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LEAP-RE

Research and Innovation Action (RIA)

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LEAP-RE
Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Geothermal Village Project Phase 2

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LEAP-RE - Contract Number: 963530

Project officer: Maria-Laura TRIFILETTI"

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Summary

EraBoru is located in central-western Afar, in Ethiopia. This exceptional geothermal site benefits from a particularly favorable geodynamic context, in a transform fault zone between the two active spreading segments of Alayta and Manda Harraro (Varet et al. 2020). A plateau 700m high affected by normal faults and open fissures through which numerous silicic peralkaline obsidian domes and pumice cones were emplaced in the last 10 to 100ky. The last being the Dabbahu pyroclastic Event (Sept. 2005) opening a sequence of basaltic diking over a length of up to 70km and a width reaching 8 cm in the period 2005-2010 (Wright et al. 2006; Hamling et al. 2009, 2010) Over a length exceeding 5 km and a width of 2-3 km, EraBoru (meaning steaming basin in Afar language) is affected by innumerable steam vents, occurring through normal faults and open fissures as well as diffuse vents at the surface of lava flows, domes and pyroclatic deposits. These hydrothermal manifestations are called "Boina" in Afar language, a name also used to describe the site (Barberi et al. 1972). And the geothermal grass (called "Fiale") is also abundant along faults and lava flow surfaces. The characteristic of EraBoru and of other sites around Dabbahu Volcano which provides an exceptional heat source (Johnson et al., 2016) is the fact that the local population developed artisanal engineering solutions allowing to condense the steam and produce potable water for people and herds. An option of real resilience, as the water is produced continuously, whatever the climate fluctuation. Gardo & Varet (2020) could speak of a geothermal civilisation as human settlements are directly relying upon this resource used locally. With Jérome Ammann, CNRS research engineer at the University of Western Britanny, an infrared drone survey was undertaken, allowing a precise, quantitative mapping of the steam vents, whether natural of engineered. Coupled with field observations, it appears that, after having located the condensation wells on steam emergences, along upper compartments of active normal faults, more efficient solutions were developed drilling in the graben filled with pyroclastic layers of silicic ash and pumice falls where no surface manifestation is observed at the surface, but under a few metres (5 and up to 20), after digging through these dry (and cold) volcanogenic sediments, a wet surface is met, in which the steam produced a hydrothermally altered clay zone. Drilling...

Approval

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LEAP-RE

Research and Innovation Action (RIA)

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Geothermal Village Project Phase 2 - D11.6

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LEAP-RE - Contract Number: 963530

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Summary

Based on the knowledge of the East African Rift System, of the science and technology partners already active in the region, and of the indigenous people expectation concerning the possibility to use the geothermal resource they know from surface manifestations, four sites representative of the diversity of geological and social conditions in the region were selected for the "Geothermal Village" project co-financed by the EU through the LEAP-RE project:

- Era Boru in the Afar Regional State in Ethiopia, where a community-based enterprise (AGAP) was established aiming to develop geothermal systems answering the needs of the indigenous people on a site where steam is present and hand-crafted at the surface ;
- Lake Abhe in Djibouti Republic, a site where spectacular travertine chimneys developed in a "forest" due to continuous geothermal activity, also producing grasslands along the lake shore for a pastoralist community which partly settled in a village where a school was recently built. The project benefits from the engagement of the National Geothermal Company (ODDEG) involved in exploration and development in the whole country.
- Homa Hills in Kenya, a geothermal site located near Lake Victoria, where thermal manifestations of low and medium temperature occur at the foot of a carbonatite volcano, identified by the local community who established a CBO in order to master the development of resource of economic interest. The project benefitted from the support of the Kenya based geothermal science and engineering company called SEPCO.
- Mashyuza in southern Rwanda, where important thermal springs are emitted from a fault, forming a limestone deposit exploited by a cement factory. The site was studied with the energy national public enterprise EDCL. The challenge there being to develop both industrial applications together with a modern SPA resort.

The present report somehow concludes the "Geothermal Village" R&D project LEAP-RE WP11), after 3 years of research in the field and in the labs, with the "Deliverable 11-6" of the task 6: "Preparation of the geothermal village demonstration".

Approval

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Research & Innovation Action

06-2025

Preparation of the geothermal village demonstration

Geothermal village

Deliverable D11.6

Version N°2

Authors:
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Disclaimer

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Abbreviations and Acronyms

Acronym	Description
AAU	Addis Ababa University (Ethiopia)
AASTU	Addis Ababa Science and Technology University (Ethiopia)
ADDS	Agence de Développement social (Djibouti)
AGAP	Afar Geothermal Alternative Power (Ethiopia)
CBO	Community Based Organization
EDCL	Energy Development Company Limited (Rwanda)
EEP	Ethiopia Energy and Power company
Géo2D	Ressources géologiques pour le Développement Durable (France)
GSE	Geological Survey Ethiopia
GV	Geothermal Village (project)
HHCBO	Homa Hills Community based organization (Kenya)
ICEA	International Conference on Energy and applications (Djibouti)
NORCE	Norwegian Energy research center
ODDEG	Office Djiboutien de Développement de la Géothermie
ORC	Organic Rankin Cycle
SPA	Special Purpose Vehicle
UNITO	University of Torino (Italy)
WP	Work Package

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Summary

The aim of the geothermal village program is to promote and develop the use of geothermal resources in areas remote from any energy distribution network. The geological and socio-economic contexts of four representative sites have been analyzed. Based on this work, solutions are proposed in this report. Site evaluations are proposed, as well as an initial assessment of costs. This document is a first step towards the definition of a demonstrator and the search for financing.

Keywords

Geothermal resources, East Africa, application perspectives, energy & water production, off-grid, community-based, demonstration site.

Introduction

Geothermal energy world-wide developed on the basis of 3 models:

- Deep high temperature resource in magmatic or active tectonic environment allowing for large scale power production feeding the electric grid;
- Low temperature resource allowing for district heating systems from deep aquifers in normal gradient areas;
- Exploitation of shallow resource allowing for local direct uses applications, eventually assisted by a heat pump, an option at present ongoing fast developments in Europe and North America.

In Eastern Africa the geodynamic conditions, with an active rift system, allow for exceptional conditions in which high temperature geothermal resource is available at shallow depth, allowing for energy production (electricity and direct uses), serving the needs of the population off-grid.

The "Geothermal Village" concept aiming at serving people's needs for energy and water on site "off-grid" was defined in 2014 (Varet et al. 2014). It was shown by Mariita et al. (2016), that hundreds of such sites did exist along the EARS, where surface geothermal resources are available at places where isolated communities are in needs of such services.

Such developments however were not achieved yet in the year 2020 when the LEAP-RE EU-AU project was launched aiming at demonstrating of the feasibility of such systems. The project allowed to access the necessary scientific resources in order to build a real demonstration on site in Africa. The scientific progresses to be achieved were identified, concerning in particular:

- The geoscientific exploration methods, allowing to characterize, on the basis of surface studies the reservoirs' properties at shallow depth, the chemical nature of the fluids and their temperatures, the 3D imagery of the pathways of the geothermal fluid from the sources to the reservoirs ;
- The drilling and testing of shallow geothermal wells for high temperature fluids, technologies not mastered by drilling companies; and so develop new expertise for them.
- Geothermal production devices adapted to local population, frequently indigenous people, already using the geothermal fluids with artisanal devices, but lacking the necessary geological and technical knowledges ;
- And of course, the knowledge of indigenous people interests for such developments, the conception of specific systems answering their expectation and ownership of maintained production devices, implying capacity building.

The built team is summarized on the table 1 with their implication domains:

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Country	University- Lab	Company	Expertise	Investigated sites.
Rwanda		EDCL	Exploration, Management	Rwanda
Ethiopia	Addis ababba university		Geology	Ethiopia
Ethiopia		AGap		Ethiopia
Kenya	University of Nairobi			Kenya
Kenya		SEPCO	Drilling-exploitation	Kenya, Ethiopia
Kenya		HHCBO	Exploitation	Kenya
Rep of Djibouti		ODDEG	Exploration - exploitation	Djibouti
France	University of Lorraine		Geology, geophysics, geochemistry	Djibouti, Kenya, Rwanda
France	University of Western Britany		Geophysics, Drone survey	Djibouti, Kenya, Ethiopia,
France		Geo2D	Geology, socio-economic	Ethiopia, Kenya, Rwanda, Djibouti
Italy	Universita degli Studi di Torino		socio-economic analysis	Kenya, Rwanda, Djibouti
Italy	Sant'Anna School of Ad vanced Studies		socio-economic analysis	Kenya, Rwanda, Djibouti
Germany	Fraunhofer Institute for Energy Infrastructures and Geothermal Syste ms		Dissemination	
Norway		NORCE No rwegian Research Center AS	Technical solution	Kenya, Rwanda, Djibouti

Table 1 : list of the partners

Based on the knowledge of the East African Rift System, of the science and technology partners already active in the region, and of the indigenous people expectation concerning the possibility to use the geothermal resource they know from surface manifestations, 4 sites representative of the diversity of geological and social conditions in the region were selected for the "Geothermal Village" project co-financed by the EU through the LEAP-RE project:

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- Era Boru in the Afar Regional State in Ethiopia, where a community-based enterprise was established aiming to develop geothermal systems answering the needs of the indigenous people on a site where steam is present and hand-crafted at the surface ;
- Lake Abhe in Djibouti Republic, a site where spectacular travertine chimneys developed in a "forest" due to continuous geothermal activity, also producing grasslands along the lake shore for a pastoralist community which partly settled in a village where a school was recently built.
- Homa Hills in Kenya, a geothermal site located near Lake Victoria, where thermal manifestations of low and medium temperature occur at the foot of a carbonatite volcano, identified by the local community who established a CBO in order to master the development of resource of economic interest.
- Mashyuza in southern Rwanda, where important thermal springs are emitted from a fault, forming a limestone deposit exploited by a cement factory. The challenge there being to develop both industrial applications together with a modern SPA resort.

The present report somehow concludes the "Geothermal Village" R&D project LEAP-RE WP11), after 3 years of research in the field and in the labs, with the "Deliverable 11-6" of the task 6: "Preparation of the geothermal village demonstration".

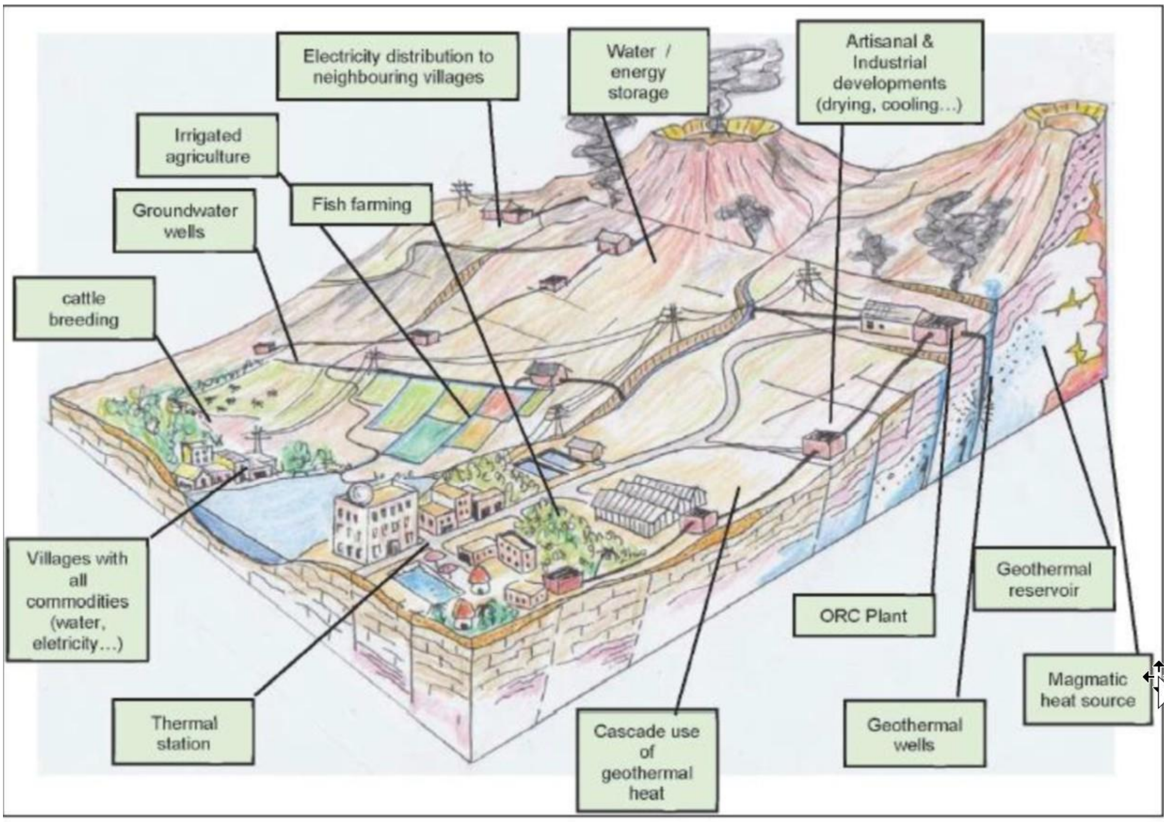

Figure 1: 3D view of the Geothermal village concept (drawn by M. Villey, in Varet et al., 2014).

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1. Background and objective

The aim of the present report was defined as follows "applying the results from Tasks 1 to 4 to planning the construction of 3 demonstrations systems and their monitoring, for a follow-up project "Geothermal Village Phase 2".

- Sites will be selected depending on the results obtained in the previous tasks.
- Action leaders will be designated depending on the countries of each site".

Let's first recall the two main challenges driving this research project:

a) The geological conditions, unique on the Planet Earth, along the East African Rift System (EARS), an active plate boundary (Fig.2), along which exceptional high heat flow allows for favorable geothermal conditions with fluids of high temperatures available at the surface and shallow depth ;

b) The environmental conditions (particularly dry climate in low-land) determining social characteristics, ranging from arid conditions allowing for pastoralist economy only (to the North, Ethiopia and Djibouti in our project as well as in Kenya, Masaï, Pokot, Turkana), to diversified agricultural and other developments (in the south, Kenya and Rwanda in our project), also prevailing in the Ethiopian highland's plateaus. In these different contexts, production of power and water resources allows to promote new activities and induce social and economic developments.

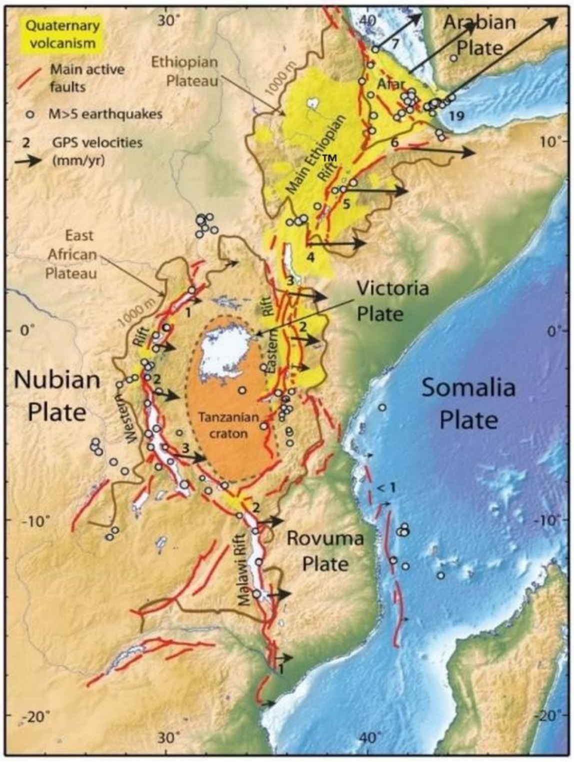

Figure 2 : the EARS plate boundaries: tectonic and volcanic activities resulting from rift motion (Calais, 2016).

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2. The four tasks implemented under LEAP-RE

Answering these challenges, Table 2 recalls the tasks as defined and engaged during the "Geothermal Village Phase 1" project numbered WP11 in the LEAP-Re Programme:

- Task 1: Geosciences including geology, geochemistry, geophysics and modelling (in green),
- Task 2 : Social and Economic studies (in blue),
- Task 3 : Conceptual Design and Engineering (in Orange),
- Task 4 : Site Feasibility Studies.

Leading to the Task 6: Preparation for demonstrators (on at least one site).

For remind, the Task 5 is devoted to dissemination of the concept and research exchange, and the task 7 will provide feedback on the development of this new exploration and production concept on the collaborative actions.

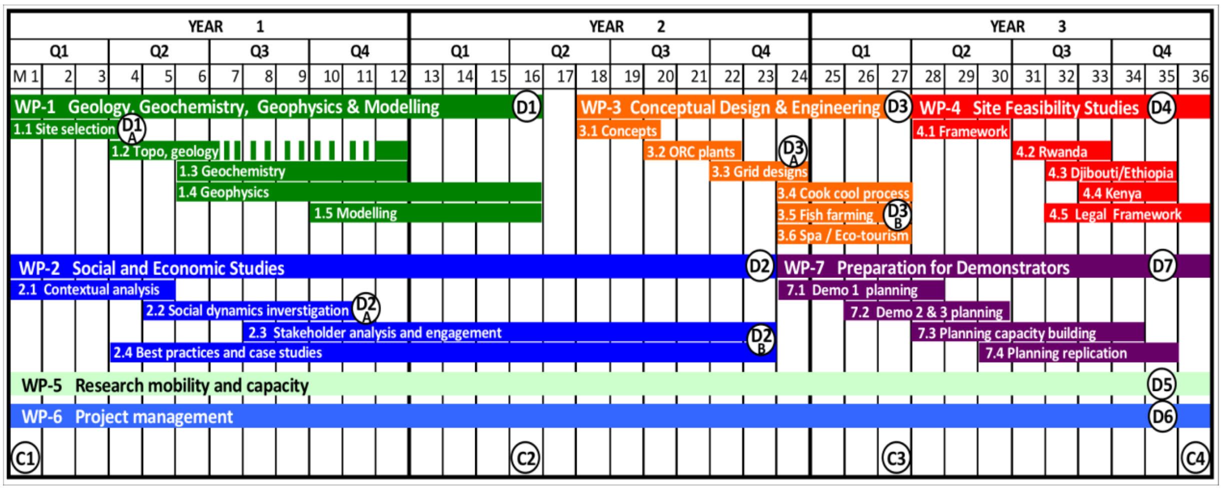

Table 2 : Original time frame, tasks (here called WP) and deliverable for GV1 project.

The conception and development of any geothermal project, particularly when innovative as in the present case, relies upon a successful identification of this natural resource, coupled with a social demand of the population and a feasible engineering solution with an adapted design.

As expected from the selection engaged in the first phase of the project, following its preparation, the 4 sites proposed display a wide variety of determinants, whether from the geology conditioning the resource, from the socio-economic characteristics of the population concerned on site, and of course from the scientific, technical, political and economic supports that can be mobilized for the following demonstration project (GV2 pilot project). This choice was made under GV1 in order to end this innovative project with a variety of pilots answering any kind of future local geothermal development along the EARS.

3. The geosciences approach engaged under LEAP-RE

Table 2 summarizes the geological parameters determining the geothermal resource on the 4 sites, showing a variety of geothermal play-types, from high temperature steam dominated systems benefitting from a relatively shallow magmatic heat source at Era Boru in Ethiopia to low-temperature fault controlled convective systems at Mashyuza in Rwanda.

At Abhé in Djibouti and Homa Hills in Kenya, we have in both cases, two distinct productive systems, one of low temperature allowing for direct use applications, and one of medium temperature (120-150° C) allowing for electricity production (with ORC solution).

For these both cases, the thermal resource depend directly on the vicinity of a magmatic chamber. A magmatic heat source occurs at 30 km, i.e. relatively far, (Dama Ale volcano in Ethiopia) at Abhé, with a potential geothermal site extending on both sides of the border which would justify a bilateral (Ethio-Djibouti) development project (Varet, 2022). Whereas at Homa Hills, the age of the volcanic system only allows for a rather deep magmatic heat source. But the carbonatites extrusions facilitated the karst development hence highly permeable convective reservoirs.

COUNTRY	DJIBOUTI	ETHIOPIA	KENYA	RWANDA
SITE	ABHE	ERA.BORU	HOMA.HILLS	MASHYUZA
GEOTHERMAL PLAY TYPE	ACTIVE GRABEN	ACTIVE VOLCANIC	MIOCENE VOLCANIC	FAULT CONTROLLED
Hot springs on site	+++	-	+	++
Steam vents on site	+	+++	+	-
Magmatic (HT) heat source	+	+++	-	-
Fault controlled convective	++	+	+	+++
Geothermal reservoir(s)	++	+++	-	-
Use on site	+	+++	+	++

Table 3 : Geological parameters determining the geothermal resource on the 4 sites selected for GV1.

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From Table 3 results, it appears that geological conditions widely differ with lack of local magmatic heat source on most sites, Fault controlled low temperature resource are well identified and documented in Rwanda allowing for a variety of direct uses applications. Intermediate temperature resources are well documented both at Abhé (Djibouti) and Homa Hills (Kenya), which can be developed in parallel with direct uses from shallow low-temperature resources.

Era Boru in Ethiopia is the most promising site in terms of geothermal resource and perspective of use. Geodynamic consideration on the area, located between the two axial ranges (active spreading axis) of Manda Harraro and Alayta, i.e. a transform fault zone, characterized by silicic volcanic units. The widest being the large Dabbahu (meaning "high mountain" in Afar language) volcano aside Era Boru, all showing crystal fractionation process at shallow depth (3 to 5 km) from the underlying basaltic source. An important meteoritic water recharge is ensured from the Teru graben at the western foot of the volcanic system, feeding the numerous steam vents. A plateau 700m high affected by normal faults and open fissures through which numerous silicic peralkaline obsidian domes and pumice cones were emplaced in the last 10 to 100ky. The last being the Dabbahu pyroclastic Event (Sept. 2005) opening a sequence of basaltic diking over a length of up to 70km and a width reaching 8 cm in the period 2005-2010 (Wright et al. 2006; Hamling et al. 2009, 2010) Over a length exceeding 5 km and a width of 2-3 km, EraBoru (meaning steaming basin in Afar language) is affected by innumerable steam vents, occurring through normal faults and open fissures as well as diffuse vents at the surface of lava flows, domes and pyroclastic deposits. These hydrothermal manifestations are called "Boina" in Afar language, a name also used to describe the site (Barberi et al. 1972). And the geothermal grass (called "Fiale") is also abundant along faults and lava flow surfaces. The characteristic of EraBoru and of other sites around Dabbahu Volcano which provides an exceptional heat source (Johnson et al., 2016) lies in the fact that the local population developed artisanal engineering solutions allowing to condense the steam and produce potable water for people and herds. An option of real resilience, as the water is produced continuously, whatever the climate fluctuation. Gardo & Varet (2020) could speak of a "geothermal civilization" as human settlements are directly relying upon this resource used locally. With Jerome Ammann, CNRS research engineer at the University of Western Britanny, an infrared drone survey was undertaken, allowing a precise, quantitative mapping of the steam vents, whether natural of engineered. Coupled with field observations, it appears that, after having located the condensation wells on steam emergences, along upper compartments of active normal faults, more efficient solutions were developed digging in the graben filled with pyroclastic layers of silicic ash and pumice falls where no surface manifestation is observed at the surface, but under a few meters (5 and up to 20).After digging through these dry (and cold) volcanogenic sediments, a hot and wet surface is met, in which the steam produced a hydrothermally altered clay zone. Drilling through this clay zone with modern tools should allow to obtain a steam production answering the needs of the local population for both energy and water production.

As a whole, Era Boru is not only a site of interest for the GV project but also for the perspective for much larger developments of this "giant" potential site (Varet et al., 2022).

However, it happened that, due to safety conditions on site (the Tigray war impacted the area, which was not accessible for two years. Therefore, despite favorable geological conditions, the necessary geophysical and geochemical surveys could not be undertaken.

Table 4 summarizes the geoscience studies completed on the 4 selected sites under LEAP-RE and the resulting development targets in terms of geothermal applications and social uses.

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COUNTRY	ETHIOPIA	DJIBOUTI	KENYA	RWANDA
SITE	ERA.BORU	ABHE	HOMA.HILLS	MASHYUZA
GEO- STUDY COMPLETED	+	+++	+++	+++
Geology	+	+	+	++
Infra-red drone survey	+	+	-	-
Fluid geochemistry	-	+	+	+
Geophysics	-	++	++	++
LOW TEMPERATURE RESOURCE	+	+++	+++	+++
HIGH TEMPERATURE ELECTRICITY PROD.	+++	++	++	-
WATER PRODUCTION ISSUE	+++	+++	++	-
SOCIAL SC. STUD. COMPL.	+	+	+	+

Table 4 : Geosciences research and studies completed on the 4 sites under LEAP-RE and resulting geothermal development perspective.

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It appears that if the surface exploration work was completed on the 3 sites of Abhé (Djibouti), Homa Hills (Kenya) and Mashyuza (Rwanda), Era Boru site could not benefit from the same efforts. This due to the internal Tigray/Federal war which affected the area for 2 years (2022-2023), forbidding any access to the area. An Infra-Red drone survey could be achieved, together with geological field controls (see the specific LEAP-RE report N°D11.2.2). However, the geophysical and gas geochemistry survey are still lacking, a must to obtain the 3D picture allowing to locate the shallow reservoir and drilling targets.

4. Resulting applications perspectives proposed

Table 4 also shows the perspectives in terms of geothermal application on the 4 sites resulting from these studies.

At one extremity (right in the table 4) Mashyuza in Rwanda offers a low temperature resource suitable for direct uses applications only.

At the other end, Era Boru (left in the table 4) allows for electricity production, eventually directly from steam turbine (as well as water production from steam condensation).

The other two sites may allow for medium temperature production, allowing for electricity production from ORC, and the variety of the thermal manifestations also open the way for direct uses applications.

In all cases, particularly the sites in Ethiopia, Djibouti and Kenya, the necessity to master high temperature outflow while drilling with shallow depth equipment is a challenge that need be mastered both in terms of technology and know-how. Within our team, SEPCO from Kenya has acquired the necessary experience, that can be transferred to local drilling companies, as shown by Omenda et al. (2024).

The kind of applications considered on each site are summarized in table 5.

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COUNTRY	DJIBOUTI	ETHIOPIA	KENYA	RWANDA
SITE	ABHE	ERA.BORU	HOMA.HILLS	MASHYUZA
APPLICATIONS CONSIDERED:				
Electricity production (off-grid)	+	+++	-	-
Drinkable water production	+++	+++	+	-
Powering lake water pumping	-	-	+	-
Agri-systems (irrigated perimeters)	++	+	-	-
Fish farming / drying	+	-	+++	+
Agro processing (drying)	+	+	+++	+++
Industrial processes	-	-	-	+++
Bathing, SPA, Steam bath	+++	+	+	+++
Ecotourism	+	+	+	+

Table 5 : Variety of geothermal applications and development perspective considered on each site resulting from the LEAP-RE study (combined geosciences, available technologies and social science).

4.1. Electricity production

The electricity production off-grid answers a real need at both Era Boru (Ethiopia) and Abhé (Djibouti). And on both sides a real perspective exists in terms of characteristics of the geothermal resource on site, with the best conditions at Era Boru (clean dry steam expected), whereas at Abhé, the medium temperature fluid expected requires an ORC.

In Djibouti, The Ministry of Energy is supporting the development of off-grid renewable energy systems, essentially solar at present, but geothermal units should benefit from similar support once the feasibility is demonstrated. Which is a challenge for Abhé project implementation.

The point is that geothermal energy allows direct use of the fluid, in addition to producing electricity. As shown in Fig.1, the GV concept is seeking for integrated development of diversified, cascade use of the fluid, with engineering designs allowing to optimize the use of both steam and brine after the electricity production (Fig.3).

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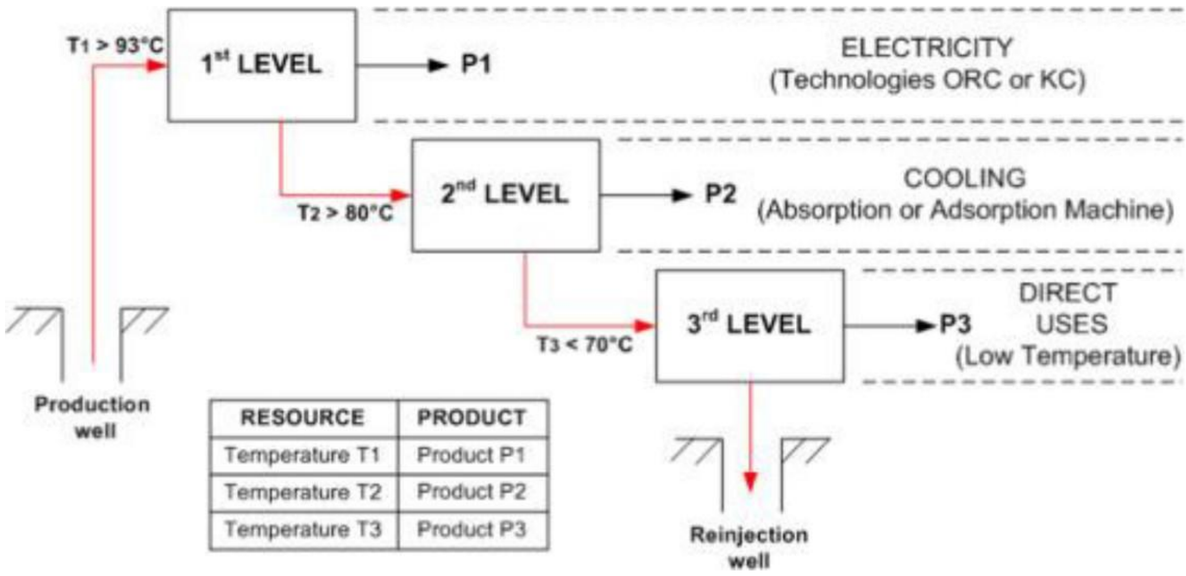

Figure 3: Cascade use geothermal energy combining various technologies, with ORC: stand-alone, flexible and portable production modules for in the range of 20 to 200 kWe, a size adapted to the production expected, coupled with cascade direct uses of the fluid serving other local needs at the low temperature, ending with the use of the water itself (Varet et al., 2014).

Homa Hills (Kenya) and Mashyuza (Rwanda) are deserved by the national electricity grid, and a community-based electricity production, even if technically feasible (the geothermal brine at Homa Hills is expected to be rather salty posing corrosion/scaling problems), will require to acquire specific technical know-how for the maintenance and negotiations with the power distribution company. At Mashyuza, the moderate temperature of the fluid will not allow for economic production of electricity, if even feasible. And direct uses perspectives are diversified and large enough for saturating the best use of the geothermal fluid.

4.2. Drinkable water production and irrigated perimeters

It is needed to emphasize the fact that, on all sites except Mashyuza (Rwanda), the demand for drinkable water is the highest priority for the population on site. The most striking being Era Boru where, in absence of any liquid water resource due to arid conditions, artisanal devices (called Boïna) allow for Afar people to condensate the naturally occurring dry steam for drinkable water production for herds and people (Fig. 4).

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Figure 4: Partial view of the artisanal steam condensation devices for drinking water production at Era Boru (Ethiopia).

A similar situation is found at Abhé (Djibouti) where the lake is highly salty, whereas the hot-springs are less salty, some of them, away from the lake, being drinkable. The priority for the village - including now a school and a tourist camp - is to have access to drinkable water, even more demanded than electricity[1] and other uses of geothermal fluids (bathing, food and handicraft processing, thermal tourism…). The site, with its extraordinary forest of "smoking" travertine chimneys (Fig. 5) is suitable for a touristic development also based on thermal applications (SPAs).

Figure 5 : travertine chimneys produced from thermal springs along tectonic fissures affecting the eastern shore of Lake Abhé (Djibouti). Photo J.Varet.

At present, some of the hot-springs are used by the local pastoralist population for irrigated perimeters (Fig.6), allowing for permanent grazing lands, independently from climate and lake level fluctuations. Such perspective could be developed for vegetable cultivation and green-housing.

[1] Even if, of course, electricity can be used for desalinization of the geothermal brine… however less costly solutions should be searched from near-surface aquifers surrounding the salty lake

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Figure 6 : hot-spring issued from the foot of a travertine chimney, used by the local pastoralist people- digging a canal and protecting an ever-green area, on the eastern shore of Lake Abhé (Djibouti). An application that could be used also for other agricultur

At Homa hills, despite a wetter climate, the need for water is high along the flank of the volcano, made of highly soluble carbonatites, with as a result meteoritic water quickly salinized when reaching and flowing on the ground. The present solution is there to carry water tanks with donkeys from the Lake Victoria uphill. A pumping (from the lake) and irrigation device did exist in the past but was abandoned due to lack of maintenance and costs of pumping. The perspective of powering the water pumping from a geothermal plant requires a specific technical, social and economic feasibility study.

The Afar population in Ethiopia and Djibouti is pastoralist and not accustomed to agriculture, but when water is available, they developed capacities to master irrigated perimeters for the development of grazing and vegetable production areas. Hence water production from geothermal resource after heat and power extraction could be used for such community-based applications, provided the fluid composition is suitable. Greenhouses may help reduce transpiration and limit evaporation.

4.3. Fish farming and processing

Fishing activities are well developed along the Lake Victoria coast at Homa Hills (Fig.7) Fishing products are exported in the country, either fresh or dried. Fish farming is also being developed in Kenya as in Rwanda. Geothermal springs are frequently found - all along the EARS - driven by normal faulting around lake shores of the rift floor. The sites selected for GV1 do not answer this characteristic, which however justify developing a geothermal pilot demonstrating the feasibility of fish processing, particularly fish drying and fish farming. Several examples in Europe, in France in particular (Etang de Tau,

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Occitanie; caviar d' Aquitaine…) show the benefit from fish farming using low temperature geothermal fluid due to constant temperature and composition of the water.

Among the 4 sites of GV1, Homa Hills should be considered for such applications. The area already benefits from a renowned fishing industry, well established on the Kenyan market, and the project should benefit from the support of the Aquaculture Academy of Homa Bay. We therefore propose to consider this as one of the most promising priorities for a direct-use geothermal pilot plant under LEAP-RE, in partnership with these regional institutions, and of course HHCBO, the local community-based partner at Homa Hills.

Figure 7: Fishing along Lake Victoria shoreline, near hot springs, at the foot of Homa Hills volcano (Photo J.Varet, 2022).

4.4 Agri-processing

Direct uses of geothermal resource offer a variety of solution in agri-processing applications. This concerns in particular fruit (mango, pineapple, banana, apple, etc…) vegetable (tomatoes, eggplant, beans…) meat, milk products and others (rice, coffee, tea…), all products gaining high value from such preservation, otherwise lost in the over-production period.

This perspective is notably valid for the two sites of Homa Hills (Kenya), where this option is favored by HHCBO, the local community-based organization, and Mashyuza (Rwanda) where the climate allows for several cycles of production per year, which geothermal drying allow to increase.

Numerous devices are available (Geoheat Centre Oregon in particular) easy to build locally (as shown for example at Eburru, Kenya). An example is provided in Fig.8.

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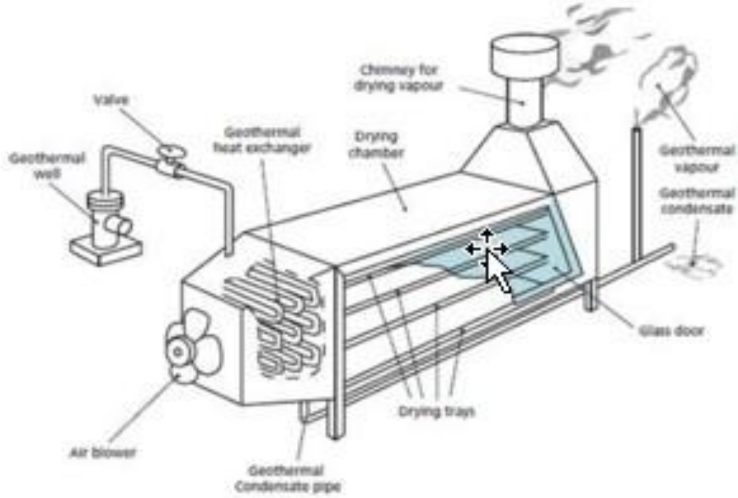

Figure 8 : Geothermal dryer for beans and grains, Indonesia (Geo-Het Centre Oregon, USA and Van Nguyen et al. 2015 in Varet UNEP report on DGUD (2022).

Besides drying, other ago-processing options can also be considered as food canning, pasteurization, dairy production (powder milk, cheese, etc…), essential oil extraction, etc (for more details, see the report published by UNEP : (Varet, J. (2022) Technical Guidebook for Direct-Use Geothermal Development in Africa. UNEP-ArGeo editors, 140p.

4.5 Industrial processes

Several industrial processes require low temperature treatments that can be achieved using geothermal heat. Within the 4 sites selected, Mashyuza in Rwanda is also the place of a cement factory, extracting the limestone deposits produced by the calcium carbonate rich geothermal springs. The first step of the cement production requires drying the limestone rich in water when extracted. This could be achieved using the heat from the geothermal system, through heat exchanger before the geothermal fluid can be used for other applications like agri-processing and bathing / thermal spas.

4.6 Thermal baths, spas and ecotourism

Eco-tourism is well developed along the EARS, mainly with the promotion of the World-renown Natural Parks with their vegetation and wild fauna. Despite the opportunities offered by the valorization of the numerous geothermal manifestations, they are still ill-developed in the region. The most well-known geothermal SPA site is located in Naivasha (Kenya) using geothermal fluids from Olkaria power plant. It was built by KenGen on the model of "Blue Lagoon" the highly touristic site in Iceland (Fig.9).

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On each of the 4 sites selected for the GV1 project, such opportunities are available, and in fact already considered as an opportunity with embryonic offers. The most emblematic is Mashyuza in Rwanda where a bathing site was created and equipped years ago, attracting tourists from the region including Burundi and DRC. But the development of the limestone extraction progressively reduced the hot-spring site, which was progressively abandoned due to lack of maintenance and development perspective. The thermal site and SPA should now be totally re-considered in the frame of a rehabilitation program including a protected "green" area with thermal springs and baths defined, built and maintained in a partnership with the cement industry. Abhé in Djibouti also offers a nice opportunity as eco-touristic destination including the exceptional landscape of the smoking travertine chimney forest, which should be classified as UNESCO site, while tourists would appreciate an eco-tourism station with thermal baths.

Figure 9 : Geothermal SPA built by Kengen at Niavasha (Kenya), using the fluid from Olkaria Power Plant visible in the back. (Source : KenGen).

5. Site selection, pilot characteristics; partners and action leaders to be engaged

5.1. Partners engaged in GV1

Table 6 summarizes the African partners engaged in each of the 4 GV1 sites. It shows a variety of local partners, from national public entity in charge of energy (EDCL, Rwanda) or specialized in geothermal development (ODDEG, Djibouti) to local community-based organizations (HHCBO, a NGO in Kenya and AGAP, a community own geothermal development company.

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In addition, the backing of an academic partner (AAU in Ethiopia) and science and technology partner (SEPCO in Kenya).

Note that the two CBOs are not direct partners but sub-contracted with a "third-party agreement", with SEPCO for HHCBO and Géo2D for AGAP.

Note however that the national academic partner (AAU) was not really involved in the project, while the two CBOs, despite capacity building engaged, did not reach the administrative, technical and economic capacity to master the pilot project implementation.

COUNTRY	DJIBOUTI	ETHIOPIA	KENYA	RWANDA
SITE	ABHE	ERA.BORU	HOMA.HILLS	MASHYUZA
LOCAL PARTNERS ENGAGED LEAP-RE	ODDEG	AAU AGAP	HHCBO SEPCO	EDCL
PUBLIC ENTITY IN CHARGE OF GTH	+	-	-	+
LOCAL SPECIFIC ENTITY (CBO)	-	+	+	-
NATIONAL ACADEMIC PARTNER INVOLVED	-	+	-	-
CAPACITY BUILDING ENGAGED	+	+	+	-
OTHER PARTNERSHIP CONSIDERED	+	+	+	+
GEOTHERMAL LEASE ON SITE	-	-	+	-

Table 6 : African partners engaged in the GV1 (LEAP-RE-WP11) project.

5.2. Other partners to be considered

In all sites, the partnership engaged for GV1 need to be adjusted in order to fulfill the requirement for the GV2 pilot conception and construction. The social sciences studies and reports (from the Universities of Pisa and Torino) and the PhD thesis under progress at EHESS by Susan Onyango (first with Géo2D, then through Sirawende Consulting) provide details on the partners encountered, ready to mobilize in the following demonstration project.

5.2.1 Concerning Abhé (Djibouti)

A local entity, representative of the local community is still lacking at present, who should master the project locally, with the support of the Regional Council, the

ODDEG is focused on the development of large size power production projects serving the grid, whereas the Ministry of Energy develop a policy of supporting the development of off-grid projects and should be associated to the pilot project which will carry several duplications on the numerous sites identified in the country.

A local academic partner, the University of Djibouti, although young, is focusing on energy (initiated the "International Conference on Energy and Applications (ICEA) from February 25–27[2] and should be encouraged to develop R&D and teaching in geothermal[3].

5.2.2 Concerning Era Boru (Ethiopia)

The unstable political environment with the Tigray war did not allow to complete the geosciences survey as for the other 3 sites.

The first priority is to engage the geochemical and geophysical surveys in order to establish a 3D quantitative conceptual model and locate exploration wells, 350 m deep. The Geological Survey of Ethiopia (GSE) expressed interest for the project.

A partner was identified – belonging to the sister organization of AGAP called APDA (Afar Pastoralist Development Association) – display the capacity to drill for water up to 350 m deep but would need an external expertise for drilling in high temperature environment (particularly steam eruptions).

SEPCO (Science and engineering Company) from Kenya, associated to the LEAP-RE project, owns the engineering expertise for drilling and tests in high temperature conditions, mobilizing local ordinary (water, mine…) drilling operators.

A new University partner, AASTU (Addis Ababa Science and Technology University) associated with University of Cergy for a geothermal teaching project in Ethiopia supported by the French Ministry of Foreign Affairs[4] would efficiently replace AASTU associated in the LEAP-RE project (see details in reference, Dupaigne et al. 2024).

The partnership with the Ministry of Water an Energy, and with EEP (Ethiopian Energy and Power), engaged by AGAP with Géo2D, should be consolidated for GV2 project.

5.2.3. Concerning Homa Hills (Kenya)

A school was organized by Géo2D and SEPCO with UNITO, SSSA and NORCE on November 15th-15th at Homa bay site in order to share GV results (social sciences, geosciences, technologies) acquired on site and discuss perspectives with the concerned partners (40 attendees) identified locally and in the county (see Annex 1).

The geoscience survey was completed, but did not really allow to develop a 3D geothermal conceptual model and complementary geophysics is needed to locate

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[2] To which Jacques Varet was invited, which allowed to present the LEAP-RE EU/AU project (see publications)

[3] https://www.facebook.com/photo.php?fbid=825148653076177Cid=100067431505725Cset=a.608300641427647

[4] To which Geo2D took part (see publications)

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the sites of exploration drilling for two targets: a medium to high temperature reservoir in the upflow zone at the foot of the Homa volcano slope and a low temperature target near to the lake shore.
- For GV2, the local community-based organization HHCBO need to develop partnerships with technical partners like the Aquaculture Academy (Homa Bay), and the local power company.
- The relation with the owner of the geothermal lease, Capital Power, also needs to be clarified.

5.2.4. Concerning Mashyuza (Rwanda)

The country was chosen by the EU/AU LEAP-RE management to organize at KIGALI on 10- 13 OCTOBER 2023, a Stakeholder Forum for local African attendants implying partners from all WPs including GV (WP11), allowing for sharing experience and engaging new contacts in view of further developments (Varet et al. 2023; Varet & Gardo, 2023).

The Mashyuza site benefitted from a complete geoscience investigation allowing to fully understand this fault-controlled geothermal system, providing a rather important flow of low-temperature fluid, and socio-economic studies allowed to target on several applications including:

- a limestone drying plant for the Cement Factory;
- a new thermal station and SPA in a protected natural environment after rehabilitation of the mining site with te support of regional authorities;
- A pilot site for agriculture products (rice, tea, coffee, fruits and vegetable) drying in partnership with the producers (peasants' community and local agro-industry).

The compatibility of these 3 applications will be an interesting challenge for the public authorities and concerned partners.

Besides the partners on each site, the overall leadership and management of the GV2 project should shift from academic to technical partners with engineering experience.

5.3. Sites selection for GV2

Following the information and considerations developed during the GV1 project and the above considerations, each of the 4 sites selected and studied display a variety of characteristics that will be of use for further pilot demonstration sites of the Geothermal Village concept in the EARS region.

Rather than selecting one site, a 4 sites pilot project should allow to support diversified developments answering the variety of geothermal resource encountered and the kind of applications best answering representative local demands in the EARS region.

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Table 7 summarizes the specificity of each site that need to be challenged by GV2 project. The GV1 project did aim at selecting one demonstration site among the 4 sites studied. But our results show that each site provide specific conditions and perspective of interest. So that a multi-sites demonstration should be considered. However, managing all these challenges in a single multi-site demonstration project is probably not realistic. If envisaged, it would require a rather complex organization and costs beyond the present capacity of the LEAP-RE Project.

The alternative is to favor initiatives at local and national levels, to be engaged in separate demonstration projects, with the support of the science, technology and management partners engaged in GV1.

As shown in section 5.2.b. each demonstration site will also require the involvement of other local partners – not present yet in the LEAP-RE present organization – in order to master specific know-hows that need to be mobilized for a successful achievement.

COUNTRY	DJIBOUTI	ETHIOPIA	KENYA	RWANDA
SITE	ABHE	ERA.BORU	HOMA.HILLS	MASHYUZA
Specificity to be challenged:				
1. Shallow drilling for dry steam				
2. Mastering steam composition	x		x	
3. drinking water production from	x		x	
4. Project management by a pastoralist entity	x			
5. Drilling through wet unconsolidated sediments				
6. Managing production from steam-brine mixture			x	
7. Driking water production		x	x	
8. Ecotourism/SPA pastoralist village compatible		x	x	
9. Two options: hotspring resort /	x			
10. Consolidating HHCBO with economic stakeholders (fishing…)				
11. Partnership with Capital Power owning the geothermal lease				
12. Solving the eco-compatibility cement factory / thermal bath SPA				
13. Managing the diversity of agri-processing with ad-hoc entity	x	x	x	
14. Public management of the rehabilitation of the mining site				

Table 7: Diversity of challenges to be met for a successful pilot demonstration on each GV1 site; major sites in green and (x) sites where such demonstrations could also be developed.

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5.4. Action leaders proposed

Action leaders are asked to be determined for each site selected for GV2.

For Abhé in Djibouti, the natural action leader is of course ODDEG, the national public institution in charge of geothermal development in the country. However, a partnership with the local community on site need to be arranged in order to make sure the project is developed aiming to answer local demand first. The branch of the Ministry of Energy in charge of powering off-grid, and the Water Resource Department of the Ministry of Agriculture, Water, Fisheries & Livestock (MAEM), should also be associated as well as the "Agence Djiboutienne de Développement Social" (ADDS) in charge of handling development projects in the most isolated rural areas.

The backing of the following external partners is also recommended:

- SEPCO (partner from Kenya) for shallow drilling of geothermal fluids,
- The backing of the LEAP-RE geoscience team for drilling location and data interpretation and modelling, including geothermal reservoir management
- the backing of the social science team for the implementation and capacity building of the local CBO,
- LeSpaFrançais[5] for the feasibility study of the geothermal SPA for both local and eco-tourism applications,
- NORCE for the overall surface engineering.
- Agro-pastoralist expert to be identified

For Mashyuza in Rwanda, EDCL is the partner engaged in geothermal development in the country. It benefits from limited technical capacities, and the project should of course imply a strong partnership with the local / district authorities who expressed a strong interest for the project. The Cimerwa cement factory present on site for both limestone mining and cement production should also be stakeholders in the project, as well as the agri-processing (rice, tea, coffee) enterprises and peasants cooperatives interested by drying facilities.

supplementary input will also be requested:

- the backing of engineering partners from GV1 (SEPCO, Géo2D, NORCE),
- as well as other EU experts to be determined with EDCL (f.i. mining rehabilitation experts, LeSpaFrançais…),
- backing from the GV1 social science team may also help solving the difficulty arising from cohabitation of the 3 entities involved:
  - the cement mine and factory
  - the agro-processing applications
  - the SPA in an ecotourism context.

For Era Boru in Ethiopia, the geothermal demonstration project should logically be placed in the hands of AGAP the Afar community based geothermal development company operating in partnership with APDA (owning drilling capacities). However, despite the capacity building actions engaged under LEAP-RE, the company is not yet in capacity to master the development of the demonstration project. The creation of a Special Purpose

[5] Who did already engage a preliminary study on the subject for ODDEG

Vehicle (SPV) benefitting from the support of EGS (Ethiopian Geological Survey) and EEP at Federal level and from concerned the Regional State entities in charge, should be considered.

in addition, the baking from GV1 partners will be requested:

- the geoscience team for geophysics, chemistry and drilling and reservoir management (SEPCO in particular),
- the social science team for consolidating the capacity building of the Afar partners (AGAP, APDA, University of Semera),
- The small ORC company (ENOGIA) for optimization of the electricity production and water condensation option.
- Concerning the academic support, we recommend to call for AASTU (Addis Ababa Science and Technology), replacing AAU present in LEAP-RE

For Homa Hills in Kenya, a similar arrangement needs to be considered with a SPV including HHCBO as well as professional partners to be précised (Fishing industry, cooperatives and local Academy and concerned authorities, and of course Capital Power Co holding the geothermal lease.

- the backing of SEPCO, engaged on site, is a must, with Géo2D and Sirawende whenever needed,
- an involvement of UNITO, from GV1 social science team will also be needed to help HHCBO to develop the capacities and manage the various components of the project,
- management of surface engineering by NORCE will also be needed.

5.5 Cost estimates

Cost estimates are difficult to establish at this stage of the project as it may vary widely on each site depending upon the application preferred (its characteristics and size), the flow-rate and quality of the geothermal fluid encountered and proved by production tests on selected targets, and the capacities of each local leader (Table 8). For instance, ODDEG favors the use of the heavy drilling equipment which they own but will not work for less than a few Million Euros per well. Whereas AGAP, thanks to the partnership with APDA, will be in the capacity to drill the necessary wells 350m deep for a few hundred Euros.

In a rough estimate (see table 8), each of the GV2 demo project would require at least half the cost for drilling (and science support activities) and half the costs for surface equipment, higher for power production (particularly when need be for ORC plant), including surface piping, pumping, hat exchangers and specific devices (drying, SPA, etc); the science and technology support should not exceed 20% of the total costs.

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Demo site type	Mashyuza (Rwanda)	Homa hills (Kenya) Abhé (Djibouti)	Era Boru (Ethiopia)
Resource identified	Low temperature (50-90°C)	Medium Temp. (90-130°C)	High temp. (steam above 130°)
Production	Hot water	Steam-brine mixture	Dry steam
Application type	Direct Use	ORC	Steam turbine
Drilling costs	300 k€	500-5000 k€	500k€
Surface devices	250k€	500k€	350k€
S&T support	150k€	200k€	250k€
Total	700k€	1200(Ke)-6000k€ (Dj)	1100k€

Table 8: Costs estimate for GV2 (rough first figures for various options).

Conclusion

The solution for solving the issue of geothermal energy development at local level along the EARS would be to engage a specific Research- Development and Demonstration (R&D and D) program financed at regional level by the African Union with the support of the European Union. The variety of possible options is such that several sites should be considered representative of this diversity in terms of geological resource, type of applications, and capabilities available on each site (each country).

Table 7 specifies the targets to be considered for each of the four sites and table 8 provides a fist idea of the budgets to be considered in 4 options, the kind of which studied under LEAP-RE WP11 GV1 project. The total budget of the GV2 Demo programme for a variety of sites representative of the diversity of the options would be of 3 to 7 M€

At present, at least 3 EU entities managing financial support are known to operate in the field geothermal development in the concerned countries:

- The Research Program Horizon Europe with the LEAR-RE and LEAP-SE Project, operating in partnership with UA (or african national R&D financing entity
- The Geothermal Resource Mitigation Fund (GRMF) hosted by the African Union Commission and financed by the European Development Fund and KFW (German Development Fund).
- Development funds handled by the EU Delegations in each African Country, driven by the demand from concerned countries.

In addition, national financial support may be mobilized from development agencies from Germany, Italy, France & Norway)

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Experience shows that GRMF procedure do not allow to support a Geothermal Village R&D project, when LEAP-RE/LEAP-SE do not allow to pay for costly and risky geothermal exploration drilling, whereas EU delegations in concerned countries ignore and have no capacity to co-fund the R&D projects managed by the EC.

The option would therefore be to engage a joint action at EU/AU level in order to find the way for and adapted support to geothermal local demonstration projects allowing for a diversified use of geothermal energy, solving the issues listed in this contribution and providing sustainable solution (Energy, water, food nexus) particularly adapted to the exceptional characteristics of the resource along the EARS and the high demand of the population concerned.

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ANNEX 1:

LEAP-RE
Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Training that took place in Pala Area Development Programme (ADP) Offices, Kokoth Kataa Location, Homa Bay, 15th and 16th November, 2023.

Organized by:
Ressources géologiques pour le Développement Durable (Géo2D)
Scientific and Engineering Power Consultants (SEPCO)

Modules:

Community development projects: promises and pitfalls

Introduction to:

· Gender and Culture

· Geology and Geothermal Technology

· Sustainability Management

Trainers:

Chris Büscher (UNITO: Università di Torino, Italy)

Fabio Iannone (SSSA: Scuola Superiore Sant'Anna, Italy)

Peter Omenda (SEPCO, Kenya)

Susan Onyango (Géo2D, France; Sirawende Company Limited, Kenya)

Walter Wheeler (NORCE: Norwegian Research Centre AS, Norway)

Trainees:

1 MATHEWS OTIENO

2 MARY WANJIRA

3 MARY AWITI AWINO

4 PAULINE OUMA

5. GEORGE OPIYO OMANJE

6. ERICK OTIENO MBAGO

7. MICHAEL OBONYO NYAMBAYE

8. JOSEPH OBISA

9. SYPROSE AWINO OCHOLA

10. WILLIS AJIGO

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11. QUINTER A. OKETCH
12. MILTON OBOTE PANYA
13. CLEMENT OCHIENG NGEGE
14. EVEREST OCHOLA DIERO
15. JEDIDAH ACHIENG OJIJO
16. CLEMENT OCHIENG OWUODHO
17. NICHOLAS AWINO AJIGO
18. DOMNIC TUJU OONGO
19. MARK ODHIAMBO OCHOO
20. JEVIS AMUONO
21. CAROLYN ONG'UDI
22. JOHN OKUMU
23. FREDRICK WAGUNDA

24FREDRICK ODHIAMBO

25. MARY A. OKUMU
26. JOSEPH ORACH
27. STELLA AMADI
28. DAVID OCHOO AJWANG
29. ORPHA AUMA MADO
30. PAMELA A. ABONYO
31. PAMELA AKINYI OTIENO
32. JANET A. OPIDI
33. DANCUN OYUGI NYARANGA
34. JOSHUA OWINO ABOK
35. GEORGE OUKO MAGAYA
36. JANE MUTA
37. GEORGE OKEYO AULO
38. TOBIAS OUMA AMBATA
39. LEGHTY ODONGO
40. JOHN OPIYO OKOMBO

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