kg/s)	Required hot water flow rate (kg/s)	Proportion of un-utilised hot water
Separated brine plus combined MW-1 & MW-17A	36.4	129	78.7	72.34	8%

Therefore, not only does cascading lead to better utilisation of energy, it also significantly reduces the cost of piping because smaller diameter pipes will be used. In addition, smaller pumps, which require less power to operate would further reduce the cost of the project.

5.3 Energy utilization

The rate of utilisation of energy in the geo-industrial park is dependent on the duration of demand by each process. Some processes are expected to consume energy all day long while the demand by others will be only for a few hours daily. This is illustrated in Table 20.

TABLE 20: Energy demand duration per process

Industry	Process	Operational period (h/day)
Greenhouse	Greenhouse heating	8
Aquaculture	Aquaculture heating	24
Drying	Onion drying	8
	Grain drying	8
Milk processing	Cleaning	2
	UHT milk sterilisation	12
	Milk pasteurisation	12
Abattoir	Cleaning	5
	Precooking and canning	8
	Equipment sterilisation	8
Tannery	Chemical processes	24
	Drying	24
Textile	Chemical processes	24
	Drying	16
Recreation	Water heating	18

Based on the assumed hours of operation for each process, and using the flow rate into each process as the weighting factor, the capacity factor for utilisation of the energy for all the assumed scenarios is shown in Table 21.

TABLE 21: Estimated duration until peak demand is achieved

Scenario	Option	Source of energy	Duration (years)	Capacity factor
Scenario 1	Option 1	Separated brine	13	51%
	Option 2	MW-17 & MW-17A	14	51%
Scenario 2	Option 1	MW-07	14	53%
	Option 2	MW-17A	13	54%
Scenario 3	Option 1	Separated brine, MW-17 and MW-17A	13	48%

The geo-industrial park is expected to begin its operations with a few industries and then over the years, more industries would be established. It was assumed that the first industries to establish their operations in the park will be greenhouses and aquaculture production units. This is because they are relatively cheap to construct and operate.

Greenhouses and aquaculture utilise about 20% of the available flow for all the scenarios. This was considered to be the demand during start-up. Over the years, the demand was expected to grow at an annual rate of 15% until all the available energy has been utilised. The time it takes to achieve maximum demand is shown in Table 21.

For all the assumed scenarios, it will take between 13 and 14 years for the design peak demand to be achieved in the industrial park.

5.4 Water recirculation

Menengai is a water scarce area. Therefore, every effort should be made to conserve as much water as possible. The water which is not used for cleaning or which does not come into direct contact with the product being processes should be recirculated back to the heat exchanger, to extract more energy from the brine. Table 22 shows the amount of water, which was recirculated for each of the scenarios under consideration.

TABLE 22: Water recirculation

Scenario	Option	Source of energy	Demand flow rate (kg/s)	Recirculated flow rate (kg/s)	Proportion of recirculation
Scenario 1	Option 1	Separated brine	36.17	9.61	27%
	Option 2	MW-17 & MW-17A	41.89	15.33	37%
Scenario 2	Option 1	MW-07	19.93	4.64	23%
	Option 2	MW-17A	19.56	4.27	22%
Scenario 3	Option 1	Separated brine, MW-17 and MW-17A	72.34	28.46	39%

It can be observed that between 60% and 80% of the fresh water will be discharged by the industries as waste water when the industries are operating at full capacity. Therefore, a reliable supply of fresh water should be established. In addition, recycling of water should be considered.

6. EQUIPMENT SIZING AND COSTING

The energy extracted from the geothermal brine will be transported via a carbon steel pipeline from the heat exchanger to the location of the geo-industrial park for utilisation by the industries. The energy carrying medium will be fresh water as opposed to geothermal brine. This means that heat exchange between the brine and the fresh water should be done. It was assumed that the length of the pipeline would be 6 km. Since metals expand when heated, the pipeline is expected to undergo linear thermal expansion when transporting hot water. This expansion will be accommodated by the inclusion of expansion loops in the pipeline design and construction. To minimize energy losses in the pipeline during transportation, the pipeline should be insulated with sufficient thickness of an appropriately selected insulating material. Finally, resistance to the flow of water in a pipeline due to friction, effect of pipe fittings and turbulence could result in substantial pressure drop in the pipeline. Pressure drop is undesirable because it could lead to insufficient flow rate of the hot water or flashing of steam in the pipeline. This is avoided by pumping the hot water to boost its pressure during flow.

Three scenarios of energy demand and five options of energy supply were considered in this thesis. In order to demonstrate how the various equipment were selected, scenario 2 option 1, which has MW-07 as the source of brine, will be used as an example in this section since it is the energy supply option in which all the different types of equipment have been used.

6.1. Heat exchanger sizing

The size of the heat exchanger depends on the available energy and the temperature difference between the brine and fresh water in addition to the overall heat transfer coefficient (Haslego and Polley, 2002). In scenarios where the low-pressure wells are used as the source of brine, each well will have its own heat exchanger. Table 23 shows the sizes of heat exchangers required for each stream of brine.

TABLE 23: Heat exchanger area

Source of thermal energy	Available energy (MW)	LMTD (°C)	Heat exchanger area (m^2)
Separated brine	22.6	55	62
MW-07	8.8	28	47
MW-17	3.3	29	17
MW-17A	10.4	35	44

When more than one source of brine is used to supply energy to the industrial park, then the area of the heat exchanger required is the sum of the heat exchanger surface areas for all the brine streams involved.

6.2 Pipeline sizing

The size of the pipeline depends on the flow rate of the water as well as its velocity. The hot water flow rate is constant as was determined by the analysed demand scenarios. The recommended flow rate of hot water in pipelines is 1-3 m/s to reduce erosion of the pipe material by the flowing water (Engineering Tool Box, 2016). When the velocity of flow is varied while the flow rate is kept constant, the diameter of the pipe required also varies. The selected water velocity should be the one that gives a pipe diameter that results in the highest net present value as shown in Figure 14, a case study of scenario 2 option 1.

As the velocity of the water in the pipeline increases, the diameter of the pipe require to allow the same flow rate of water decreases. At a flow rate of 1.8 m/s, the net present value of the project was at its highest value of 2.45 MUSD. This corresponds to a pipe diameter of 5 inches. Hence, a 5 inch diameter pipeline was selected as the most economical pipe size for transporting hot fresh water from the heat exchanger at MW-07 to the industrial park.

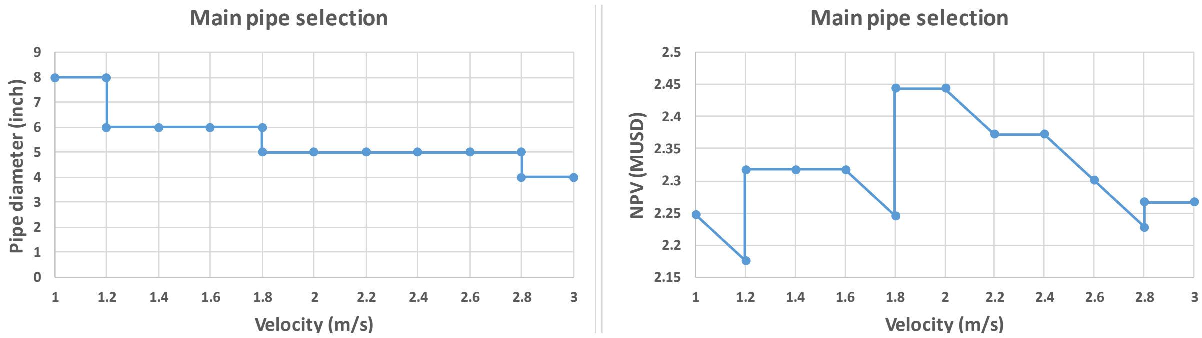


FIGURE 14: Sizing of a water pipeline

The pipeline system was assumed to be composed of three major sections:

a. Main pipeline, which carries fresh hot water from the heat exchanger to the industrial park.
b. Return water pipeline, which carries the recirculating water from the industrial park to the heat exchanger.
c. Brine reinjection pipeline, which carries brine from the production well to the reinjection well across the heat exchanger.

The optimal pipe sizes for all the scenarios and the three major pipeline sections are shown in Table 24.

TABLE 24: Selected pipe sizes

Scenarios		Main pipeline		Return water pipeline		Brine reinjection pipeline	
		Velocity (m/s)	**Pipe diameter (inch)**	**Velocity (m/s)**	**Pipe diameter (inch)**	**Velocity (m/s)**	**Pipe diameter (inch)**
Scenario 1	Option 1	1.6	8	1.2	4	2	12
	Option 2	1.6	8	1.4	4	2.8, 2.4	6, 8
Scenario 2	Option 1	2	5	1.4	3	2.8	6
	Option 2	2	5	1.4	3	2.4	8
Scenario 3	Option 1	1.2	12	1.4	8	2.1, 2.4	5, 8

Scenario 1 option 2 gets its energy from MW-07 and MW-17A while scenario 3 gets its energy from separated brine, MW-17 and MW-17A. Each of these options is connected to two low-pressure wells. This means that each of these options has 2 reinjection pipelines for the low-pressure wells as shown in Table 24.

As the flow velocity of water through the pipeline increases, the same quantity of water can pass through a section of a pipe of a progressively smaller diameter. However, pipes are manufactured in fixed size diameters. Table 25 shows the pipe diameters, which were considered and their nominal sizes (Morvay and Gvozdenac, 2008). If the required pipe diameter is not available, then the next bigger size was selected.

TABLE 25: Available pipe sizes

Pipe size (inch)	2	3	4	5	6	8	10	12	14	16
Nominal pipe size (mm)	50	80	100	125	150	200	250	300	350	400

6.2.1 Thermal expansion

Depending on the source of brine from which the energy was to be extracted, the fresh water would be heated to a temperature of between 110 and 135°C. This would result in linear thermal expansion of the pipeline. For a 6 km carbon steel pipeline, the extension is shown in Table 26 (Harvey, 2015).

TABLE 26: Linear thermal expansion

Hot water temperature range (°C)	Linear thermal expansion (mm/m)	Extension (m)
20-125	1.3	7.8
20-150	1.6	9.6

This extension was accommodated by the use of expansion loops. This means that more pipe material would be required to construct the loops, thereby increasing the total length and cost of the pipeline. The length of the loop leg was determined by the extension between anchors and the selected pipe diameter. Assuming the allowable extension between anchors is 200 mm, the length of the loop leg is shown in Table 27 for various pipe diameters (Harvey, 2015).

TABLE 27: Expansion loop leg length

Pipe size (inch)	2	3	4	5	6	8	10	12	14	16
Loop length (m)	3	3.6	4	4.5	4.8	5.5	6	6.8	7.3	7.6

Figure 15 shows the configuration of a hot water pipeline including an expansion loop. When the pipe undergoes thermal expansion, the extension would be accommodated by the loop. The length of the loop leg is denoted by X and its value is as shown in Table 27.

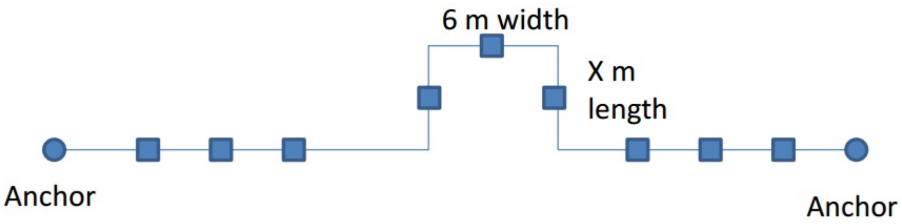


FIGURE 15: Section of a hot water pipeline between two anchors (Harvey, 2015)

6.3 Pump sizing

The size of a pump is determined by the flow rate the pump is expected to deliver as well as the head it is supposed to generate. The head of the pump is in turn selected depending on the expected pressure drop in the pipeline.

6.3.1 Pressure drop

As water flows through a given length of a pipeline, it experiences some resistance to flow. This resistance is a function of the flow profile as well as relative roughness of the pipe. The relationship between these two factors is called the coefficient of friction and it results in pressure drop (Harvey, 2015). The flow profile and relative roughness in turn are functions of the flow velocity and pipe diameter; and their effect on pressure drop for all the five energy supply options is shown in Figure 16.

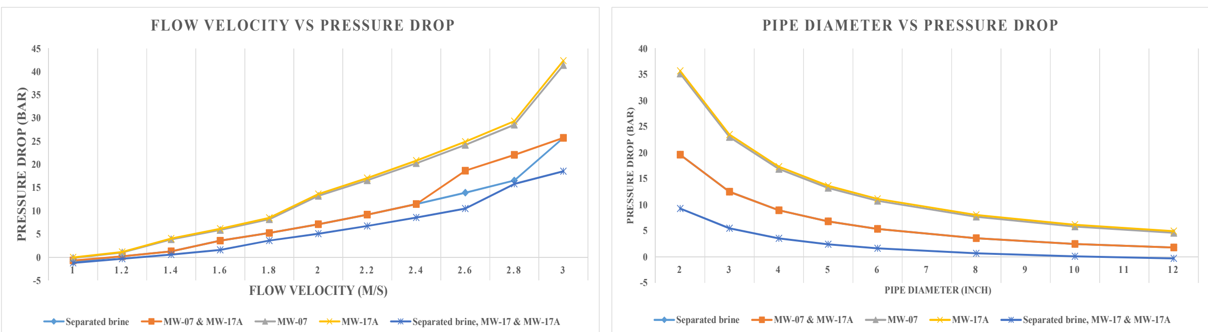


FIGURE 16: Pressure drop as a function of flow velocity and pipe diameter

High flow velocity results in increased turbulence while smaller diameters results in higher relative roughness; both of which cause the coefficient of friction to increase. This results in a higher pressure drop. It was also observed that the more the flow rate through a pipeline, the less the pressure drop.

The construction of expansion loops requires the use of at least 4 pipe fittings per loop, mainly elbows. A 6 km pipeline will have 39 loops and at least 156 elbows which further lead to more pressure drop. A regular 90° flanged elbow was estimated to have an equivalent length of 4 m as per Equation 4 (Munson et al., 2011)

$$L_{eq} = \frac{K_l * D}{f} \tag{4}$$

where L_{eq} - Equivalent length (m);
K_l - Component constant (0.3 for a regular 90° flanged elbow);
D - Pipe diameter (m);
f - Coefficient of friction.

When the loop leg length, the equivalent length of fittings and extension due to thermal expansion were accounted for, the pressure drop in a pipeline increased. The topography also affects pressure drop depending on whether the elevation is ascending or descending. It was assumed that the hot water will flow downhill, an elevation of 30 m from the heat exchanger to the industrial park, resulting in head gain. However, due to the high pressure loss caused by friction and the effect of elbows, there was a net pressure drop in the pipeline in all but scenario 3. The exception for scenario 3 was due to its high fresh water flow rate. The return pipeline would follow the same path as the main pipeline and therefore, recirculating water would be pumped uphill, an elevation of 30 m. Brine from MW-07 would be pumped uphill, an elevation of 15 m while brine from MW-17 and MW-17A would flow downhill an elevation of 95 m.

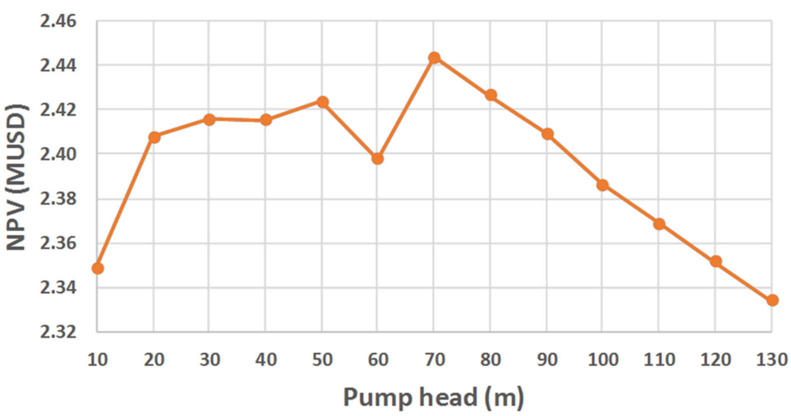


FIGURE 17: Pump selection

Pressure drop is counteracted by the use of pumps. The selection of a suitable pump is based on its head as well as the flow rate it can deliver. Since the flow rate for each option is known, the selection of the pump was based on the head of the pump. The pump head which resulted in the highest net present value was selected as shown in Figure 17, a case study of scenario 2 option 1.

When a small pump head was selected, then many pumps with a small power rating were required by the system to overcome the pressure drop, resulting in a high investment cost which diminishes the net present value. When a high pump head was selected, then a pump with a high power rating was required. This pump costs more money and consumes more power resulting in diminishing net present value. A pump with a head of 70 m was selected because it proved to be the most economical. The pumps selected for all the other scenarios and options are shown in Table 28.

The brine to the reinjection wells flow by gravity for all the scenarios except in the case of MW-07 where brine flows uphill and required be pumping. In scenario 3, the hot water in the main pipeline did not require pumping because it has a high flow rate which resulted in a relatively lower pressure drop.

TABLE 28: Pumping requirements

Scenarios		Main pump		Return pump		Reinjection pump	
		Pump Head (m)	Number of pumps & power rating	Pump head (m)	Number of pumps & power rating	Pump head (m)	Number of pumps & power rating
Scenario 1	Option 1	40	1 * 29 kW	60	2 * 9 kW	-	-
	Option 2	40	1 * 27 kW	60	2 * 13 kW	80	2 * 54 kW
Scenario 2	Option 1	70	2 * 23 kW	90	2 * 6 kW	80	2 * 54 kW
	Option 2	70	2 * 24 kW	90	2 * 6 kW	-	-
Scenario 3	Option 1	-	-	90	1 * 36 kW	-	-

6.4 Insulation selection

Insulation impedes the loss of energy from the pipeline to the environment. Insulation selection took into consideration the insulation material as well as its thickness and the expected temperature drop in the pipeline.

6.4.1 Temperature drop

The temperature difference between the hot water flowing in a pipeline and the ambient temperature results in loss of energy from the water to the environment. The farther the water flows from the heat exchanger, the more the energy loss will be. To minimize the energy loss, the pipeline should be insulated. Insulation creates resistance to the flow of heat from the hot water to the environment, hence, a suitable insulating material should have a high thermal resistance. This relationship is shown in Equation 5 (Morvay and Gvozdenac, 2008):

$$\dot{Q} = \frac{(T_{out} - T_{Amb})}{R_{Thermal}} * L_{pipeline} \tag{5}$$

where T_{out} - Outlet temperature of the fresh water from the heat exchanger (°C);
T_{Amb} - Ambient air temperature (°C);
$R_{Thermal}$ - Thermal resistance of the pipe material, insulation material and cladding material (m. °C/W);
$L_{pipeline}$ - Length of the pipeline (m).

Table 29 shows the different insulation materials which were considered, their thermal properties as well as the temperature drop that occurred over the 6 km long pipeline when an insulation thickness of 50 mm for all the different scenarios under consideration was assumed.

TABLE 29: Thermal insulation (Morvay and Gvozdenac, 2008)

Properties of insulation material				Temperature drop (°C)				
				Scenario 1		Scenario 2		Scenario 3
Material	Approx. max. temp. (°C)	Density (kg/m^3)	Thermal conductivity (W/m. °C)	Separated brine	MW-07 & MW-17A	MW-07	MW-17A	Separated brine, MW-17 & MW-17A
Mineral wool (glass) insulation	230	16	0.065	4	4	5	6	3
Mineral wool (rock) insulation	850	100	0.043	3	3	4	4	2
Magnesia insulation	315	190	0.058	4	4	5	5	3
Calcium silicate insulation	800	210	0.058	4	4	5	5	3

Rockwool was therefore selected as the most appropriate insulating material because of its superior thermal resistance, which resulted in the least temperature drop across all the scenarios and options.

In addition to the high thermal resistance, an insulating material should be of a sufficient thickness to further slowdown the loss of heat. Figure 18 shows the effect of varying the thickness of rock wool on the temperature drop in the hot water in a pipe for all the scenarios and options.

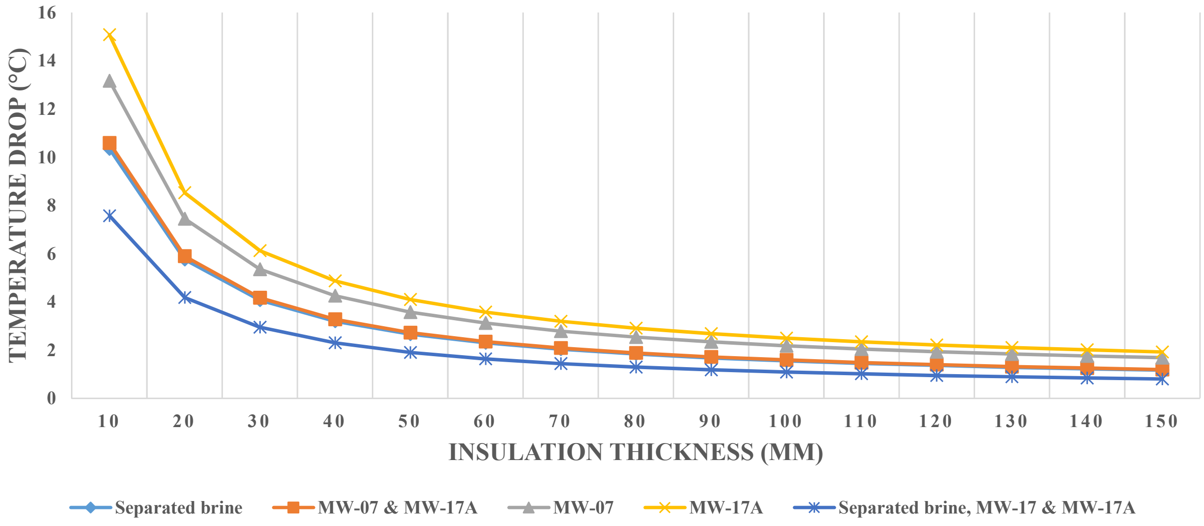


FIGURE 18: Temperature drop as a function of insulation thickness

A thicker layer of insulation resulted in a lower temperature drop because of increased thermal resistance. As the thickness of insulation increases, the rate of temperature drop decreases. It was also be observed that streams carrying a heavy flow rate have lower temperature drop than streams carrying less flow rate. 50 mm thickness was selected because thicker insulation material prevented temperature drop to a small degree.

Assuming a rock wool insulation thickness of 50 mm, the temperature of the hot water at any point along the pipeline is shown in Figure 19.

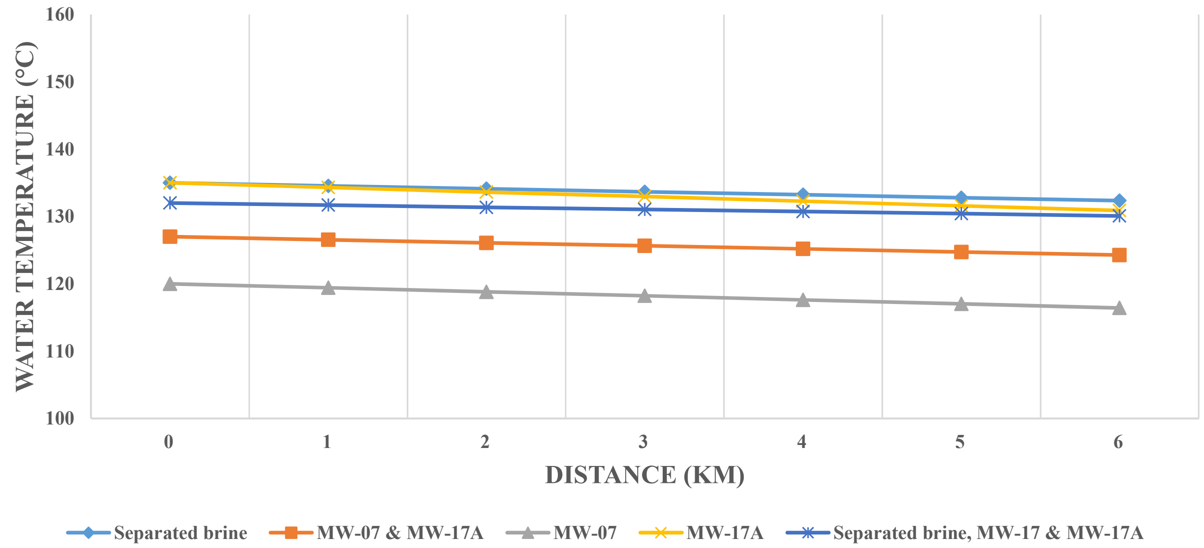


FIGURE 19: Temperature of hot water along a pipeline

It was observed that the initial temperature of the hot water to a large extent determines its final temperature, the temperature drop notwithstanding. If a stream of hot water had a high initial temperature, then its temperature at any given point along the pipeline was higher than for streams with lower initial temperature.

6.5 Equipment costing

The supply of thermal energy to the Geo-Industrial Park for utilisation by the industries requires the installation of various equipment. These include pipelines, heat exchangers, pumps and insulating material. The acquisition and installation of these equipment cost money. This cost would to a large extent determine whether or not the project would be profitable in the long run. In addition, studies to ascertain the feasibility of the project, project designs consultancy services, environmental impact studies and project permitting costs also affect the profitability of a project. These costs are of capital nature and are referred to as investment costs. Investment costs are incurred before a project becomes operational. During the operational period of a project, expenses would be incurred to run various activities. These expenses are referred to as operating cost.

6.5.1 Investment costs

The cost estimates for the equipment considered in this project was estimated from methods found in literature. These methods only provide averages for values collected from different sources. The cost estimates may not represent the current market price for the equipment, but are only indicative of what the price was when the method was developed.

a. Pipeline

Pipelines are used to transfer brine from the production well to the heat exchangers for energy extraction and from the heat exchangers to the reinjection wells. In addition, hot fresh water is transported from the heat exchangers to the industrial park and recirculated from the industrial park back to the heat exchangers using the pipelines. Different pipe sizes were selected based on the flow rate of water/brine involved. As is common with geothermal applications, the selected material for the pipeline was carbon steel. Table 30 shows the estimated costs for various sizes of carbon steel pipes.

TABLE 30: cost of carbon steel pipes (Garrett, 2013)

Pipe diameter (inch)	2	3	4	5	6	8	10	12	14	16
Cost ($/m)	28	39	52	66	92	105	131	154	190	207

b. Insulation

Rockwool insulation was selected for the pipeline carrying hot water from the heat exchanger to the industrial park. The cost of a 50 mm insulation on various pipe sizes is shown in Table 31.

TABLE 31: Cost of insulating material (Garrett, 2013)

Pipe size (inches)	2	3	4	5	6	8	10	12	14	16
2 “ thickness mineral wool (glass) insulation	13	17	21	25	29	36	44	52	59	69

If a different insulation thickness was to be considered, then the cost of the insulation material would be estimated using Equation 6 (Garrett, 2013):

$$C_2 = C_1 * (\frac{S_2}{S_1})^e \tag{6}$$

where C_1 - Cost of S_1 ($);
C_2 - Cost of S_2 ($);
S_1 - 50 mm insulation thickness;
S_2 - The selected insulation thickness (mm);
e - Size exponent,
0.5” insulation thickness – 0.4;
1” insulation thickness - 0.55;
1.5” insulation thickness -0.7;
3” insulation thickness -1.5.

c. Heat exchanger
Extraction of heat from the brine to the fresh water is necessary in order to control the spread of scaling and corrosion in the system. The extraction was achieved through the use of heat exchangers. Stainless steel G316 was selected as the material for the heat exchangers because of its ability to resist corrosion from geothermal fluids. Equation 7 was used to estimate the cost of these heat exchangers based on the area of the plates (Garrett, 2013).

$$C_{hex} = 100 * A^{e} * M_{f} * I_{f} \tag{7}$$

where C_{hex} – Cost of heat exchanger ($);
A – Surface area of heat exchanger (m^2);
e – Size exponent (0.78 for plate and frame);
M_f – Material factor (1.1 for stainless steel G316);
I_f – Installation factor (1.53 for stainless steel).

d. Pumps
Pumping of hot water/brine in the system is necessary to move the fluids uphill and also to counter head loss caused by the effect of turbulence and friction as the water flows in the pipes. The cost of the pumps was based on the power rating of the pump as shown in Equation 3 (Garrett, 2013).

$$C_{pump} = \left(1.25 * P_{pump} + 3.2\right) * 1000 * I_{f} \tag{8}$$

where C_{pump} - cost of the pump ($);
P_{pump} - pump power (kW);
I_f - Installation factor (2.05).

The various scenarios and options under consideration had different combination of equipment used to supply energy to the geo-industrial park. Table 32 shows a summary of the cost of various equipment in each of the scenarios and options under consideration.

TABLE 32: Cost of equipment for energy supply to the geo-industrial park

		Scenario 1		**Scenario 2**		**Scenario 3**
	Equipment	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Option 1**
Main Pipeline	Pipeline	685,268	685,268	416,656	421,985	1,025,757
	Insulation	230,356	230,356	152,756	154,751	341,469
	Heat exchanger	27,004	36,230	21,675	20,705	45,830
	Pumps	106,213	99,340	171,190	178,063	-
Return pipeline	Pipeline	319,920	400,688	239,562	239,562	643,620
	Pumps	74,974	102,464	54,356	54,356	130,267
Reinjection pipeline	Pipeline	-	590,400	275,520	314,880	511,680
	Pumps	-	289,553	289,553	-	-
Feasibility studies, designs and permits		200,000	200,000	200,000	200,000	200,000
Total		**1,643,734**	**2,634,299**	**1,821,268**	**1,584,301**	**2,898,622**

It is important to note that since the brine reinjection pipeline, which carries the separated brine was constructed as part of the electricity generation project, its cost is not included in the industrial park project.

6.5.2 Depreciation

The assets owned by a business are depreciated annually for accounting purposes in order to estimate their new book value after taking into account wear and tear, degradation due to exposure to the environment and obsolescence. This means that depreciation is not an actual cost but a perceived loss of value of an asset with time. Different assets have different rates of depreciation which are expressed as percentages of the initial cost of that asset. These percentages are based on the estimated useful life of an asset, which depends on accounting and industry practices. The assumed useful life and rate of depreciation for the assets considered in this project are shown in Table 33.

TABLE 33: Rates of depreciation

Depreciation		
Item	**Useful life (years)**	**Rate of depreciation. (%)**
Pipeline and insulation	40	2.5%
Heat Exchanger	10	10%
Geothermal well	25	4%
Pump	10	10%

The difference between the value of an asset in the previous year and depreciation in the current year is called the book value of that asset at the end of the current year. It is this amount which appears in the balance sheet of the business.

6.5.3 Financing costs

The acquisition and installation of the equipment as well as other works which should be done in order to supply the geo-industrial park with energy would require a substantial sum of money. This money will be realised through equity financing where GDC will use its own resources/investors' resources, debt financing which involves borrowing from banks or multilateral financial institutions or a combination of both. The choice of the financing mechanism selected will depend to a large extent on the risks inherent in the project, which in turn determines the expected return or the interest rates demanded by the investors or the financial institutions respectively. Table 34 shows the assumed financing mechanisms for the various components of the project.

TABLE 34: Financing considerations

	Equity financing (%)	**Debt financing (%)**	**Interest on loan (%)**	**Repayment (years)**
Feasibility studies, designs and permits	100%	0%	6%	5
Pipelines and insulations	0%	100%	6%	15
Heat Exchanger	70%	30%	6%	5
Pumps	70%	30%	6%	7

One of the reason for conducting the feasibility studies is to assess the viability of the business. It is therefore in order that GDC should finance the feasibility study using its own resources. The other equipment are financed using a combination of both equity and debt.

Where debt financing is selected, an annual cost referred to as interest is charged on the principal amount remaining at the end of the previous year. Interest starts to accrue immediately a loan is absorbed into the business. The repayment of the loans would start one year after the operations begin in the industrial park.

6.5.4 Operating cost

Operating costs are categorised into two. The operating costs which depend on the level of production are referred to as variable costs while fixed costs are independent of the level of production.

a. Fixed costs
   i. Staff salaries – GDC has employed 11 permanent members who will be working to develop the industrial park. These staff will draw an average salary of $16,400 per person per year.
   ii. Equipment maintenance – preventive and corrective maintenance of equipment would be carried out on a regular basis to ensure the equipment are available whenever required. An annual rate of 3% of the initial cost of the equipment would be spent on maintenance.

b. Variable costs
    i. Electricity – the delivery of hot water to the park, recirculation of return water from the park to the heat exchanger and delivery of brine to the reinjection well from some of the low-pressure wells would require pumping.
    ii. Water – extraction of energy from brine requires a continuous stream of cold fresh water at the heat exchanger. This water is supplemented by the recirculating water from the industrial park.

Since the variable costs are dependent on the rate of production, an average value of $ 0.95/m3 has been estimate to cover all the variable cost.

c. Shared cost – some assets are shared between the operations of the geothermal power plant and the operations of the industrial park. The costs incurred in order to keep these assets in good operating condition will be shared proportionately between the power plants and the industrial park depending on the amount of energy extracted by each operation. The shared costs include the following:
    i. The cost of drilling made up wells to compensate for the decline in well productivity. On average, one make-up well will be drilled every 4 years at a cost of $ 3.7 million
    ii. The cost of maintaining the 11 production wells which are connected to the separator stations and the brine reinjection pipeline
    iii. The cost of maintaining the brine reinjection pipeline and the insulation on it.
    iv. The cost of financing accruing from the funds borrowed to drill the 11 production wells as well as to construct the brine reinjection pipeline.

7. ENERGY PRICING STRATEGY

Energy from a geothermal resource is either electrical or thermal. Kenya has been generating geothermal electrical energy for over thirty years but the use of thermal energy is not well developed in the country. As a result of the use of geothermal electricity, a feed-in tariff of 0.088 USD/kWh has been adopted in Kenya (Ministry of Energy, 2012). However, there exists not tariff for thermal energy in Kenya.

With the establishment of the Menengai geo-industrial park, thermal energy from the geothermal resource would be sold to the industries as an alternative to fossil fuels. Therefore, this energy should be priced so that it is competitive against the fossil fuels while at the same time ensuring GDC does not operate at a loss during the running of the industrial park. The proposed strategies for determining the tariff for the thermal energy are as follows (Fridriksson, 2016):

i. Cost-plus pricing.
ii. Pricing relative to the price of competing alternatives.

7.1 Cost-plus pricing

The cost-plus pricing strategy assumes that the revenue which a business expects to generate in a particular period of operation should be able to cover all the costs incurred during the same period and comprise of the following:

a. All the operating costs incurred during that period;
b. The depreciation of the assets during that period;
c. The profit margin, which is calculated as a percentage of the book value of the assets at that period. That relationship is illustrated in Equation 9.

$$R_{expect} = OP_{Expect} + D_{expect} + P_{expect} \tag{9}$$

where R_{expect} - Expected revenue in a period of operation;
OP_{Expect} - Expected operating expenses in a period of operation;
D_{expect} - Expected depreciation of assets in a period of operation;
P_{expect} - Expected profit during a period of operation.

The annual operating expenses include variable costs, fixed costs and shared costs. The shared cost between the power plant and the industrial park, must be determine when the source of the thermal energy is the separated brine. This cost is then shared proportionately between the power plants and the industrial park depending on the amount of energy consumed by each.

The basis for apportioning the shared cost between the power plant and the industrial park is exergy, which refers to the work that the energy in a given volume of water can do. The amount of exergy is dependent on the temperature of the fluid and the ambient environmental temperature. As long as the fluid temperature is above ambient, then it has a positive exergy.

The profit margin is what determines the profitability of the business. An appropriate profit margin should be high enough to ensure that the geothermal energy is sold profitably but at the same time, it should be low enough to ensure that geothermal energy is competitive compared to the alternative sources of energy.

7.1.1 Exergy

The sources of energy which were taken into consideration generated hot water at different temperatures. Assuming that the ambient temperature in Menengai is 25°C, the value of the exergy for each of the scenarios and options is shown in Table 35.

TABLE 35: Exergy and tariff values

Scenarios	Source of thermal energy	Water temperat. at the heat exchanger (°C)	Exergy (kWh/m^3)	Min. tariff for hot water ($\$/m^3$)
Scenario 1	Separated brine	135	19.3	1.99
	MW-07 & MW-17A	127	16.8	1.91
Scenario 2	MW-07	120	14.7	2.39
	MW-17A	135	19.3	2.30
Scenario 3	Separated brine, MW-17 & MW-17A	132	18.3	1.82

The minimum tariff at which the geothermal energy should be charged for the scenarios and options under consideration is also shown in Table 35. Since the energy is contained in water, the tariff was expressed in $/m3 by dividing the expected revenue in a given period by the amount of hot water generated during that period.

It was also observed that the higher the fluid temperature, the more the exergy it contained. This exergy was calculated using Equation 10 (Aravind, 2010).

$$X = \frac{[(H - H\_0\ ) - T\_o * (S - S\_0)]}{3.6} \tag{10}$$

where X - Exergy of a stream of hot water (kWh/m^3);
H - Enthalpy of hot fresh water at the heat exchanger (kJ/kg);
H_0 - Enthalpy of fresh water at ambient temperature (kJ/kg);
T_o - Ambient temperature of fresh water (K);
S - Entropy of hot fresh water at the heat exchanger (kJ/kg K);
S_0 - Entropy of fresh water at ambient temperature (kJ/kg K);
3.6 - conversion factor (kJ/kg to kWh/m^3).

7.1.2 Allocation of shared costs

The Menengai geothermal project will support both geothermal electrical power generation and an industrial park where thermal energy will be utilised. In some instances, the electrical power generators and the industrial park will be sharing the same infrastructure such as the geothermal wells and the brine reinjection pipeline. However, this will not be the case when only the low-pressure wells are used to supply the energy to the industrial park because they will not be connected to the power plant. In instances where the sharing of infrastructure occurs, then the costs, which are incurred during the operation of the power plants and the industrial park must be shared proportionately between the two facilities.

The proposed method to be used to determine the proportion of energy from the geothermal wells, which is utilised at the industrial park versus what is utilised at the power plants is based on the use of exergy. This method is used in Iceland by the energy authority to separate the books of accounts for the energy companies, which generate both electrical and thermal energy from geothermal. This is expressed in Equation 11 (Orkustofnun, 2011).

$$C_{ratio} = \frac{1}{2} * \left[\left(\frac{x * Q}{E + (x * Q)} + \frac{x * \dot{Q}}{P + (x * \dot{Q})} \right) \right] \tag{11}$$

where C_{ratio} - Proportion of the extracted energy which is utilised in the industrial park (%);
x - Exergy contained in a stream of water (kWh/m^3);
Q - Water supplied to the industries in a given period (‘000 m^3);
E - Electrical energy generated using the shared resources in a given period (kWh);
$\dot{Q}$ - Maximum hot water flow rate (m^3/h);
P - Maximum electrical power capacity (kW).

When separated brine is used as the source of thermal energy for the industrial park, then it means that the energy from the geothermal wells is being shared by the power plants and the industrial park. It has been assumed that the power plants will be rated at 105 MWe and have a capacity factor of 95%. The demand for hot water in the industrial park was discussed under each scenario in Section 5.2 while the capacity factor of utilisation of energy is as shown in Table 21 in Section 5.3.

The portion of the shared cost which is allocated to the industrial park is illustrated by Equation 12.

$$C_{Park} = C_{Total} * C_{ratio} \tag{12}$$

where C_{Park} - Proportion of the shared cost which is allocated to the industrial park (MUSD);
C_{Total} - Total cost incurred in operating the shared resources (MUSD).

When a well, which is not connected to the power plant is used as the source of thermal energy for the industrial park, there is no shared cost. Therefore, all the costs associated with operating the energy supply system are allocated to the industrial park. However, when separated brine of a combination of separated brine and low-pressure wells is used to supply energy, then the tariff will have both the shared cost as well as the cost incurred in the delivery of hot water to the industrial park.

7.2 Pricing relative to the price of competing alternatives

Industrial diesel oil (IDO), a blend of diesel and heavy fuel oil is the main source of thermal energy for power generation and steam/water boilers in small industrial applications in Kenya. Heavy fuel oil (HFO), which is a residual of crude oil refinery, is used mainly by power generators, boilers and furnaces in big industrial applications. The approved standard for IDO and HFO marketed in Kenya is shown in Table 36 (Total Kenya, 2016). The prices of these fuels as at December 2014 when a barrel of petroleum was costing $55 are indicated in the same table (Kenya National Bureau of Statistics, 2016). Wood fuel is yet another source of fuel used in Kenya especially for tea processing and its price is also shown in Table 36 (Kiruja, 2016).

TABLE 36: Alternative sources of energy

Fuel	Kinematic viscosity	Pour point	Sulphur content	Gross calorific value	Density (kg/m^3)	Cost
IDO	Maximum 10 cst at 40°C	Maximum 12°C	Maximum 1.8%	Minimum 44.8 MJ/kg	960	0.77 $/litre
HFO	Maximum 180 cst at 50°C	Maximum 27°C	Maximum 3.7%	Minimum 41 MJ/kg	990	0.6 $/litre
Dry wood				14.4-17.4 MJ/kg	370	0.2 $/m^3
Electricity						0.15 $/kWh

For ease of comparison, the cost of IDO, HFO and firewood was converted to $/kWh. This was achieved by first recalculating the calorific values for each fuel in terms of volume by applying the respective densities. This was then converted to kWh by dividing it by 3600 seconds per hour. Dividing the volumetric cost by this value gives the cost of energy in $/kWh.

If the energy demanded by the industries according to the three discussed scenarios was to be supplied from the conventional sources of energy instead of geothermal energy, then the associated prices of energy would be as shown in Figure 20.

Firewood is the cheapest source of energy but because of the danger of deforestation, it is not considered to be a viable source of industrial energy. Geothermal is therefore the cheapest viable option. All the analysed scenarios were found to be cheaper than heavy fuel oil by more than a factor of two. Heavy fuel oil was the cheapest viable alternative source of energy.

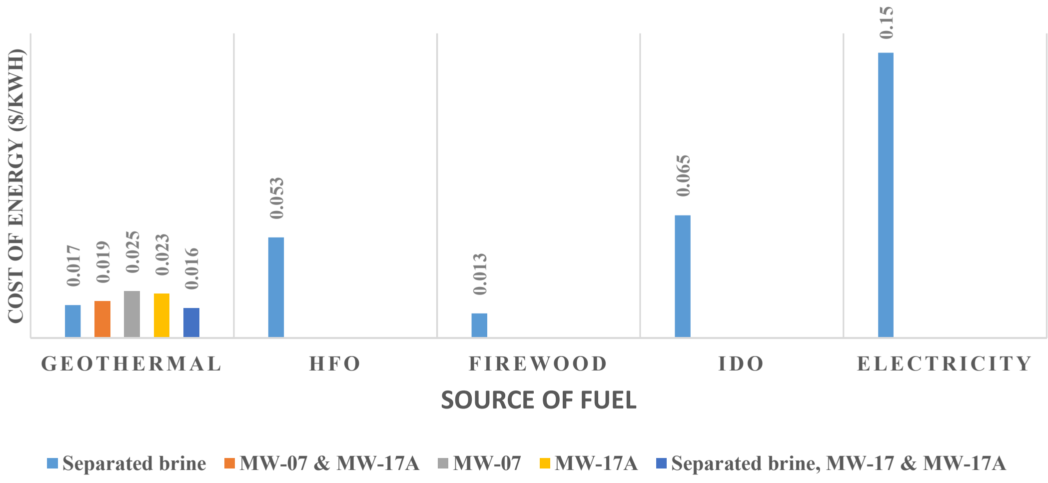


FIGURE 20: Comparison of the price of alternative sources of energy

7.3 Geothermal price determination

The price of geothermal energy illustrated in Figure 20 represents the minimum price at which the energy should be charged to avoid operating at a loss. However, since this price is significantly lower than that of the alternatives, it makes business sense to charge a higher price than this.

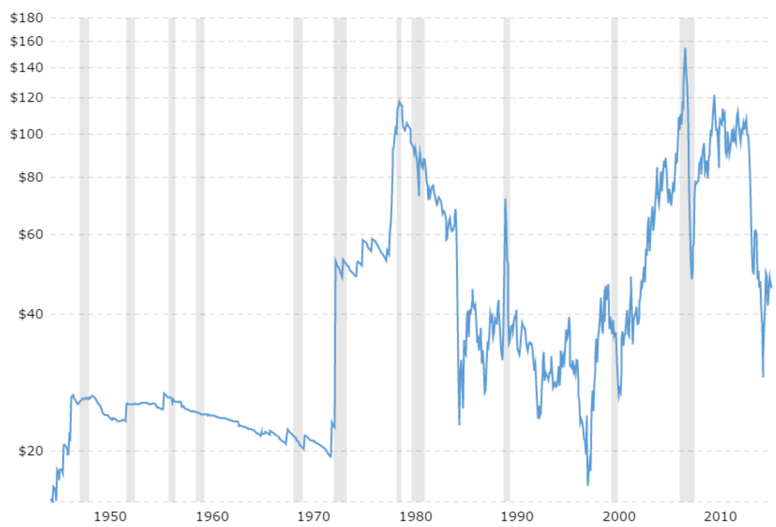


FIGURE 21: World petroleum prices (Macro Trends, 2016)

In recent years, Kenya has been making discoveries of petroleum reserves and the country is on the verge of becoming a petroleum producer. The effect of this is that the prices of petroleum products could fall substantially. In addition, history has shown that the price of petroleum has been fluctuating greatly over the years due to several market and geo-political reasons. This fluctuation was observed to be as high as up to 70% over a five-year period in some instances as shown in Figure 21.

In 2014, the price of crude oil was 55 $/barrel, which corresponded to a price of 0.6 $/litre of HFO in Kenya at the time.

Water is the medium used to transport the extracted energy in geothermal brine from the heat exchanger to the industrial park. Therefore, the industries will purchase hot water in order to utilise the energy contained in it. The price of energy obtained from HFO was found to be 0.053 $/kWh. This corresponds to a HFO price of 0.6 $/litre. The price of hot water which corresponds to this price of HFO was found to be 7 $/m^3 as shown in Figure 22. It was the highest price at which the hot water could be priced relative to the competing alternative sources of energy, hence the ceiling price.

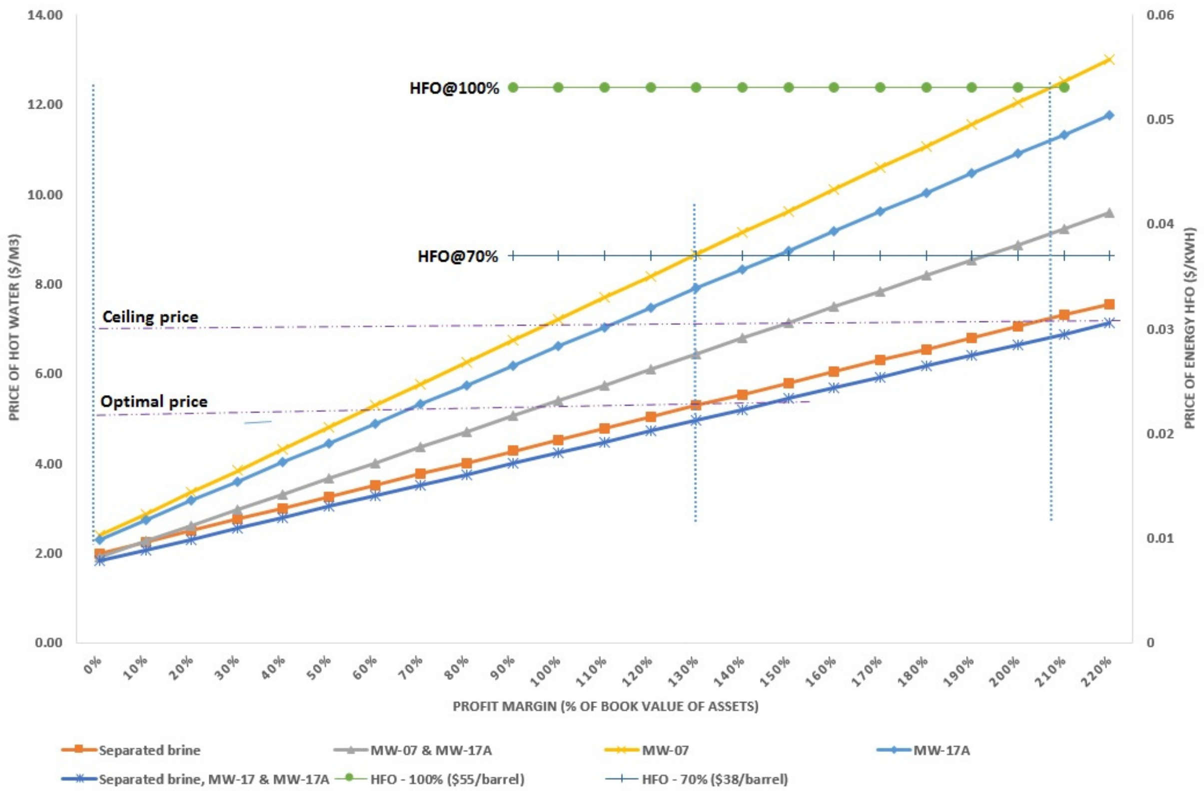


FIGURE 22: Price sensitivity analysis

The price of energy from HFO when a litre of HFO was sold at $0.6 is denoted as HFO@100%. It is however important to price the geothermal energy by taking into consideration the uncertainty associated with the price of petroleum, which would in turn reflected on the price of petroleum products such as IDO and HFO. This would ensure that geothermal energy remained competitive even with fluctuating petroleum prices. It was assumed that the geothermal energy should be priced at 70% of the price of HFO (HFO@70%). Therefore, the price of hot water was determined to be 4.95 $/m^3$, a price which is competitive against the other alternative fuels for all the scenarios. This is the recommended optimal price of hot water and it corresponds to 70% of the price of HFO.

The profit margin calculated as a percentage of the book value for each of the scenarios are indicated on the x-axis. When the hot water is charged at the ceiling price, the profit margin on scenario 2 option 1 (MW-07) is 97% of the book value and 55% at the optimal price of the hot water.

7.4 Price distribution

Due to cascading of energy, a cubic metre of hot water can be used to supply energy to more than one thermal process. When this happens, then the price of the hot water should be distributed among all the thermal processes involved. The criteria for distributing the price among the thermal processes involved in cascading was developed based on the temperature at which the hot water enters into each of the processes. The higher the temperature in a stream of water, the higher the weight assigned to it as shown in Table 37.

TABLE 37: Distributed price of hot water

Temp (°C)	Score	Weight	Weighted score	Normalized score	Price of hot water ($/m^3)
< 40	0.1	1	0.10	0.01	0.05
40 - 70	0.25	2	0.50	0.05	0.25
70 - 90	0.5	3	1.50	0.15	0.74
90 - 110	0.75	4	3.00	0.30	1.47
110 - 130	1	5	5.00	0.50	2.45
Total			**10.10**	**1**	**4.95**

The summation of the price of hot water for all the temperature bands was 4.95 $/m^3, which was determined to be the optimal price. A graphical representation of this distributed price is shown in Figure 23.

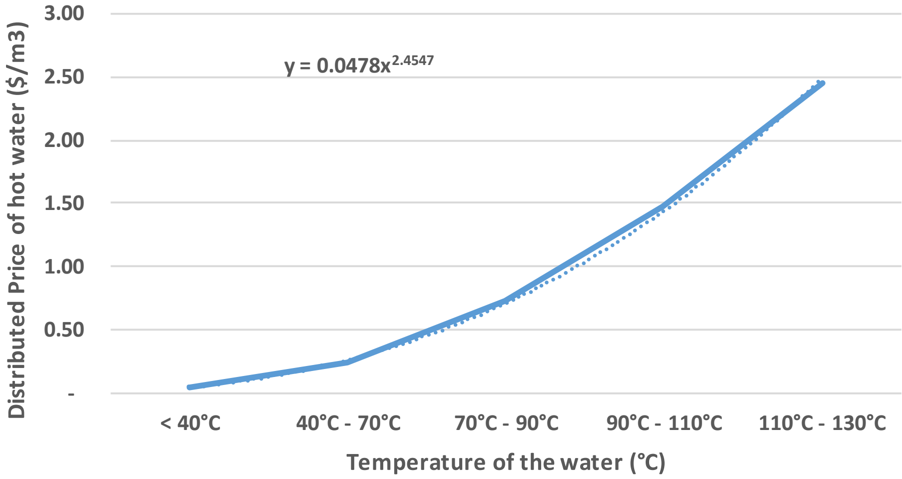


FIGURE 23: Distributed price of hot water

As a stream of hot water is cascaded down from one thermal process to the next, the energy contained in that stream decreases. Therefore, the downstream process will have access to lower energy than the upstream process and; this should be reflected in the price of hot water to each process.

8. PROJECT PROFITABILITY

Various metrics are used to assess the profitability of a project. A project should be implemented only when it has proved to be profitable after assessment. The most important metrics which were used to determine the profitability of this project were the net present value (NPV) and the internal rate of return (IRR). In assessing the profitability of this project, it was assumed that future cash flows would be discounted at a rate of 10% per annum. A project life of 25 years was also assumed. For all the scenarios under consideration, the project was found to be profitable as shown in Table 38.

TABLE 38: Profitability assessment

Item description	Scenario 1		Scenario 2		Scenario 3
	Option 1	Option 2	Option 1	Option 2	Option 1
Minimum price of hot water ($/m^3)	1.99	1.91	2.39	2.30	1.82
Investment cost (MUSD)	1.64	2.63	1.82	1.58	2.90
NPV of total cash flow (MUSD)	5.87	5.45	2.44	2.63	10.88
NPV of free cash flow (MUSD)	6.17	5.90	2.71	2.90	11.47
IRR of total cash flow (%)	29%	23%	20%	22%	30%
IRR of free cash flow (%)	100%	53%	36%	50%	127%
MIRR of total cash flow (%)	17%	15%	14%	15%	17%
MIRR of free cash flow (%)	24%	21%	19%	21%	26%
Payback period (years)	6	8	10	9	6

It was observed that the payback period of the project is between 6 and 10 years while the IRR is between 20 and 30% for all the scenarios and options under consideration. The net present value was found to be between 2.44 and 10.88 MUSD.

In order to demonstrate how some of the project profitability metrics were analysed, scenario 2 option 1 was used as a case study.

8.1 Cash flow analysis

Cash flow in a business is critical to ensure that operations proceed smoothly. During the first four years, the project is under construction and the only cash flow into the project is of capital nature as shown in Figure 24.

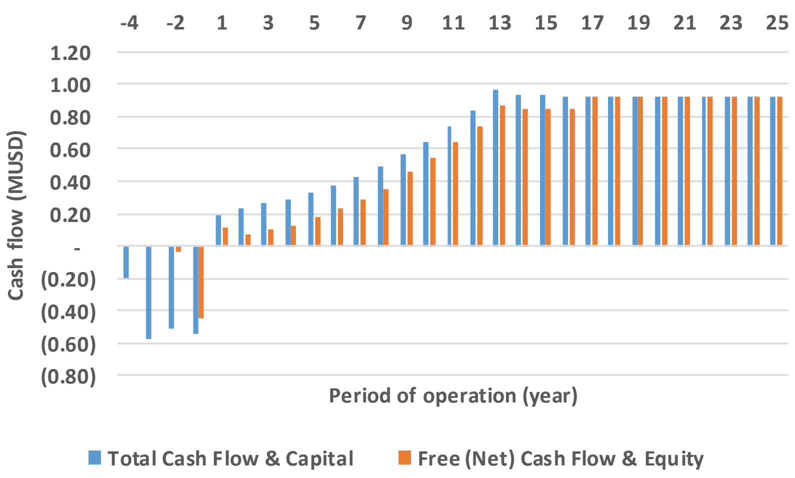


FIGURE 24: Cash flow

On the third year of construction, the loan borrowed during the previous year began to earn interest resulting in a negative free cash flow. On the first year of operation, 20% of the available energy was sold to the industries and it generated revenue which resulted in a positive cash flow. The amount of energy sold increased annually by 15% until the 13th year of operation when the peak demand was reached. On the 16th year of operation, all the loans were repaid hence the total cash flow and capital became equal to the free net cash flow and equity.

8.2 Net Present Value (NPV)

NPV measures the profitability of a business by estimating the present value of future streams of cash flows. A discounting rate is used to calculate the present value. The minimum acceptable rate of return (MARR), which an investor is willing to accept after factoring in risks and the opportunity cost of foregoing other projects was estimated and used to discount future streams of revenue.

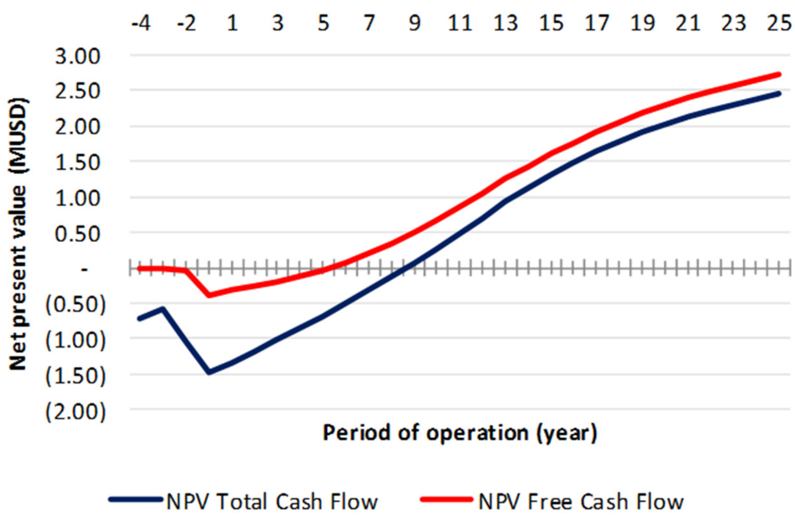


FIGURE 25: Net Present Value

A MARR 10% for the project was assumed which resulted in a NPV of 2.44 MUSD and a payback period of 10 years as shown in Figure 25.

A project with a NPV greater that zero is considered profitable, though the higher the NPV the better. Initially, the NPV was negative and continued in the same trend during the four years of development. However, when operations began, the project began to generate revenue. The NPV began to increase and on the 10th year of operation it became positive. At this point, the project had broken even and was considered profitable.

8.3 Internal Rate of Return (IRR)

IRR estimates the rate of growth a business is expected to generate. When comparing different projects, a project with a high IRR would be preferred to one with a lower IRR. The IRR is described as the discounting rate which makes the net present value of all cash flow equal to zero for a given project. Figure 26 shows the IRR for the project.

The project was found to have an IRR of 20% after 25 years of operation.

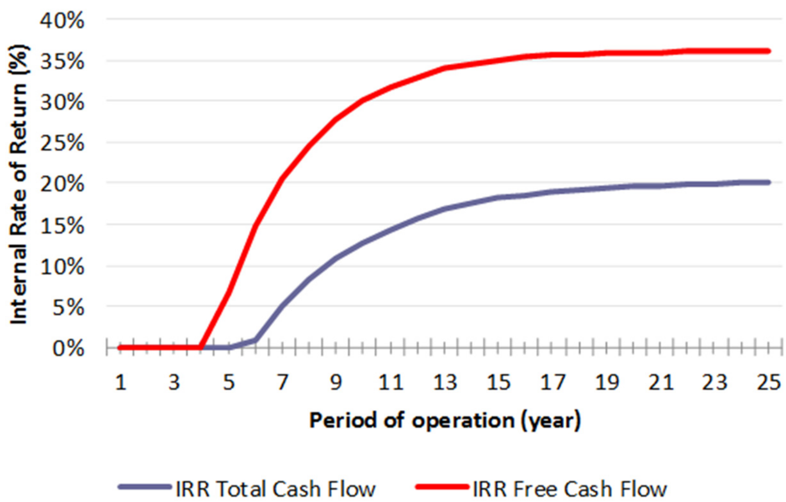


FIGURE 26: Internal Rate of Return

8.4 Cash flow ratios

8.4.1 The Debt Service Coverage Ratio (DSCR)

This is the ratio of cash flow after tax to debt service (interest on loan plus loan repayment). It is used as an assurance to the financiers that the company will be able to pay back its debts (Björnsdóttir and Jensson, 2015).

8.4.2 The Loan Life Coverage Ratio (LLCR)

This is the ratio of NPV of cash flow calculated until the end of loan repayment period to the outstanding principal amount. The ratio shows the number of times the cash flow can repay the outstanding debts throughout the planning horizon (Björnsdóttir and Jensson, 2015).

The minimum acceptable level for these ratios is 1.5 as shown in Figure 27.

Both the DSCR and LLCR are above the minimum acceptable ratio except in the first two years of operation when the DSCR is below 1.5. As the loans got serviced over the years, the ratios continued to become bigger

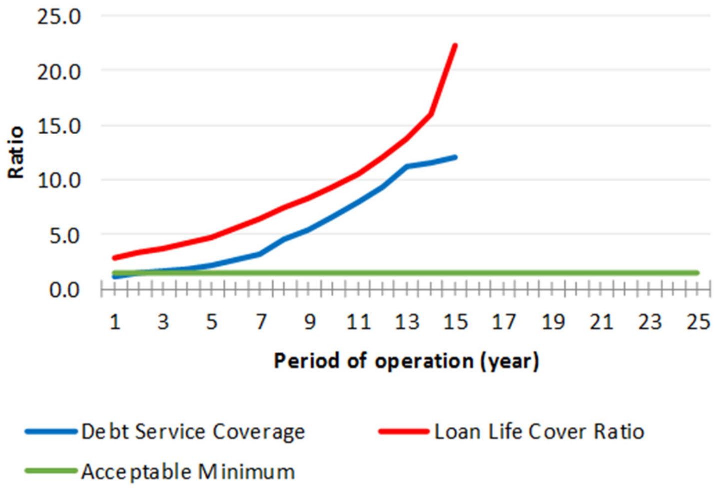


FIGURE 27: Cash flow ratios

8.5 Profitability risk analysis

The viability of the thermal energy supply project to Menengai geo-industrial park was based on several assumptions. When the reality is found to vary from these assumptions, the viability of the project might be affected. This is considered to be a risk factor in the analysis. In order to test the robustness of the assumed assumptions, a sensitivity analysis on a number of factors was done.

8.5.1 Cost sensitivity analysis

The costs incurred in setting up and running a project affect it profitability. When the costs increase, the profitability of a project is expected to decrease if the other factors are held constant. Since the costs used in this project are just estimates, it is important to assess the impact of any variations from the assumed value. This is shown in Figure 28.

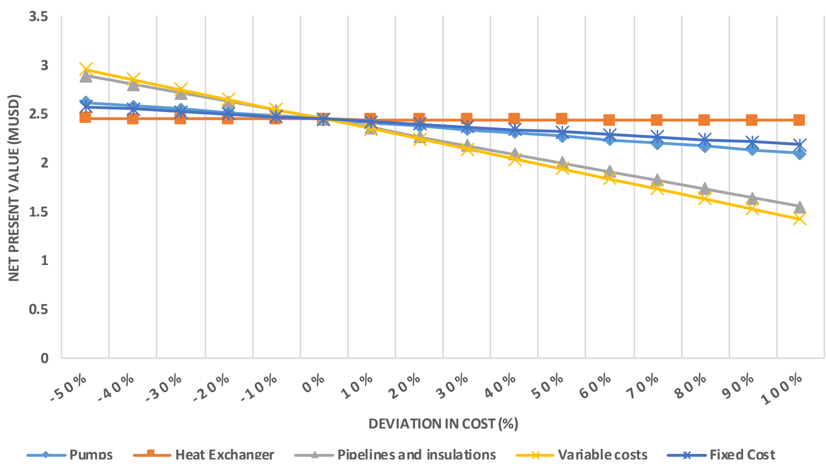


FIGURE 28: Cost sensitivity analysis

It was observed that the project is still profitable even if the costs are doubled. The variable costs as well as the cost of pipeline and insulation have a relatively bigger impact on the profitability of the project when they are varied.

8.5.2 Revenue sensitivity analysis

The potential of the project to generate revenue is influence by among other factors the capacity factor of the pipeline and the rate of annual growth in demand which both influence the amount of hot water sold to the industries. In addition, the price at which the hot water is sold also determines the revenue to be generated. A sensitivity analysis of these factors is shown in Figure 29.

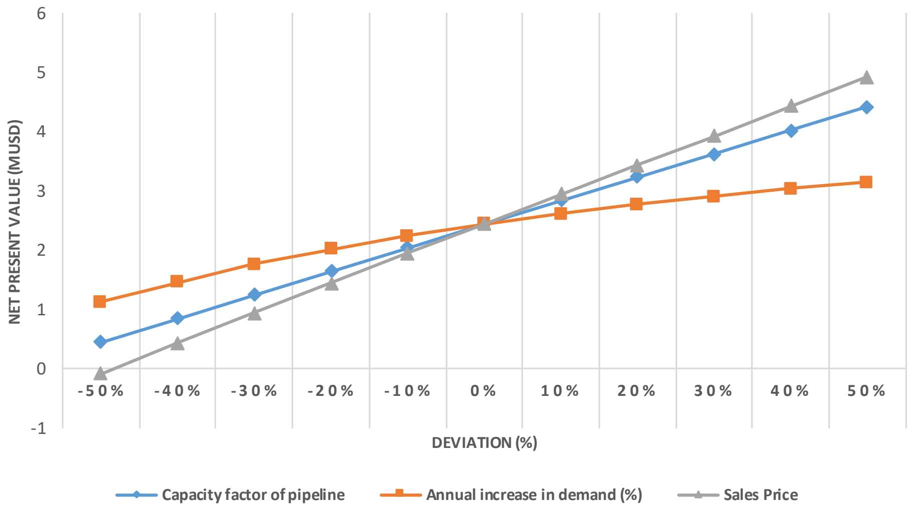


FIGURE 29: Capacity factor, demand growth and sales price sensitivity analysis

A change in the sale price of hot water and the capacity factor of the pipeline have a bigger effect on the profitability of the project than a change in the annual growth in demand.

9. DISCUSSION

All the five options, which were considered as possible alternatives for supplying energy to industrial park were found to be profitable and any of them could be developed. It is however important to consider other attributes besides profitability which might influence the decision on the best option to develop. This was done by comparing the performance of each option against all the attributes (Goodwin and Wright, 2004). The identified attributes are as shown in value tree in Figure 30.

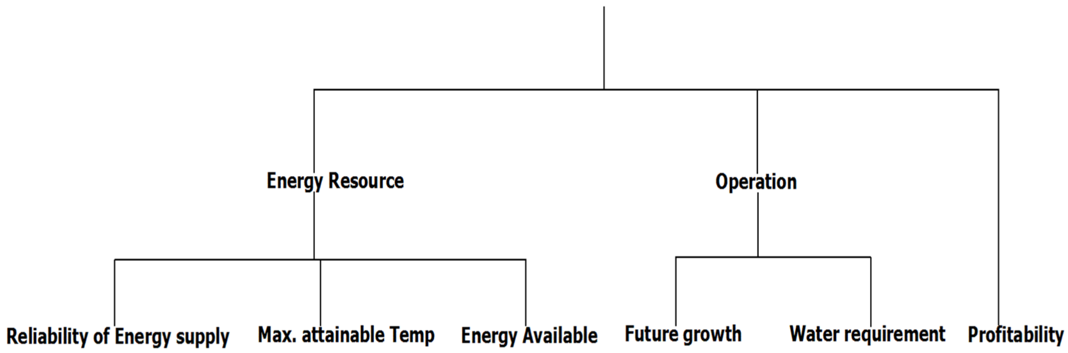


FIGURE 30: A value tree for the attributes

Three sets of attributes dealing with the operation of the industrial park, the geothermal energy resource as well as the profitability of the options under consideration were identified. These were broken down further into lower level attributes as discussed below.

a. Resource reliability – the productivity of a geothermal well declines over time due to a number of reasons such as pressure drop in the reservoir. This would in turn affect the amount of energy available for utilization. An option connected to many geothermal well was considered to be more reliable because the effect of declining productivity would be compensated by the other wells as opposed to an option with just one well.
b. Maximum attainable temperature – different thermal processes require energy at different temperatures. During heat exchange, fresh water extracts energy from the brine. If the water attains high temperature during heat exchange, it would be more conducive for utilization. This is because it would be capable of supplying energy to a wider range of thermal processes with varying temperature requirements.
c. Energy available for utilization – there is a limit on the amount of energy that can be extracted from brine depending on its chemical composition and flow rate. The amount of energy available for extraction from a stream of brine determines the number as well as the capacity of industries that it can support. The higher the amount of energy available, the more desirable that option will be.
d. Water requirement – thermal energy is transported to the industries using fresh water as a medium. Menengai is a water scarce area and therefore, options requiring less water were preferred to those requiring a lot of water.
e. Potential to accommodate future growth in demand – with the passage of time, more industries might be interested to establish their operations at the industrial park. In addition, existing industries might wish to expand the capacity of their operations. It is desirable that a selected option should have the capacity to accommodate this kind of growth. The more unutilized energy there is in an option, the more desirable it is.
f. Profitability – when the cash flows from the different options were discounted, they all turned out to be profitable. However, the more profitable an option was, the more attractive it is to be developed.

The attributes are shown in Table 39

TABLE 39: Attributes

Attributes	Scenario 1		Scenario 2		Scenario 3
	Option 1	Option 2	Option 1	Option 2	Option 1
Profitability (MUSD)	5.87	5.45	2.44	2.63	10.88
Energy available for utilization (MWt)	22.6	19.2	8.8	10.4	36.3
Resource reliability (number of wells)	12	2	1	1	14
Maximum attainable temperature (°C)	131	123	115	129	129
Water requirement (kg/s)	36.17	41.89	19.93	19.56	72.34
Potential for growth - unutilised energy (%)	24%	4%	7%	11%	8%

The performance of an option against each of these attributes was determined by assigning to it a score of between 0 and 100. The option, which was found to be the most desirable on that attribute was assigned a value of 100 while the least desirable was assigned a value of 0. The other options were assigned a value in between 0 and 100 depending on the perceived preference.

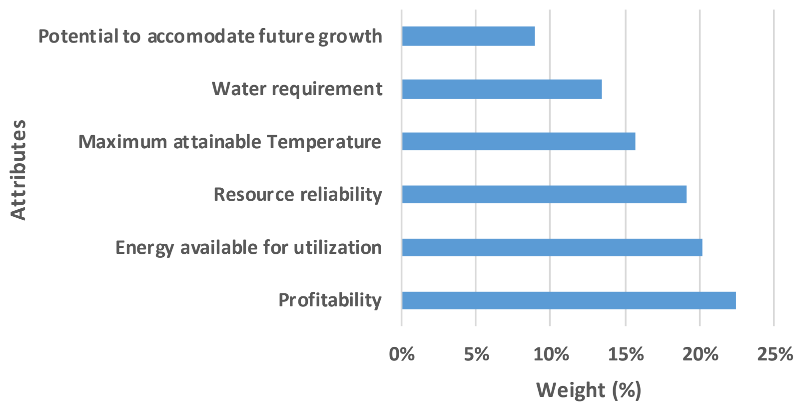


FIGURE 31: Weighting of the attributes

The attributes were then weighted to determine the order and degree of importance for each. The most important attributes were given a higher score, which was then normalized as shown in Figure 31.

Using the assigned score and weight, an aggregate score was computed for each option. The option with the highest aggregate score was considered to be the most desirable option to develop for thermal energy supply to the industrial park as shown in Figure 32.

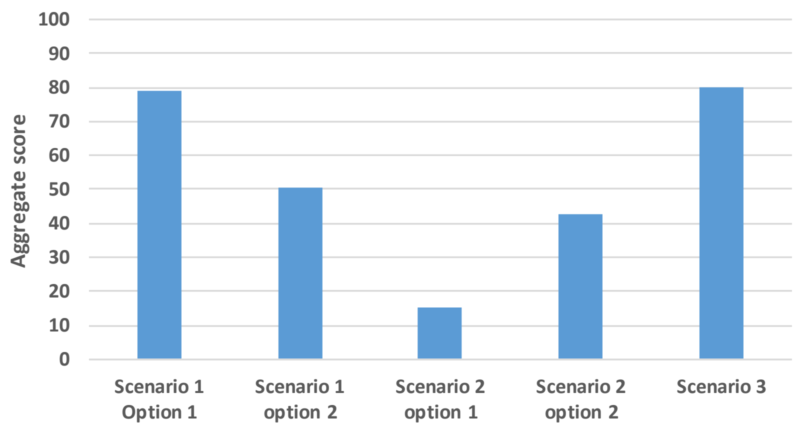


FIGURE 32: Aggregate score

In scenario 1, the best option for energy supply is option 1 (separated brine) while for scenario 2, the best option is option 2 (MW-17A). Scenario 3 had only one option, a combination of separated brine, MW-17 and MW-17A.

10. CONCLUSIONS

The analysis of the thermal energy available in Menengai for utilisation by the industries involved the creation of energy demand scenarios and options of delivering this energy to the industries. The conclusions, which can be drawn from the analysis are as follows:

1. The government of Kenya, through the ministry of industrialisation, innovation and enterprise development is keen to leverage on the country's natural competitive advantage in agriculture to drive the industrialisation agenda.

2. The location of Menengai close to the source of industrial raw materials, nearness to a market for industrial goods, nearness to clean and reliable sources of energy among others makes it an ideal location for an industrial park.

3. The energy demand in the industrial park was found to be between 6 and 22 MWt depending on the capacity of the industries under consideration.

4. The energy can be supplied from separated geothermal brine, brine from low-pressure wells, or a combination of both.

5. Heat exchangers should be used to extract energy from the brine to minimise the extent of silica scaling in the system.

6. The highest temperature obtained from the heat exchange process was 110 - 135°C, depending on the source of brine.

7. Cascading of energy results in a reduction of hot water demand by up to 60%.

8. Geothermal energy should be priced lower than alternative sources of energy so that it can be competitive. When it is priced 30% lower than HFO, the hot water would be sold at 4.95 $\$/m^3$. However, a range of 2.39 – 7 $\$/m^3$ was established.

9. The energy supply project has a payback period of between 6 and 10 years and an internal rate of return of between 20 and 30% depending on the scenario and option under consideration.

10. In scenario 1, the best option for energy supply is option 1 (separated brine) while for scenario 2, the best option is option 2 (MW-17A). Scenario 3 had only one option, a combination of separated brine, MW-17 and MW-17A.

11. RECOMMENDATIONS

In order to ensure that the project to supply thermal energy to an industrial park in Menengai is a success, the following recommendations have been made.

1. Fresh water is an important resource whose availability should be assured. The supply of fresh should be assessed to establish a reliable source. Water recycling, recirculation and rain water harvesting should also be encouraged.

2. The planning of the industrial park should be done in a way that makes cascading of energy among thermal processes possible.

3. GDC should initiate utilisation of thermal energy in Menengai by establishing greenhouses and aquatic units during the first year of operation. These facilities should then be leased to investors or local community members.

4. An insulated hot water storage tank should be constructed to store hot water, which is not utilised immediately instead of recirculating it while still hot. This would help to increase the capacity factor of the pipeline.

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