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Direct Use of Low Enthalpy Deep Geothermal Resources in the East African Rift Valley

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ABSTRACT

Geothermal energy is already harnessed across East Africa to provide hundreds of megawatts of electricity, with significant plans for future expansion towards generation at the gigawatt scale. This power generation utilizes the high steam temperatures (typically more than 200 °C) that are available in several locations in Kenya, Ethiopia and elsewhere. The presence of these high enthalpy resources has deflected attention from the often attractive low and medium enthalpy resources present across a more extensive portion of the region. Geothermally heated water at cooler temperatures (<90 °C) could be widely produced by drilling shallower and cheaper boreholes than those required for power production. This low enthalpy resource could be widely exploitable throughout the Rift Valley, offering a low carbon, sustainable, reliable and commercially competitive source of heating, drying and cooling (via absorption chillers) to local farmers and growers, and for low temperature commercial and industrial uses. Applications of this type would displace expensive fossil fuels, reducing costs and carbon emissions as well as improving the region's energy and food security. The power input for pump systems can be accommodated by relatively small generators, so direct heat projects could be beneficial to consumers in areas with no grid access.

1. INTRODUCTION

Geothermal energy is a well-established, low carbon and sustainable base-load technology. Since the first success in generating electricity from geothermal steam at Larderello, Italy in 1904 (Dickson and Fanelli, 2013), power has now come to be produced from geothermal sources in 24 countries, with a total installed capacity in 2010 of 10,898 MW (Bertani, 2012).

Aside from electricity generation, the *direct* use of geothermal energy is one of the oldest, most versatile and commonly found forms of energy consumption. Direct heat sources have been widely utilised across the globe for thousands of years – geothermal bathing and heating systems were common across Europe and the Mediterranean in Roman times (Dickson and Fanelli, 2013), and Japanese artefacts near the Yuda hot spring (Iwate Prefecture) date from before 11,000 B.C (Fridleifsson, 2001). In 2010, direct applications of geothermal energy were reported in 78 countries worldwide (Lund et al., 2011), with a total installed thermal capacity of 48,483 MW_t – a 72% increase from 2005. (Note: in this paper, the term 'heat' refers to various processes including heating, drying and cooling.)

Where the geological resource is suitable, geothermal energy is recognised as offering a plausible low carbon development pathway for developing nations. Direct heat use could potentially make a large contribution towards this goal – for heat production, geothermal is around 3% as carbon intensive as natural gas (which is less carbon intensive than diesel or fuel oil). The carbon intensity of direct geothermal heat will vary from project to project with the requirement for pumping, but generally deep geothermal heat can be seen as one of the cleanest and greenest energy technologies. Geothermal heat can also increase energy security by reducing local dependence on fossil fuel imports.

This paper has the following objectives:

i) Outline the direct geothermal heat use opportunity available in the East African Rift Valley.

ii) Provide examples of successful direct geothermal heat use in the Rift Valley and elsewhere.

iii) Explore how direct geothermal heat use could be exploited in the Rift Valley, with particular emphasis on further data requirements, government policies and funding sources.

2. SCOPE FOR WIDER DIRECT USE IN THE RIFT VALLEY

The spreading centre of the East African Rift System stretches from the Gulf of Aden in the north to Malawi and Mozambique in the south. The eastern branch, which forms the Ethiopian and Kenyan rifts, possesses by far the most extensive geothermal resource base in Africa and one of the most extensive in the world (Teklermariam, 2006). Building on early exploration in the 1960s (Simiyu, 2008), countries along the Rift Valley have recently surged forward in their geothermal power development as their rapidly increasing populations and economies seek dependable base-load power. Geothermal energy has proved commercially competitive with hydro and fossil fuel alternatives, and Kenya and Ethiopia are planning an expansion of their geothermal capacity towards the gigawatt scale.

Since its beginnings the Rift Valley's geothermal industry has focussed almost entirely on electricity generation. This focus is natural, as power is more valuable per unit generated and more versatile than direct heat. This paper argues that this concentration on large scale, strategic geothermal power production has overshadowed the potential for direct heat production, and that as a consequence its utilisation in East Africa remains in its infancy. There are some small-scale examples installed in Ethiopia

(Teklemariam and Kebede, 2010), where Lund et al. (2011) estimate the total installed capacity to be 2.2 MW_t; and *Section 3.2* outlines the Oserian Development Company's direct use system at Lake Naivasha, Kenya. Elsewhere in the Rift Valley, there are no other reported large-scale direct use applications.

The opportunities for direct heat use in the region appear significant – both on a small, community level and for large-scale commercial applications. Geothermally heated water at cooler temperatures (85-90 °C) is widely available in areas along the Rift Valley and can be produced by drilling much shallower and therefore cheaper boreholes to less than 1,000 m depth. These could be deployed at a commercially competitive cost for use in large-scale industrial processes such as drying and curing, or to heat greenhouses: the agricultural and floricultural industries consume large quantities of heat throughout the Rift Valley. This generally requires the combustion of imported fossil fuels (such as fuel oil) which are expensive, subject to price volatility and carbon intensive. Low-mid enthalpy direct heat geothermal resources sufficient to meet demands of this type are likely to be available across the region.

The Rift Valley's direct heat resource could also be exploited by smaller farming and growing communities. It offers a sustainable, reliable and relatively cheap source of heating which would help improve food security, with efficient drying schemes reducing crop wastage. As a non-intermittent and despatchable resource, it would be particularly valuable to small-scale commercial enterprises that lack a constant heating demand: crops could be dried at a communal scale, boosting local productivity. Additionally, the electricity demand of such small systems will be minimal, allowing them to be deployed in off-grid communities.

In summary, relatively shallow geothermal energy offers an opportunity to develop a comparatively cheap and practical low carbon heat technology that could be used for a variety of purposes by farmers and growers in the Rift Valley countries, leading to improvements in agricultural productivity.

3. DIRECT HEAT USE CASE STUDIES

In this section we present two examples of successful African direct heat use projects. The second case study of Oserian Flower Farm at Naivasha, Kenya is the only large-scale example of direct use in the East African Rift. We have also included the first case study describing direct heat use in Southern Tunisia.

3.1 Greenhouse Heating, Southern Tunisia

Geothermal energy in Tunisia is limited to direct use applications owing to the country's low enthalpy resource (Ben Mohamed and Said, 2008). Tunisia's hot springs ('hammams') have been used for bathing for thousands of years (Ben Dhia, 1990).

The geothermal resource is located in the south of the country, and has been commercially exploited since the 1980s. In 2010, Tunisia had an estimated 43.8 MW_t of installed thermal capacity, the bulk of which is used for greenhouse heating (Lund, et al. 2011). This figure is somewhat misleading, as of the geothermal *fluids* extracted, nearly 73% are used (following cooling) for oasis irrigation, with only 25% used for greenhouse heating purposes (Ben Mohamed and Said, 2008). This is as a result of southern Tunisia's arid desert environment – the substantial deep aquifers provide a valuable water source for the region.

Unheated greenhouse development began in coastal regions of Tunisia in the mid-1970s. However low night time temperatures of below 7 ^{o}C (and below 5 ^{o}C in desert areas) made early crop production for European export difficult (Said, 1997). To combat this the Continental Intercalaire aquifer, which reaches depths of 2,800 m and temperatures of up to 80 ^{o}C has been exploited for geothermal heating (Ben Mohamed and Said, 2008).

Drilling began in the mid-1980s, financed by the United Nations Development Programme (UNDP) and by 1986 the first geothermal energy was in use in Southern Tunisia's greenhouses. This was a major revolution for the use of small-scale direct heat geothermal resources and Tunisia's export potential boomed as the introduction of heated greenhouses dramatically increased agricultural productivity. Vegetable production in the Kebili region increased nine times from 210 tonnes in 1988 to 1,935 tonnes in 1995. From 1996-2001 the average vegetable production was 2,830 tonnes per year (Ben Mohamed, 2002). Whilst much of the increase in productivity was caused by the expansion of agricultural areas rather than increased yields, geothermal direct heat use was the impetus for the rapid expansion. Tunisia had 217 ha of greenhouses in 2010, and plans to increase this to 315 ha by 2016 (Lund et al., 2011).

Figure 1 shows the interior of a typical geothermally heated greenhouse, with a simple polypropylene piping arrangement providing heat to the crops (tomatoes make up approximately half of the produce grown in the greenhouses, along with several melon varieties). The simplicity and low cost of the heating infrastructure makes this type of direct use application especially favourable for developing countries.

Figure 1: Greenhouse heating in Tunisia (Ben Mohamed and Said, 2008).

Water used in the heating systems is cooled and ‘recycled’ for irrigation. Ben Mohamed and Said (2008) suggest a scheme which would maximise the geothermal resource (shown in Figure 2), with greenhouses, hammams and oases all located within reach of a pumped water network. As water is in such short supply, and is not re-injected into the aquifer, systems such as this could help prevent over-exploitation of the area’s resource.

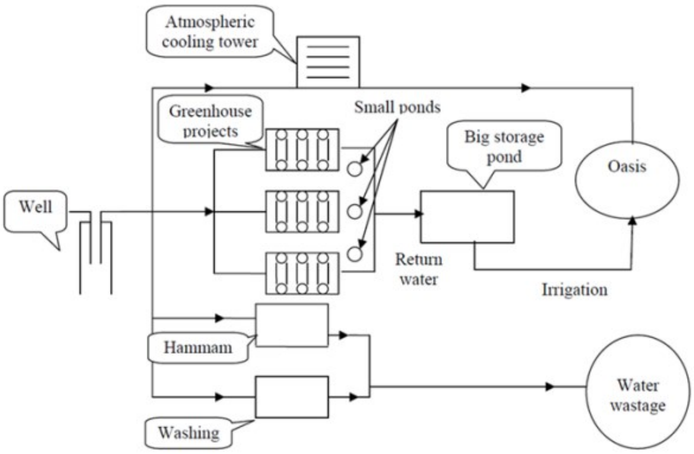

Figure 2: Configuration for maximising the geothermal resource (Ben Mohamed and Said, 2008).

Direct heat use in Tunisia is an excellent example of the potential benefits offered by geothermal energy. If managed well, direct use applications can boost crop productivity for export, enhancing a country’s economy. Tunisia’s grasp of the potential of its deep geothermal resource has enabled these benefits to be exploited – despite the relatively low enthalpy environment. With a higher enthalpy resource, the installed infrastructure could provide low carbon heating on an even larger scale.

3.2 Oserian Flower Farm, Naivasha, Kenya

Kenya hosts the vast majority of the East African Rift Valley’s installed geothermal energy capacity, with other countries in the region less advanced in their geothermal development. However, Ethiopia is set to expand its geothermal capacity dramatically in the near future, with projects planned on the gigawatt scale. Kenya’s geothermal prospects and their relation to the Rift Valley are clear to see (Figure 3), but are focussed on high enthalpy geothermal electricity production with little emphasis on direct use.

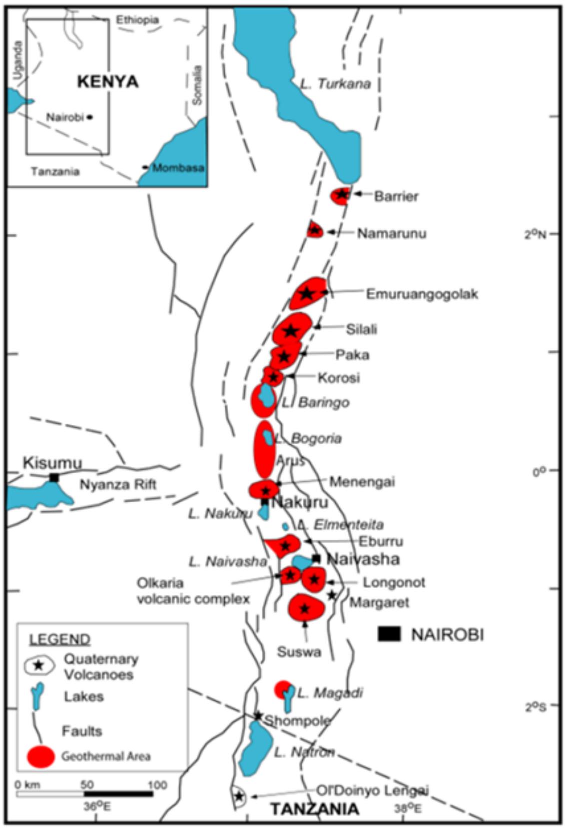

Figure 3: Geothermal prospects within the Kenyan Rift (Omenda, 2007).

As with many regions around the world, Kenya's hot springs have been used for bathing and cleansing ceremonies throughout history (Tole, 2001). Today, the Lake Bogoria Hotel uses geothermal waters from the nearby Loboi hot spring for swimming pool heating. Elsewhere, the Eburru community condenses steam from fumaroles for domestic purposes and flower drying (Mariita, 2010). However, these are both relatively small-scale examples of geothermal direct utilisation. The country's best example of large scale direct use is greenhouse heating at Lake Naivasha.

Oserian Development Company owns and operates a large flower farm at Lake Naivasha (Knight et al., 2006), close to the established Olkaria geothermal power complex (Figure 4). It is the only company in Kenya to utilise geothermal energy for direct use applications on a commercial scale (Mburu, 2014) and is a prime example of using high enthalpy geothermal resources for a direct use application alongside a successful power generation operation. Since 2003, the firm has extracted geothermal fluids from an exploration well drilled by KenGen in 1983 (Mburu, 2009). The well was isolated from the main Olkaria geothermal power plant production areas, and had a very low power production potential. The geothermal fluids were initially used to heat 4 ha of greenhouses, and following the scheme's initial success, a second nearby exploration well was installed with a 1.2 MW_e binary generation plant, which provides electricity alongside additional heated fluid to the farm (Knight et al., 2006). By 2010, Oserian Development Company had invested heavily into its geothermal utilisation efforts (Mariita, 2010) which included the two geothermal power plants installed and operated by the company as well as the direct use component.

Figure 4: Geothermally heated greenhouses at Oserian (Mwangi, 2006).

The geothermal fluids are currently used to heat 50 ha of greenhouses through a system of piped loops. Without heating, early morning humidity in the greenhouses can rise to 100%: heating reduces this to below 85%, alleviating fungal growth and eliminating the need for chemical fungicides. Additionally, the heated fluids are used to sterilise fertilised water, reducing fertiliser wastage; whilst carbon dioxide from the geothermal well is used to enhance photosynthesis (Mburu, 2014) (as Lake Naivasha is situated at approximately 2,000 m above sea level (Mariita, 2010), there is reduced atmospheric pressure and consequently lower CO_2 levels). Low CO_2 levels will lead to reduced photosynthesis within the crops and consequently restrict productivity. The natural CO_2 content at Lake Naivasha is 250 parts per million (ppm), which is increased to 850 ppm at Oserian by pumping 27 tonnes of CO_2 from geothermal wells into the greenhouses each day (Reinders, 2009).

The Oserian scheme is a flagship case study for geothermal direct heat use in the East African Rift Valley. The enhanced crop production (the number of stems per metre has increased by 30% (Reinders, 2009)) and efficiency provided by the geothermal heating system highlights the potential for this technology throughout the region. The resource is widely accessible across the Rift Valley, and further exploitation at this commercial scale could vastly improve the area's already impressive agriculture and floriculture industries.

4. EAST AFRICAN DIRECT HEAT USE POTENTIAL

As outlined in *Section 2*, there is scope for the widespread deployment of direct heat use systems throughout the Rift Valley, with *Section 3's* case studies highlighting the commercial benefits of the technology. The installations in Southern Tunisia provide an example of exploiting a relatively low enthalpy resource (compared to the Rift Valley) in an inexpensive, technologically straightforward manner (see Figure 1). The small scale at which geothermal technology has been deployed in Tunisia has allowed local farmers and growers to benefit from the resource. In contrast, the Oserian Flower Farm in Kenya is on a larger, industrial scale. More expensive and technologically complex than the Tunisian installations, it demonstrates the considerable benefits to the agricultural and floricultural industries of deploying direct use geothermal in the Rift Valley. These two examples show how direct heat use can provide an effective, sustainable and low carbon alternative to traditional fossil fuel heating supplies.

Exploring similar opportunities throughout the Rift Valley could open up an exciting and valuable new sector in the region's deep geothermal energy industry. In this section we discuss how the potential for direct use in East Africa can be determined, and focus on the financial, policy and data requirements of the technology's roll-out. Using the case studies presented in *Section 3*, we consider the two alternative applications of direct use heat – small community scale projects and large-scale commercial ventures. Both offer benefits to the East African Rift countries and are readily available throughout the region.

4.1 How Much Direct Heat Could Be Productively Used?

It is clear that a large number of agricultural and industrial sectors in East Africa could make use of direct geothermal heat: the dairy industry, brewers, large scale food preparation, the tanning and curing industries, covered horticulture and floriculture, and crop drying to name a few. Where geothermal resources are accessible at the surface communities are quick to exploit them (see Figure 5). However, robust data on the scale of the current heat use are not easily accessible.

Figure 5: Community scale direct use agricultural drier near Eburru, Kenya.

Due to the relatively high price of fuel oil, much of this heat demand is currently unmet. For example on the small, local scale, many crops are dried in the sun rather than being artificially heated. The latter option is often too expensive for farmers but the former increases the vulnerability to crop wastage (Hodges et al, 2011). On the commercial level, productivity in the Kenyan floriculture sector (as the example at Oserian demonstrates) would certainly be boosted by using direct heat to increase greenhouse temperatures.

Given the rapid economic growth occurring in several Rift Valley countries, one would also expect an increase in demand for cooling and air conditioning into the medium and long term. Using absorption chillers, geothermal direct heat sources could also be utilised to meet this form of heat demand.

At a policy level, an obvious first step towards planning for direct geothermal roll-out would be to estimate the total market for direct heat across these sectors, including reference to the temperatures required. Following this, a high-level strategy to deploy the technology could be developed, with targets for planned installed geothermal capacity set out.

4.2 Funding a Roll-Out of Direct Geothermal Heat

A well-recognised feature of geothermal energy is its requirement for up-front capital expenditure. This is less acute for direct heat projects, as the boreholes will be much shallower, but will still represent a constraint. Drilling a borehole will generally be beyond the financial capacity of small-scale farmers or even community associations. Potential industrial customers will be better placed, and for those currently burdened with large fossil fuel heating costs a deep geothermal direct heat project may be commercially attractive.

The issue of initial drilling risk, a familiar problem to geothermal developers, also applies to direct heat projects. As the target temperatures are low compared to power projects, this risk may be lower, but the permeability risks are still significant. Without regionalised sub-surface analysis through a programme of test boreholes, offering robust advice to potential developers will be difficult.

One obvious potential funding source for direct heat projects would be the various international development agencies such as the World Bank, United States Agency for International Development (USAID) and the UK's Department for International Development (DFID) amongst others. Indeed, the initial drilling programme for the direct heat greenhouses in Tunisia was funded by the UNDP (see *Section 3.1*). Since 2000, flows of overseas development aid have been strongly focussed on meeting the Millennium Development Goals, with Goal 7 specifically focussed on the environment. It contained the following target: 'Integrate the principles of sustainable development into country policies and programmes' (WHO, 2008). To help achieve this aim the Climate Investment Funds (CIF) were created in 2008, and are administered by the World Bank (Porter et al., 2008). More recently the UN's High Level Panel on the Post-2015 Development Agenda advised that sustainable development must be put 'at the core' of development efforts, and advocated a 'profound economic transformation…by harnessing innovation, technology, and the potential of business' (UN, 2013).

Delivering geothermal energy, of all types, would appear to be in very good alignment with these high-level development objectives. Rift Valley countries exploiting their direct heat resource will generally be using it to replace expensive and carbon-intensive imported fossil fuel heat. As noted in *Section 1*, the low requirement for electricity means that direct heat systems need not be confined to areas with access to the grid; remote (and generally poorer) communities could also benefit.

Development and CIF funds are already being allocated to deep geothermal power development (through the German government-owned development bank KfW's risk insurance instruments, and the Scaling up Renewable Energy Programme (SREP)), though there has been little focus so far on direct heat projects. One factor here is that the amounts of funding required to carry out shallow geothermal test wells are often *smaller* than the normal programme size familiar to development agencies.

We would urge that development agencies reconsider how they can engage with the geothermal direct use sector, as relatively large gains could be achieved in return for a modest funding commitment (the Tunisian example in *Section 3.1* was remarkably cheap – the UNDP's initial funding came to $80,000 (UNDP, 1988)). Well-planned demonstrator projects in the Rift Valley countries could offer significant productivity gains for poorer communities off the electricity grid – a priority group for development assistance.

5. CONCLUSION

There is clear scope for exploitation of the East African Rift Valley's low enthalpy, relatively near-surface direct heat resource. A quantity (currently of unknown size) of unmet heat demand throughout the region could be supplied by direct use geothermal, and a proportion of costly and carbon-intensive fossil-fuel heat use could be displaced. This paper has explored existing examples in East Africa and elsewhere of the benefits of direct geothermal heat utilisation, and we have the following observations.

i) Discussion of the potential for direct geothermal heat would be enhanced by the collation and publication of robust data on the current and potential direct heat consumption across the Rift Valley countries. This market could be split into two categories:

   a) existing heat demand in locations suitable for *in situ* conversion to a direct use geothermal system (similar to the Oserian Flower Farm, *Section 3.2*); and

   b) the predicted amount of *additional* heat demand that would arise from developments using geothermal direct use schemes.

   This data would also help identify the sectors best suited to using the technology.

ii) A country and/or region-wide strategy could be usefully developed by involved Governments and/or international development agencies to enable the expansion of direct use. This would involve identifying in-country Government, industrial and academic experts working with the best suited sectors to collaborate with geothermal direct use experts. A high-level strategy could then be generated.

iii) Building on existing investment and funding allocations into the region's geothermal power development, funding sources such as the CIF and other international funding schemes could examine the scope for widening their future programmes to include direct heat utilisation projects. Support for direct use demonstrator projects could be implemented along the same lines as the power-focussed Scaling up Renewable Energy Programme (SREP). This promises to be significantly cheaper per unit of renewable and sustainable energy delivered than the power equivalents.

Achieving these steps would significantly improve understanding of the region's direct heat resource, and could open up considerable opportunities for investment in the Rift Valley countries. The deployment of direct use geothermal at a small local scale as well as in larger industries could offer a realistic low carbon and sustainable alternative to fossil fuel heating, including those communities with no access to the electricity grid. At the same time, benefits to productivity and poverty reduction could also be achieved that would be consistent with a low carbon development pathway for the Rift Valley countries.

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