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The "Geothermal Village" Concept:

A new approach to geothermal development in rural Africa

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ABSTRACT

Besides the development of geothermal power production for meeting the electric demand of the country through an interconnected grid, there is a need to also consider geothermal development to meet the demand for electrical power and energy of the human settlements close to these resources. Some of these settlements are at present and in the foreseeable future, too small and remote to be covered by the national grid. The "Geothermal Village" concept aims to answer this issue. Quite a good number of places, especially along the East African Rift Valley system, display these characteristics; where small village settlements, often semi-nomadic, are located in the vicinity of hot springs or fumaroles in active volcanic and tectonic environments. In some of these settlements geothermal resources are available and can be used for small or medium size development ranging from a few hundred kilowatts up to a few megawatts. The "Geothermal Village" concept includes the production of electricity, using shallow geothermal wells and small-size ORC binary plants, the production of heat for food drying, the production of geothermal fluids for sanitary and other applications such as ecotourism and bathing as well as the pumping of groundwater for feeding cattle and irrigation of small perimeters for crops and vegetable production. A site was identified for a first demonstration project in Northern Kenya, in the volcanic district of Barrier located at the boundary of 3 counties on the southern side of Lake Turkana. The feasibility study of the project shows that such a project would answer the needs of the local settlements up to a radius of 40 km. This demonstration project would open the path to similar developments in the rest of Africa, notably along the Rift system.

1. INTRODUCTION

In Eastern Africa, which is the birthplace of mankind; one currently finds a paradox. Whereas some populations encounter under-development to the point of being among the poorest in the world, important resources – essential to life and mankind, that is water and energy – are available locally yet untapped due to lack of knowledge of the natural conditions below the surface of the earth, of technology and know-how, and of financial means to transform the resources and link them to viable economic activities. The concerned populations are ironically hence left in a vicious cycle of poverty and basic survival.

In the driest areas, where the rainfalls do not exceed 100mm/year, the availability of water and vegetation for feeding the domestic animals on which the community's survival depends is rather limited. Only a few artisanal wells or thermal springs offer water points, when it is not the condensation of the steam on fumarole sites that allow for extracting the minimum amount of water necessary for human consumption.

All along the East African Rift (EAR) system, which cross through the whole continent from North to South, the earth geodynamic characteristics provide specific conditions, known around the world as an important geological and geographic feature, but mostly unused as yet for human development. A huge amount of energy is released from the hot upper mantle and derived volcanic products to the surface allowing for geothermal energy resources to be available at depth on numerous sites all along the rift system. It is at present essentially used for major electrical production feeding the national and regional distribution network under development. But it could equally serve the needs of the population in isolated areas away from the grid which otherwise would never be served if local production systems are not made available.

The technology exists, and has been demonstrated successfully by several hundred systems installed in various parts of the world (America, Europe, Asia…), enabling the production of electricity from shallow geothermal resources through simple technologies (wells drilled with 4WD transportable rigs), and portable ORC (binary) plants. These have been proved to produce electricity at a competitive price with diesel generators of similar size (ranging from 100 to 3.000 MWe). However in our case, if the electricity is an issue, the major opportunity presented is to also extract and distribute water obtained from similar shallow wells at the existing aquifers.

This in turn allows for the development of a rural economy, based on simple techniques easily mastered by the local population that will directly benefit from the system, by the optimal, cascade use of power, heat and water. The relatively closed economy is maintained, but with a capacity to produce more, sell derived products and hence enter the economic field, become potential players of future developments, enabling the implementation of successive units also serving the surrounding villages and townships. The most isolated and deprived site then turns to become the center of development for the region.

Kenya is the leading country in Africa for geothermal development and also encounters local conditions in which very poor population – among the world's most deprived – are and will be for a long time away from any other development route.

Therefore the government and its specialized arm GDC are keen to promote such a demonstration. The Barrier site, located in northern Kenya, not far from Ethiopia and close to the borders of the 3 counties of Samburu of the necessary resources and conditions. Population surveys show that the needs exist, and the potential demand on site and around is sufficient to sustain the system in the long term.

However, compared with other feasibility studies in which the consumers pays for a production device, we are in a situation in which the system to be built will provide the future capability of the population to pay for the future developments but not the initial one. It is therefore a case in which donor agencies, supplementing Kenyan public efforts, are required as otherwise the poverty cycle within these populations would never be broken. It is however shown that, in the long run, the Geothermal Village concept will facilitate a unique economic and social development for a population of 50.000 people of the said counties.

It is envisaged that the demonstration will not only spread locally in the surrounding villages, up to a point of reaching the capacity to connect with the national and regional grids, but will also allow for similar "Geothermal Village" projects to be developed along the EAR and elsewhere in the world. At least hundred similar sites exist in Africa, which will be surveyed under the US "Power Africa" fund in Kenya, Ethiopia and Tanzania, that will be implemented during the next 3 years, thanks also to a first demonstration.

2. SMALL-SIZE GEOTHERMAL DEVELOPMENTS ANSWERING THE NEEDS OF ISOLATED SITES

2.1. The ORC technology

The cheapest type of electricity from a geothermal source is the direct flash of the steam in a turbine. This however necessitates the use of deep wells in order to reach sufficiently high temperatures (above 150°C) and implies an industrial approach that is not suited for rural areas. ORC technologies allow producing electricity from fluids at intermediate temperature (from 90°C to 150°C). In the geological context of the EAR, such fluids can be produced from shallow wells using equipment similar to those used for water drilling. Such light equipment are practical in rural areas and eventually available locally. There is just some need for staff training and to purchase some specific equipment in order to manage the hot temperature of the fluid and prevent blow out and skin burning. As the geothermal fluid, once produced from the well is piped and, contained in a separate loop, precipitation and environmental effect of the geothermal fluid can be controlled.

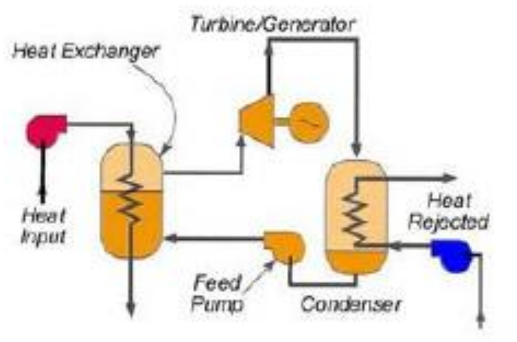
In this modular Organic Rankine Cycle (ORC) binary technology, the heat from the flow of the geothermal fluid is transferred to the organic working fluid in a heat exchanger. The working fluid is vaporized and the vapor drives the turbine and the generator. The secondary organic working fluid has to be chosen carefully in order to minimize supply costs and chemical hazards. These field-proven power units are simple to install and operate, and have near zero environmental impact: if the equipment is well conceived and manufactured, the secondary fluid is kept in a closed loop and doesn't get into contact with the atmosphere or population.

The experience exists worldwide for such small-size developments of real economic and social interest. They can be low or medium enthalpy applications, the most profitable ones combining both. There is a great number of sites of successful low enthalpy rural developments worldwide (see J.Varet, 2012 for France) and there were 50 ORC plants operating below 5MWe in 1999, whereas since 2007 the number has exceeded 200. Currently, off-the-shelf binary equipment is available in modules of 200 to 1000kW and above. Due to the increased manufacturing volume and continuous developments, the specific price of ORC is expected to decrease significantly in the near future.

In the US, the Wabuska Geothermal Resource, located some 100 km southeast of the City of Reno (Nevada, USA) with a 1750 kWe capacity from 2 units, is a privately-owned site producing electricity at a competitive price with diesel oil production. The Empire geothermal resource located 100 kilometers north of the same city is equipped with 4x1.2 MWe ORC units which produce from a fluid ranging in temperature from 118 to 150°C. The Fang Geothermal Resource, located in a rural setting near Chang Mai (Thailand) designed by BRGM (France) is equipped with a 250kWe generator exploiting a 500 litres/minute hot spring at 116°C since 1989. Recently, binary power plants have been installed in France, Austria and Germany in application to medium-low temperature geothermal sources extracted from deep, Enhanced Geothermal Systems (EGS) fractured reservoirs. Whereas such units could be developed in Europe from normal gradient areas implying deep drillings, medium-low enthalpy geothermal resources can be available, in specific geological environments (active geodynamic zones such as in the EAR), at relatively low depth (100 to 1000 m); this situation enables meaningful reduction of drilling and perforation costs on the total cost of the plant, and widens the opportunities for diffusion of these renewable energy production technologies.

If small scale and off-grid ORC geothermal power projects are technically and economically feasible based on deep resources in normal gradient areas of Europe, their feasibility is even more in high gradient areas found in geodynamically active regions such as the EAR. The costs of power production is much cheaper than the Diesel generator they substitute (around half) . Operational issues related to infrastructure, reservoir management, well field facility and power plant maintenance must be properly addressed. The success of these small-scale geothermal power projects is largely due to the involvement of local interested parties and agencies as active participants in the development, financing, ownership and operation of the projects.

Several manufacturers from N. America, Europe and Japan have proposed small size (0.2-2.0 MWe) standard machinery and power conversion systems. This is a key element for a large diffusion of geothermal binary cycle plants. The development of the market of such plants for "Geothermal Villages" in EAR should facilitate the transfer of the know-how and reasonable construction capabilities of such systems in Africa. This could be part of the deal to be negotiated for the first demonstration in order to lower the price of the relevant first and successive plants.



Source: Barber-Nichols

Figure 1: The ORC binary geothermal electric production.

2.2. The advantages of isolated sites

The advantages of ORC small-size geothermal plants for isolated rural development are the following:

- The plants are transportable: an entire plant of 0.2 to 1 MWe including the air cooling system built on a single skid fits in a standard trans-ocean container easily carried to the construction site by ordinary truck.
- Binary ORC power plants can accommodate a wide range of geothermal fluid temperatures (90 to 150°C)
- Although the plant design and construction necessitates high engineering and technical levels, only semi-skilled labor is needed to monitor plant operation, on a part time basis. The plant can also be monitored at distance, with remote control. This notably is the case in which several villages are equipped with similar systems allowing for a unique service base with skilled staff.
- The system is emission-free, being composed of closed loops.
- Several wells need to be drilled, whether for geothermal fluid production or cold water production. All the wells themselves can be drilled by truck mounted rigs (heavy duty water-wells rigs), generally available locally.
- Besides the first heat exchange in the binary plant, the project advantageously associates electricity production with other low enthalpy applications. A “cascaded” use of the thermal energy, with successive heat exchangers allows for diversified associated applications (refrigeration, food drying, green housing, fish farming, washing…).
- The geothermal fluid itself is ultimately valuable for specific applications: bathing, balneo-therapy and/or mineral production: silica, carbonate, lithium…
- In case of excess production, the remaining fluid can be re-injected in the geothermal system and reused in the geological loop underground.
- The piping costs are low. The geothermal wellheads are located near to the plant and the fluids can be transported in inexpensive plastic or carbon steel pipes.

2.3. **Geothermal fluid characteristics and net electric power output**

Of course, the thermodynamic efficiency of the plant will directly depend on the temperature of the geothermal fluid. It will range from 6 to 12% depending on the temperature in the 80-150°C interval (Fig.2). This in turns means that 88 to 94% of the thermal potential of the geothermal fluid remains available for other energy uses, notably low enthalpy applications.

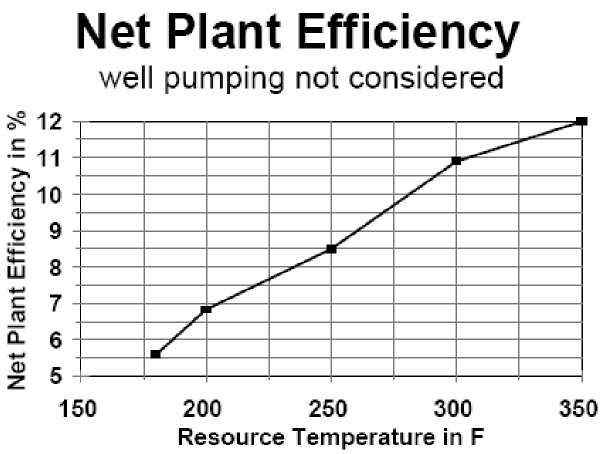


Figure 2 (after Nichols, 1984).

Figure 2: Net plant electric efficiency for binary ORC systems as a function of the temperature of the geothermal resource

This means that – for a given electric power output, the needed fluid flow rate will increase substantially with decreasing temperatures. This is not necessarily a problem, as it frequently happens that higher discharges can be obtained from lower temperature shallow geothermal sources. Fig.3 provides figures of the flow-rate needed in order to cover a net electric power output in the range of 200 to 1000kWe for geothermal fluids ranging from 80 to 150°C.

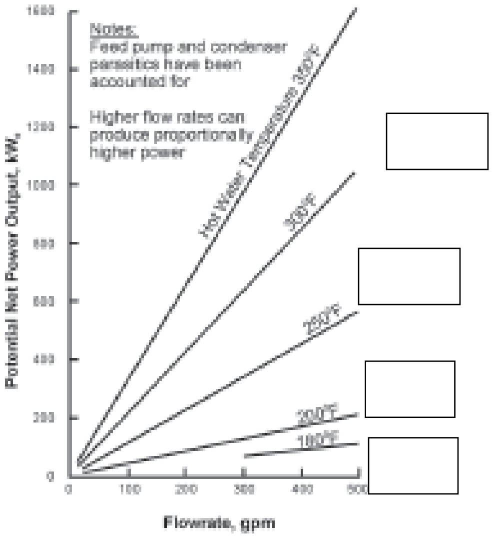


Figure 3: Electric power net potential output according to temperature and flow-rate from the geothermal source

2.4. Economic feasibility calculations

The main variable concerning the cost of electricity produced from ORC geothermal plants is the net capacity of the plant. Of course, the cost of electricity produced will decrease with the increase of the size of the unit. But the characteristics of the plant (size of the heat exchangers and ultimately the composition of the organic fluid) will also vary according to the temperature of the geothermal fluid. The consequence is that the price of the plant will generally slightly increase for lower temperatures. But the case of the cold source should also be taken into account. Cold river or ground water availability will provide better conditions – and cheaper devices – than air cooling systems.

The costs of geothermal plants as a whole also include of course exploration and drilling costs as well as field development (piping, etc.). Although in the case of cascade use of the geothermal water (for direct heat applications and geothermal fluid exploitation), these cost are shared between the various applications, it would be a somewhat artificial approach for an integrated energy production device.

1. Exploration: 200.000$
2. Wells: 325.000$
3. Field: 94.000$
4. Power plant: 659.000$
5. Total: 1.278.000$; that is a plant cost / installed kW of 2.200$

Assuming drilling costs dominate exploration costs, a group of sites would have an average of only two to three unsuccessful wells per site. It is unclear whether an exploration program for small geothermal projects would achieve this rate. Another critical input to the calculation model is the resource temperature and depth. The 120ºC temperature of the resource at 300 meters can however be expected in well-chosen sites in the EAR context. Overall, capital costs represent about 55%–80% of the cost of electricity generation, and operation and maintenance costs represent about 30%–45% (Entingh 1991). In summary, for reservoir temperature ranging from 100 to 140°C, and production well at a depth ranging from 200 to 1000m and injection wells at 200 to 500m depth, the following costs are encountered for a 300 kWe plant operating with 120°C resource temperature:

3. THE "GEOTHERMAL VILLAGE" CONCEPT

3.1. Objectives

The project is aimed at optimizing the value of natural resources that are available on site, but presently untapped; in particular poor regions where at present people live at the first, nomadic, self-supporting stage of mankind organization. Such populations are particularly fragile, being isolated and directly depend upon climate for their food and water needs. Away from communication routes, from any facility like energy, water, health, education, they are directly vulnerable to epidemic diseases, malnutrition, infant mortality and famine resulting from climate change.

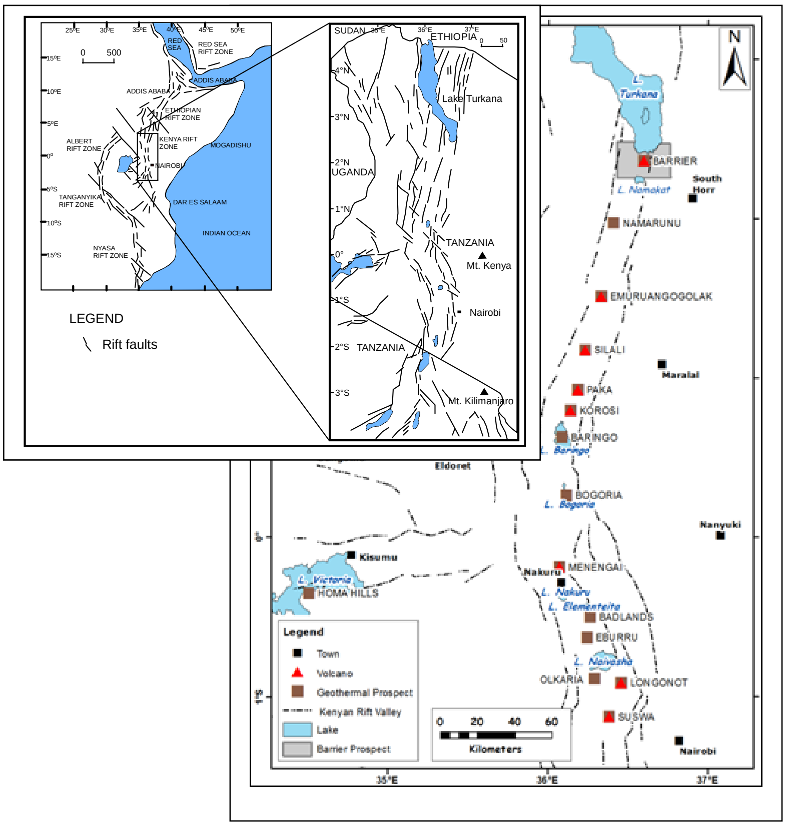


Figure 4: Schematic map of Kenya showing where the major geothermal sites are located (in red) along the Rift Valley. The cartoon shows how the Rift Valley of Kenya fits in the whole East African Rift Valley system. The proposed site at Barrier for a first Demonstration is represented as a grey rectangle.

In the regions determined by the specific geology of the EAR, the earth surface is particularly rugged (hard, black, lava surfaces, soft tuffs mobilized by wind storms…), affected by faults scarps, open fissures, and volcanic reliefs that cut through the region and limit the facilities of land communication. The water infiltrates and is not available at the surface except when heavy rains produce flooding of the lower plains. But underneath this "bad land", real natural resources do exist and can be mobilized (Fig.4). Presently, major geothermal and groundwater developments in the world, including African facilities existing in this field (like ARGeo or GRMF under the African Union), are built for large-size projects responding to massive needs. But we hope, through this research and demonstration, to facilitate the local development of small-size geothermal units valorizing the whole resource available through "cascade use" of the energy from the upper electricity production, to the heat, cooling and freezing applications, down to the direct use of the mineral water, to becoming eligible for financial support.

3.2. Populations' interests

As a matter of fact, besides other renewable energy options, some of the applications of the geothermal resources are already familiar to target local populations on site. Human settlement in African desert area is frequently on the site of geothermal emergences as it provides humidity for vegetation growth, water for cattle breeding or pure drinkable resource (eventually by steam condensation of the fumaroles), and facilities for other services (washing, treatment of specific diseases…). The degree of appropriation of the resource by the local communities can hence be quite high, even with artisanal digging of thermal wells and pools, and construction of local facilities (like steam condensation and mineral water collection). However there are also geothermal resources that have not yet been subjected to local uses and appropriations, especially when usable surface manifestations are weak or lacking[1]

Hence, the implication of geothermal resources use for the local population differs from solar, wind or mini-hydro energy solutions which need to be totally "imported" with respect to pre-existing habits. This in turn means that such small-scale geothermal energy development project can only be developed successfully with the close consultation and collaboration of concerned local parties. It should in fact rely upon the direct interest and mobilization – once informed – of the local population. The success of such initiatives therefore relies upon the direct interest and mobilization – once involved – of the local population. Although this "natural appropriation" of the geothermal resource has to be improved by disseminating proper information and

[1] Hydrothermal surface manifestations are not only liquid or gaseous, but may also consist of mineral deposits (as silica or carbonate), alteration products (as clays), or phreatic explosion craters showing the presence of high temperature fluids underneath.

training to the community in regards to modern uses and technologies, local participation and governance at all stages of the project is a determining cause of success for the “Geothermal Village” project concept.

3.3. Project management

The valorization of such valuable resources, using knowledge, science and technology that is provided from outside local people’s background by the project management, has to be beneficial primarily to the local population, which will quickly understand the economic, social and environmental advantages that will result from the quantitative and qualitative changes induced by the project. This is facilitated by the fact that the movement can be progressive (from water availability for the family and cattle, to other more sophisticated uses, like lightning, or communication facilities resulting from the electric power availability). The project management is aware and prepared to deal with such options.

The intervention of a skilled entity – Geothermal Development Company of Kenya (GDC) – is of course needed to properly locate the geothermal development. Based on sound resource assessment, with a wide experience in geothermal fields’ exploration and developments of large size, GDC will be backed by Géo2D, which develops small- size geothermal projects including cascade use of the energy, with other partners like Electerre. Other enterprises dealing in civil works and drilling activities, the installation of the ORC and of other devices for the various uses of the geothermal fluid will also be mobilized

Cascade use of the thermal properties of the resulting geothermal fluid will engage more familiar developments, but at a scale that has not been seen before. Sanitary and environmental conditions, even if not experienced, will be welcomed and preserved once properly installed. Additionally, at the end of the pipe (Fig.5), the direct use of the geothermal fluid balneotherapic properties, previously lost, will be recovered, thanks to the heat exchangers. Artisanal or even industrial applications will make the population proud of this successful development. This will help contribute to green tourism development (ecotourism, local product sales, bathing and recreation…).

The dissemination of the information to the local population, its association to the various aspects of the construction and maintenance using proper training is essential. This approach will induce the permanent presence of the local population on the site, and will facilitate continuous development of the local energy and water grid, through modular steps, as a result of increasing local needs.

Let’s recall that once a first power plant is installed on a site, thanks to appropriate drillings of production and eventually injection wells (especially in case undesirable effluents need to be removed from surface systems), other drillings generally can be done in the vicinity, allowing for a modular development of the site, by successive adjunction of other similar, or even larger, power plants. This allows for electricity distribution to nearby villages or rural townships that are at present not served by the national grid.

The implementation of the geothermal village and induced development (for the local population and the surrounding villages), will induce the development of the local grid due to the availability of a new more powerful and continuously producing renewable source. It can allow connecting other sites including pre-existing power production and local distribution (for instance a pre-existing fuel-powered engine that was set to be closed). This will generally induce an adaptation of the whole electric network in order to accommodate the new production system (ensuring base load).

The (technical and social) know-how acquired through this demonstration will be valorized on other sites in Africa through the creation of an ad-hoc subsidiary before the end of the project. This entity will keep a share in the local entity, together with other public (local authorities derived) and private partners (especially related to the diversity of end-uses).

4. METHODOLOGY FOR SITE IDENTIFICATION AND DEVELOPMENT

Satellite and ground-based studies of the Kenya sector of the EAR system reveals active magmatic and/or aqueous fluid movement beneath 40% of the volcanoes, and similar results emerging from systematic mapping along the Ethiopian and Tanzanian rift sectors (e.g., Peccerillo et al., 2003; Biggs et al., 2009; Ebinger et al., 2013; Omenda et al. 1993; Varet 1978, 2012).

The first step is to map the small but multiple geothermal areas that would be adapted to these new forms of geothermal exploitation. This requires an inter-disciplinary approach including geology, volcanology, hydrogeology, fluid geochemistry, shallow crustal geophysics, power engineering (notably ORC units) applied in cascade use of energy (green housing, food drying, thermal bathing, green tourism). A systematic socio-economic approach will be included in order to serve the needs and maximize the benefit for local populations.

The survey of geothermal fields that could supply these innovative units will be carried out from Afar to Kenya down to Tanzania, with the grant from the “Power Africa” USAID program using available data (notably numerous reports from past geothermal exploration programs or active research projects currently not available in the international journals.

4.1. Geological surveys: Hydrothermal and groundwater resources

In each country, a geological research team will be established to map appropriate sites. Each team will at least include a geologist to identify the hydrothermal emergences (hot-springs, fumaroles, hot-wet grounds), measuring temperatures and flow-rates and eventually undertaking sampling for chemical analysis. This will be obtained by combining data being acquired through undergoing projects, or available from the published scientific papers or professional reports, study of satellite images and air photographs, with field controls or studies to be engaged when necessary. It will equally imply the contribution of a hydro-geologist in charge of identifying the presence of groundwater resource on the site or in the immediate vicinity. The outcome of the site investigation will be to determine the depth of the resource to be accessible by shallow drillings. In some areas, MT, seismic, gravity, aeromagnetic data are being acquired or exist to constrain the depth to the resource.

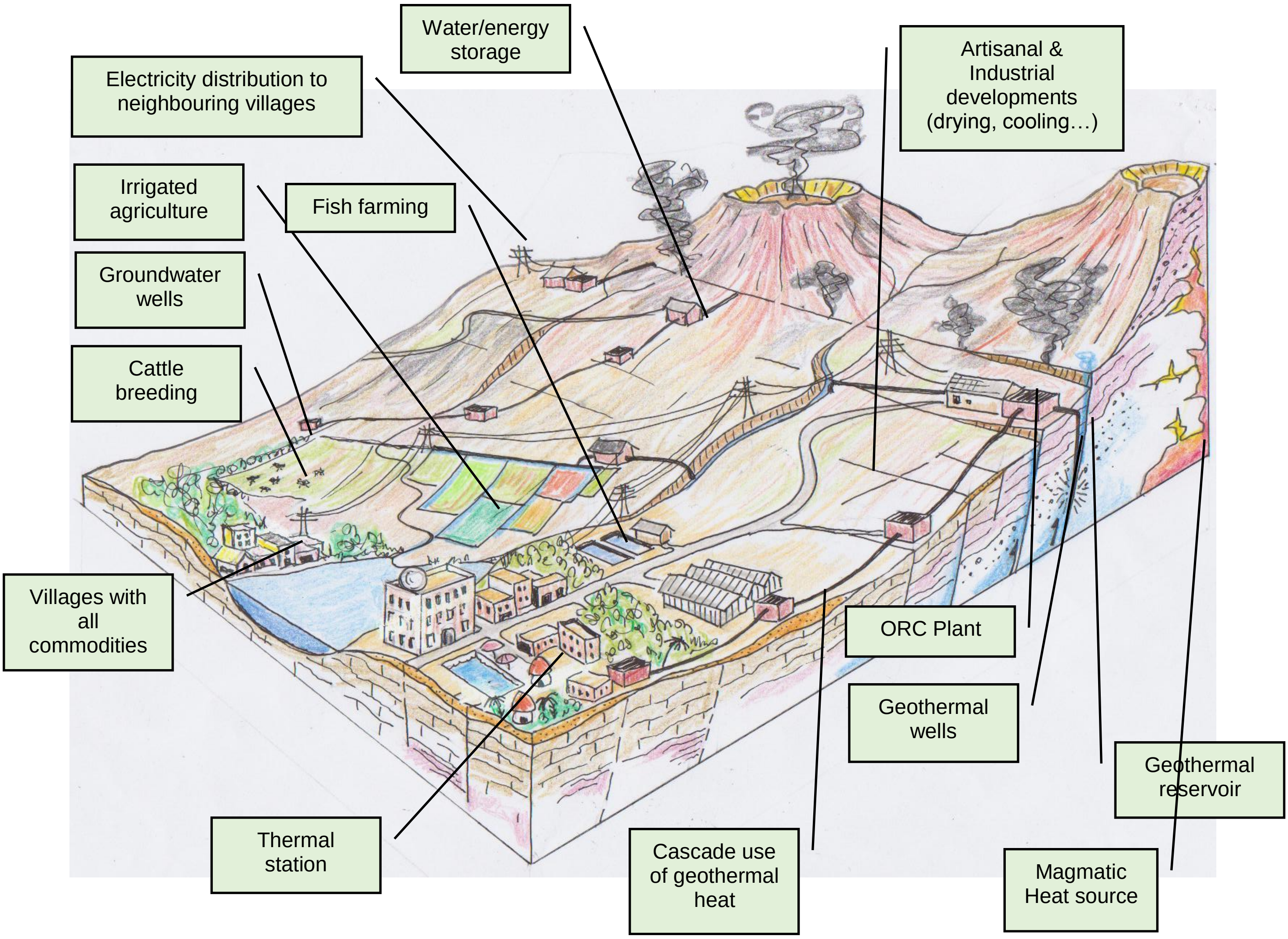


Figure 5: Scheme summarizing the "Geothermal Village" concept to be implemented at Barrier (Samburu district, Kenya), intended for spreading around the site shown here through electric lines feeding the nearby villages and small towns presently not receiving any energy service. On site, the geothermal fluid extracted from shallow leakages (faults driven) of the deeper high temperature geothermal reservoir allows for production of electricity from medium temperature fluids (110-150°C) thanks to ORC binary plant. The plant also uses a low temperature source, provided by groundwater extracted from shallow reservoirs with production wells and pumping. The electricity produced continuously by the plant, besides feeding the local needs and nearby villages through an electric network, is used in non-peak periods to pump the groundwater both for plant watering and other uses, and also for large storages in tanks located on the upper hills above the village. The geothermal fluid is, after first heat extraction for the electricity production, also used for thermal applications (drying food and agricultural products, green-housing, fish farming…) through successive heat exchangers, as well as, at the end of the pipe, for direct thermomineral applications (including local uses –such as swimming pools - and touristic developments). After J.Varet, M.Villey, 2013.

4.2. Social studies

The social dimension is essential, as the first objective is to answer the needs of the local population. This implies collecting, on each site, information concerning:

- The number of people living on the site, at proximity, and eventually people affected/targeted by the project.
- The activity of the local community on site, and the way the water and energy will modify (i.e. improve) their lives.
- The gender issues, as women are generally in charge of water and energy (wood- supply) in these communities, and the way to handle the resulting changes.
- The need for electricity and water for crop cultivation (irrigated perimeters, greenhouses), fish farming, food conservation (drying, cooling).

- The relations to regional and central government on these issues.
- The general conditions, the access to the site, as well as safety conditions. (Fig.6).

Figure 6: Some views of the demonstration project area at Barrier : water well, Tum village main street, typical housing.

4.3. Adapted technological solutions

Through collective work of each inter-disciplinary team, the various possible technological options will be considered for each site:

- Complementary scientific investigation to be achieved in order to site and determine the targets in terms of depth.
- Drilling activities to be engaged for catching both geothermal fluids at the convenient temperature and groundwater to be pumped out.
- Choice of the type of binary ORC plant to be installed in order to both respond to the electrical needs and adjust to the resource expected character.
- Type of low-enthalpy applications to be developed: cascade use of thermal energy for food drying, green-housing, or other thermal applications (i.e. eco-tourism).

With the identification of both groundwater and hydrothermal resources on each site, as well as with the acquisition of engineering capabilities and socio-economic conditions to be met for successful implementation, the project will determine the conditions for:

- the development of new irrigated land allowing for new crop cultivation and/or an increase in productivity of the existing ones (both cattle breeding and crops cultivation).
- the production of local combined energy production devices (electricity from small portable ORC plants, heat for food drying and food conservation)
- hydrothermal fluids production for bathing, medical and other sanitary applications including sustainable touristic developments

These activities are expected to eventually contribute to improved socio-economic life of communities around the sites where the geothermal activities will take place. In the area the highest workload and family responsibility generally lies with women. Women will particularly benefit, given their role thus gender issues will be addressed. The results of the research also satisfy core aims of regional programs, including ARGeo run by UNEP for replication at (Eastern-Africa) regional level.

5. EXAMPLE OF A FEASIBILITY AT BARRIER (SOUTH OF LAKE TURKANA, KENYA)

5.1. Major findings

Barrier Volcanic Complex (BVC) geothermal prospect is situated on the floor of the northern sector of the Kenya rift, immediately south of Lake Turkana. The volcano complex is characterized by four distinct volcanic centres namely Kaloleyang, Kakorinya, Likau West and Likaiu East (Fig.7). Reconnaissance surveys by Dunkley et al. (1993) indicated occurrence of strong surface manifestations, signifying the presence of a hydrothermal system. Consequently, GDC as part of its mandate to develop geothermal resources in Kenya carried out detailed surface exploration work in BVC in 2011 to establish the potential of the prospect, covering an area of more than 900 km^2 (Laga, 2011).

Various geoscientific methods were employed including geological mapping to determine the volcanological evolution of the volcano and also the structural controls of the geothermal system. Geophysical methods included mainly resistivity techniques composed of transient electromagnetic (TEM) and magnetotellurics (MT). Geochemical techniques included collection of gas and steam condensate samples from fumaroles to determine the nature of the geothermal reservoir while ground radon and CO_2 surveys were undertaken to indicate the presence of geothermal reservoirs and also to map permeable zones.

Results of the geoscientific surveys indicate presence of a geothermal resource under BVC. The heat source, which is still active as indicted by recent lavas which erupted in 1921, is associated with shallow magmatic intrusives beneath the volcanic complex. Estimated gas geothermometry temperatures give mean subsurface temperatures of over 281ºC. The high temperature resource area is of about 60 km^2 and using a conversion rate of 15 MW_e/km^2, the volcano has potential of over 750 MWe. The resource in BVC is suitable for electric power generation and direct use applications. However further infill surveys are required before drilling is commenced so as to refine the model to be able to accurately site the wells, notably for small size geothermal plants tapping shallow geothermal resources.

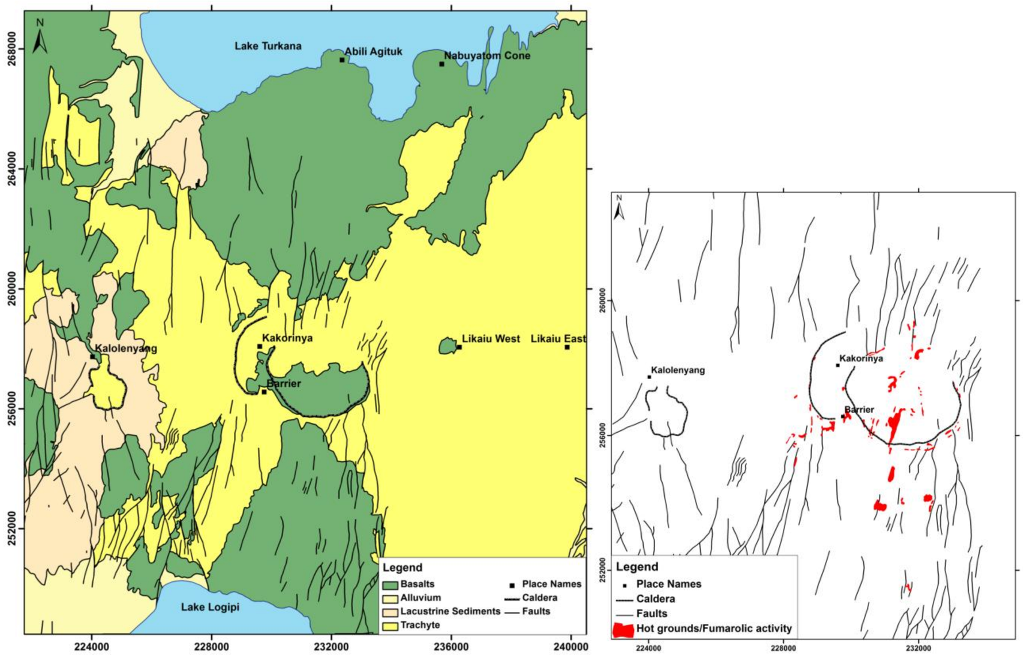


Figure 7: Simplified geological map of the Barrier Volcanic complex, with location of the fumaroles and hot springs in the central part (Lagat, 2011).

5.2. **Feasibility study of the Geothermal Village case in Barrier, Northern Kenya**

In the case of the present "Geothermal Village" project, a temperature of at least 120°C is expected from the wells to be drilled at 500m depth. The wells will be positioned in order to encounter a good fracture permeability, allowing for a total flow of at least 200m^3/h. This is a realistic objective as the drilling of several wells is planned. At 120°C, the current technology allows for a production of 1MWe with a flow rate of 160m^3/h and 2MWe with 300 m^3/h. If the action aims at a first demonstration of an ORC plant of 1 to 2MWe, the project as a whole, in the successive years, is aimed to reach 5MWe or more, in order to serve the increase of the demand on site and in the surrounding villages plus the extension of the grid. In fact, the drilling program will be considered also with the objective of reconnaissance of the geothermal resource for expanded future developments on the site.

The calculation shows that, for a total investment in the geothermal production device of 3.5 M€ (i.e. the ORC plant itself plus the necessary wells), with a price of 10 cents of € per kWh (current sales prices in Kenya), and a production of 8.000.000kWh/year for a 1 MWe (a realistic figure for such plants), the yearly income would reach 800.000€ a year, that is an amortization in 4 and half years only. As 35% of the electricity produced would be consumed and distributed on site for pumping and local consumers freely served, the income would be reduced to 0.5M€ per year, with a pay-back time of 7 years. With a 2 MWe output, the sales would be more than 1M€ with a pay-back period of less than 4 years. Considering realistically that, after a few years, the enriched population in the Geothermal Village would accept to pay for the services which evidently are continuously improving their standard of life, the income could be even larger, and the development of the project self-paying for further units.

If the distribution costs (mainly the transmission from the plant to each village, that is 17.000€/Km) is also incorporated in the calculation, the pay-back time can be calculated on the basis of the electric power sold, providing high, but still economically viable figures: an additional 425.000€ for a village at a distance of 25 Km (that is the case for Tum and South Horr) and of 680.000€ for a distance of 40 Km (the case of Loyangalani, also a higher consuming center). At a distance of 65 Km (as in the case of Lokori), the transmission line would cost 1.1M€, making the economy of the link more dependent upon the total sales (to be detailed). This shows that, economically, the project is viable, including the link with at least the 2 villages of Tum and South Horr plus the township of Loyangalani, which is by far the largest and fastest growing in the area.

Even if the precise economic and financial picture remains to be better ascertained after in-depth enquiries to be done in the first months of the project implementation, the present data shows an economically feasible project, as also shown by the calculation below. The calculation was made providing the economic and financial results over a period of 25 years, for a plant of 1MWe, with realistic assumptions of sales, (considering that 35% of the electricity produced will be used on site for pumping water for free distribution to the local population during the first years), with the idea that it is only when the project impact will have been felt that they will be able to pay.

The calculation does not take into account the economic and financial dimension of the large amount of thermal energy, and water (whether hot or cold) made available locally as a result of the project. The thermal output of the system is at least 5 times the electrical output that is at least 5 MWth in the action period, and 25 MWth within the 5 successive years. That is 40.000.000kWh(th) made available in year 3 and up to 200.000.000 in year 8.

5.3. Expected results

As a whole, this project will demonstrate that similar initiatives can succeed and be replicated on a large scale along the EAR system, as there are numerous suitable sites that have the required conditions. The project will:

1. Demonstrate that several such geothermal sites exist in the EAR, by providing a systematic mapping and inventory of these natural occurrences, suitable for local developments away from the interconnected electrical grid (Fig. 8);
2. Prove that several of these sites are suitable for immediate developments considering the social factors, notably the presence on site of communities deprived of energy and eventually water sources;
3. Show that experience acquired in Africa and other places (USA, Europe, Iceland, etc) and technological solutions could be transferred and replicated, taking into consideration the necessary adaptations (such as climate and culture);
4. Show that production of geothermal fluids (and groundwater) by shallow drilling can allow a technically and economically feasible development to occur at a later stage;
5. Draw from a few sites, like Barrier, the conditions necessary for the success of such developments, particularly concerning the resource parameters (geothermal energy and groundwater), the social involvement, especially related to gender issues, and the technological options to be envisaged;
6. Provide guidelines for further developments (pre-feasibility and feasibility studies, site development and operation) that can be used by various stakeholders: local communities, enterprises, NGO's, public authorities, financial institutions, etc);
7. Build capacity of the involved institutions;
8. Promote Science & Technological knowledge transfer on such geothermal methodologies;
9. Disseminate information using appropriate communication tools and channels to various stake-holders.

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