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Geothermal Atlas for Africa Project (GAA): Steps to Outline the Maps of Engineering and Social Sustainability of Geothermal Resources

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ABSTRACT

Geothermal Atlas for Africa (GAA) is one of the LEAP-RE projects aimed at developing a geothermal atlas for Africa on different scales, dealing with all topics related to geothermal energy, thanks to the cooperation of many expert partners from different scientific sectors. The main aspects are those concerning geoscientific, engineering, and sociology. The geoscientific aspects, quite prevalent in the first year of GAA, are treated by Jolie et al. (2022) in a separate manuscript. In this work, the local scale engineering and socio-economic aspects related to the sustainable use of the available geothermal resources are discussed. The first relevant achievement of Engineering science (Task 9.2) is a simulation tool to assess the optimal technologies based on geothermal resource type. The potential utilization of medium and high enthalpy resources for power generation has been assessed. To do this, a calculation model was developed on the basis of the characteristics of the geothermal resource and provides a selection of the most suitable power plant technologies and related preliminary sizing. The model is able to incorporate not only the optimized thermodynamic performance of flash and/or ORC binary cycles, but also the minimization of economic (LCOE) and environmental costs (LCA-single score). With regards to the social aspects (Task 9.3), a desk research was performed on the African context in order to address the main challenges related to the economic, social, and environmental of geothermal stand alone plants, looking for the ones managed by or with an high involvement of local communities. The desk research will allow identification of variables used by the communities to maximize the economic, environmental, and social benefits. Data for these variables can be gathered from scientific

and grey literature, which allow a sufficient triangulation of information. Such a multi-approach methodology can provide the scientific community with data to ensure sufficient comparability of geothermal case studies. Both qualitative and quantitative primary and secondary data comprising demographics, social, economic, and institutional drivers of geothermal energy utilization were obtained in this way.

The long-term expectation is to identify and classify factors in order to build the basis for further research and to help practitioners who are willing to replicate similar studies for different sites in Africa, in potential combination with other renewable energies plants.

1. Introduction

Low to high enthalpy **geothermal resources** exist across the **African continent**, however, the **utilization** is still **minimal**. East Africa has well-known high enthalpy geothermal resources due to its highly tectonic and geologically active setting (East African Rift [EAR] System). The potential for power generation related to this **favorable geological** condition is extensive, but geothermal development has (to date) been limited to Kenya and Ethiopia. Kenya is leading the development with an installed capacity of 690 MWe, largely at one site (Olkaria), demonstrating that large-scale development of renewable energy resources can be done in this part of Africa. The current focus is mainly on high-temperature resources (i.e., East African Rift), while low-medium systems are neglected, even though they could provide sustainable heat/energy sources for direct-use, agriculture and industrial purposes, tourism, etc. If the development of other large- and small-scale systems (both electrical and direct use) is to be achieved, then it is imperative that we have a sufficient understanding of: (1) the location of the **geothermal resources** (from low to high-enthalpy) on the continent, (2) the existing **surface infrastructures,** and (3) **social needs and demands**. However, the current situation is that knowledge about all three aspects in Africa is scattered. This project aims to implement a ***Geothermal Atlas for Africa*** by identifying collecting, compiling, and (re)processing existing data to create an up-to-date Atlas that can be distributed in pdf format, and further developed into a Geographic Information System (GIS), to help identify the spatial distribution of resources. Capacity building will enable transfer of specialist skills and enhance knowledge, both contributing to longer-term benefits from this project.

The Geothermal Atlas for Africa (GAA) project covers Work Package 9 of the LEAP-RE program, funded by the European Union's Horizon 2020 research and innovation program. This project aims to provide a comprehensive overview of low- to high-enthalpy geothermal resources on the African continent, suitable for power generation, plus other technologies that allow direct use of the resource for heat/cooling production. This is achieved by handling, evaluating, and classifying geoscientific information (e.g., geology, geochemistry, geophysics), technological information (e.g., existing power plants, installed capacity), and social aspects, with a multi-scale approach (local, regional, continental). The results will be made available through a Geothermal Atlas for Africa.

The objective of the first months of the GAA period has been mainly to weave a connection between the various partners of the project, as well as experts in the sectors mentioned above, through systems for sharing knowledge and ideas. Moreover, the first phase of the work that has started includes an overview of available information and data. The involvement of all partners in the work has allowed a synergistic approach to data collection and a study on how to make them uniquely available.

2. Geothermal Atlas for Africa (GAA)

2.1. Geothermal African context

In the review of socio-economic context for analysis of African countries, we highlight the state of Geothermal Countries, use of geothermal energy, the drivers of energy transition and challenges in Africa. The discussions are on a variety of scales from continental to regional and country specific. To date, almost half of African countries have undertaken national resource assessments for one or more renewable energy sources. Geothermal assessments are on-going in seven countries. (IRENA). The assessments show Africa's geothermal resources to be found mainly in the East African Rift System, where a large geothermal potential remains untapped (BGR, 2016). At the end of 2020, Kenya was the continent's only substantial producer of electricity from geothermal power, with a generation capacity of 823.8 MW. Ethiopia, the only other African country currently producing geothermal energy, was operating a 7.3 MW pilot plant. At the end of 2019, 1 GW of new geothermal capacity was being planned in Djibouti, Uganda and the United Republic of Tanzania (IEA, 2019a). In Djibouti Resource exploration for geothermal energy commenced in 1970. This resulted in the identification of at least 22 potential geothermal areas. The most promising prospects were found to lie along the main northwest-southeast rift spreading axis of the Afar rift trend. In Ethiopia exploration of the geothermal resources in Ethiopia began in the 1970s. The most prospective sites are located within the Main Ethiopian Rift (MER). The Geological Survey of Ethiopia (GSE) started research in 1970 which identified at least 120 hydrothermal sites in the rift valley, of which 24 could be high-enthalpy resources suitable for power generation and direct use (Kebede and Woldemariam, 2018).

2.2 Geothermal Energy Use

Geothermal energy in Africa has been utilized in many ways, including crop drying, aquaculture, greenhouse heating, and bathing. In Kenya the energy use is common in drying cereal, flowers, and pyrethrum (IRENA, 2020a). In Djibouti, trapping of steam for water production from steam condensation has been the main direct use, with potential for direct use in drying fish, aquaculture heating, desalination and space cooling at several sites close to large populations centers (Moussa & Souleiman, 2015). In Ethiopia, besides traditional artisanal use, geothermal fluids are used for domestic water production through steam condensation (Nebro et al., 2016). In numerous sites in the Eastern Africa region, hot springs are used with a bathing facility open to the public. Despite the conservative level of utilization, large potential exists for direct use, for example industrial applications, greenhouse heating, bathing and aquaculture.

2.3 The drivers of energy transition

For many of the African countries, hydropower or fossil fuels are still the main sources of electricity. The energy transition now underway is driven by increasing pressure for climate change mitigation, energy and development needs, and enabled by technological developments, changing energy costs, energy security and digitalization. Policy makers in Africa are at variance in creating enabling frameworks that reflect and set the path for transition. As there is no single policy that can achieve desired trajectories, a set of mutually reinforcing policies, tailored to specific country contexts and objectives, continue to be placed at the core of the transition (United Nations & IRENA, 2021).

Challenges in geothermal development are:

- Limited awareness about the potential and benefits of direct use applications among policy-makers, entrepreneurs and communities;
- Limited public financial resources for the exploration phase – before the resource is proven – notably due to regulatory gaps and lack of adequate policies in some countries:
- Shortage of local skilled geothermal workforce;
- Political will in some cases has affected the speed of action on geothermal development.

2.2 GAA Project design

The GAA project was structured according to different areas of work for about 20 partners. Principally, 3 scientific fields were identified: Geoscience, Engineering, Social. In addition, two other important working groups are involved in the project, and they deal with the implementation of the atlas and capacity building.

In particular, the partners belonging to the geoscience work area aim to develop the comprehensive GIS project as a working document for data collection (shapefiles, reports, pdf documents) including all metadata. A great amount of work has been done reviewing existing literature and identifying key documents relating to geothermal activities in different states of Africa. (Djibouti, Rwanda, Madagascar, Tunisia, Morocco, Cameroon, Burundi, Mozambique). Most of these are derived from above-ground geothermal exploration. 10 geothermal play types have also been identified and mapped. Also, higher-resolution investigations were also undertaken, for example assessing currently available structural geological data for the Main Ethiopian Rift (MER) (Trumpy et al. 2017). The project has also benefited from existing continental and regional datasets already held by project partners, such as the EARTH and TARGET models (Jones, 2020,2022).
The Engineering science group will analyze the thermodynamic data of geothermal resources to establish possible solutions for the exploitation of these resources. To do this, work is underway to create and develop a tool for choosing the most appropriate technological solutions for electricity, heat/cooling and direct use.

The social sciences sector has divided its work mainly into two actions:

1) Socio-economic analysis for African countries has been performed. It was developed as a framework for the study and a data collection tool, to collect socio-economic data for context analysis. The populations in some remote areas that need energy for their daily lives have also been identified.
2) Analysis of examples of renewable energy development across Africa has been started and is still ongoing. A protocol has been defined and designed to identify cases of renewable energy development through both scientific literature and other sources. This study will provide a state of the art 'benchmark' for African countries for the commercial development of renewable energy sources.

A working group dealing with the Implementation of Atlas is essential, as the final phase of the project will deal with the digitization and conversion of the geology and geological structure on a national level to the GIS format. It is also important to identify and create GIS layers of data covering hot springs and geothermal boreholes. Moreover, it compares the land surface temperature from MODIS satellite (day and night) and Landsat 8 satellite in order to identify anomalously high areas of heat flux.

The knowledge obtained, and the finalized atlas will be shared and disseminated via the capacity-building task.

2.3. GAA Project goals

This project aims to provide a comprehensive overview of low- to high-enthalpy geothermal resources on the African continent, suitable for power generation, plus other technologies that allow direct use of the resource for heat/cooling production. This is achieved by handling, evaluating, and classifying geoscientific information (e.g., geology, geochemistry, geophysics), technological information (e.g., existing power plants, installed capacity), and social aspects, with a multi-scale approach (local, regional, continental). The results will be made available through a Geothermal Atlas for Africa. The objective of the first 18 months of the program has been mainly to weave a connection between the various partners of the project, as well as experts in the sectors mentioned above, through systems for sharing knowledge and ideas. Moreover, the first phase of the work is dedicated to a review of available information and data. The involvement of all partners in the work has allowed a synergistic work of data collection and a study on how to make them uniquely available.

3. GAA on-going activities

3.1 GAA Task 9.1 Geoscience

As an example of the work being undertaken in Task 9.1, this section reports data from just one of the partners in Task 9.1 - a local-scale, Egypt-focused study. Other work undertaken within task 9.1 is reported in Jolie and Jentsch (2022).

The first step was to map the temperature of the Egyptian national land surface from daytime and nighttime remotely sensed data to enable mapping of potential geothermal indicator areas. Operational Land Imager (OLI) Landsat-8 satellite images acquired in December, January, and February 2021 were used to classify lithological units and identify structural features using a mixture of digital image processing methods. OLI-8 images were also used to calculate the Earth's surface temperature. To overcome these, multi techniques have been applied, such as the altitude correction approach has been applied by elevation data (SRTM-30 m). Also, to help isolate the geothermal signal, winter-acquired data (December to February) were used and applied to LST mapping as described by Romaguera et al. (2018). Analysis also focused on multi-source data sets (e.g., Landsat8, MODIS) with multi-temporal images in order to increase reliability of conclusions (Figure 1).

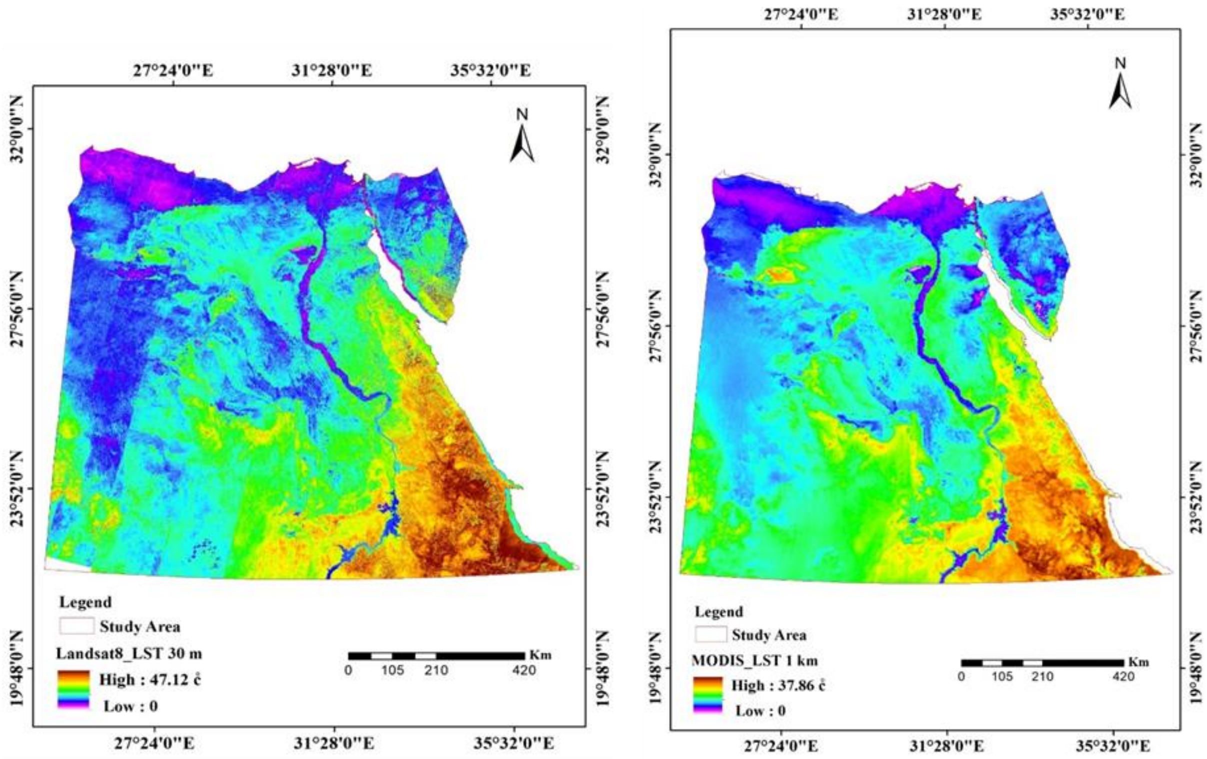


Figure 1. Land surface temperature: Landsat data (Left), MODIS data (Right)

Tectonism governs the surface outcrops of the basement rocks of Egypt, with about 90 percent of these rocks buried beneath a Phanerozoic sedimentary layer. Basement exposures are found in the eastern part of the Eastern Desert, southern Sinai, the southeastern part of the Western Desert, and Gebel EL-Oweinat in the southwestern corner of the Western Desert. Elevated heat flux is found in these regions.

The thermal properties of the different geological units are critical for storing and channeling geothermal energy and heat flow from depths to the surface. Both igneous and sedimentary rocks can contain significant geothermal reserves. Basement, Carboniferous, Paleozoic and Mesozoic, Triassic/Jurassic, and other rock types are found in the research region. Upper Cretaceous, Eocene, Oligocene, Miocene and Quaternary. Geothermal heat and high thermal conductivity can be found in or near bedrock in the Eocene and Quaternary, Oligocene and Miocene, and Carboniferous deposits. Similarly, sites along geologic contact zones between basic and Tertiary rocks, such as the Zeit Formation, the Southern Gharib Formation, and the

Belayim Formation (Miocene) in Egypt, appear suitable for geothermal exploitation (Figure2).

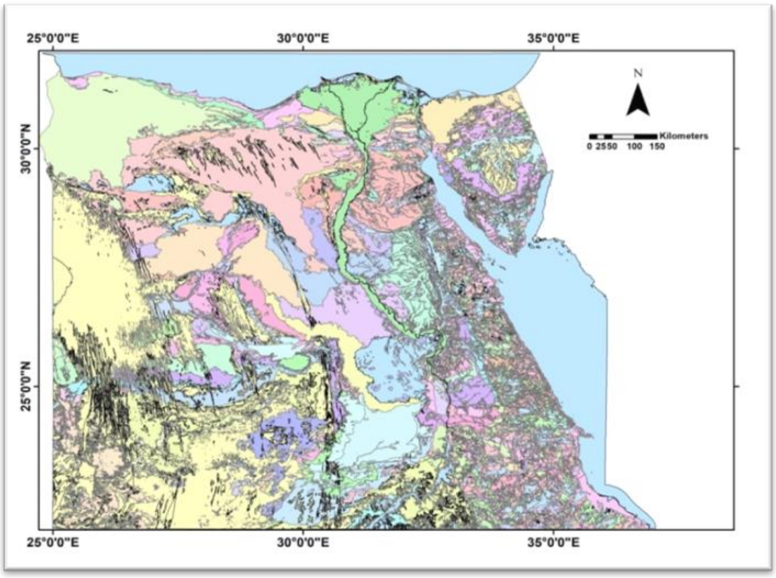


Figure 2. Geological map of Egypt (1:500'000 scale)

The resulting favor map was validated by comparing hot springs and thermal water wells. The results show that surface thermal manifestations (hot springs), such as Ayun Musa, Ain Hammam Faraun, Hammam Musa and Ain Sukhna, fall into the high geothermal vulnerability category.

Other wells and hot springs fall into the category of 'moderate geothermal favor'. The most promising onshore geothermal regions are located on the western coasts of the Red Sea and Gulf of Suez. El-Gouna, located south of the Gulf of Suez. This greater geothermal potential could be related to higher heat flux through deep geological structures along the Sinai triple junction between Africa, Arabia, and Sinai (Figure 3).

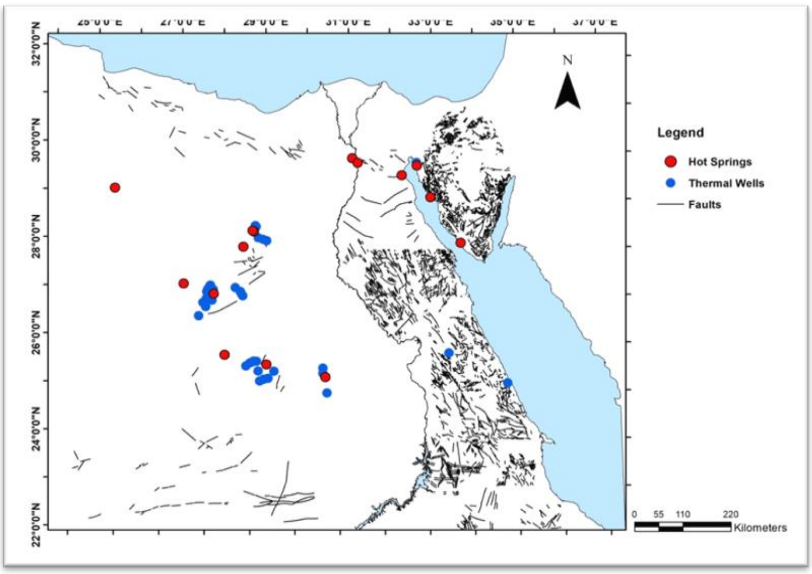


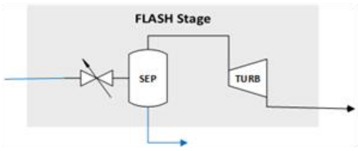
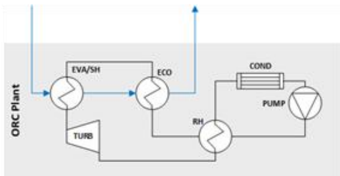
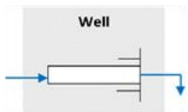
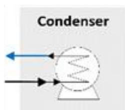
Figure 3. Hot springs and thermal wells

3.2 GAA Task 9.2 Engineering science

The work being carried out is mainly in two sections: thermodynamic and environmental modeling.

Concerning thermodynamic modeling, a code was developed that analyses different thermodynamic configurations to determine the best solution for electricity production. Two simplified models were produced: flash stage and ORC plant. Given the complexity of these two systems, the thermodynamic behavior of the components was modeled with specific metamodels. Simple correlations were used for all other components. Each thermodynamic block gets the conditions of the geothermal fluid as input and provides a preliminary dimensioning and capital cost of each component as outputs (Table 1). In addition, the blocks provide the geothermal frost output conditions so that the code can connect them in series.

Table 1. Thermodynamic blocks

Component	Parameters	Scheme
Flash Stage	*Input:* input brine conditions, relative quality in the separator (x_{rel}), condenser temperature *Output:* power generated, Output brine condition, Output vapour condition, Stage Capital Cost	
ORC Stage	*Input:* input brine conditions, RH dimension, condenser temperature, ORC fluid *Output:* net power output, output brine condition, stage capital cost, condenser power and temperature (for DH purpose)	
Well	*Input:* reservoir condition, well depth, brine flow rate *Output:* well capital cost, output conditions, number of wells	
Condenser	*Input:* input conditions, condenser temperature *Output:* condenser capital cost	
DH heat exchanger	*Input:* input conditions, outlet brine temperature *Output:* heat exchanger capital cost, DH power	

The code combines those components to form a geothermal plant considering three main sections:

- **Production section**: models the raising of the fluid from the reservoir
- **Surface plant section**: models the power extraction from the brine, it can be configured by chaining multiple ORC or Flash stages in series and adding a water condenser or a DH heat exchanger, if needed.
- **Re-injection section:** models re-injection of the fluid into the reservoir.

In addition, the best surface plant is chosen using a configuration search tree methodology. The code starts from a simple configuration and adds one block at a time. The software stops when the increase in system complexity does not increase the thermodynamic performance (Figure 4).

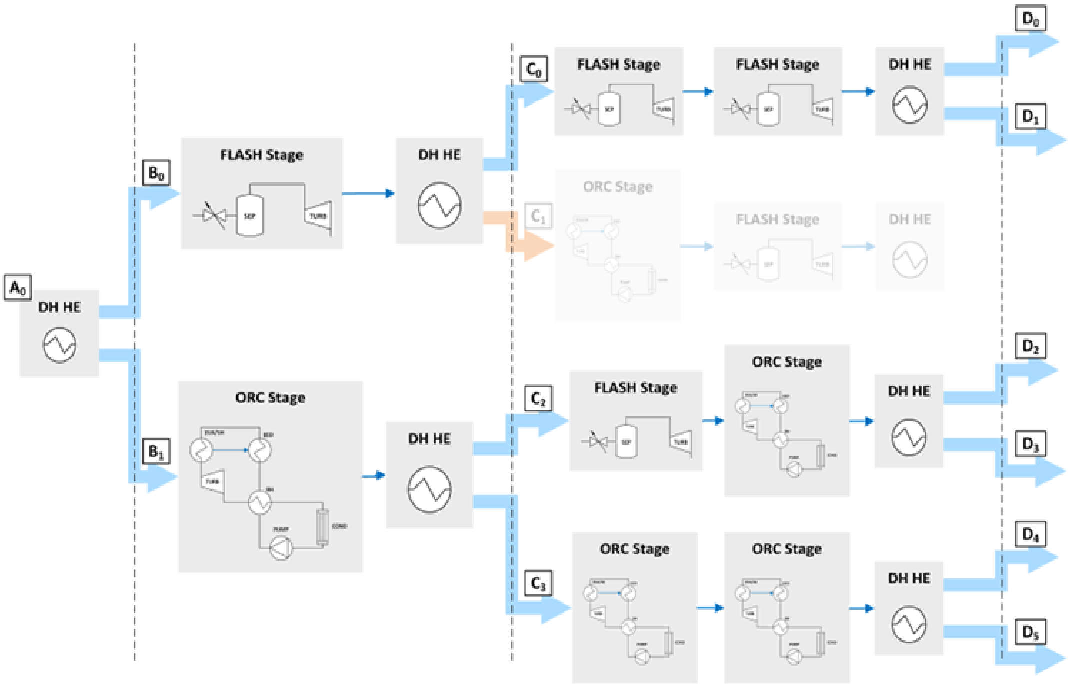


Figure 4. Software configuration search tree

The second part, on environmental modeling, begins with analysis of many case studies (Karlsdóttir et al., 2015; Karlsdottir et al., 2020, Basosi et al., 2020, Fiaschi et al., 2021, Tosti et al., 2020), with special focus on the life cycle inventories found in literature about some existing geothermal plants. Data were taken from the mechanical components and each type of material was classified. Correlations were then calculated between the amount of material and the size of the mechanical components. Thus, a parametric model for the Life Cycle Assessment was obtained. This model takes the dimensions, calculated as output from the thermodynamic model, as input, and it is possible to assess the environmental impact as a single score indicator. A block diagram for the environmental modeling of a turbine is given as an example (Figure 5).

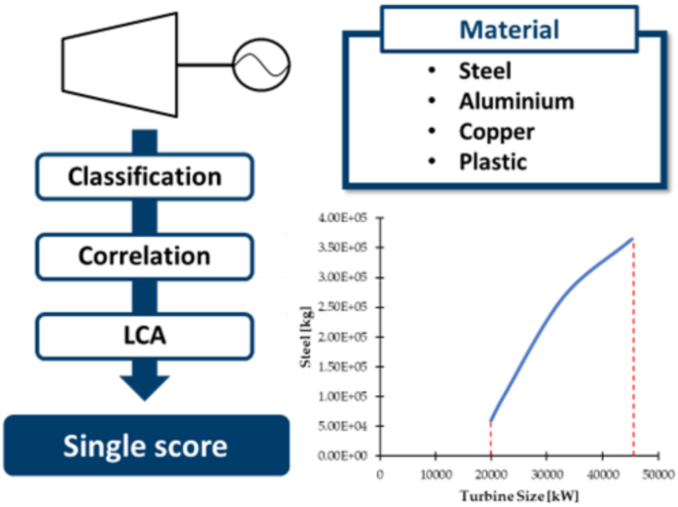


Figure 5: Environmental modeling block diagram: Turbine example

3.3 GAA Task 9.3 Social Sciences

Regarding the socio-economic analysis of the context, information used was that available from desk review of existing documents, other tasks, databases (national and international) and field interviews to deliver the Geothermal Atlas for Africa. The review illuminated: the energy balance in Africa, the drivers of energy transition; the political economy of energy transitions/gainers and losers; geothermal energy in Africa, and the state of energy in geothermal countries. Furthermore, the synthesis focused on continental, regional and country specific contexts.

Analysis of cases of renewable energy development across Africa (action n.2) focused on identifying cases of geothermal energy developments (and also potentially other renewable ones considering the scarcity of geothermal experiences in the African continent) to provide a collection of good practices implemented by various actors in order to understand drivers for success and barriers (e.g. cultural-based drivers or barriers, drivers for community engagement, regulatory barriers, etc.). In order to identify such cases and factors, a systematic literature review was performed. A rigorous protocol was set up, as shown in the following Table n.2.

Considering that premise, several definitions to include the cases of renewable energies have been included (see “keywords” in table n.2). Energy poverty (Reddy, 2000) and Renewable Energy Communities (Bauwens et al. 2022) were included to highlight the potential of the latter initiatives in order to enhance economic, environmental and social benefits for local communities and fight energy poverty (Ambole et al., 2021) in South Saharan Africa.

Table 2. Systematic Literature review protocol.

Purpose	Represent successful cases of renewable energy initiatives in Africa
Research Question(s)	1. How has the Renewable energy development grown and evolved through the years in Africa? What are the future challenges for the academia/real implementations?" 2. What factors affected a successful implementation, considering economic, environmental, and social benefits? Which business models have been adopted to support such best practices?
Keywords	renewable energy communities; bottom-up initiatives; micro-grid; stand-alone/standalone plant; rural energy communities; energy poverty; Africa.
Database	Web of Science, Scopus
Inclusion Criteria	• Period: 1985-2022 (10th of June 2022) • Document: articles published (or in final process "early access") on peer-review journals (when is not clear: excluded) • Language: English
Exclusion Criteria	• Where inclusion criteria are not verified; • When Renewable Energy initiatives are not the topic (errors due to the database) • When the article is far from the purpose (see RQs) àDefault option on WoS (ie. No management evidences)

After several trials and different algorithms, the articles resulting from a first extraction were n.179 on Web of Science and n.191 on Scopus. After a duplication check and the application of inclusion criteria, n.70 articles were considered. After additional searches and a 2nd review check, a total of n.39 articles was selected to be included in the analysis.

4. Lesson learned

4.1 GAA Task 9.2 Engineering science

As a preliminary result, several metamodels were obtained, referring to the flash stage and the ORC system. The first step was to use a wide range of input values for the two blocks (Table 3). A homogeneous distribution was made to have about 500 different conditions, and through a parametric analysis all these conditions were analyzed. Some of these scenarios were eliminated due to extreme and not exploitable conditions (e.g., excessively low flow rates and fluid temperatures), so that the number of conditions was reduced by 10%.

Table 3. Input variable range

Parameter	Range (Flash stage)	Range (ORC Plant)	Units
T_{in}	80-250	80-250	°C
$\dot{m}_{brine\ in}$	1 – 200	1 – 200	kg/s
x_{rel}	0-1	NO	-
η_{turb}	0.75-0.95	0.75-0.95	-

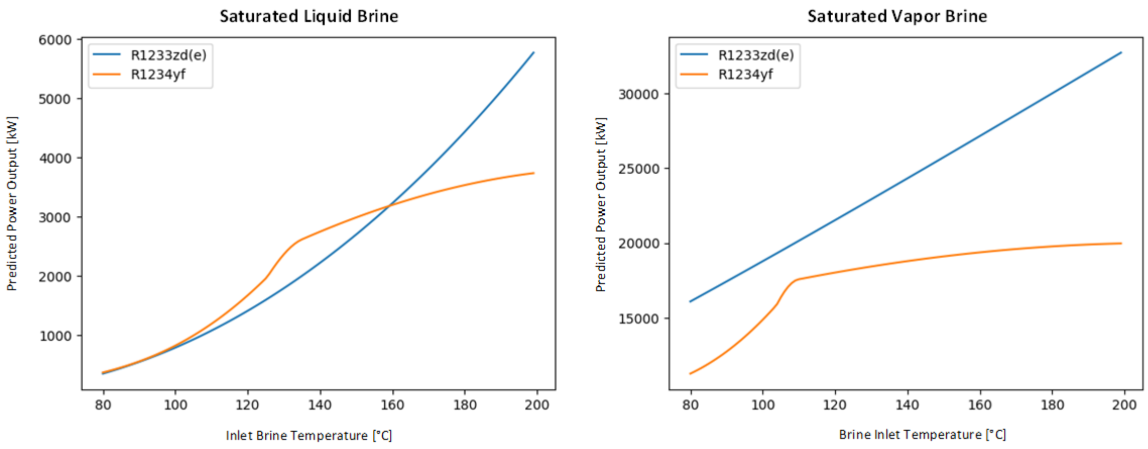
With the obtained data, metamodels were made, which allow to represent the thermodynamic behavior of the analyzed mechanical components and also speed up computational time. Specifically, at this moment 4 thermodynamic variables for the flash stage (temperature and flow rate at the separator, plant efficiency, turbine work) and 4 for the ORC plant (maximum pressure of the cycle, flow rate ratio, net work produced and heat absorbed by HRSG) are evaluated. A quality indicator Q representing the prediction error is defined at each metamodel, the higher its value (with maximum 1) the smaller its error. For the flash stage case in the calculation of turbine work W_{turb} the indicator was found to be about 0.8. Following a parametric analysis, the input that conferred uncertainty was identified, which was x_{rel}. So, for this component the range of x_{rel} is reduced between 0.2 and 0.8. Below are the variables calculated for the two main blocks and also their quality indicators (Table 4).

Table 4. output variable calculation and relative quality indicator.

Flash Stage			*ORC plant*		
unit	variable	Q	unit	variable	Q
[° C]	$\mathbf{T}_{separator}$	0.99	[kPa]	$\mathbf{P}_{sat}$	0.94
[kg/s]	$\mathbf{m}_{separator}$	0.99	[-]	$\mathbf{m}_{ratio}$	0.99
[-]	η_{tot}	0.99	[kW]	$\mathbf{W}_{net}$	0.99
[kW]	$\mathbf{W}_{turb}$	0.98	[kW]	$\mathbf{Q}_{HRSG}$	0.99

Having obtained the first metamodels, interesting trends can be identified for both flash stage and ORC block. Particularly for the ORC block more than one metamodel was developed, as the thermodynamic variables calculated vary greatly depending on the phase of the geothermal fluid (saturated vapor or saturated liquid) and also the type of organic fluid that is selected. In our case we developed the metamodels with both saturated liquid brine and saturated vapor for two different working fluid configurations: R1233zd(e) and R1234yf. As can be seen from Figure 6, the working fluid R1233zd(E) is preferable to R1234yf under all geothermal fluid temperature conditions except when the geothermal fluid is in saturated liquid conditions and has a value between 80°C and 150°C.

Figure 6. Different working fluid comparison



To show the validity of the developed metamodels, they are applied to a case study analyzed in the literature. The Castelnuovo plant in Italy, which is an ORC plant using R1233zd(E) as the working fluid, is chosen as the comparison term. In particular, we will focus on the main components of the plant, as well as the turbine and heat exchanger, and also the overall efficiency of the system. The metamodel of the ORC system with geothermal fluid in the form of saturated steam, a condition actually present in the case study, is used. Because the current metamodel does not take into account the heat recuperator unit, and in the Castelnuovo plant this mechanical component is present, a modification was made to the plant model (in fact it was eliminated from the calculations so that the comparison was plausible).

The following table (Table 5) shows the values for the quantities of interest from Castelnuovo reference case study (Fiaschi et al. 2021), the modified reference case, and the result of the developed metamodel

From the results obtained from the metamodel, it denotes that the calculation of plant size and organic fluid flow rate is consistent since the percentage difference from the case study is minimal. The evaluation of the heat absorbed by the geothermal fluid has a larger percentage difference, but as a primal sizing and for simplicity of calculation it turns out to be consistent.

Table 5. Comparison of real case studies: Castelnuovo Geothermal Power Plant

	Castelnuovo Power plant			Fiaschi et al. 2021	Fiaschi et al. 2021 *modified	Metamodel	Error
input	Brine Temperature	°C	T_{in}	180	180	180	
	Brine Flow rate	kg/s	m_{brine}	11.09	14.28	14.28	
	Turbine isentropic efficiency	-	η_t	0.88	0.88	0.88	
output	Net Power output	kW	W_{net}	5000	**5000**	**4946.97**	**1.1%**
	Heat from geothermal fluid	kW	Q_{HRSG}	26894	**34306**	**30571**	**10.9 %**
	Mass flow rate ration	-	m_{ratio}	-	**9.43**	**9.04**	**4%**

4.2 GAA Task 9.3 Social Sciences

The framework adopted was top-down, focusing on the global factors influencing the context of geothermal resources development at the continental level, regional and country level.
Regarding the case studies, in order to map such initiatives and systematize them, SSSA has followed the approach proposed by Bauwens et al. 2022 for the characterization of Renewable Energy Communities. The three main dimensions observed were: the meanings attached to "community"; the energy-related activities pursued by communities; the objectives pursued by communities.
Considering the meanings attached to "community", first results show that renewable energy initiatives present a strong connotation linked to territorial proximity. Participatory processes need to be strengthened, also considering the introduction of intermediaries to cover the design and initial investment phases. In addition, such processes must take into account the needs of communities severely affected by energy poverty, to avoid the vicious circle due to economic poverty that can affect the possibility for users to access the use of renewable energies. Moreover, the actors involved in such initiatives are both private, as MNEs and foreign direct investments (D'Amelio et al., 2016), and no-profit, like NGOs (Ahlborg, 2018).
Regarding the technology more diffused, as anticipated, solar photovoltaic is the most easily accessible (Ambole et al., 2021; Cabanero et al. 2020). Nevertheless, other renewables can be evaluated, such as geothermal, capable of providing other uses – greenhouses for agriculture, thermal tourism, etc.
Regarding the objectives, there is still a predominance of the economic component but, especially in the African contest, the former seems to be not separated from the social component. Environmental goals, to date, are just ancillary, basically due to the renewable energies wide availability. The other objectives (political, infrastructural innovation, etc.) appear to be minor, basically due to local and community context factors.

5. Conclusions

This project aims at realizing a Geothermal Atlas for Africa and is structured by strong synergy and networking with all participating European and African partners. Collaboration makes it possible to create a network in order to exchange information and link two continents, and especially link experts from different fields. In fact, and as reported here, several topics are covered, from geological to engineering to social aspects.
Regarding the engineering field, preliminary results have been obtained from a model being developed. This has resulted in a preliminary sizing and rendering of the thermodynamic behavior of surface components of electric generation plants for high-medium enthalpy resources. The accuracy of the model allows for results with very low errors in terms of thermodynamic aspects. Further code-development work is needed in order to allow the model to complete several other aspects (such as the well model, optimized plant selection), and also to improve environmental analysis which is currently associated with unduly high errors.

Africa’s unique context has contributed to the flux in the current geothermal development. The continent is wide, with widespread potential for geothermal development. Global pressures and technological developments are only beginning to bear on the need to shift focus away from fossil energy dependence. Resources are needed to speed up assessments of the geothermal resources. There are challenges to be overcome, including political will, skilled manpower, knowledge of usage beyond direct usage, and global economic factors.
In addition, geothermal energy seems to be a way to pursue environmental and social goals, but also economic ones, such as fighting energy poverty. Lessons could be learnt from other existing experiences, such as off-grid Solar PV plants. In comparison, geothermal energy could provide additional benefits, like secondary use of the energy (greenhouses, thermal tourism, etc).

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