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

Report about the outcome on scientific collaboration of 11

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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 concept is rather specific, as the unique geological and geodynamic context of the East African Rift System (EARS) allows for the production of energy and water from shallow resources elsewhere available at several km depth. Therefore, allowing for less costly and locally manageable solutions. But if advantageous, examples of such systems do not exist yet, and require R&D and demonstration of the technical economic, and socially supported local solutions. In the frame of the GV LEAP-RE project, the geological and socio- economic contexts of four representative sites have been analyzed. The sites are representative of the variety of both the geothermal resource and the demand of the population concerned locally. Based on this work, which was divided in several specific scientific approaches: including geosciences, social sciences, technologies, capacity building, solutions are proposed in this report, adapted to the condition of each site characteristics. 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 relevant financing.

Approval

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Report about the outcome on scientifc collaboration of WP11

Version N°2

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Table of content

List of figures

List of tables

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Abbreviations and Acronyms

Acronym	Description
WP	Work Package
GV	Geothermal village
UL	Université de Lorraine
UBO	Université de Bretagne occidentale
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

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ODDEG	Office Djiboutien de Développement de la Géothermie
ORC	Organic Rankin Cycle
SPA	Special Purpose Vehicle
UNITO	University of Torino (Italy)

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 concept is rather specific, as the unique geological and geodynamic context of the East African Rift System (EARS) allows for the production of energy and water from shallow resources elsewhere available at several km depth. Therefore, allowing for less costly and locally manageable solutions. But if advantageous, examples of such systems do not exist yet, and require R&D and demonstration of the technical economic, and socially supported local solutions.

In the frame of the GV LEAP-RE project, the geological and socio- economic contexts of four representative sites have been analyzed. The sites are representative of the variety of both the geothermal resource and the demand of the population concerned locally.

Based on this work, which was divided in several specific scientific approaches: including geosciences, social sciences, technologies, capacity building, solutions are proposed in this report, adapted to the condition of each site characteristics.

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 relevant financing.

Keywords

Geothermal resources, community, demonstration, development, economy, engineering, geoscience, geothermal.

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1. Introduction

The "Geothermal Village" program aims to promote the development of solutions for exploiting geothermal resources for use outside of large distribution networks.

Geothermal energy is a permanent resource that is not subject to night-day cycles or climatic variations. It is available underground at depths ranging from 1 to 5 km for electricity generation (i.e., temperatures above 150°C), depending on the geological context. This resource provides access to heat that can be used for domestic, artisanal, or industrial applications.

Geothermal is a flexible, full-time energy source, that allows to answer local needs and serve surroundings through energy and water networks. With the objective to introduce stand-alone electric and thermal energy our African-European R&D group aims to provide template case-studies adapting geothermal energy resource and off-grid systems to community needs in Africa. After field studies already engaged, sites with different thermal and socio-economic characteristics will be selected, developing for each a suitable energy plan. We aim to keep the technology level appropriate to local operation, maintenance and even replication, which furthers the long-term objective of capacity building, economic and social welfare, encouraging young educated people to stay on their homeland. These systems can supply fresh water and supplant oil and firewood which, in addition to environmental and health benefits, reduces the domestic expense and workload on women and girls allowing time for education and productivity.

This project directly addresses most if not all objectives and roadmaps of sustainable development including access to water and clean energy, climate resilience, developing capacities at individual and institutional levels to engage modular developments and to adapt to further changes, through smart grid, off grid, stand-alone systems and processes and appliances for productive uses.

This report reviews the operation of the "geothermal village" program, presenting the following topics in succession:

- The geological context and a reminder of the objectives,
- The division into tasks,
- The main results,
- The operational elements of the program.

The purpose of presenting these sections is to provide feedback on the program's operation, thereby assessing its advantages and disadvantages and presenting proposals for improvement. These feedbacks and proposals are synthetized in the last two sections.

2. Background and overview of objectives

The East African Rift (EAR), with its two branches, has significant geothermal potential with numerous hot springs and steam vents, often at high temperatures (Figure 1). This continental structure is associated with lithospheric thinning, which generally leads to an increase in heat flow. These active deposits are associated with a wide variety of geological

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features, including active or ancient volcanic systems, fault zones, and lithological heterogeneities.

Several large deposits are exploited for mass production, and the energy produced in the form of electricity is often exported outside the territory where it is produced. This is particularly the case in Kenya, where production is far ahead of other countries.

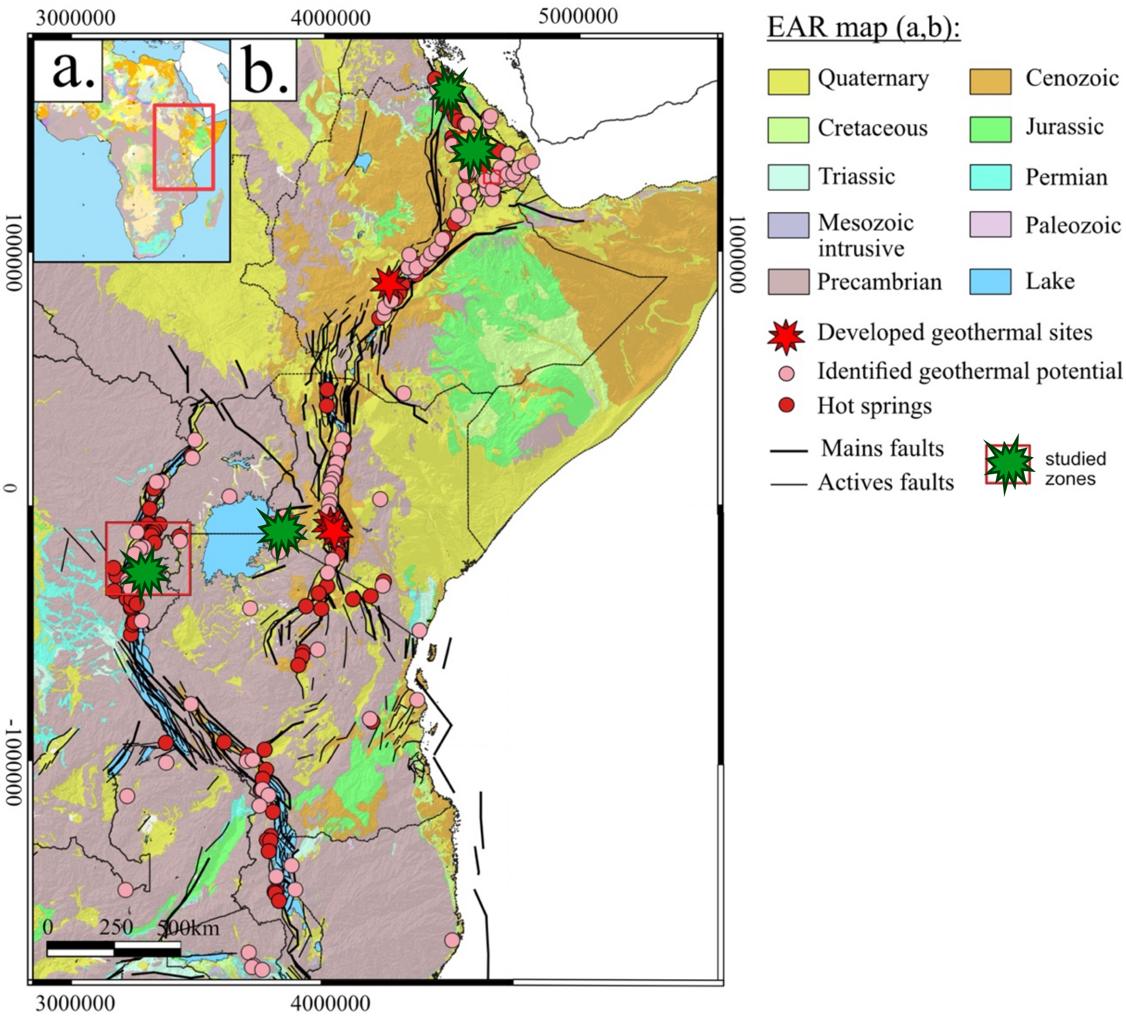

Figure 1-a- global location of the East African Rift. b- geological setting of the East African Rift, and location of studied sites (from Piolat et al 2025).

The objective of this project is to target and develop the production of energy resources, electricity, water and heat in areas far from electricity or carbon-based energy distribution networks. These regions are often occupied by small population units and attract little interest in regional development plans. The aim is to promote the development of small production units that are adapted to local demand and can be maintained and managed locally. This can be illustrated by Figure 2, which shows the concepts of local production and consumption.

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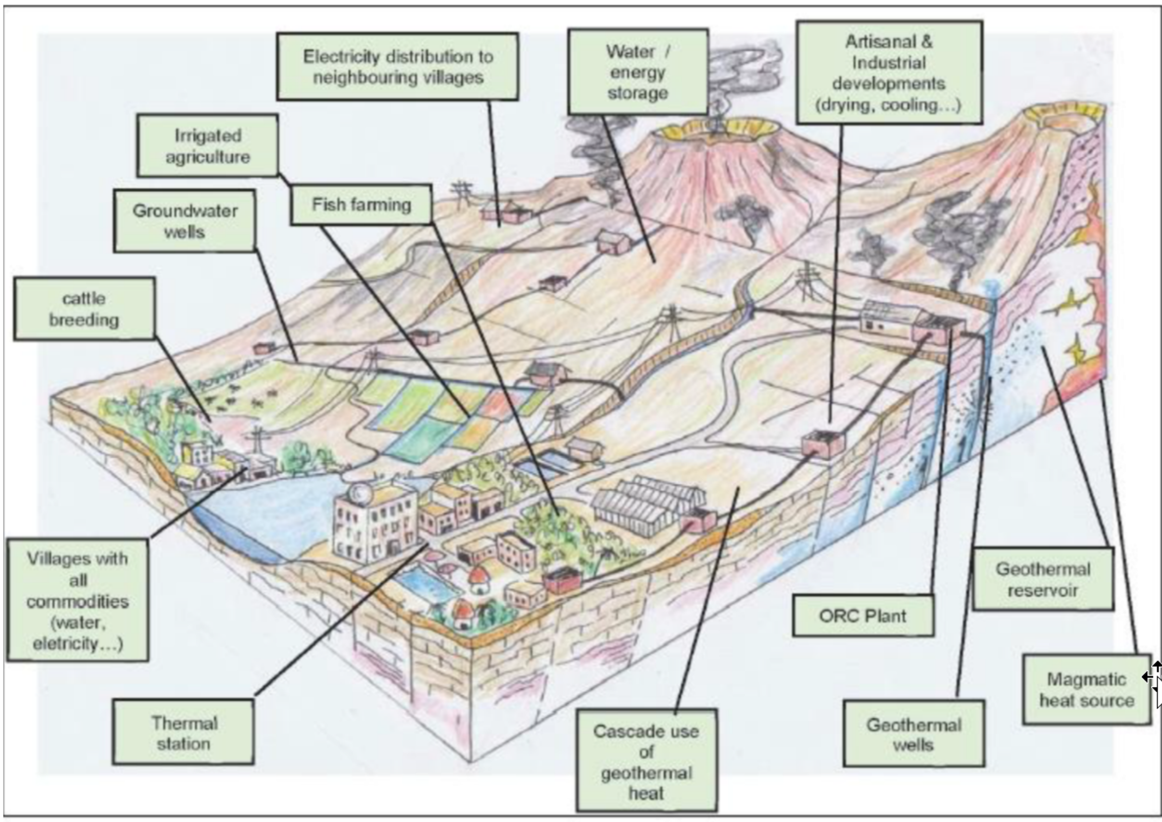

Figure 2- schematic representation of geothermal village concept (from Varet et al., 2014).

This program answers three main objectives. The first objective of this program was to test adapted acquisition protocols and identify resources with low-cost protocols. The second objective was to define a protocol for analysing the socio-economic context and identifying the expectations of the populations. The third objective concerned the exploitation of the resource, with the definition of a technological solution adapted to the resource and the expectations of the populations.

Four sites were studied because they have specific geological and/or socio-economic characteristics representative of the diversity of such geothermal sites along the EARS (tables 1 and 2) :

- The Lake Ahbé site in the Republic of Djibouti is characterized by a pastoral socio-economic context and a geothermal system far from the heat source (volcano) with circulation through faults.
- The Mashyuza site in Rwanda is characterized by an industrial and agricultural socio-economic context and a geothermal system controlled by fluid circulation in faults bordering a rift.
- The Homa Hills site in western Kenya (Nyanza Rift) is characterized by a socio-economic context of a fishing village and an ancient carbonatite volcano (Miocene) in which a geothermal system developed with surface manifestations.
- The Era Boru site, in the Afar regional State of Ethiopia, is characterized by a pastoral socio-economic context exploiting artisanal shallow steam well built in a particularly active geothermal system located along the spreading segment of the Afar Rift.

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Table 1: geological parameters determining the geothermal resources on the 4 sites selected for GV1

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	+	+++	+	++

The development of underground resources, particularly geothermal resources, requires a long-term process compared to other renewable energies. The development of wind or solar power sites generally takes two to five years, depending on the size of the fields to be developed.

Table 2 : Variety of geothermal applications and development perspective considered on each site resulting from the LEAP study (combined geosciences, available technologies and social science).

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	+	+	+	+

The development of relatively high-enthalpy geothermal resources involves deep drilling (to depths of over 1,000 m), which requires different phases of work. The standard

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methodological development protocol comprises three successive stages. These are described briefly below.

- In the first stage, or phase 1, geological, geophysical, and geochemical surveys are conducted to define an area of interest, its potential, and initial technical exploitation solutions. This stage generally lasts between one and three years.
- In the second stage, or phase 2, a high-resolution analysis is conducted to define the reservoir geometry and drilling strategy. This phase lasts at least 1 to 2 years.
- In the third stage, or phase 3, one or two exploration-production wells are drilled, combined with well testing and stimulation tests to assess the reserve. This final phase lasts approximately two years, before industrial exploitation begins.

This means that the minimum time between the start of the reconnaissance phase and the start of exploitation is approximately seven years. These technical timeframes do not consider administrative delays, which can significantly extend development times. It is during phases 1 and 2, in particular, that societal and economic analyses are carried out to identify the expectations of the population and develop technological solutions.

Of course, the aim of the Geothermal Village (GV) project is to tap the geothermal resource at shallower depths due to the favourable conditions prevailing in the EARS, and develop tools allowing to reduce time and budget in the exploration phase of these local geothermal devices answering local needs

The Geothermal Village program is part of phase 1 of the protocol described above and will be limited to this scope for the investigation of the geological characteristics of the resource, as well as the socio-economic analysis of the various sites. This work is limited to phase 1 due to the duration of the program and the allocated budget. During this program, a new geophysical prospecting tool was tested. This tool provides a 3D image of electrical resistivity and chargeability for a cube measuring 3 to 4 km across and up to 1 km deep.

A specific objective of this program is to consider an approach for developing knowledge and appropriating geothermal resources by capacity building of local populations and to develop an implementation plan. This involves disseminating information and resource models the local populations and institutions, as well as to industrialists likely to develop these exploitation technologies locally.

Thus, for each site, geological solutions are identified (D11.2), socio-economic contexts and population expectations are analysed (D11.3), and technical solutions and estimates of the budgets required to reach the development phase are also proposed (D11.4 and D11.6). The dissemination elements and the communication test in the form of a week-long training course are presented in reports D11.5 and D11.6.

The present report (D11.7) concludes this sequence with the synthesis of the scientific outcomes of the whole GV (D11) LEAP-RE project.

3. The WP 11

The WP 11 « Geothermal Village » is composed by several tasks summarized here after. The actions proposed for each are presented in rapport (d11_1.pdf).

Wherever possible, as in the case of the Rwanda and site, geological reconnaissance and societal analysis fieldwork was conducted during the same site visit with an interdisciplinary team composed of researchers from UL, Santa Anna, and Norce.

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For the 3 other sites, the work could not be carried out simultaneously and was therefore the subject of separate visits for geosciences, social sciences and appropriate technology approach, but joint meetings with the local population and stakeholders were arranged with the local partners (SEPCO for Kenya, ODDEG for Djibouti, AGAP for Ethiopian Afar and EDCL for Rwanda).

3.1. The division of the WP into tasks

Task 11.1.: R&D Geosciences

This task is dedicated to the definition of geological models for the different geothermal plays represented by each studied site. Therefore, different tools of geophysics, geochemistry and geology were used.

Several modifications for the driving of the tack occurred. Initially, this task should have been led by UBO and UAA, whereas, in fact, UL took the lead and managed the field work for Djibouti, Rwanda and Kenya sites in cooperation with the local partners (ODDEG, EDCL and SEPCO). For the site in Rwanda, some colleagues of Norce jointed the field team. For the Ethipian site, Geo2D drove the field work in collaboration with UBO team for a specific data set on thermal images acquired by IR drone in collaboration with UBO teeam. Complementary data were added for the Ethiopian and Rwanda sites by Geo2D and Norce teams respectively.

The buildup of the geological models was driven by UL and Geo2D in collaboration with NZ colleagues for the Djibouti site.

Note that in Ethiopia, the project was badly impacted by the Tigray-Federal war in the years 2022-2024, which did not allow to engage the geophysics, hence reducing the capacity to elaborate the 3D modelling allowing to best locate the exploration wells, for which a local company was identified (APDA, sister community-based entity of AGAP).

This task was the subject of the specific deliverable : D11.2.

Task 11.2.: R&D Social sciences

This task was driven by the Italian team composed by researchers of the Universita degli Studi di Torino and of the Sant'Anna School of Advanced Studies at Pisa and by Susan Oniango initially from Geo2D. The four sites were investigated separately by different teams, in partnership with local entities involved in the project (ODDEG on Djibouti, HHCBO in Kenya, EDCL in Rwanda and AGAP in Ethiopia), which developed their specific capacities in this field thanks to this project, with the aim for them to be able to manage the implementation of phase 2 of GV project (pilot).

This task was the subject of the specific deliverable : D11.3.

Task 11.3.: R&D engineering sciences

This task was driven by the Norce team in collaboration with the other teams. For each site, several solutions for the resource exploitation were proposed based on the geothermal potential and on the expectations of the people.

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Task 11.4.: Feasibility studies on 3 relevant sites

This task was driven by Geo2D and Norce. The objective was the selection of 3 sites out of 4 initially selected. Data for all the 4 sites were presented, and technical solutions proposed for all of them.

The tasks 11.3 and 11.4 were the subject of the specific deliverable : D11.4

Task 11.5.: Transfer knowledge and capacity building

This task was driven by Frahenhoffer in collaboration with the other teams. The objective of this task was to disseminate information, manage training between teams, and transfer technology and skills between the different teams. Another major objective of this task, also involving all partners, was to disseminate scientific results at conferences and in the form of articles in peer-reviewed journals.

Task 11.6.: Preparation of the geothermal village demonstration projects and piloting

This task was driven by Géo2D in collaboration with the other teams, particularly SEPCO and NORCE. For this task, evaluations of the technical and economic solutions were conducted. An evaluation of the associated cost was done.

Task 11.7 : Project management

This task was conducted by UL in order to organize interaction between the different teams and assume the coordination with LGI and UE.

Assessment and feedback on the division in tasks

The organization in tasks made it possible to cover the various topics associated with the exploration of geothermal resources without overly segmenting the actions. These topics associated the different European and African teams and specialties, and it was therefore necessary to ensure communication between stakeholders from different cultures who, initially, did not necessarily share a common vocabulary and had differing expectations. The tasks were sufficiently broad in terms of theme, with in fact the same objective of allowing for successful developments, made it possible to overcome this problem.

3.2. Participants

For this project, based on four different sites in four different African counties, fourteen institutions from four African countries and five European countries partnered in the program (table 3). The European countries are represented mainly by academic teams, five in total, with the University of Lorraine and the University of Western Brittany for France, the University of Turin and the Sant'Anna School of Advanced Studies for Italy, and the Fraunhofer Institute for Energy Infrastructures and Geothermal Systems for Germany, as well as two companies or agencies, Géo2D for France and Norce for Norway. African countries are represented by five agencies, associations, or companies, with EDCL in Rwanda, AGAP in Ethiopia, SEPCO and HHBO in Kenya, ODDEG in the Republic of Djibouti, and by two universities, Addis Ababa University (AAU) in Ethiopia and the University of Nairobi (UoN) in Kenya. The activity of AAU has been limited due to the political context.

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Table 3: Partners involved in the GV (LEAP-RE 11) project with their specific expertise and involvement in the project

Country	University- Lab	Company	Expertise	Investigated sites.
Rwanda		EDCL	Exploration, managment	Rwanda
Ethiopia	Addis Ababa University		Geology	Ethiopia
Ethiopia		AGap	Local development	Ethiopia
Kenya	University of Nairobi		Social studies	Kenya
Kenya		SEPCO	Drilling-exploitation	Kenya, Ethiopia
Kenya		HHCBO	Local development	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, conceptual modelling, feasibility	Ethiopia, Kenya, Rwanda, Djibouti
Italy	Universita degli St udi diTorino		socio-economic analysis	Kenya, Rwanda, Djibouti
Italy	Sant'Anna School of Advanced Studies		socio-economic analysis	Kenya, Rwanda, Djibouti
Germany	Fraunhofer Instit ute for Energy Inf rastructures and Geothermal Systems		Dissemination	
Norway		NORCE No rwegian Research Center AS	Technical solution	Kenya, Rwanda, Djibouti

Assessment and feedback on the composition of the team.

This asymmetry in the relationship between companies and universities in EU and AU countries is probably one of the causes of interaction problems between teams, with each group of partners having different concerns (scientific publications, concrete pilot

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conception…), when the aim is to be able to train local populations and academic and industrial partners in new concepts and characterization tools.

In the context of a possible continuation of the program in a phase 2, "Geothermal Village 2," it would be important to integrate and train more African academic teams to develop dissemination and training activities. Indeed, agency and industrial teams are too focused on their immediate concerns to take charge of these dissemination activities, even locally. Having partners who can disseminate information, methodologies, and concepts is an important factor. The aim is to be able to train local populations and academic and industrial partners in new concepts and characterization tools.

3.3. Tasks, tasks managers, and their objectives

Each task was managed by a European partner and an African partner. In reality, the African partners felt that they were not particularly involved in this work. This was most likely because they were mainly agencies with limited staff availability for these missions. However, for tasks 11.1 and 11.2 in particular, their participation in the work carried out at the various sites was significant (in terms of time spent and number of staff involved) and decisive for the success of the work and the quality of the data acquired.

Review and feedback on task management.

It seems important to involve more academic partners in this task management initiative, as they may have the time to take an integrated view of the actions that agencies may not have time to take due to operational constraints. Exploring and exploiting the subsoil is a long-term process that requires the availability of personnel, which may not be compatible with the allocated budgets or short-term objectives. Therefore, while collaboration with local agencies, companies, and associations has been a key factor in the program's success, the integration of African academic teams in each country would certainly have been a factor in improving the program's operation.

4. Main results

4.1. About Geological models: very different types of reservoirs

The geological contexts found in the four areas of interest enable the capabilities of various specific geological objects to be tested and defined. These are listed in Table 2. Various typical cases of geothermal plays are identified in the literature (see in particular Varet, 2022, 2024 concerning geothermal play types in Africa), but only those associated with the specific contexts of the East African Rift are included here, with cases of active graben, active and ancient volcanism of different nature (basalt, carbonatite) , and fault systems. Each of these sites is associated with indicators of geothermal system actively functioning and the capacity to use the resource without developing significant infrastructure. These results are presented in reports D11-2 and D11-6.

This phase of characterizing the geological context of the site is a key element in the early stages of exploration. It helps to remove a number of uncertainties that can hinder development. In particular, it involves identifying the types of geological objects (reservoirs in particular) that may be targeted for drilling. This characterization phase highlights resources that are not explored by site development companies looking for large sites

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allowing for electricity sales for the grid. These sites, we targeted, are located either in areas with low population density, and therefore few potential customers, or in areas that are poorly documented geologically and therefore have no identified resources. The Geothermal Village program helped to document these two aspects and identify low-cost exploration and exploitation solutions.

4.1.1. Approach developed

In addition to identifying geothermal production sites in areas far from the national grid and serving isolated populations, this program sought to define a methodology using prospecting tools with relatively low implementation costs. As part of this approach, we used geophysics, in particular magnetotelluric tools, electrical tomography using resistivity and chargeability, and topographic and thermal imaging by drone adjusting on the specific conditions on each site (table 4). The interpretation of these data was based on geochemical data (for sites in the Republic of Djibouti and Kenya) and surface geological data (for all sites) acquired during the program. Previously acquired data were also available and were used to construct geological models. These new data were either acquired by one of the partners or by external service providers. They are either available in the literature or have been made available by one of the partners.

Table 4. Summary of surface exploration tools (geoscientific) engaged in the LEAP-RE GV1 project and used in the geothermal site modelling in view of exploration drilling (not engaged in the frame of the project).

COUNTRY	DJIBOUTI	ETHIOPIA	KENYA	RWANDA
SITE	ABHE	ERA.BORU	HOMA.HILLS	MASHYUZA
Magneto-telluric	X		X	
Resistivity chargeability	X			X
topographic and thermic imageries	X	X		X
Géochimistry	X		X	X
Géology	X	X	X	X
Old Data	X	X	X	X

These data are synthesized to build one or more geological models that can then be used to evaluate resources and precise exploration drilling targets.

As part of this program, the aim was to test the implementation of these tools at sites with different access and environmental conditions. The data acquired have been used to improve existing geological models. The 3G (geological, geophysical, and geochemical) characterization strategy could also rely upon the acquisition and interpretation of topographic and thermal imagery by drone to define areas of interest.

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4.1.2. Summary about the four targeted sites.

The four targets that had been predefined are characteristic of different geological contexts relevant of the diversity of the EARS (see table 4). Analysis of the methodology adopted, the data acquired, and the models constructed and applied to these four sites allow to identify various areas for development.

- In terms of the tools used, these include electrical tomography and chargeability tools, as well as drone-based mapping and thermal imaging tools.

Joint resistivity and chargeability measurements make it possible to define areas of hydrothermal reactivity and areas that are efficient for fluid transport by distinguishing between three types of responses or geo-electrical facies.

- The first geo-electrical facies is that of the host zones, which correspond to healthy areas unaffected by current or past hydrothermal circulation and therefore not very favourable for resource exploitation. This is a low-conductivity, low-chargeability facies.

- The second facies is that of very mature areas that have already undergone intense hydrothermal circulation and are not very favourable for resource exploitation due to their low permeability, but which may be resource storage areas. This is a highly chargeable and moderately conductive facies.

- The third facies is that of targeted areas with good drainage where the fluids have reacted little with the surrounding rock. This is a low-loadable, highly conductive facies. These are the current areas of hydrothermal circulation, which constitute the active reservoir and are the areas to be explored.

The second innovative tool used in this program is the use of drones for topographic and thermal imaging of the surface of the area of interest. Given the relatively shallow depth of the resource, combined with numerous surface manifestations, this tool has enabled the identification of areas of interest. This analysis has led to the recognition of preferential drainage zones as well as barrier zones, to be incorporated into the static models of the resource.

In terms of knowledge acquired, this involves making available the data collected, and the reservoir and resource models constructed. The characterizations obtained are compiled in a database and can be made available to the community and used to interpret subsurface and well geophysical acquisitions, or to construct circulation and resource assessment models. This includes petrophysical data obtained from around 100 samples collected at various sites, geochemical gas data, geological data, and geophysical data. The static models constructed from tomography and all the program data can serve as a reference for evaluating the potential of other areas of interest. They can also be used in preliminary studies to size the objects involved in the reservoirs.

4.2. About Socio-aspects: a new integrative approach

The four GV cases are Homa Hills in Kenya, Lac Abhé in Djibouti, Mashyuza in Bugarama province in Rwanda, and Era Boru in Afar region state of Ethiopia. The analysis performed to support the development of GV concept in the four pilots consist of the following five socio-economic actions.

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Action 1 analyzed the socio-economic context of target countries. Data collected are summarized in the figure 3.

Demographic characteristics	**Access to Services**	**Energy Use Sources**
• Age • Level of education • Household size • Livelihoods • Incomes • Economic activities • Vulnerability - various	• Education • Roads • Health • Water	• Biomass • Solar • LPG • Electricity
Use of Geothermal	**Membership to social networks**	**Environmental Issues**
• Water sources • Irrigation • Religion • Health	• Women group • Business /professional • Welfare association	• Pollution • Land degradation • Deforestation

Figure 3: summary of socio-economic data collected on the 4 sites selected for GV – LEAP-RE

Action 2 covered the analysis of socio-anthropological aspects and community appropriation dynamics of local populations involved in the geothermal projects and the identification of other suitable stakeholders.
Action 3 addressed stakeholders' analysis through the implementation of stakeholders mapping and the development of stakeholder engagement strategies.
Action 4 focused on the identification and analysis of best practices in initiatives and projects for supporting renewable energy developments at community level in Africa, if possible related to geothermal energy.
Action 5 identified and designed business model archetypes and related guidelines for the development of GV concept in the four pilots and other contexts.

4.2.1. Summary about the four targets

The main results of this task are summarized here after :

Action 1, a context analysis of the sites.

Results show a large variability of the household respondent profiles.

Action 2, socio-anthropological analysis and dynamics.
The GV concept is designed in such a way that its new development activities should co-exist with the local community’s way of life and/or build onto already existing uses of the geothermal features. The idea is that the concept should become part and parcel of the local community’s way of life. Thus, as an example, beliefs of a given population that considers the sites as sacred places should be accommodated within the development activities of a project premised on the GV concept. The social dynamics and issues within the populations targeted by GV indicate that women and girls are more disadvantaged and have lower status compared to men and boys owing to gender disparity; a situation that can have a negative bearing on their participation levels in a GV concept project. These

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situations of gender inequality are manifested in other areas such as education levels as well as economic and decision-making power. Coupled with the fact that Direct Use geothermal development on which the GV concept is based has a close relation with gender roles, this scenario of gender relations presents a case for the inclusion of a gender component in GV demo and GV concept initiatives.

Action 3 stakeholder analysis

Different contexts are represented by our 4 sites.

- Of all four cases, the Homa Hills GV site in Kenya constitutes the largest site in terms of geothermal spreading (3) and size of the community. Hence, there are various internal (community) and external stakeholders of concern to GV, but of major importance is the relation between the CBO representing the Homa Hills community and the private developer owning the geothermal license for a large size project serving the grid. Developing GV in part depends on the latter's cooperation. The CBO would do well to assess its preferred and possible development options for GV in relation to/ together with the private developer and make a GV vision or development plan for the foreseeable future based on that.
- The Mashyuza GV site in Rwanda is, like the one in Kenya, a populated area, with many and different types of stakeholders already or potentially involved. Again, different stakeholder relations are of concern to GV, but one that requires special attention is that between the community and the cement factory Cimerwa – considering the latter's impact and potential influence on GV's prospects. This in turn necessitates the involvement of local and (sub) national authorities that should help bring about a social arrangement that ensures a coexistence of GV with Cimerwa's activities and plans.
- Quite different from the Kenya and Rwanda GV cases are the GV sites in Ethiopia and Djibouti. The latter t wo are situated in more remote areas than the former two, with (much) smaller communities that have (even) less social infrastructure and services available. They are both inhabited by clans of the Afar ethnic group, an Indigenous Peoples (IPs) group with own traditions and (pastoralist) lifestyle – according to which the design of GV should be adapted.

Action 4 GV similar experiences

Our analysis is built on both desk research on grey literature and on scientific literature, through a systematic literature review. The first main result is that GV doesn’t exist yet, not even Africa has similar experiences in geothermal energy. GV demonstration engagement requires a proficient workforce and can develop this through collaborating with established organizations (e.g., CBOs) to instruct locals for project execution and maintenance.

Action 5 Business model archetypes for GV in the four sites

The experiences we collected through our field work in Homa Hills (Kenya), Era Boru (Ethiopia), Lac Abhé (Djibouti), and Bugarama (Rwanda) design economic and social business models aiming to ensure project sustainability and community ownership. Our analysis for the GV potential business models led to replicable models for empowering communities across East Africa with clean energy and improved livelihoods.

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4.2.2. Test model for training local actors in the presentation of geothermal resources: the Homa Hills experience

A two-day training session was designed and tested on November 15-16, 2023, at the Pala Area Development Program (ADP) Offices, Kokoth Kataa Location, Homa Bay. The speakers were 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), and Walter Wheeler (NORCE: Norwegian Research Centre AS, Norway). Four modules were covered: Community Development Projects: Promises and Pitfalls, Gender and Culture, Geology and Geothermal Technology, and Sustainability Management for 40 participants.

This session validated the concept, duration, and content of the presentations for an audience of professionals and non-professionals for the dissemination of information to the public, administrations, and industry.

4.3. Engineering sciences and feasibility studies

For each of the sites that could be assessed, geological production capacities and population expectations in terms of resources (mainly electricity, heat, and water) were evaluated. These two sets of information were compared to assess their degree of suitability. These elements are summarized in Tables 2 and 3. The appropriate solutions are based on the direct use of heat or require appropriate technological developments with the implementation of ORC cogeneration systems for electricity production and the development of grain or fish drying systems. The use of water for human or animal consumption will require treatment and desalination (and therefore a supply of electricity). The use of water for agriculture will involve an assessment of the available resource and its rate of renewal to avoid rapid depletion.

4.4. dissemination of results in the form of articles in peer-reviewed journals and at numerous international conferences.

The data acquired and their interpretations have been published in various forms, including articles in peer-reviewed journals, book chapters, and conference presentations (see D11.5). The dissemination of data and results from the "geothermal village" program will continue for another two to three years, as the volume of data acquired is significant and will require some time to be fully processed and evaluated.

Presentations have been made at conferences specializing in geothermal energy in Africa (Argéo, Leap-re meeting) at relevant workshops and conferences organized in the concerned countries (Ethiopia, Djibouti, Kenya…) as well as at more general national and international geoscience conferences (EAGE, EGU, EGC). The presentations focused on the GV concept and the results obtained during the program. During these various conferences, contacts were made with different European and African partners, which could help to broaden the dissemination of concepts and data and build new programs, particularly for phase 2 of GV.

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4.5. Training activities for African teams

During the activities carried out at the various study sites, the teams were composed of staff from European laboratories and agencies, as well as staff from agencies and universities in the country concerned. During the fieldwork, training sessions were provided to our African colleagues in response to their requests. These included:

- Training in geophysical characterization techniques for teams from Djibouti, Rwanda, and Kenya.

- Training in geochemical characterization techniques for teams from Djibouti and Kenya.

- Training in geological characterization techniques for teams from Djibouti and Rwanda.

- Training in societal analysis for all teams.

- Training in mediation for teams from Kenya.

Assessment and feedback on the social sciences fieldworks and its value.

The results obtained are of good quality and meet the stated objectives within the allocated budgets. They constitute an original approach in line with the program's objectives. They have enabled the development and validation of tools for subsoil analysis, socio-anthropological analysis, and socio-economic development that can be replicated at other sites. They provide a solid basis for continuing the development of the program in phase 2 (GV2).

In several cases, the fieldwork was conducted in a multidisciplinary manner. This approach should be generalized as it allows for direct exchanges between the different specialties and complementary action on site.

5. Feedback

5.1. How did the program work

The program was developed with two coordinators per task, one European and one African. Coordination within each task was complicated. As indicated above, coordination worked on a site-by-site basis, depending on the actions taken in the field.

Managing a team of researchers and engineers from different specialties and cultures, working on different sites, is difficult due to differences in "habits."

The task managers were not very involved in the scientific coordination, with UL and Santa Anna leading the field activities. However, it is important to highlight the strong involvement of the African teams in the coordination and organization of field activities at each site.

Video conference meetings were organized throughout the program to meet the administrative management needs of the program, but also to meet operational needs, organize work on the sites, discuss results, and put them into perspective. On site, mutual presentations were made to the teams present.

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Overall, the actions worked well, as shown by the quality of the results.

5.1.1. Difference and expectations between European and African teams

The difficulties outlined above, mainly in scientific coordination, may have various causes. One important difference between European and African teams is that European teams are mainly academic or similar, while African teams tend to be applied results oriented industrial and/or state agencies nivolved in larger programs. This has probably led to a difference in approach to the issues to be addressed and the characterization and treatment process.

The two African university teams were from Addis Ababa University (Ethiopia) and the University of Nairobi (Kenya), the former of which was not heavily involved in the program, mainly due to the political context.

The African teams were heavily involved in the data acquisition phases (geosciences and socio-economics) due to their direct interest. They were less involved in the cross-analysis and dissemination work, except for the organization of the presentation week, which was handled by the Kenyan teams on site.

Greater involvement by African academic teams might have made it possible to develop a more effective network of African partners by promoting the dissemination of data and methodology through their access to students, for example. Agency teams are mainly involved in activities in their own countries, not necessarily because of a lack of interest, but certainly because of a lack of time and budget.

In particular, there was a lack of funding to enable African colleagues to come to Europe for discussions and training.

The European teams were mainly academic, with a focus on methodological developments which, even when applied at the various sites, were not the primary concern of the African teams. Therefore, involving one or more operational partners on the European side could help to ensure this connection.

During the Phase 2 program, attention should be paid to this issue of representativeness of “profiles” in order to facilitate exchanges and the dissemination of information. The aim of this proposal is to improve the quality of a program that has worked very well and achieved its objectives.

5.1.2. Coordination of interdisciplinary teams on site

The joint coordination and management of activities at each site were effective and benefited from significant commitment from African partners at each site. This support included the delivery and collection of equipment and the shipment of samples, which were critical and administratively burdensome tasks. Their support in organizing on-site transportation was crucial to the completion of the work.

5.2. On promotion and dissemination activities

Promotional and dissemination activities were carried out throughout the program, including participation in conferences, on-site training, and training activities in Europe for two African master's students.

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5.2.1. Publications-dissemination

The number of publications is substantial, with contributions to conferences and articles in peer-reviewed journals. Further publications are expected over the next two to three years. The authors of these publications are representative of the partners involved in this program. However, African colleagues could be more involved in steering these publications, but again, it is likely that their status does not allow them to take on this responsibility due to availability issues.

5.2.2. Training

On-site training activities were carried out at the request of colleagues and are in line with the program's objectives. These included training for a Djiboutian master's student and a Rwandan master's student at UBO.

Case studies (data and context) were used in research internships for second- and third-year students at ENSG and in the Geosciences master's program at the University of Lorraine. The field works and the sampling were used as material for geophysical data treatment and interpretation, petrophysical properties were measured on the samples coming from the sites. The context, working on field case studies as part of a scheme to contribute to the development of geothermal resources in Africa particularly motivated the students. This led to discussions among the various student associations about developing collaboration with equivalent associations at African universities.

Due to a lack of financial resources and administrative admission constraints, it was not possible to bring in more students for master's training in particular. It is therefore necessary to ensure the availability of a pool of students whose level is compatible with admission to a master's program.

One specific aspect of the training concerns the CBOs, either existing, as in Ethiopia (AGAP) and Kenya (HHCBO), or to be created (as at Abhé, Djibouti). The need is huge for these entities, both on specific aspects (energy, water, direct uses…) as well as on basic management issues (accounting, legal, reporting…), and time and money is needed is lacking to answer such long-term issues.

5.3. A limited budget that enabled initial recognition

Programs concerning the subsoil and its use always take place over a long period of time, around ten years, between the initial exploration phases and the exploitation of the resource. The GV1 program, designed to carry out a preliminary study on four sites, has helped to resolve geological and societal uncertainties at various sites.

Exploratory drilling is expected to cost at least €1 million prior to production drilling. Reconnaissance drilling through slim holes or targeting shallow reservoirs, is less expensive, and is certainly the option to consider for GV2 demo project, as it would serve as proof of concept even if not optimal at long term for full exploitation of the resource.

6. Programme continuation context

This first phase of the GV program, GV1, has helped to “raise” and answer a number of questions, in particular by identifying tools that can contribute to the identification of resources and the socio-anthropological and socio-economic contexts for the development

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of these resources. An assessment of technological production solutions has been carried out, leading to an initial cost estimate.

Classic programs for the exploitation of underground resources are long-term programs lasting between 5 and 10 years, roughly speaking. Even if the limited size and shallow nature of the resource should allow to reduce costs and times. In any case, the results obtained during GV1 correspond to the first 2 years and lead to the pre-definition of one or more targets that will need to be characterized in high resolution surface methods. Once this second stage has been completed, a drilling plan can be proposed, which, depending on the country's regulations, will have to be evaluated (with impact studies) before it can be implemented. The third stage will be drilling and productivity testing, followed by the fourth stage of installing the production unit and commissioning.

The development of underground resources now requires significant consideration of societal aspects in all parts of the world. This is particularly important within the GV program, as resources must be developed to meet local needs, with provision and management by local communities. It is therefore crucial to have a thorough understanding of the specific geological, environmental, and societal characteristics. These three aspects are complementary and require strong interaction and consultation between multidisciplinary teams in order to propose solutions that are acceptable and appropriated by to the local population and its relevant entity (CBO).

Table 5 : Costs estimate for GV2 (rough first figures for various options).

Demo site type	Mashyuza (Rwanda)	Homa hills (Kenya) and 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€

The work carried out as part of GV1 has led to the development of an innovative approach that integrates exploration, exploitation solutions, and local needs.

As part of GV1, costs have been estimated for each site (Table 5, see D11.6), indicating the associated technological solutions (see D11.4). To validate the GV program concept, it is therefore necessary to complete the process and find a new tranche of funding.

Conclusion

The LEAP-RE 11 GV project allowed to bring the necessary information, allowing to propose solutions for solving the issue of geothermal energy development at local level along the EARS.

The different scientific tasks (geosciences, social sciences, technologies, feasibility studies) carried on the 4 selected sites, representative of the diversity of the resource

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and of the social demand were applied on all sites, except in Ethiopia where the safety conditions (Tigray war) did not allow to engage the geophysics, a necessary step for preparing the costly exploration drilling, not permitted in the context of the present LEAP-RE project.

The European Union is otherwise engaged in the geothermal development in East Africa, through the GRMF (Geothermal resource Mitigation Fund), but this facility is not adapted to local projects away from the national grid. Although located at the Africa Union Seat in Addis Ababa, the procedure ignores the R&D projects also managed by the EU in partnership with the AU.

As the next phase (GV2) of the Geothermal Village project would imply exploration drilling at present supported by GRMF, the solution 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.

As shown by the results of LEAP-RE 11 GV project, the variety of possible options along the EARS is such at several sites should be considered representative of this diversity in terms of geological resource, local social demand, type of applications, and capabilities available on each site (each country).

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).

Experience acquired in the frame of the LEAAP-RE 11 GV project shows that GRMF procedure do not allow to jointly 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 the R&D projects managed by the EC and have no capacity to co-fund them.

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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