PROCEEDINGS, 46th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 15-17, 2021
SGP-TR-218

Optimization of Geothermal Greenhouses Design for Kenyan Fresh-cut Flowers

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Keywords: Greenhouse heating, Greenhouse cooling, cascaded use, Flowers cultivation

ABSTRACT

Kenya is among the top countries that export fresh-cut flowers to Europe, Russia and China. The fresh-cut flower farming involves greenhouses to limit evapotranspiration and for ease of disease and pest control. Since these activities are labor-intensive, flower farming employs a significant number of farmhands which accounts for more than a tenth of employment provided by the Kenyan agricultural sector. Unfortunately, flower farms use lots of chemical pesticides, fungicides and herbicides, some of which find itself in local freshwater lakes and rivers. One farm, Oserian Development Company, situated near Olkaria geothermal field uses brine to heat its greenhouses thus saving a lot on chemical fungicides by raising dew-point temperatures that occur at 0100-0600 hours. The greenhouse warming reduces humidity levels from 100% to 85% the chances of dew forming on leaves thus limiting the growth of fungi. This research paper seeks to optimize the greenhouse design for both optimal flower growth and dew-point eradication. Besides, the paper integrates cascaded use of geothermal greenhouses with absorption chillers for cooling of fresh-cut flowers thus maximizing brine utilization and saving on electricity for running the coolers. Since a significant number of fresh-cut flower farms are located near developed geothermal prospects, coupling the two will enhance the performance of flower growing and reduce the overall cost thus making Kenyan flowers competitive price-wise in global markets.

1. INTRODUCTION

Kenya is among the top five exporters of fresh cut flowers to EU and Russia, closely rivaled by competing nations such as the Netherlands, Colombia, Ecuador, Ethiopia, Israel among others, each in a fierce struggle to expand its share of the rosy market. Kenya is ranked 4th, after Netherlands, Columbia and Ecuador, exporter of cut flowers to Europe(Akena, 2018). From 2011 to 2020, Kenya has racked up 6.5% global share of the market (Adeola et al., 2018), which is projected to grow modestly by 4.5-5% from 2021-2025. Figure 1 shows how aggressively the floriculture industry grew from 2000 to 2018, making it one of the fastest-growing sectors in Kenya.

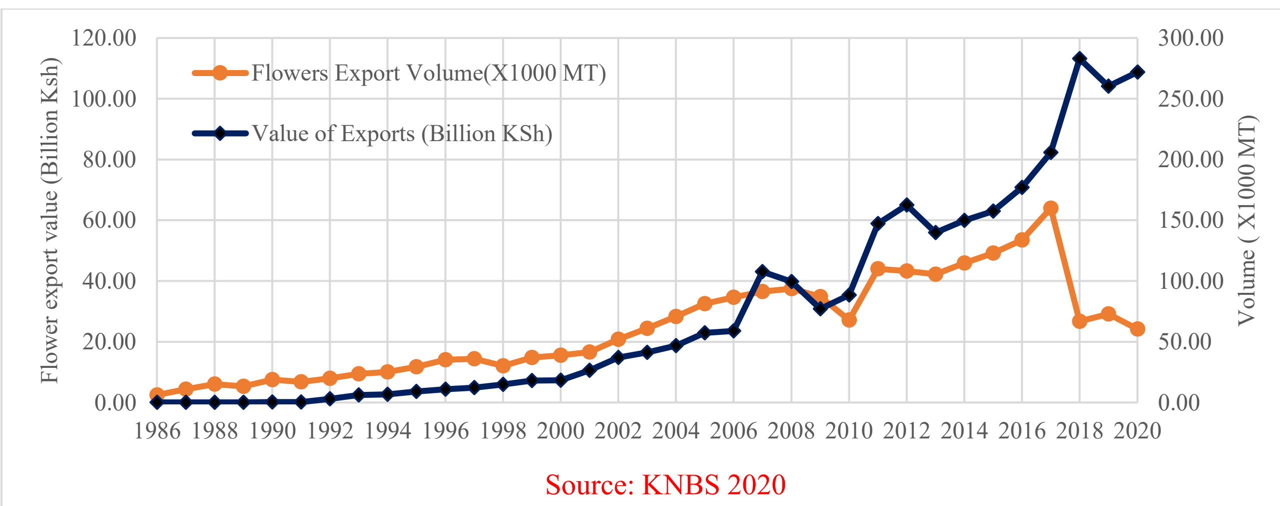


Figure 1: The growth of Kenyan fresh-cut flower industry by volume and value.

The importance of Floriculture to the Kenyan economy cannot be overstated. The horticultural export industry, mainly composed of flowers (72%), fresh vegetables (19%) and fruits (9%) by revenue has seen recent tremendous growth that has positioned it as the second foreign exchange earner to Kenya after tea export. Besides, floriculture employs over 300,000 people directly and many others indirectly. With China, UAE and USA becoming recent market targets for Kenya, the industry is projected to grow some more shortly.

1.1 History of the Kenyan floriculture industry

The kick-off of the Kenyan floriculture industry was majorly driven by tough flower growing conditions in the Netherlands driven by high costs of labor, energy, land, greenhouse construction as well as stringent regulations on environmental pollution(Rikken, 2011).

Hence, many flower-growing companies and farmers moved to Kenya. Kenya's attractiveness for flower growing is anchored on rich andosols with a stable equatorial climate all year round and availability of water resources for irrigation. Almost even day and night hours coupled with high light intensities induce the roses to produce intense colors and excellent shelf life(Rikken, 2011).

However, the success and fast growth of the Kenyan floriculture industry has significantly been contributed by the availability of other driving factors as

- Cheap workforce adept in horticultural management.
- Efficient road transportation system from the farms to the airport and domestic markets.
- Air cargo carriers with direct flights to EU (Kenya Airways).
- Import duty exemption of Kenyan flowers into EU.
- Logistics and cold chain transportation services ensuring reduced losses of flowers due to damages.
- Incentives from the government supporting growers and exporters.
- The Kenyan shilling is weaker than the dollar and euro and depreciates quickly with most global economic hardships hence making Kenyan flowers cheaper in the global market and added profit margin for the flower exporters.

From the early 1990s to 2005, 95% of flower farms were located around Lake Naivasha but the last decade has seen the flower farms move into other regions such as Kiambu, Nyeri, Nyandarua, Kericho, Kajiado and Trans Nzoia.

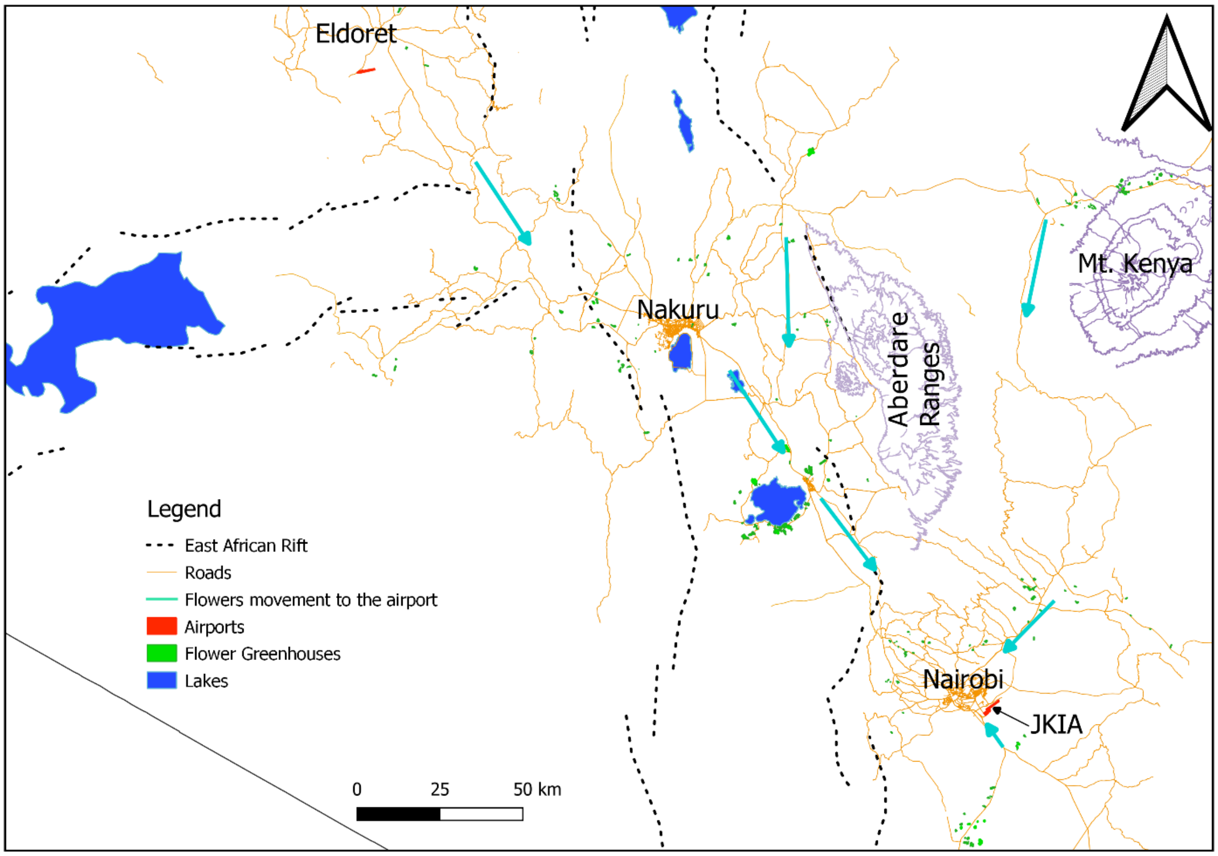


Figure 2: Map showing flower growing greenhouses scattered in different parts of Kenya and the road routes the fresh-cut flowers use to arrive at Jomo Kenyatta International Airport(JKIA) for export to EU and other global markets.

It is easy to infer from Figure 2 that a good road transportation system permits flower farms to penetrate further from Nairobi into areas with fertile, cheaper lands in addition to cheaper labor. The northern slopes of Mount Kenya and Trans Nzoia have seen a recent growth in flower cultivation in acreage.

According to data from the Ministry of Agriculture in Kenya, the main types of flowers cultivated in Kenya from 2010 to 2016 were roses, carnations, lilies among over 40 varieties. Roses are mostly preferred because of their shorter growth time as well as their ability to produce deep beautiful hues if cultivated in regions with plenty of sunshine such as near the equator.

1.2 Challenges facing the Kenyan flower industry

Flowers' selling point is their impeccable leaves and petals; free from diseases and damages. To control disease and pests in greenhouses, farmers use lots of chemical fungicides, pesticides and other chemicals that are not only harmful to the workers in the greenhouse but to the surrounding environment especially water bodies into which the rainwater surface runoff washes the remnants of these harmful chemicals. Besides, flowers accelerated growth rates translate to high rates of evapotranspiration that require high volumes of water. (Mekonnen et al., 2012) estimates that the water footprint of one rose flower is 9 litres and their research found that just six big flower farms around Lake Naivasha were consuming over 50% of the whole volume of water that was used for irrigation in the entire Lake Naivasha basin. Then from the 2000s, experts started to notice that Lake Naivasha was shrinking fast, Figure 3, and contained increased amounts of pollutants that destroyed a significant amount of its original biodiversity. Among the pollutants identified were lead, copper, zinc, manganese, cobalt, chromium(Olando et al., 2020).

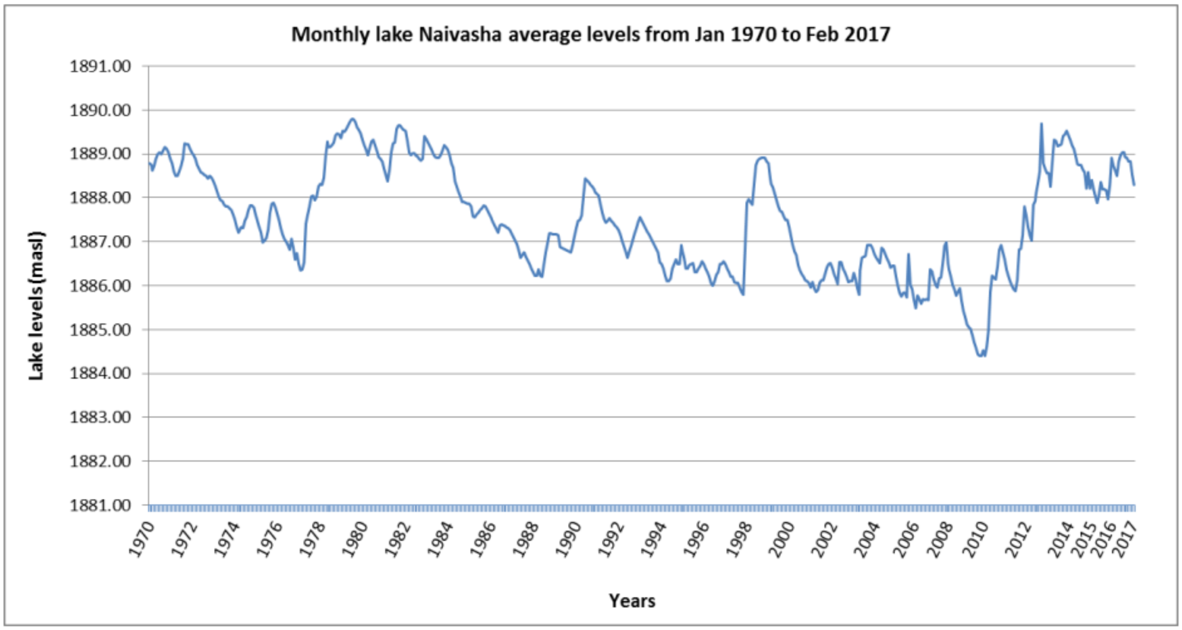


Figure 3: Variations in the levels of Lake Naivasha in over 40 years, due to an imbalance between the amount of lake recharge, evaporation, underground discharge and amount of water abstracted for human activities(KenGen Company, 2018)**.**

In addition, the nitrogen fertilizers and human waste from a fast-growing population of flower workers that got washed to the lake encouraged eutrophication that led to the death of a large quantity of fish, eliciting outcry from Kenyan and international conservation organizations. To survive the farms were encouraged to adopt water-saving practices with an additional requirement of recycling the fluids containing fertilizers. Another pertinent issue of farming around the equator is its constant high ambient temperatures most of the year-round; flowers need cold rooms to slow their growth and blooming. Refrigeration of large volumes of cut flowers consumes lots of electricity and electricity does not come cheap in Kenya, despite its milestones in geothermal energy development.

This paper investigates the possibilities of mitigating some of the aforementioned challenges by direct use of geothermal energy by redesigning the greenhouses to incorporate the cascaded use of hot geofluids. However, the use of geothermal energy is limited to the farms situated on the floor of the Kenyan Rift that are close to the geothermal resources or located at regions with high geothermal gradient. Figure 4 shows that a significant number of big flower farms are located close to the two already developed geothermal resources; Olkaria and Menengai fields.

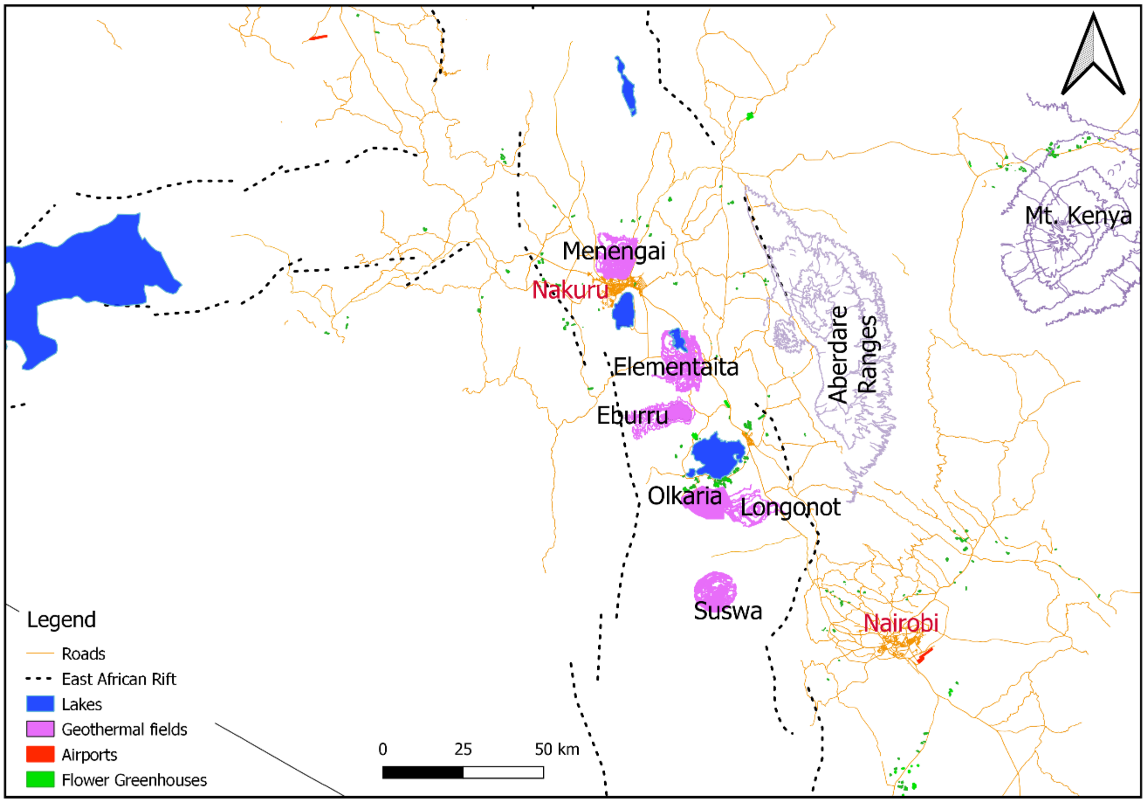
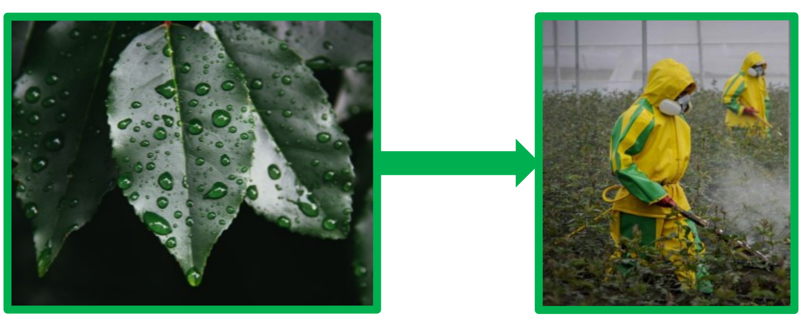


Figure 4: Map showing relative proximity of flower growing greenhouses to geothermal resources in Kenya.

2. KENYAN FLOWER INDUSTRY AND DIRECT USE OF GEOTHERMAL ENERGY

Kenya is ranked globally among the top ten and first in Africa nations with installed electric geothermal energy. But in terms of direct utilization of geothermal energy, Kenya is ranked 57th globally and 4th in Africa(Lund & Toth, 2021). Oserian Development Company(ODC) is a privately owned flowers growing farm sandwiched between lake Naivasha and Olkaria geothermal field. Their proximity to a developed geothermal field has enabled them to incorporate greenhouse heating and CO_2 enrichment to optimize the cultivation of roses. According to (Mburu, 2014), ODC uses one of KenGen's low enthalpy well, OW-101, located 288m away from the greenhouses to heat 50ha of rose flower greenhouses. Oserian has 120ha of cultivated rose flowers, 50ha of which is geothermally heated by circulating fresh water at 55°C through pipes running across the greenhouses. The 1617m deep well with two-phase 14.7t/h flowrate, 135-140°C and enthalpy of 1475kJ/kg also provides CO_2 as NCG which is separated from brine and fed into the greenhouses. Conventionally, the condensed moisture on crop leaves encourages the growth of fungi, (Petal Botrytis and Downy Mildew), necessitating the use of chemical fungicides in the greenhouse. By employing greenhouse warming at early hours of the morning when outside temperatures drop below dew point temperature, the crops are provided with a stable optimal environment, 85% humidity, for growth as well as the operational costs of spraying fungicides are reduced since fungal growth is significantly impeded(Land O' Lakes, 2013).



5: Workers spraying chemicals in a greenhouse.

A 2013 study report by Land O' Lake showed that the Oserian flower farm reduced costs of heating fuel by 70% and overall operational costs by 5-10% from adopting geothermal heating in greenhouses(Land O' Lakes, 2013). This study also showed that greenhouse heating maximized production to meet market peak periods, (market timing), with additional benefits of shortened crop production cycles with a consistent quality of flowers thus improving overall production per hectare by 15-20%. Besides, the fertilized water used in ODC's hydroponic irrigation systems is sterilized using geothermal steam to allow for recycling, thus saving on water and fertilizer usage.

Figure 6: (a) Oserian heat exchanger system harnessing geothermal fluids from well OW-101. (b) Pipes running within the greenhouse to circulate hot fluids (Mburu, 2014)**.**

At ODC, electricity is used for pumping water for irrigation and other uses as well as for cold storage rooms. Rose stems need to be cooled to 5-8°C to stop growth before they are processed. Rooms for cool flower processing and cold storage with refrigeration of 60-120 tonnes capacity represent huge electric loads in the rose flower export industry. It takes 24hours for a rose stem to move from harvest to Dutch flower auction and another 24 hours for it to be for sale in a retail store in Europe(Land O' Lakes, 2013). During transportation to the airport and consequent shipping to the market, the flowers are preserved at 2°C. The shipping follows a simple flow chart shown in Figure 7.

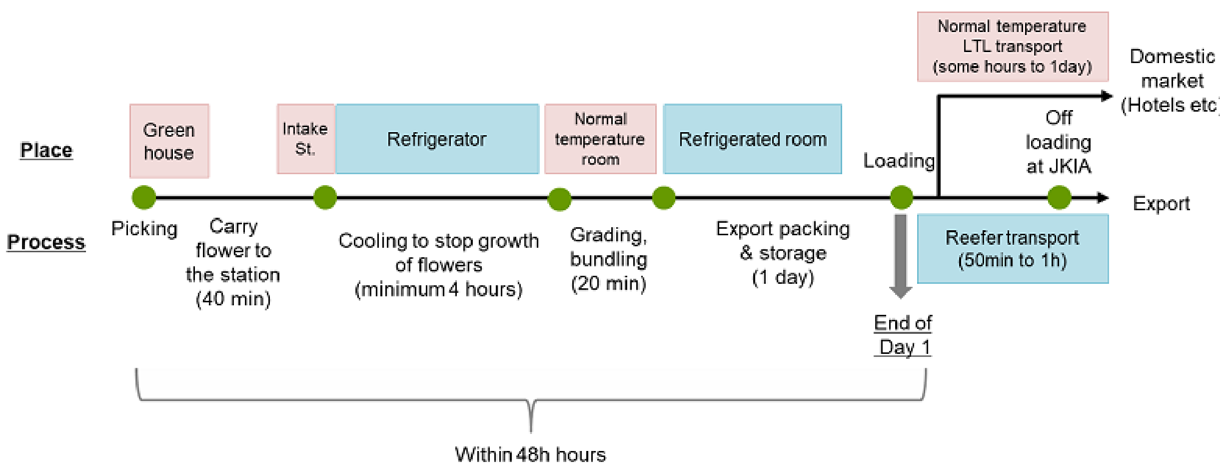


Figure 7: Simplified flow chart of cut flowers from the time of harvest at the farm to the market and the type of refrigeration conditions required along the shipping route (Nippon Express, 2020)**.**

The cost of electricity for large scale commercial entities in Kenya is high, \$0.09-\$0.11/kWh due to a large portion of it, 27-30%, being generated from imported diesel. Electricity provided by Kenya Power and Lighting Company (KPLC) is also not reliable with unpredictable disruptions that can last from a few hours to a full day. The ODC saw the need of generating their own cheaper and reliable electrical power by using a 1.3MW backpressure steam turbine coupled with steam supply from OW-202 and 1.6MW binary plant utilizing fluids from well OW-306. The binary plant and back pressure steam plant were commissioned in 2004 and 2006 respectively(Land O' Lakes, 2013).

Figure8 shows how proximity to the three wells, OW-101, OW-202 and OW-306 has been beneficial to ODC enabling it to utilize geothermal energy without including the high costs and risks involved with resource exploration and well drilling.

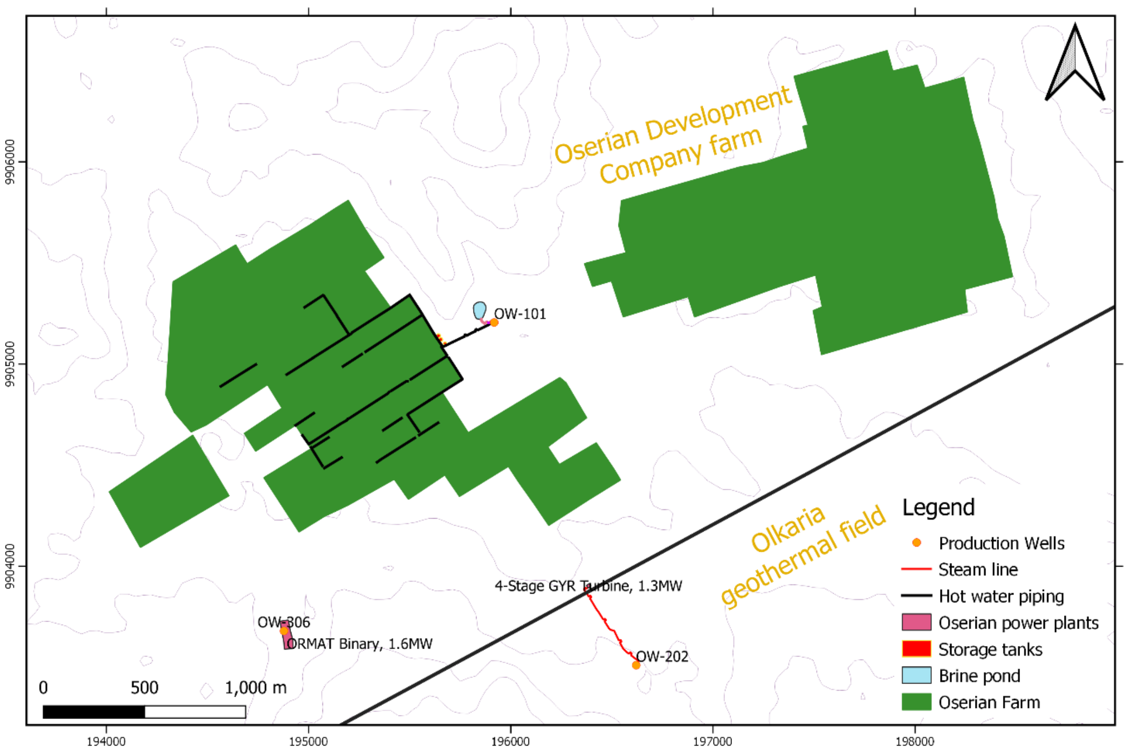


Figure 8: Location of Oserian greenhouses relative to the geothermal wells that supply hot fluids for both direct use and electricity generation.

2.1 Direct utilization of geothermal energy in the Japanese flower industry

Japan is among the leading nations in direct utilization of geothermal energy and is ranked 7th globally by the 2019 survey on direct use(Lund & Toth, 2021). The main direct utilization scenarios of geothermal energy in Japan are recreational spas(Onsen) and greenhouse heating. One good scenario where the geofluids are used for both greenhouse heating and cooling is near Yamagawa Power Station in Kagoshima Prefecture. The power plant wells are located less than 10km to the east of Kaimondake Volcano and 900m away from the East China Sea shoreline. It is owned by Kyuden Mirai Company and managed by Kyushu Electric Power company. The power plant uses its 12 production wells to produce 30MWe via single flash turbines and 4.99MWe from the binary power plant. 80% of brine is passed through an ORC binary plant before being reinjected at 100°C while 20% of brine is reinjected hot at separation temperatures. There are 9 reinjection wells. About 3t/h of brine at 100°C is piped via steel pipes to about 30 greenhouses located within the vicinity of the power plant.

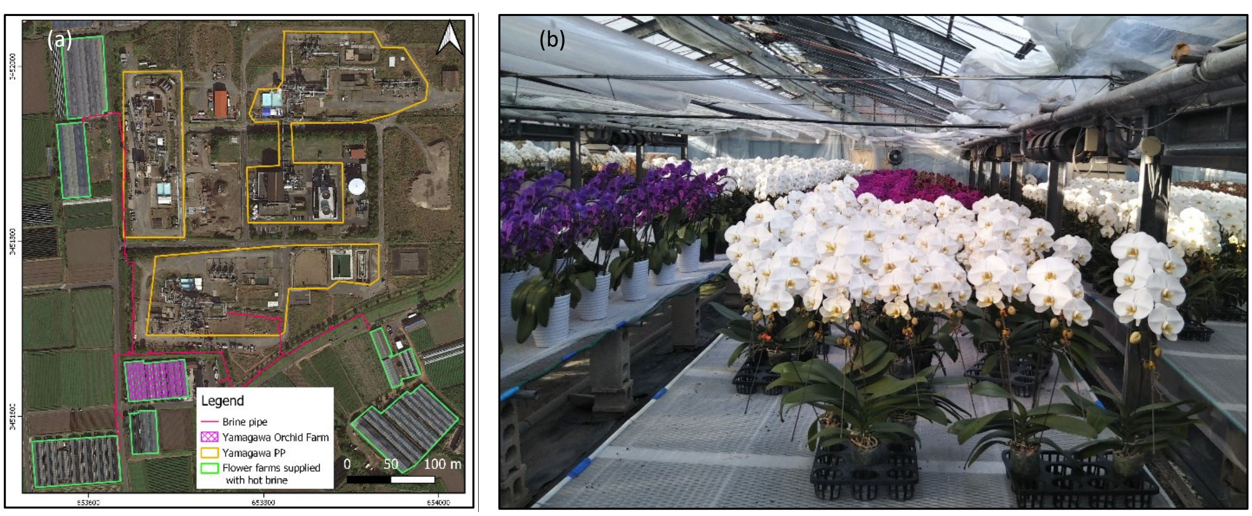


Figure 9: Photos (a) showing proximity of Yamagawa power station and the flower farms supplied by brine at 100°C (Base map is Google Satellite image) and (b) showing orchid growth in a nearby greenhouse.

One of the flower farms supplied with brine from the power plant is Yamagawa Orchid farm located to the immediate south of Yamagawa power station. As shown by Figure 9(b), the greenhouse farm cultivates different kinds of orchid flowers for the domestic market in Japan. The farm uses geothermal fluids to heat the greenhouse during winter by passing hot water through steel pipes laid on the ground. The hot water is also piped overhead through fan-operated heat exchangers to heat the air to the recommended temperatures and humidity for optimal growth of orchids. During summer the farmer uses a Johnson Controls-Hitachi HAU CL100XEX absorption chiller, with a cooling capacity of 316.5 kW. The absorption chiller uses hot water at 88-90°C to cool water from 12-5°C. The chilled water is then used to cool air via a heat exchanger which is conducted into the greenhouses via overhead polyethylene film ducts. And the cool water from the water-air heat exchanger is ran through the same piping, as used during heating, to cool the greenhouses from the floor. This combination of optimized cooling and heating piping and air ducts enable the farm to efficiently control temperatures in the 0.3ha greenhouses. The orchids grow optimally at 25-30° and humidity of 60-80%; dropping the temperatures to 20°C creates artificial winter that induces the orchids to bloom shortly after(Naik et al., 2014). Once again, by controlling the temperatures in the greenhouse, the farm is able to control the flower blooming all year round.

Since winter heating requires more heat input, the farm has its shallow well of 100m depth that produces 6t/h of hot fluids at 80°C by pumping in addition to the hot brine provided by the Yamagawa power station. The farm's economics have improved since installing the $100,000-dollar absorption chiller by reducing total electricity bills (for fluid pumping, air compressors and air conditioning) by 30% yearly. The cost of brine piping from the power plant and absorption chiller is subsidized by the government. A single pot of orchids costs from $100-500 in the Japanese market though they take at least 3 years to mature.

3. OPTIMIZATION OF KENYAN GREENHOUSES FOR DIRECT UTILIZATION OF GEOTHERMAL ENERGY

This topic takes into account the successes of both flower farms from Japan, (Yamagawa Orchid), and Kenya, (Oserian Development Company), as a foundation of optimizing the industry for reduced capital investment and operational costs in a bid to maximize profits and compete price-wise in the global market. To achieve this, the design of hot water piping needs to be optimized to incorporate chillers in a cascaded use of heat as well as in material selection for circulation of hot water in the greenhouses and cold air in the cold storage rooms.

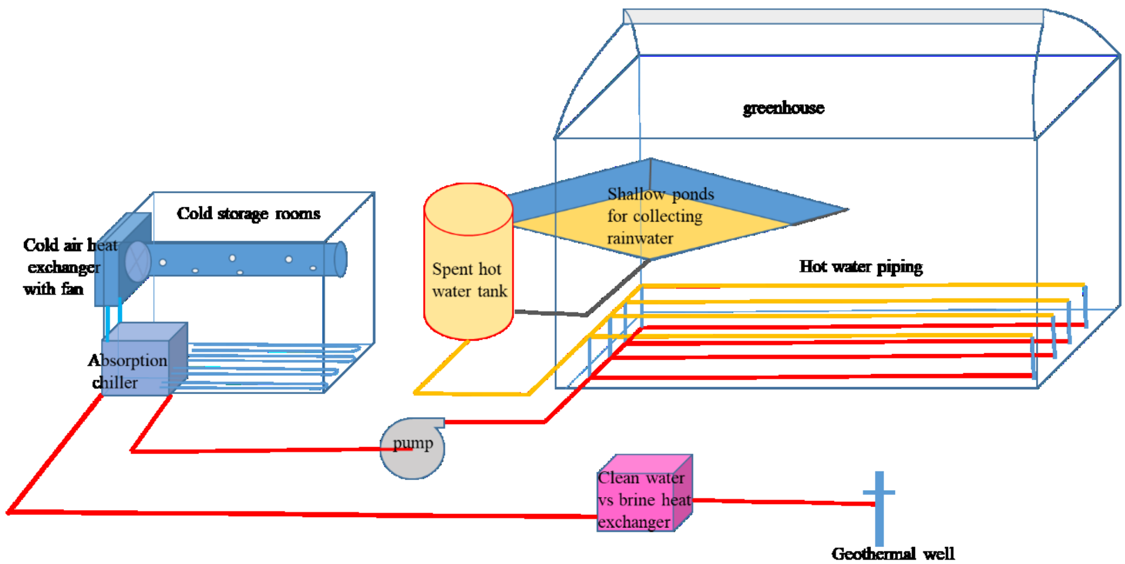


Figure 10: A simplified model of an ideal flower greenhouse with cold storage rooms and wastewater ponds or for collecting rainwater for irrigation in the greenhouse.

Figure 10 shows a simplified model that enables optimization of space, material, heat, electricity and water to be evaluated depending on the crop being cultivated and ascertain the best tradeoffs to achieve the least cost flower greenhouse operations. From this ongoing research, the Kenyan greenhouse near Olkaria can achieve up to 15% improvement in flower production and up to 45% reduction in electricity bills used for cold storage. The integrated heating and cooling in cascaded use also allows flower farms to cut up to 10% in water usage hence saving the lake by reducing the amount of water abstracted from Lake Naivasha. The research also shows farms that are close to each other can organize for combined wastewater treatment to limit the impacts of flower growing to the surrounding environments.

4. CONCLUSION

There are over 20 flower farms located around Lake Naivasha and many others located within the Kenyan Rift floor. Due to faulting at the East African Rift, many regions in the valley floor have residual magmatic bodies at shallow depths of 8-10km giving them an abnormally high geothermal gradient of >3°C/100m especially within or around geothermal fields as well as most prospects. So far only Oserian Development Company has managed to adopt sustainable geothermal resource utilization into flower farming, hence cutting down on water usage, wastewater disposal and chemical fungicide applications. The Yamagawa Orchid Farm has managed to reduce the electric load on air conditioning and cooling of greenhouses thus reducing operational cost by incorporating an absorption chiller powered by geothermal fluids. These two cases indicate that geothermal utilization has the potential of not only improving agricultural production but also saving the environment from harmful chemical fungicides if well incorporated and optimized into greenhouse operations. Although the economic viabilities have not been outlined in detail, the case studies show the possibilities of improvements, which unfortunately depend on the locations of the geothermal resource, flower farms, the market and the type of flowers grown. Changing existing greenhouses is capital expensive and requires extensive a priori knowledge on the benefits of incorporating new equipment such as chillers, their piping and heat exchangers. As it is done in japan, the air ducts can be fabricated from cheap polyethylene films hence massively reducing initial costs and fan power due to their reduced friction to airflow. Kenya is facing fierce competition for global flower market share, especially from Ethiopia, Colombia, Ecuador and Netherlands and it is therefore crucial that it takes advantage of all the resources it has, including geothermal energy, to maintain a foothold of its flower market share.

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