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Considering Future Feasible Agricultural Projects for Direct Use of Geothermal Energy at Eburru Geothermal Field

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Keywords

Direct use, Eburru, Crop drying, Crop calendar, AHP, Site selection, Priority vector

ABSTRACT

Direct use of geothermal energy is highly dictated by economics, thermal needs and quality of thermal energy available. Among the factors that discourage direct use is prohibitive costs of brine piping, low probability of project sustainability as well as the remote location of geothermal resources. To overcome these challenges, it is crucial to match geothermal resources with local thermal needs and settle with applications that request minimal piping and pumping of brine, with fewer or zero well drilling and with minimal environmental impacts. This paper tackles these challenges through thermal load identification, via crop-calendar at Eburru geothermal field. The available exploration geothermal wells are matched to possible application scenarios and the best application scenario chosen through the Analytical Hierarchy Process (AHP). The most economical crop drying plant should be located near well EW-01, (Site A), with a shallow percolation pond as a dumping option for exhausted brine.

1. Introduction

Geothermal energy is renewable, highly reliable and comes with a smaller carbon footprint compared to fossil fuels, 90g $\left({CO_2}/{kWh}\right)$(Bloomfield et al., 2003). Unlike other conventional renewable energies, hot geofluids can be transported for kilometers to regions where utilization takes place before being reinjected back into the ground. Temperatures of geothermal fluids can range from 30°C for GSHP and direct use (Jalilinasrabady et al., 2013; Yasukawa et al., 2009) to 310°C for electricity production (Ármannsson, 2016; Jalilinasrabady et al., 2010). This wide temperature range, 30°C-310°C, coupled with transportability of geofluids inside pipes adds to the attractiveness of geothermal energy for both electricity production and direct use. In many countries that experience winter and summer seasons, the direct use of geothermal energy exceeds the capacity used in power production (Fridleifsson et al., 2008; Zheng, 2019), because it is cheaper to install shallow wells for GSHP compared to developing a geothermal power plant. Kenya however, is located in the equator with an average altitude elevation of 1000-

2000m above sea level. Thus, its average yearly temperatures are about 25°C and GSHP is less popular there.

Nonetheless, Kenya's economy largely depends on agriculture, with its main cash crops being tea, fresh cut flowers, coffee and vegetables as shown in Figure 1.

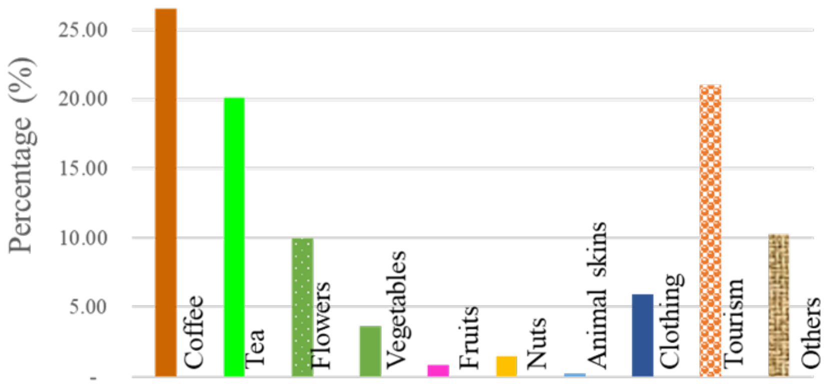

Figure 1: Kenyan main income generators by percentage.

Agricultural activities of growing and processing these products require immense energy inputs, especially in greenhouses, coolers and tea factories. Geothermal energy can step in to augment the conventional energy sources. For instance, the Kenyan tea processing industry cuts down up to 15 trees to just process 1 metric ton of black CTC tea. In 2018 alone, Kenya exported a total of 492,990MT of tea, implying that more than 6.4 million trees were cut down as fuel.

In addition, Kenya's staple food consists of grains such as maize, beans, rice, wheat, millet and sorghum. It is estimated that the yearly consumption of maize per capita ranges from 80-100 kg (Onono et al., 2013). Since maize and the other grains are cultivated in rain-fed arable lands of the Kenyan highlands and western regions, recent climatic changes have seen frequent prolonged droughts impact grain production significantly to the point that importation of maize, wheat and rice is necessary to meet the ever-growing demand. Figure 2 shows the deficit between the increasing demand and maize production rate.

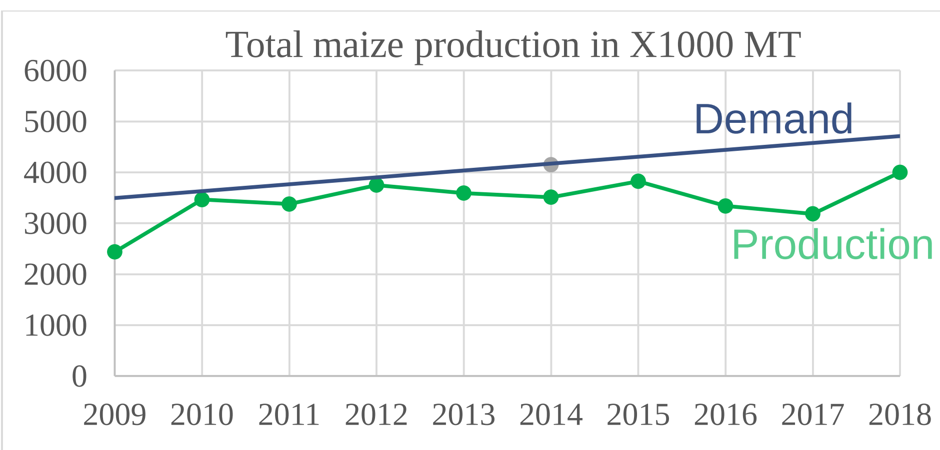

Figure 2: Maize production trend for the last decade.

Apart from drought, postharvest grain loss is a serious problem in Kenya, especially for maize where it is estimated that 20-24% of the harvested grains is lost through poor drying and storage (Dudi, 2014; KARI, 2008). This affects the farmers economically and aggravates food security to a country whose demand for maize exceeds local supply (Onono et al., 2013)The postharvest loss of grains manifests itself as 15% grain rot and 9% pest damaged during sun drying activities. Of the 76% good grains, 35% are of degraded quality due to discoloration by mud and dust caused by ground spreading during sun drying, where the grains get trodden by people and animals. This just goes to show that Kenyan agricultural activities can do much better with high quality energy inputs from geothermal energy sources. One good example of geothermal utilization in Kenyan agriculture is by Oserian Development Company. A 2013 study report by Land O' lake showed that the Oserian flower farm reduced costs of heating by 70% by adopting geothermal heating in greenhouses (Land O'Lakes, 2013) and by 85% on fungicides (Mburu, 2014). In addition, the farm has been able to cultivate two famous flowers "Sweet Vuvuzela" and "Queen of Africa" (Figure 3), which they testify would have been uneconomical to farm without geothermal energy.

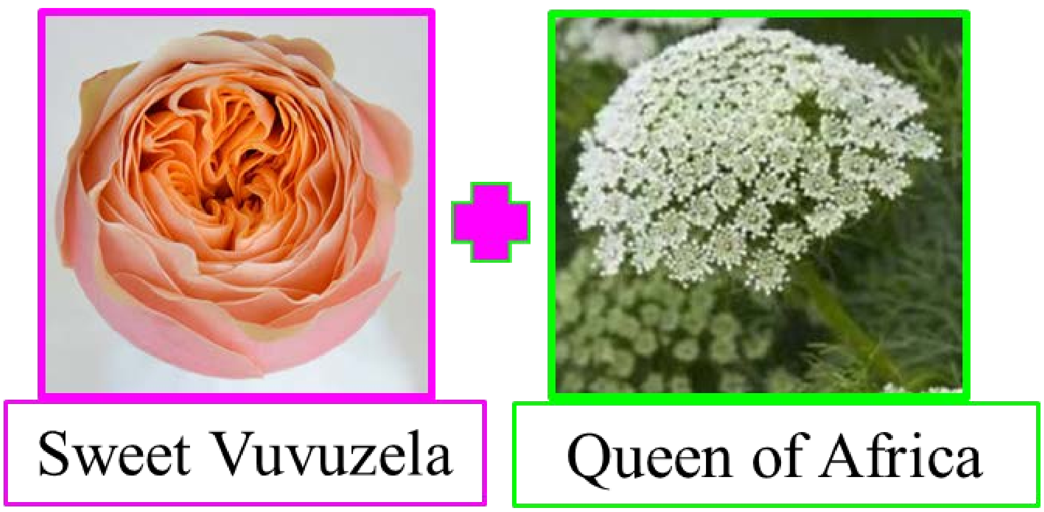

Figure 3: Unique flowers cultivated at the Oserian Development Company.

1.1 Available geothermal resources

Development of geothermal energy for electricity in Kenya has seen tremendous growth in the last decade, with geothermal installed capacity growing steadily from 129MW in 2009 to over 687 MW in 2019. This growth has enabled production of great volumes of geothermal brine, 3137-3500ton/hr at Olkaria and 544ton/hr at Menengai, with temperature ranges of 100-185°C. Re-injecting this brine at 100°C, to discourage silica scaling, could provide up to 250MWt of energy that can be put into direct use especially in greenhouse warming, crop drying and milk pasteurization. With ongoing projects at Menengai and Olkaria domes, the electric production from geothermal is expected to exceed 1000MW by 2023, thus giving an additional 2000ton/hr of geofluids which translates to an additional 100MWt. This huge volume of available thermal energy, coupled with existing thermal demands in agricultural sector, is the motivation of the current research to find the most economically suitable direct use activity and site for Eburru geothermal fields.

1.2 Reservoir Characteristics of Eburru Geothermal Field

Eburru is a Quaternary volcano, elevated at 2800m, located in between the Olkaria geothermal field and Lake Naivasha in the south, and the Badlands geothermal prospect and Lake Elementaita in the North. The geothermal manifestations in Eburru include fumaroles, hot springs, thermally altered grounds and series of faults and fracture network systems with general N-S trends and minor E-W trending faults (Maithya and Fujimitsu, 2019). The Eburru geothermal field has an estimated reservoir volume of 3km^2 at a depth of 1500-2000m from the ground surface (Figure 4(b)), with temperatures ranging from 190-280°C (Maithya et al., 2020; Maithya and Fujimitsu, 2019; Mwarania, 2014). Already six wells exist in this field: Well EW01 produces two-phase fluid, wells EW04 and EW06 produce low enthalpy single-phase fluids, and the remaining wells are unproductive. Well EW01 is connected to a 2.4MW power plant. Previous studies show that the unproductive wells hit the periphery of the reservoir where temperatures range from 140-170°C. Research indicates that Eburru, being a small reservoir, can support the production of 10-20MWe for 30 years (Maithya et al., 2020; Mwarania, 2014).

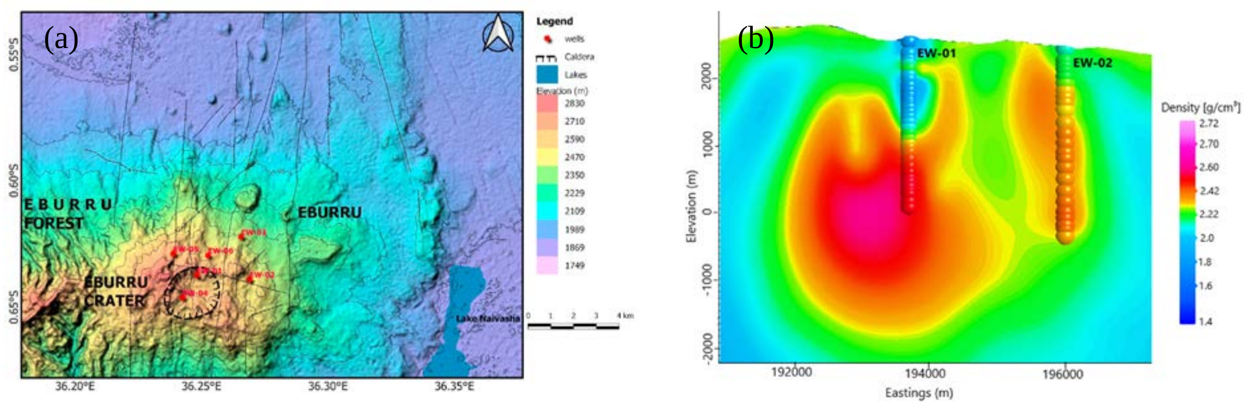

Figure 1: (a) Eburru volcano with location of drilled wells, (b) Density model from analysis of gravity data (Maithya et al., 2020).

2. Methodology and Decision Making Tools

Direct use projects are highly governed by economics. Thus, it is crucial to evaluate and select projects that:

a) require less initial capital costs,
b) have high positive impact on society,
c) have less environmental impact,
d) require less maintenance cost,
e) substitute use of costly and polluting fossil fuels,
f) have shorter payback period,
g) are sustainable for the project's life cycle, among other desirable criteria.

Such combination of criteria may not be possible for most geothermal fields depending geographic location, available surrounding economic activities and thermal demands. In addition, prioritizing some criteria over others may present conflict, especially when minimizing cost and maximizing utilization. Among the main key criteria that decide on a project's initial capital coat is project location. The location selection directly influences fluid piping and pumping cost and transportation cost of goods among other factors. This paper incorporates use of Multi-Attributes Decision Making (MADM) tools in selection of most economical direct use projects, for a geothermal field, considering all the criteria involved and, thus, striking a comprise that provides the best utilization scenario.

In addition, the use of GIS mapping of crop farms, roads and available geothermal resources paints a more detailed picture used to decide which parts of the region have a higher concentration of which type of crop, accessibility of farms by road network and which geothermal resource have better accessibility to roads and other key infrastructure. Relating this information to AHP decision tool helps to formulate the best utilization scenarios for the geothermal energy.

2.1Thermal load identification

Eburru has an agricultural community with most of their farms dedicated to growing maize, beans, potatoes, vegetables and pyrethrum. They also keep sheep, goats, cattle and poultry, though in a small subsistence sort of a way. As Figure 5 indicates, most farmers dedicate lots of acreage to maize crop since it serves as a staple crop and offers its stalks and cobs as animal feed and fuel.

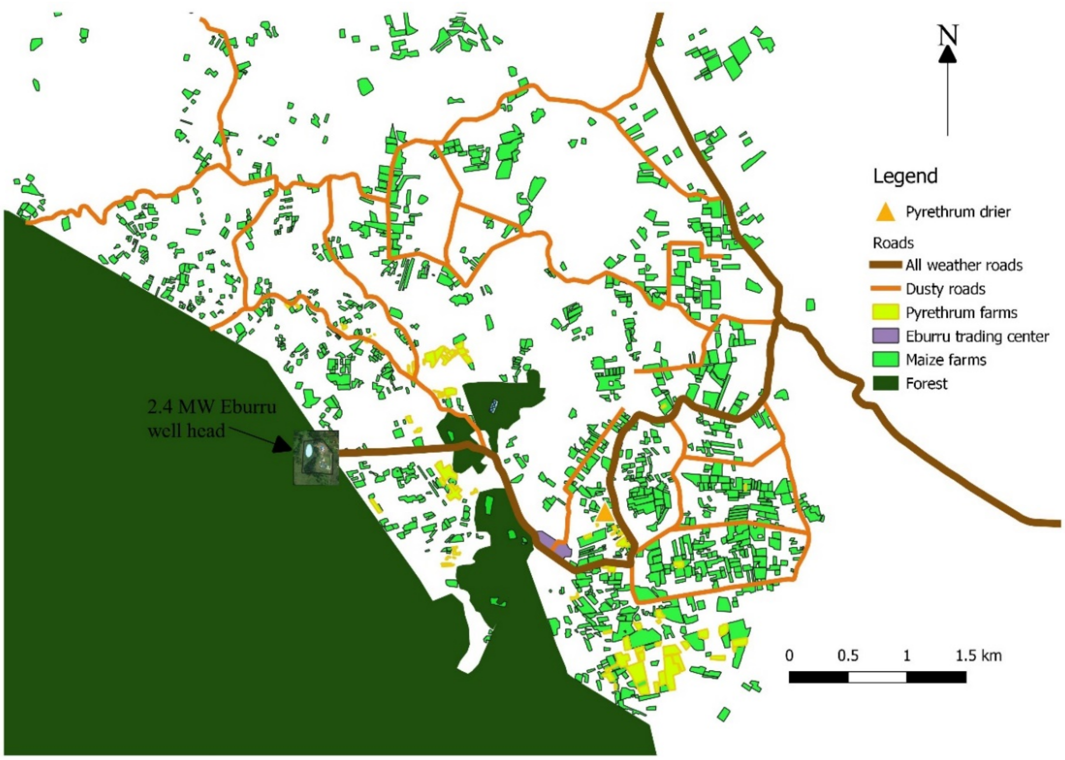

Figure 2: Map of Eburru farms.

Thermal demand for crop drying can be calculated as heat energy required to dry maize, beans and pyrethrum. The cultivated Eburru region has elevation of 2200-2650m asl with a highland microclimate. Maize and bean planting take place in March-April, and harvesting of beans occurs in July- August. Maize is harvested between months of December and January. Pyrethrum is a perennial plant and is picked (harvested) every 2-3 weeks, depending on rainfall being received at that particular period (Kroll, 1964).

In the Eburru region, the Morgen and Ol Jorai areas have over 370 hectares of cultivated maize and beans. Cultivation of beans is not as widespread, since beans discourage use of herbicides for weeding, and just 30-40% of farmers in this region plant beans. Average estimated crop productivity of 4900 kg/ha for maize harvested at moisture content of 25% and 2533 kg/ha for beans harvested at 18% moisture content are used to calculate energy required to dry maize and beans to 13.5% for storage and trading. Energy provided to dry grains include energy used to raise the temperature of the grains to the drying temperature, energy used to evaporate the moisture from the grains and energy used to raise temperature of the remaining moisture to evaporation temperature. For a fixed bed drying system, this energy per kg of grain dried at 60-80°C and moisture content of 13.5% can be represented in a simplified empirical Equation 1

$$Q = \left(C_w \times (T_{evp} - T_a) + h_{evp}\right) \times 0.881\left[(1 + MC_{wet}) - (1 + MC_{final})\right] + 0.881 \times C_{corn} \times (T_{evp} - T_a) + h_{loss} \quad 1$$

Where h_{evp} is the heat of evaporation of water from maize and beans is given as 2791.2 kJ/kg(Brooker et al., 1981). $h_{loss} = 435\text{kJ/kg}$ is the heat lost from the dryer exhaust and walls of heat exchangers, piping and the dryer. MC_{wet} and MC_{final} are the moisture content of grains in percentage after harvesting and after drying process, respectively. $T_{evp} = 60°C\ and\ T_a = 25°C$ are drying temperature and ambient air temperature respectively. C_w is specific heat capacity of water (about 4.148 kJ/kg-°C) while $C_{Corn=}2.63 - 3.03\ \text{kJ/kg} - °\text{C}$ is specific heat capacity of maize at moisture content of 13.5%. C_{Corn} is estimated via Equation 2(Verma and Prasad, 2000)

$$C_{corn} = 1.3066 + 1.2045MC_{final} + 0.0198t \quad 2$$

Where t is temperature in °C.

This translates to a thermal demand of 1340×10^6kJ and 295×10^6kJ for drying maize and beans from Eburru locality. The drying process also requires electrical energy to power air fans, cranes, conveyors and others. It is difficult to estimate the electrical energy required, as it is dependent on type and number of machines involved as well as the drying technology used. A study on LPG fired maize dryer in Uganda found that energy required to drive fans is approximately 0.047kWh/kg of dried grain (Mugabi and Driscoll, 2016). This translates to 279×10^6kJ and 61×10^6kJ for maize and beans respectfully.

The Eburru region has 26ha of land under pyrethrum cultivation. As Eburru receives 890-1010 mm of well-distributed rainfall yearly (Figure 6), pyrethrum flowers are harvested every 2 weeks each hectare producing (on average), 150kg of dried flowers (Kroll, 1964). This translates to 3911 kg/ha of dried pyrethrum flowers per year. Pyrethrum flowers are harvested at 75% moisture content and dried to 12% moisture content (Sun, 1994). To limit enzymatic oxidation and deterioration of pyrethrin content, optimal drying is done at 80°C for 6 hours (Githinji, 1982).

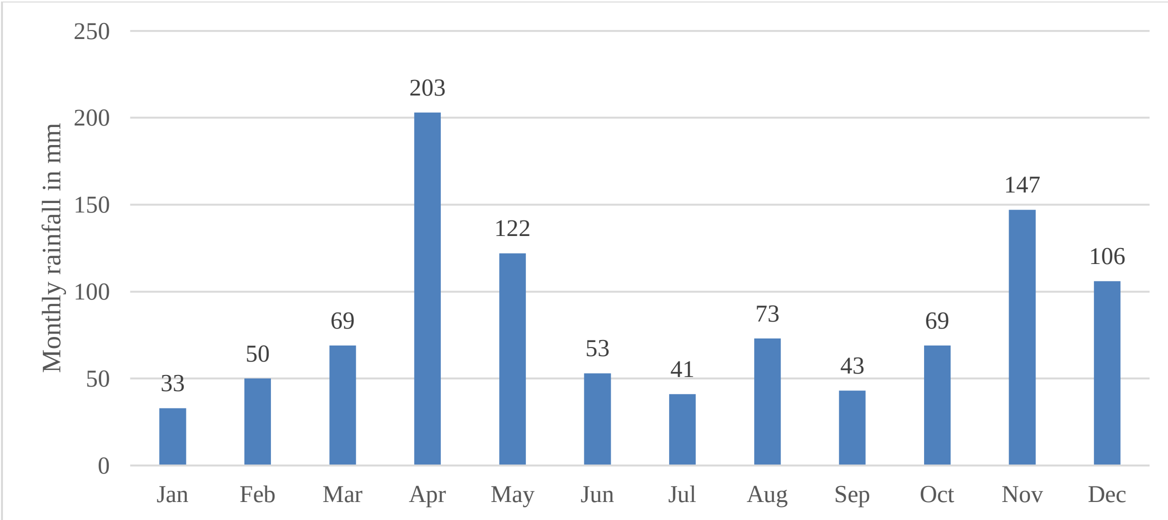

Figure 3: Rainfall pattern for Eburru region.

For a fixed bed drying system, drying energy per kg of pyrethrum flowers can be represented in a simplified empirical Equation 3

$$Q = \left(C_w \times (T_{evp} - T_a) + h_{fg}\right) \times 0.893[(1 + MC_{wet}) - (1 + MC_{final})] + 0.893 \times C_{pyr} \times (T_{evp} - T_a) + h_{loss} \qquad 3$$

Where h_{fg} is the heat of evaporation for pyrethrum flowers at 80°C and is given as 2550 kJ/kg (Sun, 1994). $MC_{wet} = 75\%$ and $MC_{final} = 12\%$ are the moisture content of flowers in percentage after harvesting and after drying process respectively. $T_{evp} = 80°C \ and \ T_a = 25°C$ are drying temperature and ambient air temperature respectively. C_{pyr} is the specific heat capacity of pyrethrum dry mass and is estimated as 1.373kJ/kg. By use of Equation 3, yearly thermal demand required to dry pyrethrum around the Eburru region is estimated as 210×10^6kJ.

It is worthy to note that the terms, $0.881[(1 + MC_{final}) - 1] \times C_w \times (T_{evp} - T_a)$ and $0.893[(1 + MC_{final}) - 1] \times C_w \times (T_{evp} - T_a)$, which represent the heat required to warm the residual moisture in dried products to evaporation temperatures have been assumed to be negligible in calculation of thermal demands in Equations 1 and 3 respectfully. Electricity required to drive fans, for the case of stationary bed dryer is estimated at 0.079kWh/kg of dried pyrethrum flowers with final moisture content of 12%. Hence, the total required electrical energy required to drive fans is 28.92×10^6kJ.

2.2 Distribution of thermal demand

The demand for thermal energy and electrical energy for crop drying depends on the crops calender, i.e. when the crops mature and their respective harvesting period. In Eburru region, three types of crops have been considered for artificial drying: maize, beans and pyrethrum. These crops have different harvesting periods as represented by Figure 7.

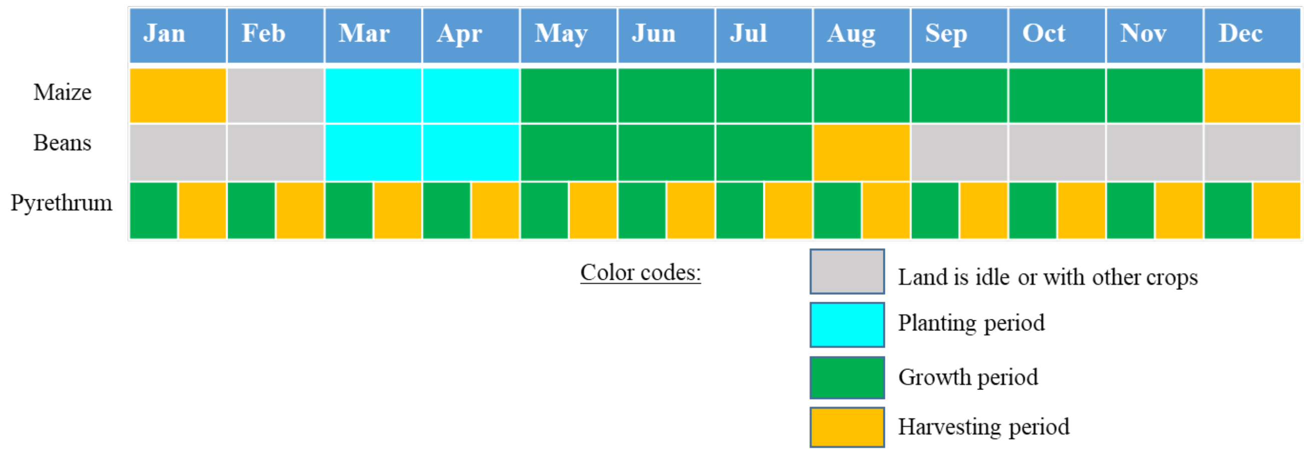

Figure 4: Crop calendar for Eburru.

Using Figure 11 for calculation of hourly energy demand during drying period, we obtain

Table 1: Hourly energy demands during crop drying periods.

Crop	Hourly thermal demand kW	Hourly electrical demand, kW	Time of the year
Maize	250	52	Dec-Jan
Beans	110	23	Aug
Pyrethrum	13	2	Jan-Dec

Distribution of this energy gives the demand curves in Figure 7 and Figure 8. As these figures indicate, the thermal and electrical energy required for crop drying in this region are very similar in pattern with only slight differences.

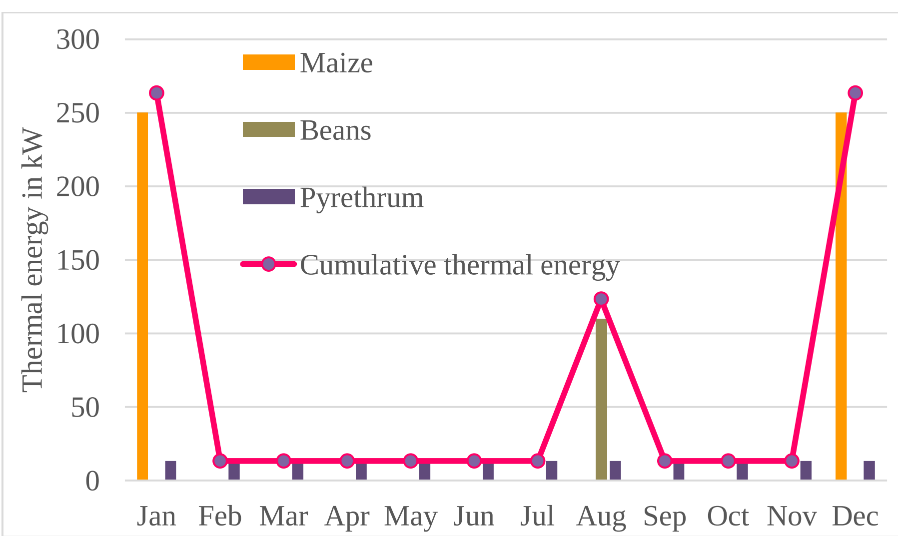

Figure 5: Hourly thermal demand for crop drying.

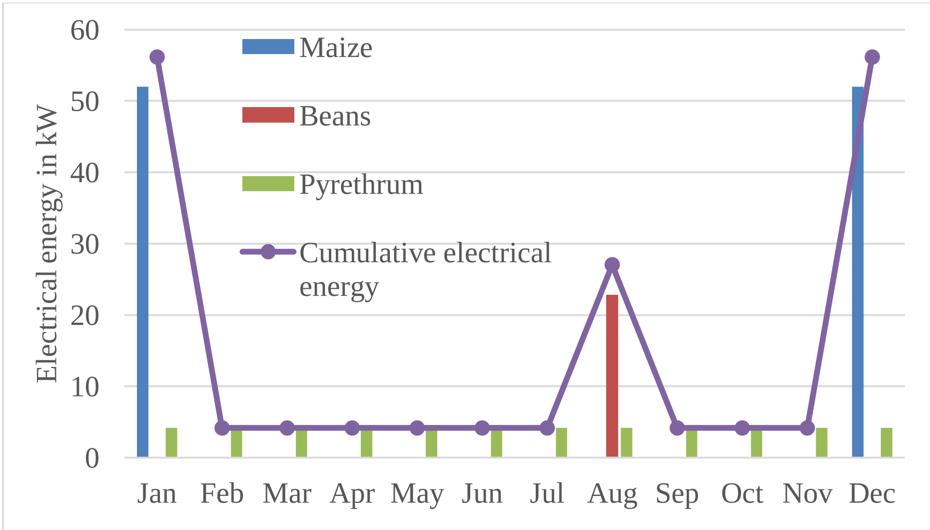

Figure 6: Hourly electrical power required for driving air fans during crop drying.

2.3 Matching energy demands to the geothermal reservoir

In direct use of geothermal energy, both steam and brine or brine alone provides thermal energy. In this paper, the scenario under consideration is where the brine is used to provide thermal energy, while the steam powers electrical generators. The demand-to-resource matching will take into consideration such parameters that indicate the quantity and quality of heat: mass flow rate, wellhead enthalpy, wellhead pressure (or wellhead temperature). Eburru has three wells that qualify for crop drying, EW01, EW04 and EW06. From literature, (Arusei, 1991; Lagat, 2003; Mwarania, 2014), the discharge and thermal characteristic of Eburru's productive wells have been estimated as shown by Table 2.

Table 2: Characteristic of the Eburru's productive wells

Well	Max Well Temp	Wellhead temp	Brine enthalpy	Steam enthalpy	Brine flow rate	Steam flowrate	Capacity
EW01	278.9°C	158.8°C	656 kJ/kg	2752kJ/kg	60,000kg/h	23,000kg/h	2.4MWe 1.57MWt
EW04	193.2°C	82.5°C	346 kJ/kg	-	38,176kg/h	-	1.0MWt
EW06	219.9°C	90°C	377 kJ/kg	-	82,989kg/h	-	2.9MWt

Utilizing brine from wells EW01, EW04 and EW06 to provide thermal energy, the following is the flow rate required to satisfy crop drying around Eburru area, Table 3, when considering each well exclusive of the others.

Table 3: Brine flow rate estimation.

Well	Brine flow rate required for crop drying			
	Maize	Beans	Pyrethrum	Max demand
EW01	2225 kg/h	979 kg/h	149 kg/h	**2,374 kg/h**
EW04	9546 kg/h	4200 kg/h	4553 kg/h	**14,099 kg/h**
EW06	7156 kg/h	3148 kg/h	1138 kg/h	**8,294 kg/h**

From Table 3, it can be inferred that each of the three wells at Eburru can provide thermal energy required for crop drying in the region. Figure 10 shows the well locations and their wellhead brine temperature. Both wells EW04 and EW06 are 1.0km farther from well EW01, with both wells EW01 and EW04 being located at Eburru forest protected zones. Wells EW01 and EW06 have accessibility via murram roads, with elevation of 2580m and 2600m asl respectively.

From Table 1, the peak electrical demand for the crop drying would require 54kW electricity line connection in 3-phase. This is readily available from Eburru 2.4MWe power plant. Since the thermal and electric energy required is way smaller than is available, Eburru stands out as a region whose geothermal resources matches the available demand for now and for several decades into the future.

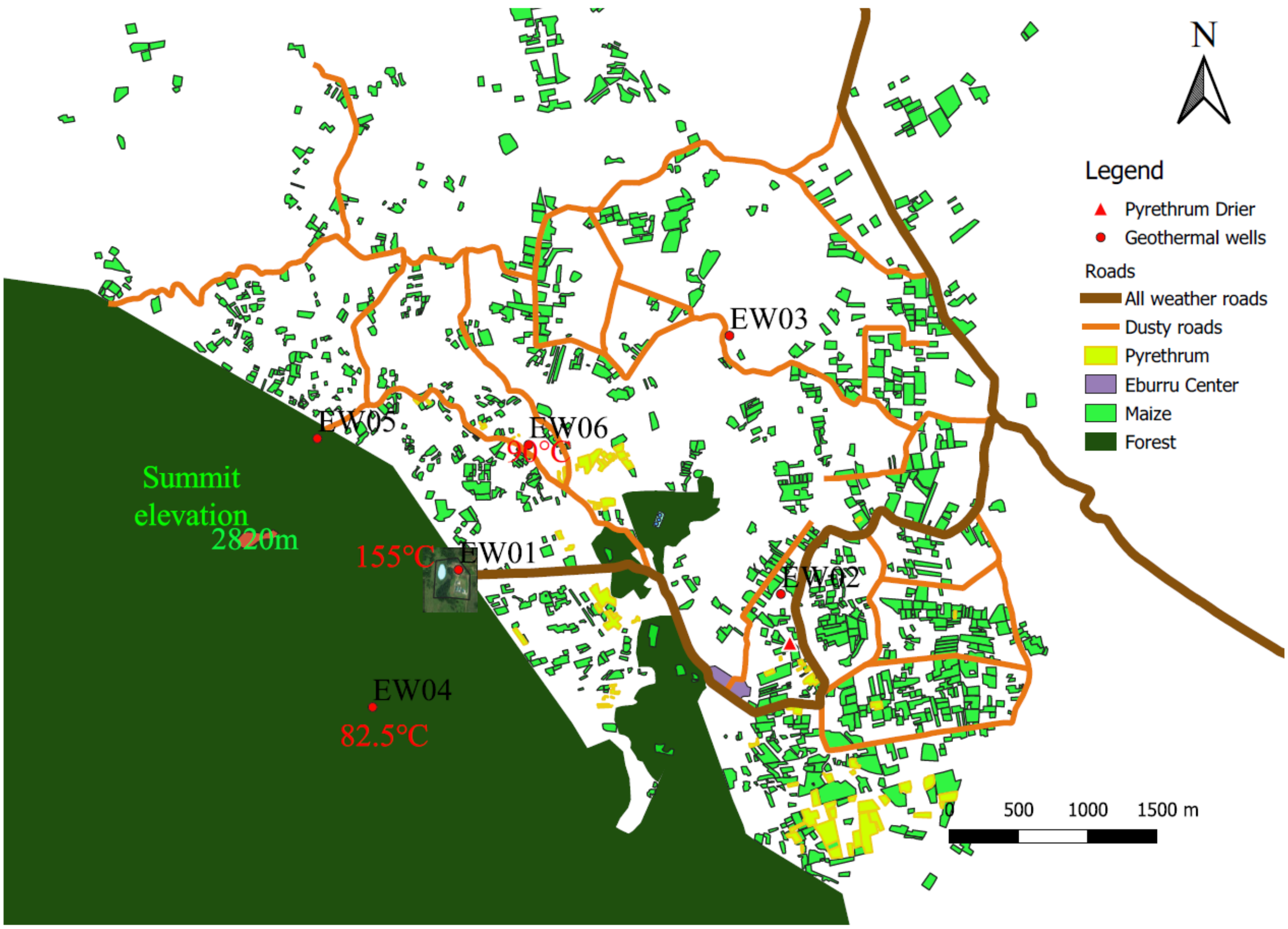

Figure 7: Well locations with wellhead brine temperatures.

2.4 Location of the crop drying plant

To reduce initial capital cost for the crop dryer, it is desirable to locate it near one of the productive wells to reduce the brine piping cost. Unfortunately, wells EW01 and EW04 are in a protected zone (Eburru Forest), and therefore a pipeline is required to conduct the brine outside the protected zone.

Figure 8: Possible locations of crop drying plants.

Three possible sites for locating a crop dryer are proposed as shown in Figure 11. As the decision process of selecting the optimal location for the dryer unfolds, it is clear several criteria must be considered. This is where the Analytical Hierarchy Process (AHP) becomes useful in aiding the decision maker to express the selection process in a structured manner (Saaty and Kearns, 1985). AHP process is expressed in a simple hierarchical chart in Figure 12 .

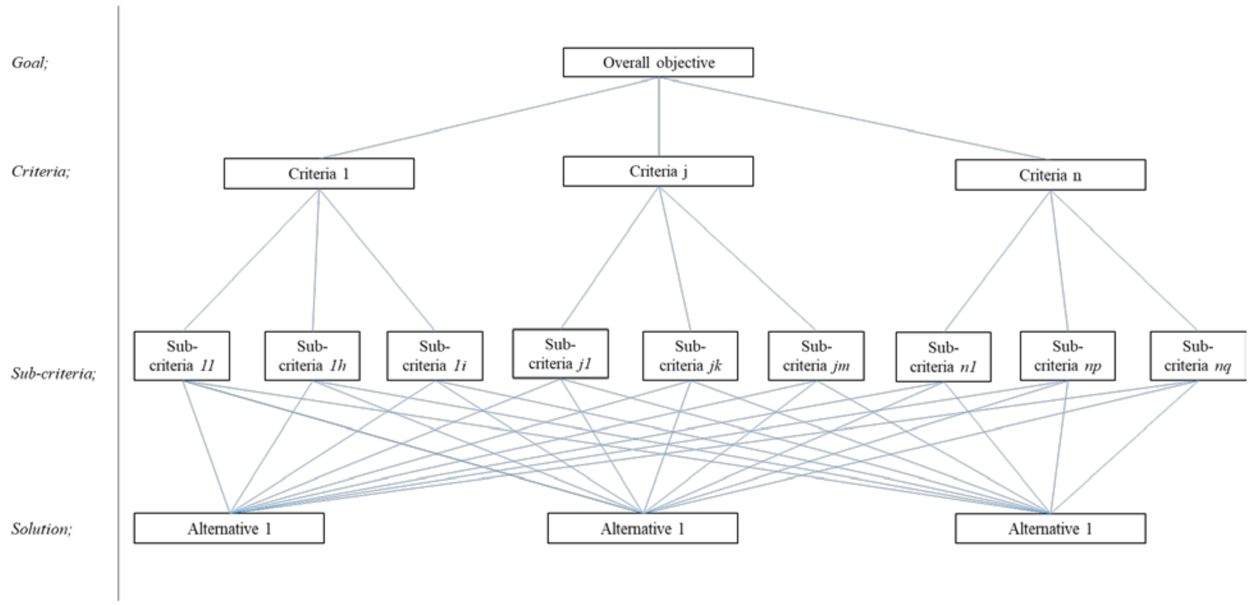

Figure 9: Simplified AHP process diagram.

In this case, the applied AHP in Figure 13.

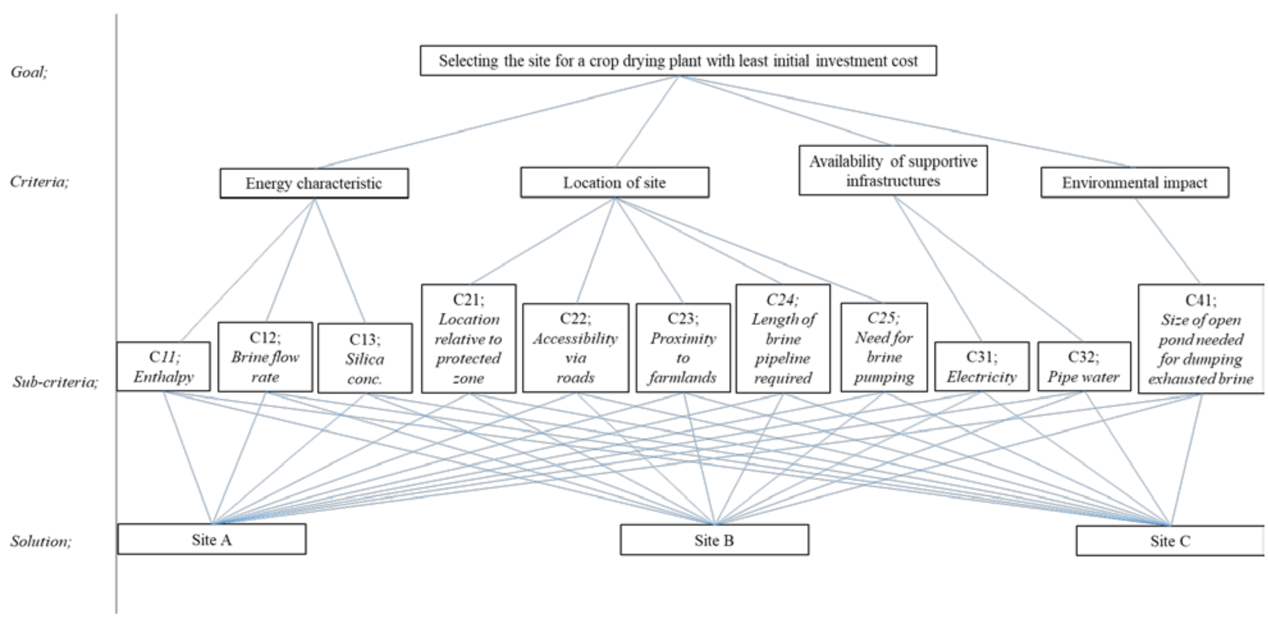

Figure 10: AHP diagram for site selection at Eburru region.

From Figure 13, a pairwise comparison is formed as follows

Which factor has the greatest consideration when selection energy project site?

	Energy	Location	Infrastructure	Environment	Evaluation
Energy	1	7	5	3	0.5825
Location	1/7	1	2	1/3	0.1024
Infrastructure	1/5	1/2	1	1/3	0.0789
Environment	1/3	3	3	1	0.2362
					λ_{max} =4.1237
					CI=0.0412
					CR=0.0460

Which aspect of energy has more influence when selecting an energy project site?

	C11	C12	C13	Evaluation
C11	1.00	2.00	5.00	0.5815
C12	0.50	1.00	3.00	0.3090
C13	0.20	0.33	1.00	0.1095
				$\lambda_{max} = 3.0037$
				CI=0.00185
				CR=0.00319

Which aspect of physical location has more influence when selecting an energy project site?

	C21	C22	C23	C24	C25	Evaluation
C21	1	1/3	1	1/4	1/3	0.0785
C22	3	1	3	2	3	0.3660
C23	1	1/3	1	1/3	1/2	0.0881
C24	4	3	3	1	3	0.3194
C25	3	1/3	2	1/3	1	0.1480
						$\lambda_{max} = 5.3243$
						CI=0.081
						CR=0.0724

Which aspect of infrastructure has more influence when selection energy project site?

	C31	C32	Evaluation
C31	1.00	2.00	0.6667
C32	0.50	1.00	0.3333

The resultant priority vector for the sub-criteria used to select the site for a crop drying plant is calculated as

Sub-criteria	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C41
Priority weight	0.3387	0.1800	0.0638	0.0080	0.0375	0.0090	0.0327	0.0152	0.0526	0.0263	0.2362

Site selection process dependents on the sub-criteria consideration and it takes the following procedure,

Site selection based on Enthalpy of nearby well				
	Site A	Site B	Site C	Evaluation
Site A	1	5	6	0.7258
Site B	1/5	1	2	0.1721
Site C	1/6	1/2	1	0.1020
			CR=	0.0780

Site selection based on brine flowrate of nearby well				
	Site A	Site B	Site C	Evaluation
Site A	1	1/3	4	0.2706
Site B	3	1	6	0.6442
Site C	1/4	1/6	1	0.0852
			CR=	0.0460

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Site selection based on accessibility to clean water				
	Site A	Site B	Site C	Evaluation
Site A	1	2	1	0.4000
Site B	1/2	1	1/2	0.2000
Site C	1	2	1	0.4000
			CR=	0.0000

Site selection based on contamination of environment by brine dumped on percolation ponds				
	Site A	Site B	Site C	Evaluation
Site A	1	2	3	0.5396
Site B	1/2	1	2	0.2969
Site C	1/3	½	1	0.1634
			CR=	0.0330

Once all the sub-criteria have rigorously been applied in selecting the most suitable site to construct the crop drying plant, all the decision weights, (priority vectors), associated with each sub-criterion are combined as in Table 4 to obtain the final decision weights for each alternative site.

Table 4: Sub-criteria contribution to the final decision.

Sub-criteria	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C41	
Priority weight	0.339	0.180	0.064	0.008	0.037	0.009	0.033	0.015	0.053	0.026	0.236	
Site A	0.726	0.271	0.333	0.258	0.540	0.333	0.258	0.429	0.400	0.400	0.540	**0.515**
Site B	0.172	0.644	0.333	0.637	0.297	0.333	0.637	0.429	0.200	0.200	0.297	**0.328**
Site C	0.102	0.085	0.333	0.105	0.163	0.333	0.105	0.143	0.400	0.400	0.163	**0.157**

From Table 4, it is clear to see that the most feasible site to install a drying plant will be Site A, with a 400m long brine pipeline from Well EW01. The weights of each sub-criteria indicate which aspect of decision-making had more impact on the site selection. Since the power plant is close by, the crop drying plant will be easily connected to electricity and piped water at a lower cost. The rigorous AHP analysis tries to consider different desirable aspects of each site and in case of a compromise, the project can adopt the second-ranked option as a tradeoff.

3.0 Conclusion

The suitability of crop drying at the Eburru geothermal field was investigated via GIS mapping of thermal demands and the best site to locate a crop dryer evaluated via the AHP ranking method. Site A was ranked as the best option with a decision weight of 0.5. Factors that contributed to choosing Site A: high brine enthalpy from well EW01, good accessibility via murram roads, requires a smaller brine dumping pond and availability of electricity and piped water. High brine enthalpy means smaller brine pipe diameter as well as a smaller heat exchanger area. Therefore, carrying out crop drying at Site A will require the least initial capital cost, coupled with minimal environmental impact in the region. Such direct use project in the Eburru region will reduce postharvest grain loss and encourage the development of other correlated industries such as animal feed processing.

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