PRELIMINARY ENVIRONMENTAL IMPACT ASSESSMENT OF GEOTHERMAL EXPLORATION AND DEVELOPMENT IN KARISIMBI, RWANDA

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ABSTRACT

In this report a preliminary environmental impact assessment for geothermal exploration and development in the Karisimbi geothermal prospect is presented. In this study previous geoscientific data are reviewed, a prerequisite for choosing good sites for three exploration wells. Also, the possible threats of the proximity of the Karisimbi prospect to the mountain gorillas, whose habitat is within the National Volcanoes Park, are discussed. Even though geothermal energy is environmentally friendly, as much less CO_2 is emitted than through the use of fossil fuels, it has adverse impacts on the environment. The immediate possible impacts on the mountain gorillas and other endemic and threatened species of animals will be caused by noise from well discharging and testing, and the unpleasant smell of hydrogen sulphide. Exploration drilling has short term socio-economic impacts and benefits on the local community. Therefore, geothermal fluid might be recycled for minimizing environmental pollution while directional drilling and re-injection of the fluid are proposed in the future. A full environmental impact assessment must be carried out prior to drilling and any potential impacts should be addressed before granting any permits. An integrated environmental monitoring program, involving all stakeholders, is recommended throughout all phases of the project. For such, information on the following is necessary: (i) knowledge of the movements of endangered species in the park, (ii) the level of geothermal gas emissions at all times and (iii) the opinion of the local people on the different kinds of disturbances and the benefits of the project.

1. INTRODUCTION

Rwanda is an East African country located along the Western Branch of the East African Rift system with a surface area of 26,338 km^2 and a population estimate of 10.1 million inhabitants (NISR, 2010). It is bordered by Tanzania in the east, Burundi in the south, Uganda in the north and the Democratic Republic of Congo (DRC) in the west (Figure 1). The country is mainly rural with about 90% of the population engaged in subsistence agriculture. It is the most densely populated country in Africa with few natural resources. The primary foreign exports are tea and coffee. Tourism is the third most

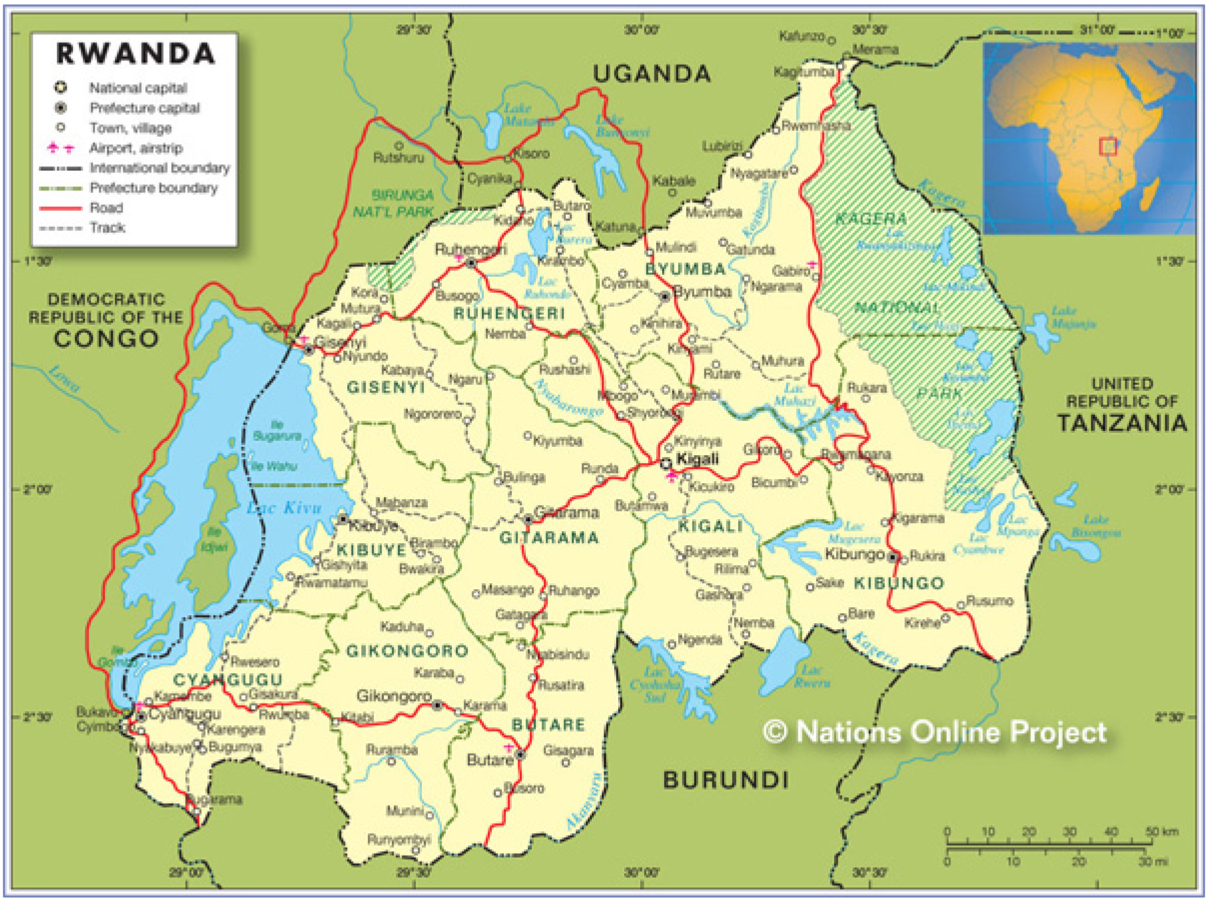

FIGURE 1: Map showing the location of Rwanda

important income source. The country has made substantial progress in stabilizing and rehabilitating its economy, which suffered heavily during the civil war in 1990-1993 and the 1994 genocide. Energy demand has grown rapidly by 25% per year due to population growth and an increase in economic activities (Kanigwa, 2009).

Traditionally, Rwanda has relied on two sources of energy: biomass contributing 90% and hydropower 10%. Other resources of renewable energies are also available such as solar energy, wind energy, micro hydro, geothermal energy, methane gas and peat (Jolie et al., 2009).

Electricity production in Rwanda has depended on hydropower since the country's independence in 1962. During the genocide in 1994, most hydropower plant infrastructures were destroyed. Since 2004, available hydropower plants have not been able to meet the demand for electrical power due to the exponential growth of the population. In addition, due to climate change patterns, the production capacity of the hydropower plants is smaller than before. To solve this problem, the Government of Rwanda (GoR) has installed thermal power plants to supplement hydropower and secure electricity for the population as a temporary solution (see below). However thermal power for electricity production can never be a sustainable solution, even though it might provide 50% of the electricity supply to the national grid. The provision of electricity is a large burden on the budget of a small country with its economy dependent on agriculture and tourism.

The population access rate to electricity is less than 13%. With an installed capacity of 84.5 MWe and an available capacity of 77.5 MWe (Table 1), the electricity price of 22 cent US/KWh is high and not comparable to that in other East African countries. The main objectives of the Government of Rwanda in terms of energy are to increase access to electricity to 50% by 2017, to reduce the cost of energy, to make energy services cost-reflective, to ensure the security of the supply and to diversify

TABLE 1: Installed and available electricity generation capacity in Rwanda in 2010

Category	Installed capacity (MWe)	Available capacity (MWe)
Indigenous hydropower	26.25	22
Imported hydro power	15.5	14.5
Micro hydro power	0.7	0.7
Indigenous* thermal power	27.8	27.8
Rental** thermal power	10	10
Methane to power	4.2	1.8
Solar power	0.25	0.25
Total	**84.7**	**77.05**

* Generators owned and run by the Government of Rwanda
** Privately owned, but rented by GoR which also supplies fuel

energy sources by developing indigenous resources like geothermal energy, peat, methane gas, wind energy and solar energy (Republic of Rwanda, 2010).

Geothermal energy is renewable, an indigenous resource, independent of weather and climate change effects, effective for on and off grid developments and for the provision of base-load power; it is environmentally friendly compared to fossil fuel burning and is not affected by oil price fluctuations. However, geothermal utilization can have some environmentally adverse impacts.

Geothermal exploration and development is less advanced in Rwanda than in Kenya and Ethiopia, the leading countries in geothermal electricity production in the East African Rift System, generating 209 and 7 MWe, respectively. Preliminary surface investigations started in 1981 in Rwanda by the French Bureau of Geology and Mines (BRGM) in the western, northern and southern provinces of the country. The institute suggested sites in the southwest (Bugarama) and northwest (Gisenyi) as sites for geothermal energy development with estimated reservoir temperatures above 100°C (Rancon and Demange, 1983).

In 2004, a renewed interest in geothermal exploration started due to significant fluctuations in oil price. Firstly, Chevron, an American energy company, applied chemical geo-thermometers in all prospects to estimate reservoir temperatures (Newell et al., 2006); secondly, the German Institute for Geosciences and Natural Resources (BGR) carried out detailed geo-scientific surveys in NW-Rwanda in 2008 (Jolie et al., 2009); and finally the Kenya Electricity Generating Company (KenGen) undertook geochemical, geophysical, and hydrogeological studies in Karisimbi. KenGen suggested a preliminary conceptual model of the geothermal system and the location of three exploration wells on the slope of the Karisimbi volcano (Mariita, 2010). Figure 2 shows the location of the Karisimbi prospect in northwest Rwanda.

Detailed geology and alteration mineralogy studies were completed in February 2011 and additional detailed geo-scientific surveys are on-going in the Karisimbi area prior to the drilling of the three exploration wells (2-3 km deep).

When the available results were combined and interpreted, the conclusion was to situate the 3 exploration wells on the flanks of the Karisimbi volcano system. If geothermal heat proves to be sufficient, additional production wells will be drilled in the same area. However, considering all the activity involved in exploration drilling, and knowing that the area borders the National Volcanoes Park (NVP) and recognizing that the area is very important for agriculture, a preliminary environmental impact assessment is mandatory prior to drilling. The NVP is a protected area because of its flora and fauna and it is the habitat of endangered mountain gorillas, *G. beringei beringei* (Sarmiento et al., 1996).

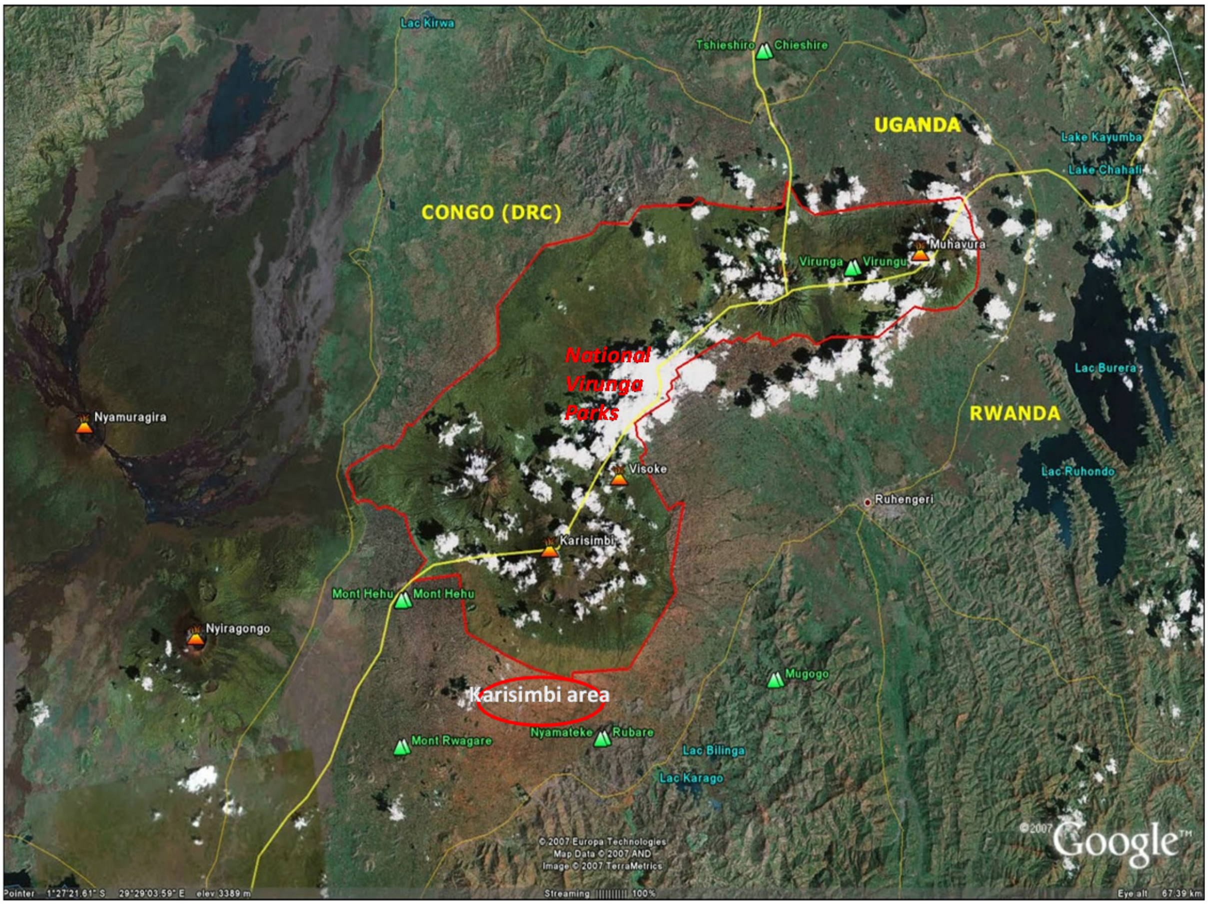

FIGURE 2: Map showing the Karisimbi area in northwest Rwanda

The main objective of this study is to assess the possible environmental impacts of geothermal resource exploration and development in the Karisimbi geothermal area.

In this report, probable environmental impacts due to geothermal exploration and development in the Karisimbi are described and discussed. Also, some recommendations on mitigation in connection with the project regarding the NVP, particularly concerning mountain gorillas, as well as on the socio-economic life of neighbouring communities and the region, are made. A brief environmental monitoring plan is also discussed. The study is limited to the exploration drilling of the 3 wells and well testing in the Karisimbi prospect, envisaging a full Environmental Impact Assessment (EIA) prior to the pre-feasibility study and the design of a well head generation unit if the resource is proven to be sufficient.

2. THE KARISIMBI GEOTHERMAL PROSPECT

2.1 Geothermal areas

There are two main geothermal prospects in the country: The northwest geothermal prospects include Karisimbi, Kinigi and Gisenyi, and the southwest prospect, the geothermal field in the Bugarama graben (Figure 3). The Karisimbi geothermal prospect is situated in the Nyabihu and Rubavu districts of the Western Province and occupies an area of about 200 km^2. The prospect lies to the south of the National Volcanoes Park (NVP), while in the east is the Kinigi area in the Musanze district of the Northern Province, and in the west, the Gisenyi prospect in Rubavu district.

2.2 Geological setting

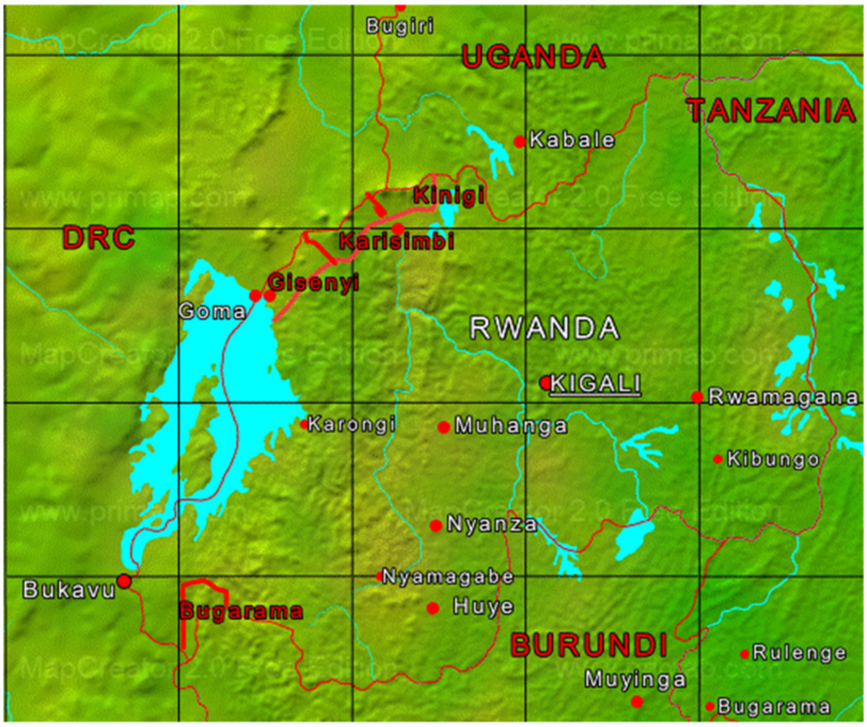

FIGURE 3: Rwanda geothermal areas

The geology of northwest Rwanda is similar to the geology of the neighbouring parts of Burundi, the DRC and Uganda. It is dominated by the Kibaran mid-Proterozoic mobile belt with local intrusions of anorogenic granites and syenites dated between 0.7 and 1 Ga (Rogers et al., 1998). The oldest rocks of Rwanda are migmatites, gneisses and mica schists of the Paleoproterozoic Ruzizian basement overlain by the Mesoproterozoic Kibaran Belt. The Kibaran, composed of folded and metamorphosed sediments, mainly schists and quartzites intruded by granites, covers most of Rwanda. Cenozoic to Recent volcanic rocks occur in the northwest and west. Some of these volcanics are highly alkaline and are extensions from the Birunga volcanic area of southwestern Uganda. Tertiary and Quaternary sediments fill parts of the Western Rift in the western part of the country.

The Karisimbi volcano is the highest of the eight major Virunga volcanoes which form a transverse chain in the western branch of the East African Rift. With an elevation of 4507 m above sea level, the Karisimbi volcano is the most voluminous of the Virunga Volcanoes Range (VVR) but has not been active in historical times. The mountain is mainly situated in Rwanda, but is also partly in the DRC (Figure 4) (De Mulder, 1985). However, the Karisimbi volcano is close to two active volcanoes in the DRC: Nyiragongo and Nyamuragira which erupted in 2002 and 2010, respectively.

Karisimbi rocks constitute a nearly complete undersaturated series. The series comprise K-basanites, K-hawaiites, K-mugearites, K-benmoreites and K-trachytes with rare subvolcanic microsyenites. Except for the K-trachytes, all Karisimbi rocks contain quartz-feldspar inclusions from the granite country rock, which only show minor reaction with the magma-like rocks of the Western Branch of the Rift Valley. Using the K-Ar dating method it has been shown that the Karisimbi lavas are younger than 0.14±0.06 Ma and some are more recent (De Mulder, 1985).

The alkalinity of Karisimbi lavas was also confirmed by Ian Smith in the study of Patrick Browne (2011) who stated "*the rocks are strongly alkaline as shown by the high total alkalies, high Titanium dioxide (TiO_2) as well as Barium (Ba), Rubidium (Rb), Tin (Nb), Lanthanum (La) and Cerium (Ce); all these trace elements are unusually high for basaltic rocks, even for alkaline rocks*". Mackay et al. (1997), using the Spaceborne Imaging Radar C (SIR-C) interferometry topography method, found that Karisimbi lava flows are 40-60 m thick (up to 140 m) and 12 km long.

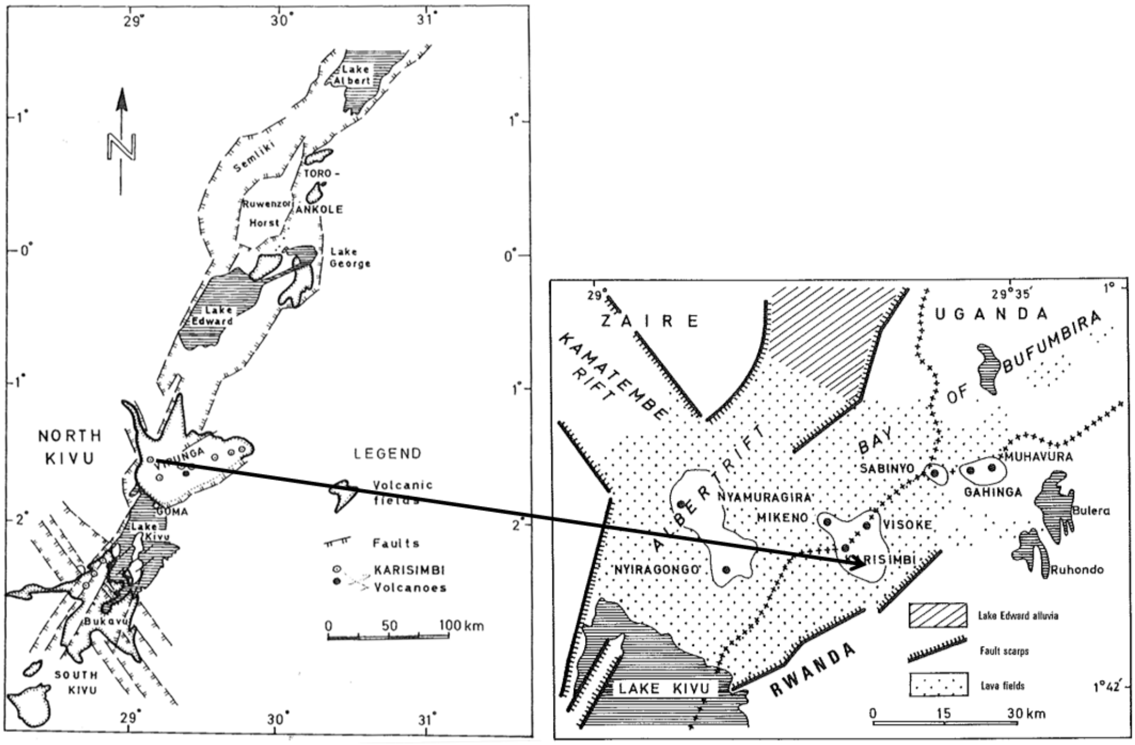

FIGURE 4: The western branch of East African Rift system showing the Karisimbi Volcano (De Mulder, 1985)

2.3 Geochemical analysis

In the Karisimbi system, the lack of geothermal surface manifestations like fumaroles, hot ground, geysers and mineral alteration might be explained by the presence of a residual low temperature volcanic reservoir (Jolie et al., 2009). Maybe some hot springs are located in inaccessible areas of the National Volcanoes Parks (NVP). The nearest hot spring is Karago, about 18 km from the Karisimbi volcano. The German Institute for Geosciences and Natural Resources (BGR) has analysed water samples of precipitation, cold groundwater, geothermal water and gas. Chemical analysis results indicated a good permeability and a subsurface temperature of over 100°C which could be used for electricity production by employing a binary fluid system. Based on chemical analysis, calcite scaling during production is to be expected while silica deposition is not possible as the fluid is undersaturated with respect to amorphous silica. In general, most of the samples are bicarbonate and immature waters representing cold groundwater or ancient geothermal systems (Jolie et al., 2009; Mariita, 2010).

Chemical analysis of soil diffuse gases suggested a structural control of diffuse emissions showing two structures SW-NE perpendicular to the structure NW-SE. The work carried out by Kenya Electricity Generating Company (KenGen) in 2009, involving geochemical surveys for radon, carbon dioxide and mercury in soil gas, confirmed the analysis (Mariita, 2010).

2.4 Geophysical exploration

In geothermal exploration, properties of the earth are determined by geophysical methods and the main focus is on parameters that are sensitive to temperature, fluid contents of rocks and structures that might reveal geothermal systems (Georgsson, 2009).

Geophysical investigations in Karisimbi started recently, or in 2008 by BGR, and then carried on in 2009 by KenGen. In total, 100 magnetotelluric (MT) and transient electromagnetic (TEM) soundings were completed by KenGen and BGR. TEM and MT are indirect electrical methods used to measure the resistivity of rocks during geothermal exploration. Geothermal water has a tendency to reduce the resistivity of its host rocks due to the high concentration of dissolved ions in the fluid and secondary alteration minerals that are formed when the hot fluid interacts with the rocks (Jolie, 2010).

Both the resistivity and the mineral alteration are temperature dependent. As the temperature becomes higher, the lower the resistivity becomes and the more intense the alteration. For example at temperatures below 220°C, zeolites and smectites are formed, while at temperatures above 250°C only temperature resistant minerals like epidote and chlorite are formed (Figure 5).

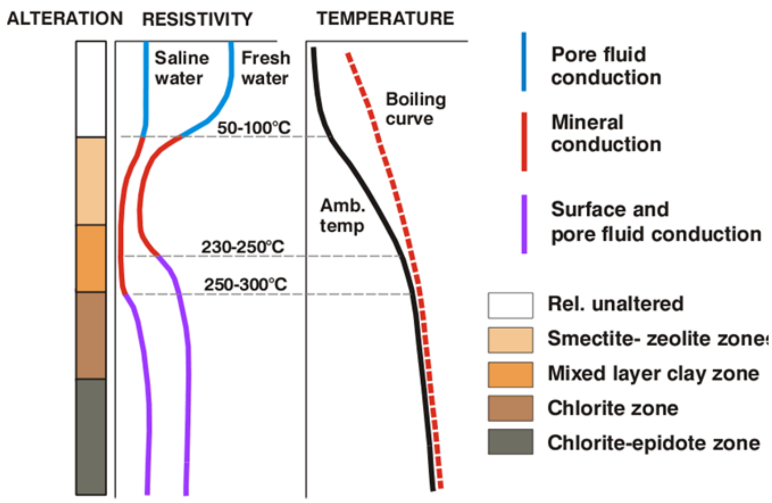

FIGURE 5: Rock alteration, temperature and resistivity (Flóvenz et al., 2005)

The TEM and MT resistivity results suggest that the southern Karisimbi area hosts a huge geothermal system of medium to high temperatures. The heat source is believed to be a magmatic intrusion located at 5000 m depth. From the combination of geochemical, geological and geophysical data, a conceptual model of the geothermal system was constructed and used to site three 2-3 km deep exploration wells on the flanks of the Karisimbi volcano (Figure 6).

The construction of a conceptual model of a geothermal system is a multidisciplinary process with particular emphasis on estimating reservoir size, temperature conditions and the overall permeability structure.

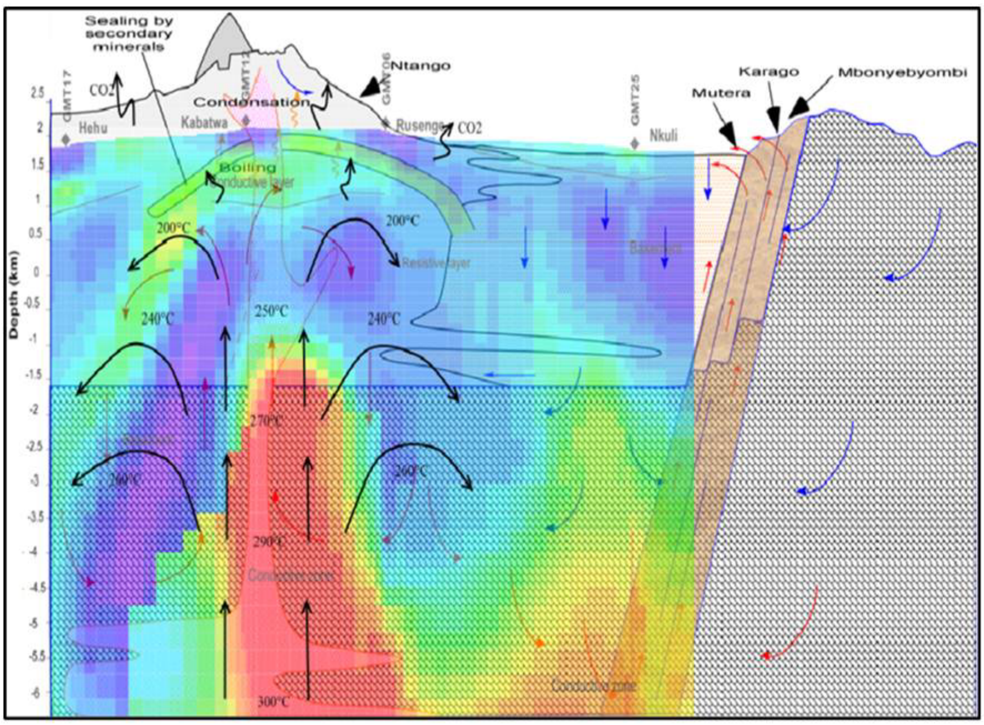

FIGURE 6: The conceptual model for Karisimbi geothermal prospect (Onacha, 2010)

3. ENVIRONMENTAL IMPACT ASSESSMENT IN RWANDA

3.1 Introduction

The current constitution of Rwanda from 2003 addresses environmental issues and ensures the protection and sustainable management of the Rwanda environment and encourages rational use of environmental resources. Rwanda has signed and ratified several international conventions and treaties for the protection and conservation of the environment (Table 2).

TABLE 2: Conventions and treaties ratified or signed by the Government of Rwanda (GoR)

Conventions and treaties	**Date of signature**	**Approval date by GoR**
International convention on biological diversity and its habitat signed in RIO DE JANEIRO in BRAZIL.	5 /06/ 1992	18 /03/ 1995
United Nations framework convention on climate change signed in RIO DE JANEIRO in BRAZIL.	5 /06/ 1992	30 /05/ 1995,
STOCKHOLM convention on persistent organic pollutants	22/05/ 2001	08 /07/2002,
BASEL convention on the control of transboundary movements of hazardous wastes and their disposal.	22/03/1989	24/08/2003
ROTTERDAM international convention on the establishment of international procedures agreed by states on commercial transactions of agricultural pesticides and other poisonous products.	11/09/1998	24/08/2003
MONTREAL international convention on substances that deplete the ozone layer.	1997	24/08/2003
CARTAGENA protocol on biosafety to the convention of biological biodiversity.	15-26/05/2000	29/12/2003
KYOTO protocol to the framework convention on climate change.	06/03/1998	29/12/2003
RAMSAR international convention on wetlands of international importance, especially as waterfowl habitats.	2/02/1971	29/12/2003
BONN convention on conservation of migratory species of wild animals.	23/06/1979	29/12/2003
Washington agreement on international trade in endangered species of wild flora and fauna.	03/03/1973	25/06/1980

However, the ratification and implementation of the above treaties and policies were very limited up to 2003, as the environment sector was controlled by the Ministry of Agriculture (MINAGRI. Since 2003 the situation has changed; environmental issues were transferred to the Ministry of Natural Resources (MINIRENA) and the Rwanda Environment Management Authority (REMA) was established in 2005.

3.2 Legislative and institutional frameworks for the environment

At the national level, environmental law N^{o} 04/2005 from 08/04/2005 was implemented, determining the modalities of protection, conservation and promotion of the environment in Rwanda. Article 5 shows the responsibilities of the GoR to establish a national policy of protection, conservation and promotion of the environment, to develop strategies and plans and additional programs aimed at ensuring the conservation and effective use of the environment. Article 6 of the same law states the fundamental right of every person in Rwanda to live in a healthy and balanced environment and the obligations to contribute individually or collectively to the conservation of the natural heritage, and historical and socio-cultural activities. Articles 85 to 113 of this law determine preventive provisions and punitive sanctions of individuals or groups of people who do not comply with this law. This law (articles 65, 67 and 68) established the Rwanda Environment Management Authority (REMA) as an implementing agency of this law. REMA was created by Act N^{o} 16/2006 from 03/04/2006 determining the organization, functioning and responsibility of REMA (Republic of Rwanda, 2005).

The law stipulates that every project shall be subject to an environmental impact assessment, before obtaining authorisation for its implementation. This applies to programmes and policies that may affect the environment; a ministerial order specifying a list of projects subject to EIA was published in the Official Gazette of the Republic of Rwanda in 2008. However in Rwanda, there are other policies and laws dealing with environmental protection for sustainable development:

- The national land policy;
- The water and sanitation policy;
- The five year strategic plan for the environment and natural resources;
- The mines and geology policy;
- The law on land use and management;
- The law on forestry;
- The water law;
- The land title and registration law;
- The law on expropriation in the public interest.

As a result of a consultative process that took place in 1998-1999 at the President's office, the future vision for Rwanda in 2020 was declared ("vision 2020"). It highlighted that natural resources and the environment should be among cross-cutting areas which cannot only be affected by economic transformation but also play a role in achieving the vision's developmental goals. The main objective of vision 2020 is to transform Rwanda into a middle-income country by the year 2020 (MINECOFIN, 2000). The Economic Development and Poverty Reduction Strategy (EDPRS) which was a medium-term framework for achieving vision 2020 covering the period 2008 to 2012, has put environment and rational land uses among other priorities (MINECOFIN, 2007). Protection of the environment and natural resources is also the pillar of the Rwandan government programme 2010-2017 in which environment protection programmes will be effected in all institutions.

Matters concerning environmental issues in Rwanda are the responsibilities of the Ministry of Natural Resources (MINIRENA) with the main role of preparing and ensuring the follow up and evaluation of policies and strategies as well as environmental protection. REMA is an agency affiliated with MINIRENA with a mandate of supervision, following and ensuring that issues relating to the environment receive attention at all levels and has the duty of implementing policies and laws related to the environment. Even though the agency is under the ministry, it has a legal status of financial and administrative autonomy.

However, for attracting investors; EIA review and approval has been transferred to the Rwanda Development Board (DRB) in the Department of Environmental Compliance.

3.3 EIA procedure in Rwanda

3.3.1 Definition

EIA is defined as an official statement of the likely effects of a proposed policy, program, or a project on the environment, alternatives to the proposal, and measures to be adopted to protect the environment. The concept may apply from inception to operation, and may also include post project analysis**.** EIA studies started in the USA in 1969 after the passage of the US National Environmental Policy Act (NEPA) which incorporated a requirement for assessing the environmental impact of major federal actions significantly affecting the quality of the human environment. Subsequently, the concept of environmental impacts has spread to many countries (Gilpin, 1995). However, every country has developed a certain process or protocol for preparing EIAs (Roberts, 1991).

EIA studies have the direct benefit of assisting developers to incorporate environmental considerations at the design stage or to change a project's site and to minimize environmental risks and financial costs. Indirect benefits include beneficial circumstances created by the project. EIA is an invaluable tool for environment management in a trans-boundary context. It provides a framework for the promotion of efficient decision making in project approval, enables the implementation of environmental safeguards to mitigate significant negative impacts, avoids ecological damage and large-scale irreversible loss of natural resources, plays a role in information dissemination between Rwanda and neighbouring countries, and widens the scope of understanding of impacts beyond its borders.

The EIA process in Rwanda provides a justification and a basis for future international cooperation and also aids in conflict resolution concerning environmental impacts at a regional level (Green World Consult, 2010). The World Bank has classified four categories of projects subjected to EIA depending on the type, location, sensitivity and scale of the project nature and the magnitude of potential environmental impacts (Table 3).

TABLE 3: Categorization of projects subjected to EIA (World Bank, 1999)

Category A	**Category B**	**Category C**	**Category FI**
Projects likely to have significant adverse environmental impacts. Impacts may affect an area broader than the sites or facilities subject to physical work.	Potential adverse environmental impacts on human populations or environmentally important areas – including wetlands, forests, grasslands, and other natural habitats; less adverse than those of Category A projects.	Likely to have minimal or no adverse environmental impacts.	Involves investment of bank funds through a financial intermediary.

In Rwanda, act N° 004/2008 of 15/08/2008 establishes the list of works, activities and projects that have to undertake an EIA (Table 4). These are classified into 4 categories: infrastructure, agriculture, works in park and in its buffer zones, and mine extraction (Republic of Rwanda, 2008). According to that act, exploration drilling in Karisimbi is classified in two categories: infrastructure and parks.

TABLE 4: List of projects and activities subject to EIA study in Rwanda

Infrastructure (I)	**Agriculture (II)**	**Parks (III)**	**Mining (IV)**
Construction and repair of international roads, national roads, district roads and repair of large bridges; Construction of industries, factories and activities carried out in those industries; Construction of hydro- dams and electrical lines, public dams for water conservation, rain water harvesting for agricultural activities and artificial lakes; Construction of oil pipelines, gas works and storage tanks; Terminal ports, airports, railways, car parks, hotels, large public buildings, water distribution networks, sanitation, public land fills, slaughter houses, hospitals, stadiums, large markets and initial installation of communication infrastructures.	Agricultural and breeding activities which use chemical fertilizers and pesticides in wetlands and large scale monoculture; Agricultural practices such as tea, coffee, flowers and pyrethrum, etc…; Works and activities that use bio-technology to modify seeds and animals	Works in parks and in their buffer zones	Work of mine extraction

3.3.2 The EIA process

An EIA study in Rwanda includes 5 steps: (1) project registration and application , (2) screening, scoping and terms of reference, (3) EIA study and report, (4) submission of an EIA report, and finally (5) decision making.

Registration and application: The developer submits to RDB a proposed project in the form of a brief description of the project applying for an EIA.

The screening process consists of the evaluation and analysis of the project description with the outcome of informing the developer whether the project requires some further environmental analysis or not or if the project requires a full EIA.

Scoping and terms of reference: Scoping is the role of the developer although EIA experts are authorised by MINIRENA. The scoping report is submitted to RDB for review and incorporated in the terms of reference for serving as authorisation for the developer to start an EIA study.

Environmental impact study and report: In this step, EIA experts produce an EIR including an environmental management plan (EMP). The developer submits the EIR and a written addendum, both documents signed by the EIA project leader. The RDB organises a public hearing during which the developer presents the project before issuing an EIA certificate of authorisation (EIACA). If the project is rejected the developer addresses his appeal to the MINIRENA. Upon project completion or relocation, the developer prepares a decommissioning plan to submit to the RDB. This plan must include a description of the existing environmental conditions and proposed restoration measures (Figure 7).

The whole process of getting an Environmental Impact Assessment Certificate of Authorization (EIACA) takes 34 days, excluding the time for EIA studies which varies depending on the magnitude and size of the project and the time it takes the EIA experts to carry out their work. The developer also has to submit an annual monitoring report and an environmental auditing report as demanded by REMA (REMA, 2006).

4. ENVIRONMENTAL BACKGROUND OF KARISIMBI

4.1 Location

As described above, the area where the Karisimbi geothermal field is located extends over an area of 200 km^2 in the Kabatwa, Bigogwe and Jenda sectors of the Nyabihu districts and in the Bugeshi sector of the Rubavu district. However, based on available geo-scientific data, the potential area has been narrowed down to 25 km^2.

4.2 Environmental geology

The Karisimbi rocks are nephelinic. Nephelinites are of ultrabasic chemical composition and are geologically typical of continental graben rifts. The rocks are highly resistant to the chemical alteration prevalent in humid tropical climates. The porosity of the rocks is very high and visible; it is estimated to be at least 25% (IGIP, 2004).

The permeability of Karisimbi rocks was also confirmed by Browne (2011) who explained the scarcity of ponds, lakes and permanent surface flow despite the high rainfall as being due to the presence of pyroclastic lavas.

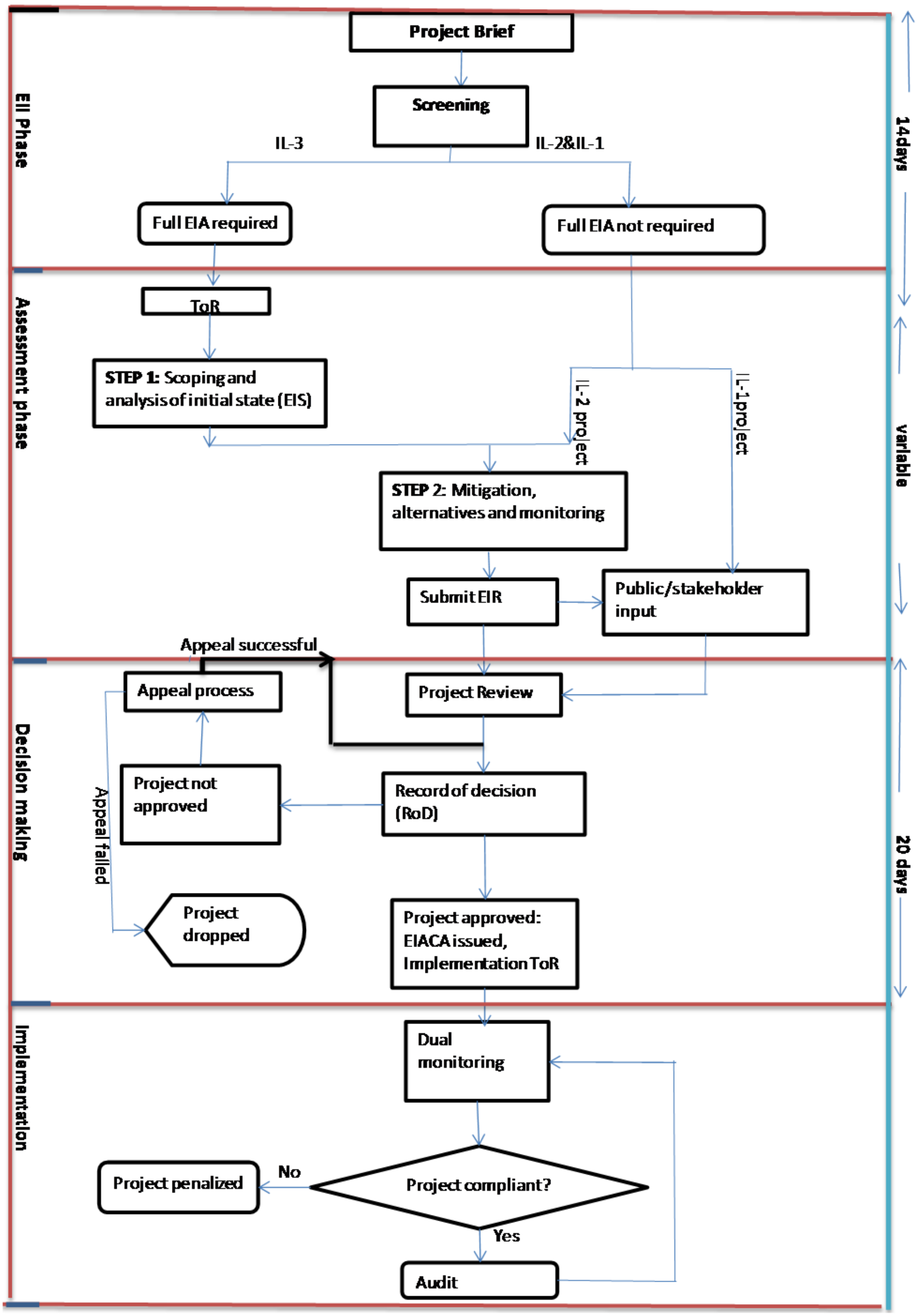

FIGURE 7: EIA procedure chart (adapted from REMA, 2006)

Several lava tunnels were found within the area with diameters ranging from 0.5 m to 10 m and lengths reaching several kilometres (Figure 8). The area hosts many small cones, some with craters controlled by north and northeast striking normal faults (Jolie, 2010).

4.3 Volcanoes National Park (NVP)

The Virunga volcanic region is made up of three parks: NVP of Rwanda with an area of 150 km^2, Mgahinga Gorilla National Park (MGNP) in Uganda, and Parc National des Virunga (PNVi) in DRC. This area of 447 km^2 encompasses six volcanoes: Karisimbi (4507 m), Mikeno (4437 m), Bisoke (3711 m), Mgahinga (3474 m), Muhabura (4127 m) and Sabyinyo (3634 m). Figure 9 shows the three national parks and 5 mountain volcanoes on the borders of Rwanda-DRC-Uganda.

FIGURE 8: Lava tunnel in the Karisimbi prospect

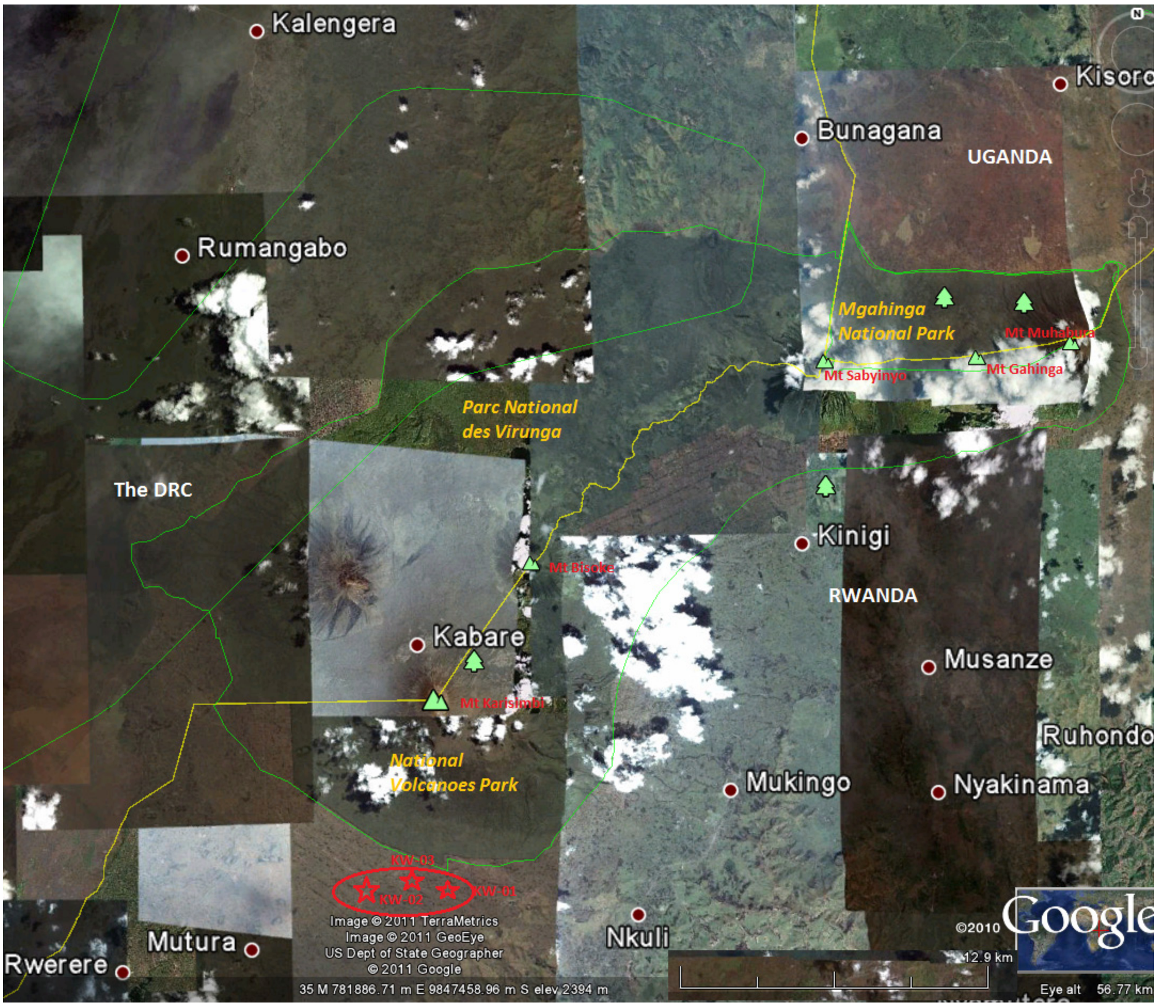

FIGURE 9: Location of drilling targets, 3 national parks and 5 mountain volcanoes on Rwanda – DRC – Uganda borders

The management of these protected areas is the responsibility of the National Park authorities in each country: the Institut Congolais pour la Conservation de la Nature (ICCN), the Rwanda Development Board (RDB) and the Uganda Wildlife Authority (UWA). Within the Albertine Rift, the Virunga Volcanoes Range (VVR) is an area of afro-mountain forest of high biodiversity importance due to the existence of mountain gorillas and other endemic flora and fauna. The Virunga Volcanoes Range is the site of the oldest national park in Africa, the Albert National Park created in 1925 in Rwanda and the DRC to protect the gorillas and their habitat for future generations (Gray et al., 2006).

4.3.1 Fauna

The species richness of the Virunga volcanoes region depends on habitat types (mixed forest, disturbed woodland, bamboo and *Hagena-Hypericum* woodland). The VVR is particularly important for the number of endemic species it contains (more than any other region in mainland Africa). The region contains 45-57% of the endemic vertebrate species found in the Albertine Rift, 56% of the threatened amphibian species, making it an important site for amphibian conservation (Table 5; Owiunji et al., 2004).

TABLE 5: Species richness, number of Albertine Rift endemics and IUCN threatened species

	Species richness	Endemic species	Threatened species
Mammals	86	18	6
Birds	258	20	4
Reptiles	43	7	0
Ampibians	47	16	9
Plants	878	124	4
Total	**1312**	**185**	**24**

A total of 258 species of birds has been recorded in the Virunga Volcanoes Range of which 20 species are endemic to the Albertine Rift, and four species are threatened (Owiunji et al., 2004). The mammalian fauna of the Virunga volcanoes adds up to 86 species of mammals of which 34 are large. 18 species are endemic, 3 near endemic, 6 species are threatened and 16 are listed by the International Union for the Conservation of Nature (IUCN). The larger species include the mountain gorilla (*Gorilla beringei beringei*), the buffalo (*Syncerus caffer*), the bushbuck (*Tragelaphus scriptus*), the black-fronted duiker (*Cephalophus nigrifrons*) and the elephant (*Loxondata africana*). Smaller species are the endangered golden monkey (*Cercophithecus kandti*), known only to occur in the Virunga Volcano, and the blue monkey (*Cercopithecus mitis*).

Results on the distribution of mammals in the VVR showed buffalo signs in the whole park except south and west of the Karisimbi volcano; elephant signs are also common in the Mikeno sectors which border the park boundary. Bushbuck and duiker signs are common around Bisoke, to the east of Karisimbi and in MGNP, while carnivore dung is common in the east (Gray et al., 2011).

Considering the duty the countries have in protecting the mountain gorillas, the important role the species plays for tourism in the parks and their importance worldwide, a detailed summary of the species is given below.

4.3.2 The mountain gorilla

Mountain gorillas are only found in Central Africa, on the border between Rwanda, the DRC and Uganda. They are confined to 4 national parks: NVP, PNVi, MGNP and one population of mountain gorillas inhabits the Bwindi Impenetrable National Park in Uganda. The IUCN places the mountain gorilla, *Gorilla beringei beringei,* as a distinct subspecies of the eastern gorilla species found in the eastern lowlands, *Gorilla beringei graueri*.

Mountain gorillas are generally larger than other subspecies and have longer hair. An average adult male weighs 160 kg and an average adult female weighs 98 kg. They inhabit high altitude and mountain forests, as well as bamboo forests, ranging from 2500 to 4000 m altitude. The forests where they live are often cloudy, misty and cold. At the foot of the mountains the vegetation is very dense, becoming less so higher up in the slopes.

They live in stable groups, each consisting of one dominant adult male of 12 years or older, called a silver back (because of a silver coloured hair across the back and hips), several younger males (called blackbacks of 8-12 years old), subadults (6-8 years old), adult females (8 years-onwards), juveniles (3.5-6 years) and infants (≤3.5 years old). Young males form bachelor groups.

Robbins (1999) realised that approximately 40% of all groups are multimale. The harem mating system of mountain gorillas is hypothesized to provide protection for females against potentially infanticidal outsider males and represents a form of long term mate guarding of females by males. Inter-group competition between males for access to females is considered to be high (Robbins, 1999).

The lifespan is 40-50 years. When the silverback is standing upright, he can be as tall as 1.7 m. The reproductive cycle for females is about 28 days, of which only 1-3 days are fertile and the gestation period is 9 months. The interbirth interval is between 3 and 5 years. A new born gorilla weighs only 2 kg. Upon reaching maturity, both males and females leave the natal group. The females usually join another group or a lone young adult male while the males remain solitary or in bachelor groups until they can attract females and establish their own group. One group of gorillas can travel over an area of 8.56 km^2 during a 12 month period.

Mountain gorillas spend a lot of their time travelling in search of food and the diet for a fully grown mountain gorilla can include up to 25 kg of vegetation a day. They are primarily vegetarian (86% of their diet is composed of leaves, celery, bamboo, shoots and stems of herbaceous vegetation) (Figure 10). They also eat small amounts of wood, roots, flower, fruits, larvae, snails and ants (Uwiringiyimana, 2011).

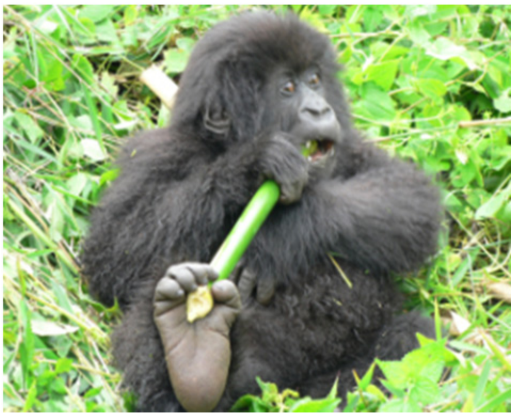

FIGURE 10: A gorilla treat

The population size of mountain gorillas in 1959-60 was estimated to be between 400 and 500 animals in the Virunga Volcanic Parks (Rwanda, DRC and Uganda). Detailed censuses carried out in 1971-1973, 1976-1978 and 1981 showed a population decline. This decline could have resulted from either a lower birth rate or an increased mortality rate. From 1981 to 1989 the population size increased and reached 309 individuals. Since then they have increased in numbers. The number of gorillas in Virunga Park is estimated to be 480 individuals according to the 2010 census (Figure 11) (Gray et al., 2011).

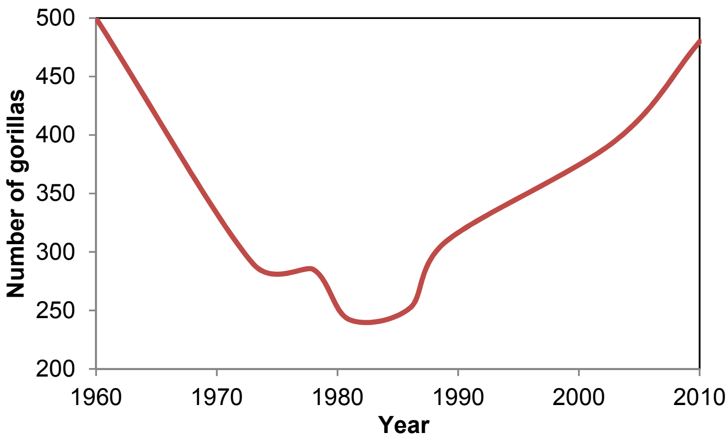

FIGURE 11: Variation of numbers of mountain gorillas 1960-2010

The main threats to the mountain gorilla population are: (1) habitat loss or modification and forest encroachment, (2) disease and disease transmission from humans in areas of gorilla tourism and (3) war and political unrest (Plumptre and Williamson, 2001). Also, a few gorilla infants are poached for potential illegal sales to zoos. They are usually not hunted for bush meat but they are frequently maimed or killed by traps and snares intended for other animals (Uwiringiyimana, 2011).

For preventing the transmission of diseases from humans, strict rules are in force to regulate tourist visiting times, the number of tourists per group, limiting the approach of humans to 7 m distance and burying human excrement deeper than 30 cm. Mountain gorillas are legally protected in the three countries (the DRC, Rwanda and Uganda) and anti-poaching teams have been created; there is extensive collaboration in ranger patrolling and the sharing of information between the three states.

The mountain gorillas are distributed in 36 social groups, which is a slight increase from the 32 groups found in the 2003 census, and is the greatest number of groups found in the VVR since the routine census began. Of these groups, 24 were habituated to tourists while 12 were unhabituated groups. The large number of groups resulted from group divisios of habituated groups and three habituated solitary males forming new groups and the habituation of one new group (Gray et al., 2011). The majority of gorillas live in the central part of the Virunga Volcanoes Range around Mount Bisoke and in the saddle area between Bisoke and Sabyinyo while fewer groups are in the southern and eastern parts of the park (Figure 12; Gray et al., 2006).

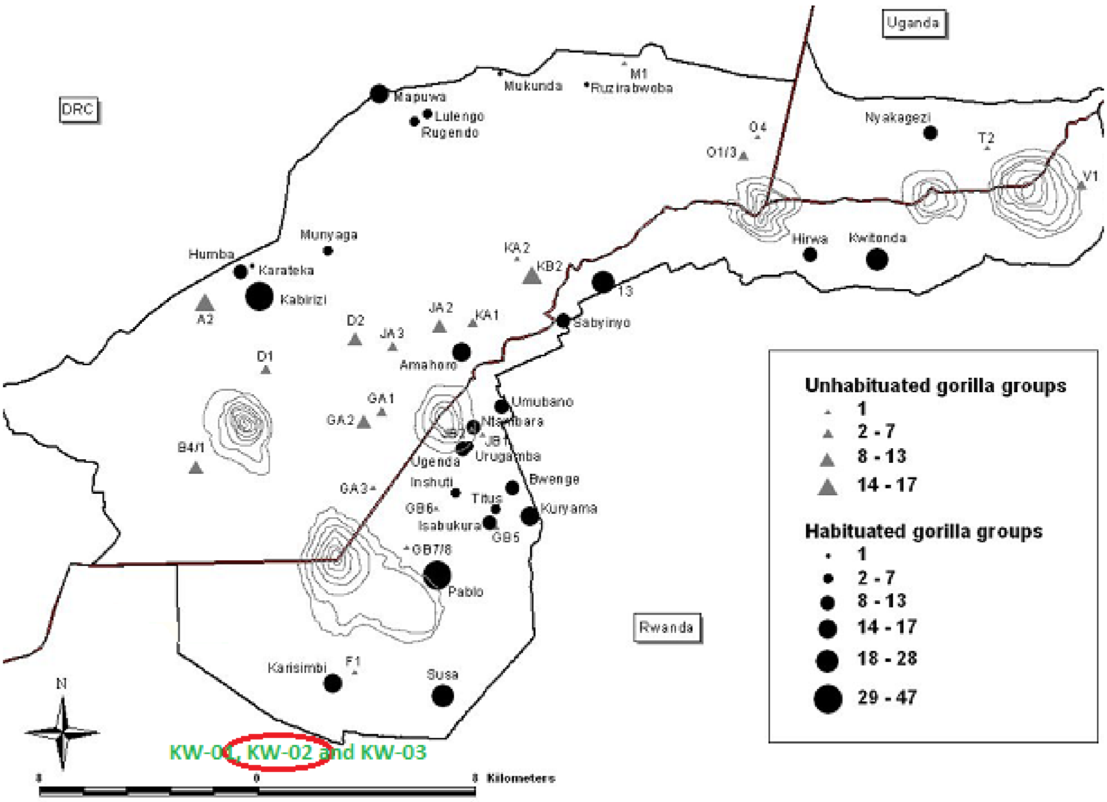

FIGURE 12: Distribution of mountain gorilla social groups in VVR in 2010

The estimated population of 480 gorillas (2010) represents a 3.7% annual growth rate since the previous census in 2003 which estimated a population size of 380 gorillas. An increase of mountain gorillas is attributed to a combination of ecological conditions and park management efforts. However, unhabituated gorillas avoid areas of high human disturbance; the high density of habituated gorillas is found in Karisoke area which also has a high level of human disturbance. That might be due to the fact that they receive extensive protection by park staff and can receive veterinary care if illnesses or snares are detected.

Another way of looking at the distribution of the gorillas across the VVR is to consider in which country they are located even though they don't recognize international boundaries. The majority of habituated mountain gorilla groups are found in Rwanda while many unhabituated groups are found in the DRC (Table 6; Gray et al., 2011).

As shown in Figure 12, drill sites for 3 exploration wells (KW 01-03) are located in the southwest part of Karisimbi and Susa, locations of habituated gorilla groups. The distance estimate using Google Earth between the two groups located on the Karisimbi slopes (Susa and Karisimbi groups) is less than 1 km.

TABLE 6: Summary of gorilla population according to the country of group location in 2010

Country	Habituated gorillas	Unhabituated gorillas	Total
DRC	84	117	201
Rwanda	259	10	269
Uganda	9	1	10
Total	**352**	**128**	**480**

4.3.3 Flora

Some 878 species of flowering plants have been recorded in the VVR, 124 endemic to the Albertine Rift and four threatened species.

The main types of vegetation found in the Albertine Rift are:

- Grassy savannahs; bush and tree savannahs of *Acacia* and *Combretum*; savannahs with xerophile thickets; and wooded savannahs having close floristic affinities with East Africa, dominant in the central part of the landscape between the towns of Rutshuru and Beni and around Lake Edward;
- Sclerophyllous forests and thickets, associated with the lava fields in the south of the landscape, in the Nyiragongo and Nyamulagira sectors in the DRC;
- Xerophile forests of *Euphorbia dawei* and *Olea europea*, endemic to the piedmonts of the rift mountains;
- Guinea-Congolese plain forests, limited to the northern part of the landscape along the Semliki River and comprising mixed formations and formations dominated by *Cynometra alexandri*
- Riparian forests;
- Sub-mountain and mountain forests with formations of *Podocarpus*, *Hagenia* and *Hypericum* and thickets of bamboo *Synarundinaria alpina*, limited to the flanks of Ruwenzori to the northeast and the volcanoes in the south;
- High-altitude barrens and thickets of Ericaceae (*Philippia benguelensis, Ph. johnstoni, Erica arborea, E. kingaensis*);
- Afroalpine barrens with giant lobelia *Lobelia sp.* and dendritic senecios *Senecio sp.*, above 3,500 m on the volcanoes and Ruwenzori;
- Degraded forests and cultivated land, generally outside the protected areas;
- Swampy areas around Lake Edward (Plumptre et al. 2003).

The main plant communities at different altitudes in the VVR are shown in Table 7.

TABLE 7: Classification of VVR vegetation zone

Vegetation zone	General characteristics	Altitude (m)
Alpine	Grasses, mosses and lichens, *Dendrosenecio, Giant lobelia*	Above 3600
Sub alpine	Main species: *Philippia johnstonii, Erica arborea, Giant Lobelia*	3200-3600
Hagenia-Hypericum woodland	Main species: *Hypericum revolutum, Hypericum absi, Hagenia abyssinica*	2800-3200
Bamboo	*Arundinaria alpine*	2500-2800
Mixed forest	Moist semi-deciduous forests with broad leaves	1600-2500
Disturbed woodland = woodland	Areas of regenerating forest that were cultivated in Mgahinga	2300-2800
Grassland	Areas dominated by grass	Various altitude
Swamp	Marsh / boggy areas	Various altitude

4.4 Stakeholders

The great variety of wildlife and bird species in VNP has attracted the attention of many research and educational institutions in the country, in the region and worldwide. The main stakeholders involved in NVP activity are listed in Table 8.

TABLE 8: National and international stakeholders in NVP conservation

National partners	International collaborators
Rwanda Development Board (Tourism and conservation)	Diane Fossey Gorilla Fund International
Karisoke Research Centre	International Gorilla Conservation Program
National University of Rwanda (NUR)	Eastern African Children's Education Fund
Rwanda Environmental Management Authority (REMA)	CARE
Kigali Institute of Education (KIE)	University of Cape Town
Higher Institute of Agriculture and Animal Husbandry (ISAE)	Tropical Biology Association
Ministry of Natural Resources	Conservation International
Ministry of Agriculture	Disney Animal Kingdom
Institute of Scientific and Technological Research (IRST)	US Fish and Wildlife
Rwanda Agricultural Research Institute (ISAR)	Zoo Atlanta (USA)
	University of Oklahoma (USA)
	University of Texas (USA)
	Lincoln Park Zoo (USA)
	Max Planck Institute (Germany)
	University of Chester (UK)
	University of Stirling (UK)
	Univeristy of Koblenz (Germany)
	University of Cambridge (UK)

4.5 Water resources of the Nyabihu district

The hydrological network of the Nyabihu district comprises many streams, brooks, springs, the Nyirakigugu pond and Lake Karago (0.27 km^2). All streams and springs are concentrated in lowland valleys between steep mountains. Residents of the Kabatwa sector rely on rainwater harvesting for their water supply through water pans and gutters on their houses. About 30-35% of the population has access to drinking water from the eleven water kiosks supplied with piped water. The vegetation redistributes water from precipitation through interception, evaporation, runoff and infiltration.

4.6 Air and water quality of the Karisimbi region

During a survey carried out in 2010 by the Ministry of Environment and Land (MINELA) through Water Supply and Sanitation (WSS) services Ltd, 5 protected springs, 7 unprotected springs, Lake Karago and Nyirakigugu pond were sampled for bacteriological (faecal coliform) and chemical parameters (temperature, pH, conductivity, dissolved oxygen, nitrogen and phosphorus, manganese, iron, sodium, hardness, fluoride, chloride and pesticide). It was found out that most constituents are within the World Health Organization (WHO) guidelines for drinking water and the Food and Agriculture Organization of the United Nations (FAO) standards for agricultural use and aquatic life protection. Pesticides were not found in any of the samples analysed. Contamination by faecal coliform bacteria was noted in some samples and is attributed to the lack of appropriate sanitation facilities, and nutrients are most likely to originate in agricultural fertilizer applications (Water Supply and Sanitation Services, 2010).

No available data on the air quality in the Nyabihu district exists, but my opinion is that the concentration of volcanic gases in the atmospheric air cannot be negligible because the 2 active volcanoes, Nyiragongo and Nyamuragira, in the DRC are in the neighbourhood. In addition, further investigations are needed on possible evapo-transpiration because the Karisimbi region is covered by clouds most of the time. Furthermore, soil emission measurements of CO_2 and H_2S were carried out by BGR in 2008 and revealed values ranging from 0 to 236.7 mg CO_2 $m^{-2}day^{-1}$ and 0.01 mg H_2S $m^{-2}day^{-1}$ (Jolie et al., 2009). This suggests that the natural gas emissions are not negligible.

4.7 Relief and climate of the Karisimbi region

The area planned for the prospect is characterized by hilly terrain with a physiographic pattern of steep hills ranging from 1460 m to 4507 m at the Karisimbi summit. The region enjoys a moderate climate with an annual average rainfall of 1400 mm. Like all Rwanda territory, the region has four main seasons: a short dry season from January to March, a long rainy season from March to May, characterized by torrential rainfall, a short rainfall season from September to December and a long dry season from June to August. Only the long dry season is clearly distinguished. The high altitude of the area favours convectional rainfall in regions close to the National Volcanoes Park. The average maximum temperature varies between 22-26°C while the average annual temperature ranges between 10-15°C. The highest temperature occurs in the rainy season and the lowest temperature in the dry season.

FIGURE 13: Flooding in Nyabihu district in 2007

During and after the period 1990-1994 of civil war along the borders of Rwanda, Uganda and the DRC and the genocide in Rwanda, there was a considerable movement of people from Rwanda to neighbouring countries. After the genocide (1994-1998), more than 3 million refugees from the neighbouring countries came to Rwanda and caused a lot of changes in the environment. Firstly, intensive cultivation of steep hills took place where traditional tools were used without soil conservation techniques . Secondly, a lot of surface soil was removed for building houses and thirdly the inhabitants practised forest cutting for firewood and construction materials. The consequence was an area very vulnerable to erosion. The 2007 heavy rain accompanied by soil erosion, flooding, landslides and landslips claimed the lives of more than 20 people in the Nyabihu district and displacement of more than 562 from the villages of Mukamira and Bigogue alone (Figure 13).

4.8 The soil type and land use of the Nyabihu district

Northern Rwanda is characterized by three types of soil: volcanic soil (andisols and andosols), clay silt soil (alfisols) and transitional soil between andisols and alfisols. All these soil classes are fertile so that local people grow different varieties of plants.

The region is agriculturally productive; residents grow a few cash crops (pyrethrum, coffee) and food crops (Irish potatoes, maize, sorghum, corn and beans) and vegetables (cabbages, carrots, onions etc.) (Table 9). The majority of the arable land is occupied by pyrethrum plantations owned and processed

TABLE 9: Crop production in the Nyabihu District

Crop type	Land area (acres)	Yield (ton/acre/year)
Beans	6,357	2
Maize	3,786	1.8
Irish potatoes	6,012	32
Wheat	1,644	2.4
Peas	1,614	14.8
Coffee	137	0.65
Pyrethrum	200	250 (dry)

by the Rwandan Pyrethrum Society (SOPYRWA) which exports the plants for the production of insecticides. There are also small plantations of cypress and eucalyptus for firewood in the region.
Dairy farming is also practiced on a small scale. Cows are kept inside, addressing the constraints of a lack of grazing land, low productivity of dairy cows, low quality fodder and the prevalence of diseases. The northern region supplies potatoes to the whole country and the neighbouring regions in Burundi and the DRC.

4.9 Tourism in Rwanda´s National Volcanoes Park

The NVP is within the Nyabihu, the Rubavu and the Musanze districts. It was established in 1925. The park plays an important role in the economy of the country by attracting many tourists and researchers worldwide who come to see and track mountain gorillas. The tourism activity is controlled by the Department of Tourism and Conservation of the RDB. Foreign visitors to the NVP accounted for 92% in 2009. NVP is the busiest of the three parks of Rwanda accounting for 49% of park visits. The gorillas attracted 82% of the guests and other scheduled activities made up the rest (mountain climbing, viewing the golden monkey, Diane Fossey's tomb and natural walking). Each foreign guest pays USD 500 for a gorilla visit, a foreign resident pays USD 250 and a Rwandan national pays USD 35. The visits are limited to 56 per day (RDB, 2009). An annual ceremony is organized in Rwanda for naming gorilla babies, commonly known as *"kwita izina"* as a tool toward sustainable conservation, creating a partnership between the local community and all other stakeholders. Various government officials, diplomats, company representatives, conservationists and community advocates attend the event.

The Karisimbi geothermal area also has other tourism attractions such as: lava tunnels, Lake Karago and the Nyirakigugu pond, beautiful green vegetation, and mountains.

In 1967, Diane Fossey established the Karisoke Research Centre between Mt. Karisimbi and Mt. Visoke, with the main objectives of studying mountain gorilla behaviour and their protection, emphasizing the need for research and development and education and training of locals. She feared their extinction. Unfortunately she was killed in 1985. Due to a civil war in the region (1990-1998) and the 1994 genocide in Rwanda, the centre was destroyed and removed from the park to the nearby town of Musanze.

4.10 Socio-economic environment of the Nyabihu district

4.10.1 Population

The Nyabihu district is among the most populated districts of the country with a population density of 535 inhabitants per km^2. The population growth rate is estimated at 2.8% per annum. The population is dispersed in rural agricultural settlements, in family hamlets and in group settlements commonly known in the local language as *"imidugudu"* or villages. Currently the Government of Rwanda (GoR) has initiated a new policy of national settlement which recommends reassembling the population in villages for easy access to infrastructures such as schools, electricity, health centres and roads. The law on land also promotes land consolidation methods in which people pool their land for farming appropriate crops in order to increase soil production. The majority of the population consists of youths and women because the men are used to having 2 or more women, even though polygamy is prohibited in the constitution of Rwanda**.** This is also attributed to the civil wars and genocide that the country experienced (1990-1998) which claimed the lives of many more men than women.

Furthermore, the GoR encourages the population to reduce population growth by providing various means such as men's vasectomies, in addition to common family planning methods. The advantages of this solution over female sterilization includes lower rates of postoperative complications, shorter recovery time, reduced cost and increased involvement of men in reproductive decision-making. Table 10 gives a breakdown of the population in the sectors bordering the Karisimbi geothermal prospect.

TABLE 10: Population of sectors bordering the Karisimbi prospect (Mariita, 2010)

Nyabihu District		**Rubavu District**	
Sector	**Population**	**Sector**	**Population**
Kabatwa	16921	Bugeshi	26921
Bigogwe	30575		
Jenda	28731		
Total	**76227**		**26921**

4.10.2 Public health and sanitation in Karisimbi area

There are 5 health centres in the four sectors of the study area while there is 1 hospital and 16 health centres in the whole district. The common diseases are malaria, respiratory track diseases, diarrhoea, skin rashes, amoebic dysentery, headaches and cholera. Most of these diseases are due to poor hygienic conditions, a poor sanitation infrastructure at household level, and poor water quality. A new policy on mutual health insurance has been set up and every citizen pays RWF 3000 per year (equivalent of USD 5) in order to benefit from medical treatments everywhere in the country. This policy facilitates access of vulnerable groups of people, to health care at a low price. Furthermore, plans exist to supply the population in the northern regions with drinking water as well as to improve hygienic conditions and work on birth control issues. Sanitation facilities are limited, usually only a small pit latrine less than 3 m deep, because of difficulties in digging into lava rocks. This causes the rapid transmission of contagious diseases. Septic holes, that might pollute groundwater, are in use in schools and large institutions.

HIV prevalence in the area is 1.4% while the rural area's average in Rwanda is 2.5%. HIV/AIDS is the third most lethal disease after malaria and respiratory diseases (NISR, 2010). Efforts are in place to make free anti retrovirus medication available to HIV infected people countrywide. Anti-retroviral therapies are also given to HIV pregnant women for preventing HIV transmission to children while giving birth. The key issue is the encouragement of rural people to change their sexual behaviour and use preventative methods (condom use, abolition of polygamy and abstinence). These family planning campaigns and HIV prevention measures involve, in all cases, local leaders, women, youth and religious representatives.

4.10.3 Education in the Karisimbi area

The Nyabihu district has 87 public primary schools and 22 secondary schools, parts of the 9 year basic education (9YBE). However, 3 higher learning institutions are found in neighbouring districts: the Kigali Independent University Campus-Gisenyi in the Rubavu district, the High Institute of Agriculture and Animal Husbandry (ISAE) and the Catholic Institute of higher Education (INES-Ruhengeri), both in the Musanze district.

The GoR promotes the construction of two nursery schools in each small administrative unit called cells. The ratio of teachers to pupils per nursery school is 1:43. The 9YBE education is now obligatory for every child and is free. In the last ten years the percentage of boys in primary and secondary schools has been high compared to girls, while 52-56 % of Rwandan people are women. The traditional culture bound women to household activity and child care but the mentality has changed now and the number of girls enrolled in primary and secondary schools has increased. It is the result of the 2003 constitution empowering women, promoting gender equality and putting women into decision making organisations and institutions.

To fight illiteracy, all old people in rural areas who did not attend schools are taught reading and writing through catch-up programmes in each cell.

4.10.4 Infrastructure

The Karisimbi geothermal field is close to a densely populated area, located 150 km from Kigali, the capital city of the country and 5 km from the main international tarmac road of Kampala-Kigali-Goma (DRC) (Figure 14).

FIGURE 14: Map showing Rwanda road network from Kigali to Karisimbi area

Cheap public transport is run by the National Office of Transportation (ONATRA-COM) subsidized by the GoR. However, private transport companies provide their services on the main road at a price set by the Rwanda Utility Regulatory Agency (RURA). For accessing the prospect, a 5 km dirt road was built out of compacted lava rocks and is convenient for motorcycles and transport trucks.

The existing electrical power lines of the Karisimbi integrated communication project traverse the prospect and residents benefit from electrical energy for house lighting. Like in the whole country, the main source of energy is biomass which is used in the form of firewood or charcoal. For reducing the pressure on forest cutting, improved cooking stoves are being utilized by a part of the population. Peat briquettes and bio gas digesters are deployed in secondary schools.

In summary, the environmental information on the Karisimbi geothermal field (20 km^2), covering a part of four administrative sectors (Kabatwa, Bugeshi and, Jenda and Bigogwe) is characterized by high population density. The drill sites are situated in farm-land owned by local people and the Rwandan Pyrethrum Society. The area is rural and the access to electricity and potable water is low compared to the national average. The predominant diseases are waterborne, related to poor sanitation and water quality. The area is characterized by steep slope mountains.

5. DESCRIPTION OF PROJECT ACTIVITIES

This section gives a detailed description of the drill pad and the activity required prior to drilling the three exploration wells, but does not include results of geo-scientific studies carried out previously. The main focus here will be on drill-site preparation, the water supply for drilling as a prerequisite for initiation, the access road to the drill sites, drilling activities, transportation and well testing. It is planned to install a well head generation unit of 10 MWe if the resource is found to be sufficient, and a skid mounted installation. These will be described in an EIR before the prefeasibility study.

5.1 Access road to the drill pad and the layout of the camp sites

The road connecting the prospect to the main tarmac road (Kigali-Rubavu) will be maintained, compacted and widened with drainage channels to ease the traffic circulation of heavy trucks.

The three wells will be drilled from separate drill pads. Therefore, 3 drill sites are needed. If we assume a drill pad size of 50 m × 80 m per well, 12,000 m^2 is needed for 3 wells. One camp site 50 m × 50 m is sufficient for the rig crew during 6 months of drilling. A space of 4000 m^2 is needed for cement storage and mixing (120-200 tons), mud and drilling materials' accessories. If it is assumed that the drill sites are 1 km apart, 2 km of 4 m wide new roads will be created for drill rig displacement (8000 m^2). In total, civil works will require a land space of 2.5 ha. The area is heavily populated; each household is assumed to own 0.4 ha of land and is made up of 6 family members. In total, 6 households of 36 people are expected to be relocated and compensated.

5.2 Water for drilling

In geothermal drilling the following different types of fluids are used: water, mud, aerated water and foam. The drilling fluid has the following main functions:

- Clean and remove cuttings from the hole;
- Cool and lubricate the drill bits;
- Maintain the stability of the borehole;
- Control pressure in the formation;
- Allow the collection of geological information;
- Protect formation zones from any damages;
- Provide power to downhole motors in the case of directional drilling.

In geothermal drilling, water is also used in a cement slurry formulation which is the reason why the water chemistry must be known.

The plan is to drill 3 geothermal wells to 3,000 m depth. That means that the water quantity required, assuming an average of 60 days per well and 3600 litres/min in total, will be:

$$WQ = \frac{3600\ l}{min} * \frac{60\ min}{hour} * \frac{24\ hour}{day} * \frac{60\ day}{well} * 3\ wells = 933{,}120{,}000\ l \qquad (1)$$

where WQ = Water quantity.

This means that a total volume of 933,120 m^3 water is required for drilling the 3 wells. Furthermore, completion testing and injection testing may require up to 10,000 m^3 per day (Nyakecho, 2008). The water will be pumped from Lake Karago (0.27 km^2, 6 m depth) to Kabatwa village at an estimated distance of 20 km (Figure 15). A water storage tank will be constructed on the summit of Kabatwa mountain and water transport will be conducted to the drill rig by gravity.

Drilling mud is used for smooth drilling for the first few hundred meters that are used for the installation of the surface casing. The drilling mud is made up of three principal components (Finger, 2010):

1. *Basic liquid:* **(**oil, salt water and fresh water);
2. *Active solids:* bentonite clays and polymers added to the water to make a colloidal suspension (called viscosifiers);

3. *Inert solids:* To increase the density of the mud without affecting the viscosity (e.g. particles of the formation or barite (if a large flow needs to be quenched).

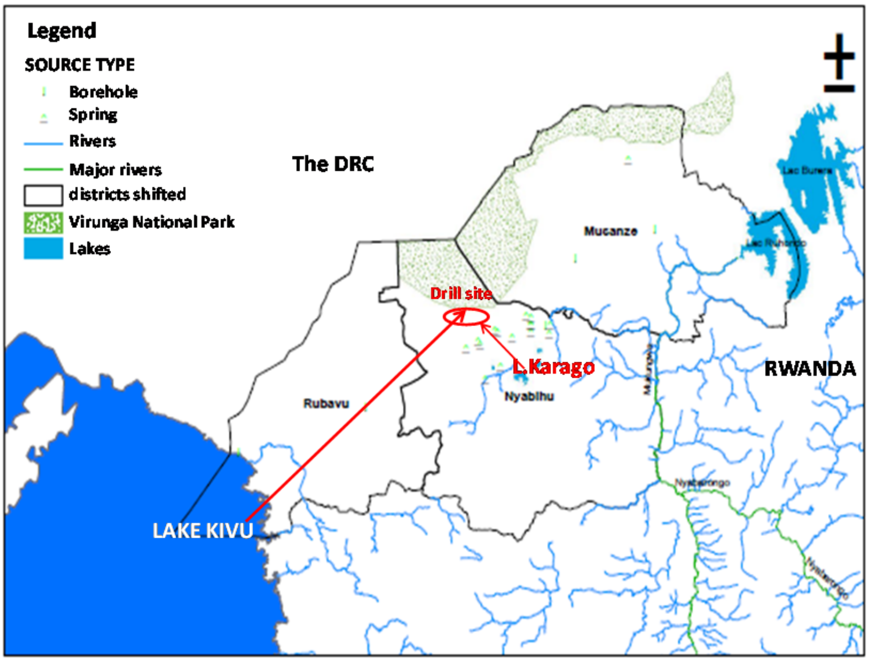

FIGURE 15: Two sources for water for drilling (Lake Karago and Lake Kivu)

There are three options for obtaining water needed for drilling: (1) from Lake Karago, (2) from Lake Kivu, (3) by drilling groundwater boreholes. Analysis of the three possibilities showed that the most feasible was to get water from Lake Karago, because Lake Kivu is far away from the site (more than 50 km), and there is no data confirming availability by drilling groundwater boreholes.

Even though drilling technology may involve recycling of the drilling fluid, a large quantity of wastewater will be discharged. Hence, a specific pond is required for not polluting groundwater or directly discharging wastewater into the environment without any pre-treatment.

5.3 Transportation

The prospect is located in a rural area; the population is not familiar with much traffic. Nevertheless, heavy trucks transporting drilling materials and vehicles transporting the staff to the site will be evident in the region. The rig will also be mobilized and demobilized three times within the expected time of the project (6 months); this requires reinforcement of road security in order to avoid traffic accidents and to maintain roads and bridges. Security measures should apply when moving the rig from a completed well to a new site.

5.4 Drill pad

The three exploration wells will be drilled using a large rig of 300 tons of hook load. The area must be cleared of vegetation, levelled and compacted to accommodate the rig. Diesel for generators and some lubrication oil and drilling mud will be transported to the site. Figure 16 represents the schematic set-up of a drill rig.

5.5 Cementing and casing

When wells are drilled to depths of more than a few hundred meters, the conventional casing practice is to set successive, separate strings of casing as the well gets deeper. The parameters determining casing design are: nominal production rate, rock properties, casing diameter, flow rate, depth to the

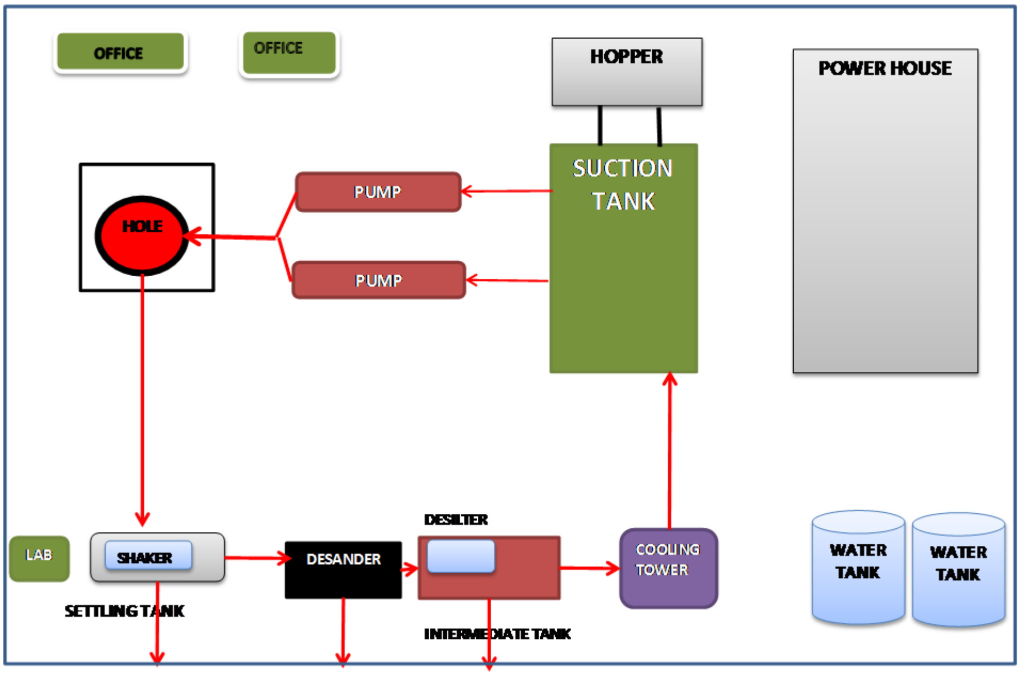

FIGURE 16: Schematic set up for a drill rig (adapted from Thórhallsson, 2011)

production zone, chemistry of the brine, expected temperature, well trajectory, kick off point if drilling is directional, length of individual casing intervals etc. (Finger and Blankenship, 2010).

The roles of casing in a particular interval are:
- Protect an aquifer from contamination by wellbore or drilling fluids;
- Provide well control in case a kick is taken;
- Isolate troublesome formations;
- Control fluid pressure;
- Define the production zone.

The provisional casing program is as follows:
- Surface casing, 26'' diameter holes, depth 60 m;
- Anchor casing, 17½'' diameter hole, depth 300 m;
- Production casing, 12¼ diameter hole, depth 1200 m;
- Production liner (open hole), 8½'' diameter hole to a nominal measured depth of 3000 m.

The cement plays a role in giving the casing mechanical support under its sometimes intense thermal cycling between production and shut-in, and to protect the outside of the casing from corrosion by in situ fluids.

5.6 Well testing and reservoir monitoring

Geothermal well testing and evaluation involve various measurements aimed at gathering information on well characteristics and production potential as well as reservoir properties and conditions. This also includes well stimulations with the purpose of enhancing the output of new productions wells or of existing wells. Well testing plays a key role during exploration drilling, production well drilling, well maintenance and geothermal field monitoring. For exploration wells, the 3 main activities involved in well testing are (Nicholson and Vetter, 1981):

1. *Temperature and pressure logging:* at all depths to determine the physical state of a reservoir, locate feed zones and determine well conditions. The logging is carried out with the well flowing or shut in.

2. *Well test design:* This involves single-well tests, such as injection tests, flow or pump-tests as well as multi-tests, such as interference tests. The main purpose is to estimate reservoir properties and well characteristics.
3. *Well stimulations:* This involves cold water injection, often at a high flow-rate, aimed at high-pressure and / or thermal stimulation, as well as chemical stimulation. Down-hole packers are commonly used during such operations.

5.7 Geothermal power plants

Geothermal power plants are classified into three types according to the types of turbines used: back pressure, condensing (single or double flash) and binary power plants for cooler liquid. Producers have used different types of discharge for different types of turbines although it is common to use single flash for the discharge of vapour-dominated or two-phase flows, double flash for relatively hot and abundant liquid dominated flows, and binary power plants for lower temperature resources. Figure 17 represents a sketch of a single-flash cycle condensing plant as an example of a geothermal power plant.

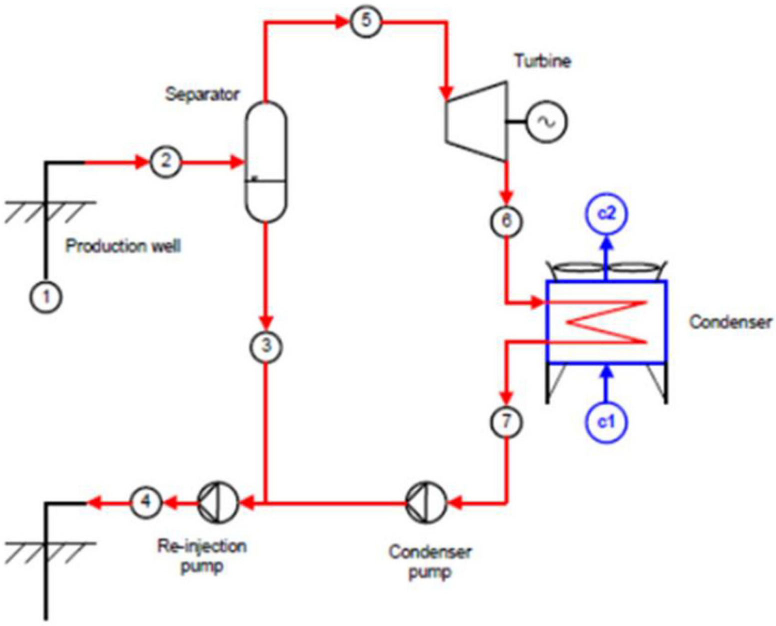

FIGURE 17: A single-flash cycle geothermal plant

If exploration wells are successful, appraisal wells for delineating the reservoir boundary are drilled, and finally production wells. Engineering design is based on the energy content and type of fluid.

The main components of a binary geothermal power plant are (Valdimarsson, 2011):
- Wells and separator;
- Vaporizer;
- Turbine converts a part of the vapour enthalpy to shaft work and then electricity in the generator;
- Recuperator is a heat exchanger between the hot exit vapour from the turbine and the condenser;
- Condenser, a heat exchanger between the hot vapour from the generator/turbine and the cooling working fluid of the cycle which may be either water or air.

6. POSSIBLE ENVIRONMENTAL IMPACTS AND MITIGATION

6.1 Environmental impacts

Environmental impacts due to geothermal exploration and development vary depending on the nature of the source, for example the utilization of high temperature systems has more environmental impacts than low temperature systems. The nature and magnitude of environmental impacts depend also on the type of fluid, i.e. whether it is liquid dominated (condensing power plant if the temperature is high enough), binary power plant if the temperature is less than 200°C), vapour dominated or dry steam. On the other hand, binary plants using higher temperature fluids are known, e.g. Olkaria 3 of Orpower in Kenya. The chemistry of the fluid also varies from one geothermal prospect to another and the site topography and meteorological conditions are important.

Impacts from surface exploration are quite minimal; they gradually become more pronounced during exploration and appraisal drilling and become significant in the power plant design and construction phase (Haraldsson, 2011). Production from high-temperature and low-temperature systems involves drilling wells to depths of 500-2500 m. The following section gives, in detail, the main negative environmental impacts associated with exploration drilling and geothermal development.

6.1.1 Impact on the water quantity of Lake Karago

Lake Karago is a small lake (0.27 km^2 surface area and an average depth of 6 m) experiencing siltation from the surrounding steep hills that reduces its depth. To pump about 1 million m^3 of water from that lake will most likely affect the biodiversity of the lake if drilling is carried out during a dry season. Lake Karago has four inlet streams (Nyamukongoro, Gihigwa, Kabusoro and Ntosho) with a total flow rate of 0.8 m^3/s and one outflow channel of 0.6 m^3/s. The calculation of the mass balance of Lake Karago has shown that it is only possible to get water for drilling from Lake Karago if the outlet channel is closed as almost half of the lake water will be needed. Lake Karago is an artificial lake resulting from flooding; the outlet channel from the lake was created to avoid damage to bordering houses of the military camps. However, the lake is among the tourism attractions of the Nyabihu district. It is used for drinking water, swimming and fishing.

6.1.2 Access and field development

The construction of access roads to the drill sites will involve the destruction of forest land and vegetation which, in that region, along with high rainfall intensity can result in erosion. This can lead to a large amount of silt being carried away by streams and rivers, draining the exploration area. New roads connecting drill pads will be built and compacted for facilitating rig movement from the site after well completion. The widening of an unpaved road from the highway to the drill site will also need the acquisition of land from residents.

6.1.3 Noise

Excessive noise from geothermal plants is typically considered during three phases: the drilling and testing phase, the construction phase, and the plant operation phase. Drilling creates noise, fumes and dust which can disturb animals and humans living nearby.

The high level of noise may cause hearing impairment, hypertension, ischemic heart disease, annoyance and sleep disturbance. Changes in the immune systems for the worse and birth defects have also been attributed to exposure to noise. The noise shall not exceed 65 DBA at a distance of 0.8 km from geothermal operations (Hunt, 2001; Table 11).

TABLE 11: Noise from some drilling activities (Hunt, 2001)

Activity	Noise level (dBA)
Air drilling	120 (85 with suitable muffling)
Discharging wells after drilling	Up to 120
Well testing	70-110 (if silencers used)
Heavy machinery	Up to 90
Well bleeding	Up to 85 (65 if rock muffler is used)
Mud drilling	Up to 80
Diesel engine (to operate compressors and electricity)	45-55 (if suitable muffling is used)

The noise comes mainly from drilling activity, but is temporary and rarely exceeds 90 dB; the noise from discharging boreholes may exceed 120 dB (Kristmanndóttir and Ármannsson, 2003). The recommended environmental noise limits in Indonesia for new developments are 55 dBA (day time) and 45 dBA (night-time) for residential, institutional and educational receptors while for industrial and commercial receptors the threshold limit is 70 dBA (day and night) (PGE, 2011).

6.1.4 Air pollution

The major gases emitted from geothermal wells and power plants are carbon dioxide (CO_2), hydrogen (H_2), nitrogen (N_2), Argon (Ar), hydrogen sulphide (H_2S) and methane (CH_4). H_2S can react with atmospheric oxygen to form sulphur dioxide (SO_2) which can lead to acid rain; this is a photochemical reaction that takes place under dry sunny conditions. In wet weather, it is usually washed to the ground and may form solid sulphur. H_2S is the greatest concern because of its unpleasant smell and toxicity, even at low concentrations (Table 12). Geothermal power plants do not emit NO_x, but geothermal gas may contain ammonia (NH_3) and trace amounts of mercury (Hg), Boron (B) and radon (Rn). Inhalation of mercury causes neurological disorders; Boron is a phytotoxic at low concentrations and this is critical in areas of fruit growing and wine making. It is proven that ammonia can cause irritation to eyes, the nasal passage and the respiratory tract at concentrations ranging from 5 to 32 ppm (Hunt, 2001).

TABLE 12: Human health effects at various hydrogen sulphide concentrations (WHO, 2003)

Exposure		**Effect/observation**
(mg/m^3)	**(ppm)**	
0.011	0.00781	Odour threshold
2.8	1.988	Bronchial constriction in asthmatic individuals
5	3.55	Increased eye complaints
7-14	4.97-9.94	Increased blood lactate concentration, decreased skeleton muscle citrate synthase activity, decreased oxygen uptake
5-29	3.55	Eye irritation
28	20.59	Fatigue, loss of appetite, headache, irritability, poor memory, dizziness
>140	>99.4	Olfactory paralysis
>560	≥397.6	Respiratory distress
≥700	≥497	Death

The conversion factor for hydrogen sulphide in air is 1 mg/m^3 = 0.71 ppm (20°C, 101.3 kPa).

H_2S is produced naturally and as a result of human activity. Natural sources account for about 90% of the total hydrogen sulphide in the atmosphere. Tolerable concentrations of H_2S in air are 100 µg/m^3 (71 ppb) and 20 µg/m^3 (14.2 ppb), respectively, based on respiratory effects for short-term (1-14 days) and medium inhalation exposures (exposure duration of up to 90 days). The health effects of short-term exposure of animals to H_2S include ocular, cardio-vascular, neurological, metabolic, hepatic and developmental effects (WHO, 2003).

Geothermal gas may be emitted during well drilling, flow testing, via open contact condensers and cooling tower systems. On the other hand they may be pumped out of the condenser and re-injected into the reservoir. Well field and plant site vent mufflers can also be a potential source of H_2S emissions.

Particulate matter may cause eye irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, and cardiovascular diseases. Geothermal power plants emit a small amount of particulate matter from cooling towers when steam is evaporated as a part of the cooling cycle. However, the amount of particulate matter is quite small compared to that from coal or oil plants (Kagel et al., 2007).

Furthermore, traffic and generator pollution is expected during the period of drilling activity and power plant construction. The primary pollutants produced by internal combustion engines are carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC), lead (Pb), and particulate matter. The principal secondary pollutant of concern is ozone (O_3) which forms in the presence of sunlight and the primary pollutants (Nikolaou et al., 1997).

6.1.5 Solid and liquid wastes

Solid wastes discharged from a geothermal power plant are not hazardous. However some pollutants can be found in the liquid or solid phases, such as arsenic. The primary wastes due to geothermal operations are bentonite drill cuttings. The non-geothermal waste is recycled or reutilized.

Geothermal fluids may contain environmental pollutants such as zinc (Zn), manganese (Mn), lithium (Li), and radioactive elements. Some geothermal fluids are hypersaline brines which can cause direct damage to the environment.

Arsenic, as an element produced in the earth's crust, can be emitted during volcanic eruptions or found in some geothermal systems. It is known to cause cancer, lung irritation, nausea, abnormal heart rhythm, damage to blood vessels and skin pigmentation abnormalities. If arsenic in relatively high concentrations is present in a geothermal system, it may end up in solid form in the sludge and scales associated with production and hydrogen sulphate abatement.

Silica is found in the effluents, or treated wastewaters, that are the by-products of drilling into some resources. It is not considered an environmental risk but silica is typically dewatered, and the silica sludge is disposed of offsite.

The problem is not only the large volume of water discharge; it is also the hot water. The release of hot water into a waterway may kill fish and plants near the outlet. Even though the temperature change is small, it may have a profound effect on an ecosystem as different species have different temperature sensitivity. Similarly, chemicals dissolved in the water may affect aquatic ecosystems. However, the technology of re-injecting the brine reduces environmental impacts. Furthermore, to release the geothermal fluid into a waterway and/or a cooling pond can contaminate shallow groundwater, causing it to become unfit for human use (Kagel et al., 2007).

6.1.6 Landscape

Geothermal power stations can be designed to blend with their surroundings by avoiding long steam gathering pipelines. Even though the Karisimbi prospect is located in productive farm land, it is known that geothermal power plants minimize the total amount of land used by only building the plant along with the number of well pads needed to support the operation. The key visual quality effects are the presence of steam plumes, night lighting in the well field and power plant and visibility of the transmission lines (Figure 18).

FIGURE 18: View of the Karisimbi area in February 2011

The land footprints for geothermal power plants vary considerably from site to site because the properties of the geothermal reservoir fluid and the best options for waste discharge (usually re-injection) are site-specific. The well fields cover a considerable area, 5-10 km^2 or more; the well pads themselves cover about 2% of the area; directional drilling minimizes the well pad area. The steam gathering pipes are usually mounted on stanchions, so that most of the area can be used for farming, pasture, or other compatible use.

6.1.7 Land subsidence

Subsidence is a slow downward sinking of the land surface when the extraction of fluid exceeds the natural inflow. In that case, the reservoir pore pressure reduces the support for the reservoir itself and the rock underlying the reservoir, potentially leading to slow and downward deformation of the land surface. The key factor is the nature of the surface layers. Clays will contract and give rise to extensive subsidence whereas lavas do not contract, and give rise to minimal subsidence. Mass removal tends to be greater from liquid dominated rather than vapour dominated systems; thus, the former are prone to greater subsidence.

Subsidence occurs in areas where the geothermal reservoir is hosted by a weak, porous sedimentary or pyroclastic formation. However, natural subsidence can occur in geothermal systems as most of them are located in tectonically active areas without any fluid extraction. Other types of ground deformations are inflation (upward motion) and horizontal movement (Kristmannsdóttir and Ármannsson, 2003). For example at the Wairakei geothermal area in New Zealand, a horizontal movement of 75 mm/year and a vertical movement of 130 mm /year occurred in two of its zones (Bixley, 1984). The major problems affected by subsidence are steam pipelines from the production field to the power house and the channels carrying separated geothermal water to waste. A total area of 30 km^2 was subsiding there by more than 10 mm/year (Kagel et al., 2007).

6.1.8 Landslides

In high relief and terrain, landslides are potential hazards. Landslides are caused by a combination of events or circumstances rather than a single specific event. A landslide can be triggered by construction operations and local geological conditions. Landslides rarely occur but may have severe effects as happened in Guatemala where 23 people were killed in 1997 (Hunt, 2001). If such events take place where a power plant is built, they would cause serious catastrophes.

6.1.9 Seismicity

Geothermal development can cause micro-seismic activity, particularly during production and more extensively during reinjection. Most high temperature geothermal systems lie in tectonically active regions where a high level of stress in the upper parts of the crust is manifested by faults. It has been shown that micro-seismic activity is more likely caused by re-injection than mass removal.

6.1.10 Hydrothermal eruptions

Hydrothermal eruptions constitute a potential hazard in geothermal exploration in liquid-dominated high-temperature systems. They occur when the steam pressure in a near surface aquifer exceeds the overlying lithostatic pressure and the overburden is then ejected and may form a crater 5-500 m in diameter and up to 500 m deep. A hydrothermal explosion occurred on 13 October 1990 in the Agua Shuca fumarole area (El Salvador) and killed close to 20 people nearby (Barrios et al., 2011).

6.1.11 Social and economic impacts

A new geothermal development project in a specific area causes some changes in the daily life and habits of the population. It may become difficult to get social acceptance for a project in the short run despite short term benefits to the community. It is better to start with smaller projects, to acquaint the local population with the presence and benefits of a new energy source, than to go immediately into completion of large projects. This is also desirable from the point of view of the development of the plant. The GoR envisages starting with a small well head generation unit of 10 MWe, followed by the development of a big power plant, depending on geothermal reservoir capacity.

The short term socio economic impacts expected are population displacement, land acquisition and resettlement of evacuated people. The most plausible benefits are casual job creation during the drilling period and improvement of roads. It will also be an opportunity for the local population to sell their agricultural products. The contractor will be requested to hire local employees, except for tasks for which local expertise does not exist.

If an example of drilling activity in an East African Country like in Kenya is taken, about 150 people would be hired to work in connection with one drill rig. However, priority would be given to local people for casual jobs and remuneration would be based on national regulations. Only the rig crew would be provided by a drilling company while geothermal staff of the Energy, Water and Sanitation Authority (EWSA) would earn their normal salary according to the national labour regulations. It is expected that all casual staff would work for six months for the completion of 3 exploration wells. It is anticipated that appraisal wells and production wells would be drilled later, depending on exploration results and the availability of funds.

The drilling activity would not require additional houses because the drill crew would have a camp site while other employees would be accommodated in the neighbouring towns of Musanze and Rubavu. Land acquisition and expropriation would be effected prior to drilling with respect to the National Land Law. Land compensation would be paid to the people by the Ministry of Infrastructure in collaboration with district authorities.

The long term benefits of geothermal development would come when the resource is confirmed. Among them are: (a) increased power supply to the national grid which would replace expensive and environmentally unfriendly fossil fuel, (b) reduction of electricity cost and promotion of business and economic growth, (c) job creation and capacity building of Rwandese nationals in geothermal sciences and engineering, (d) improvement of infrastructure for development within the area, (e) the Government of Rwanda shall benefit from carbon credits because of a reduction in carbon emissions, etc. (Mariita, 2010).

6.1.12 Public health and safety

Many people will move from different regions into the Karisimbi area, the majority being males who might carry contagious diseases. Most of the staff will be far from their families for a long period of about 6 months and would interact with the local population. They will have a lot of money compared to the local people so that they could conquer young ladies in exchange for money. This may favour prostitution and consequently an increase in sexually transmissible diseases and HIV/AIDS. Hence, the contractor shall provide the drilling personnel with preventive measures such as condoms.

As with other power production facilities accidents such as well blowouts, turbine failures, and fires, can take place during various phases of geothermal activity.

The contractor has the responsibility to minimize the likelihood of accidents to project workers whether directly employed or subcontracted, especially accidents that could result in lost work time, different levels of disability or even fatalities. Workers should be provided with a fact sheet or other readily available information about the chemical composition of liquid and gaseous emissions with an explanation of potential implications to human health and safety.

6.1.13 Impact on mountain gorillas

Exploration drilling will be carried out in the vicinity of the National Volcanoes Park; the most probable threat to mountain gorillas will be the noise and geothermal gases. Of the gases, H_2S is most likely to cause problems because of its unpleasant smell. The response of mountain gorillas to noise and H_2S smell is completely unknown because such a project has never been developed in a mountain gorilla habitat. But, in Hell's Gate National Park of Kenya, baboons, gazelles and buffaloes adapted to geothermal development activities (Mariita, 2010). The wind speed measurements from the 2 neighbouring meteorological stations of Ruhengeri and Gisenyi give an average wind speed of 21.6 km/hour and 46.8 km/hour, respectively. The wind direction varies between north, northeast and northwest.

Human disturbances to mountain gorillas during exploration drilling are not expected, but well testing activities and gas emissions may affect, directly or not, the two social groups of gorillas living in Karisimbi. In this study, the noise and pollution tolerances considered are for human beings; no guidelines for the mountain gorillas are available.

The release of geothermal gases into the atmosphere may change the ambient air quality and affect mountain gorillas. Well discharging and testing activities will destroy vegetation and change the view of the area. The use of silencers may reduce the effects. However, the magnitude of impacts during exploration drilling is minimal compared to power plant operation.

The noise may cause mountain gorillas to migrate further away from the site.

6.2 Mitigation measures

This section presents the mitigation measures proposed to overcome the above environmental impacts due to geothermal exploration and development in the 3 sites in Karisimbi:

Access and field development: Destruction of vegetation and forests, from construction of access road to drill site and site preparation, may be minimized by planting fast growing trees which bind soil and planting grass crops or low vegetation to reduce soil erosion. After well completion, it is desirable to restore the site with the soil removed before drilling.

Social aspects: Local authorities will be contacted before the general public becomes aware of the planned activities. The purpose of the project has to be explained to and appreciated by them; long term costs and benefits need to be listed in detail. All potential stakeholders such as environmental groups, park management institutions, and local community groups need to be informed on the operations planned and their implications, risks and benefits during regular public meetings and briefings. Close collaboration with the local population and provision of honest answers to their questions and concerns are essential, accompanied by educational activities for the general public and schools (Engine coordination action, 2008).

Noise level: Noise inevitably occurs during exploration drilling, construction and production phases of geothermal development. Air drilling is the noisiest (120 DBA). Therefore, suitable muffling and noise constraining operations such as tripping or cementing during daytime may be used. Various measures are taken during drilling if muffling is required: drill rig engines may be kept inside enclosures, rubber mats distributed widely within the rig, and a sound muffling cap made to cover the mast. Construction of screens of sound absorbing material such as vegetation can reduce the impacts of drilling noise. During well discharge, the use of silencers reduces the noise level. Well discharge is the noisiest phase of geothermal development and can take up to 30 days per well but often much longer. But, in some places, this time is cut down to about a week. This time can be cut in order to reduce noise effects on the local population and the mountain gorillas. The noise protection barriers at the drill site reduce the noise level while the use of a relatively silent drill rig can also mitigate.

Liquid and solid waste disposal: It is not acceptable to release liquid wastes from geothermal drilling immediately into a waterway. It is better to use a minimal quantity of drilling fluid and recycle it as extensively as possible. In difficult situations, the construction of flocculation ponds is mandatory for settling particulate matter from the fluid and the sludge is subsequently disposed of separately into a liquid phase. However, preliminary studies might be carried out in advance, to find out how to prevent the contamination of groundwater. Solid wastes generated during geothermal exploration are drill cuttings and mud which could be stored in a sump for disposal. Sumps provide secure storage for drilling mud and cuttings as they are lined with impervious materials to prevent leaching.

Safety and public health: The drilling contractor should provide personnel and visitors on site with personal protective equipment as follows (Bassett and Davies, 1995):

1. *Hearing protection:* earplugs or ear mufflers;
2. *Respiratory protection:* respirators and/or breathing apparatus;
3. *Eye and face protection:* goggles, visors, spectacles, face screen etc.;
4. *Protective clothing:* safety footwear, overalls etc.

It is desirable to reduce work time at elevated temperatures and to ensure access to drinking water. The contractor should be asked to shield surfaces with which workers come into close contact such as hot equipment, pipes etc.

The drill crew will reside in a camp site but will interact with the local population. The drill crew and locals should be informed on Sexually Transmissible Diseases and HIV/AIDS and provided with condoms. MININFRA and the municipality have to inform and mobilize the population on project activities during meetings even before drilling starts. After completion of the 3 wells, the camp site will be demobilised and the rig crew will leave the country. The project operators have to work closely with various HIV/AIDS organizations working in the project zone of influence in order to achieve the best results.

Gas emissions: Gas emissions from geothermal power plants are negligible compared to those of fossil fuel combustion-based power plants. H_2S and mercury are the main potential air pollutants associated with geothermal power generation. CO_2 is the major geothermal gas and, even though its emissions are smaller than from fossil fuel plants, it is quite significant and needs to be monitored. Mercury (Hg) is usually in very small concentrations and a substantial part may stay in the liquid fraction.

The most effective method for reducing geothermal gas emissions is re-injection of the brine or non-condensable gases into the formation. If re-injection is not deployed, H_2S and non-condensable mercury are vented. If necessary, abatement systems to remove H_2S and Hg emissions from non-condensable gases can solve the problem. The principle of the method is that in the absence of significant moisture, hydrogen sulphide reacts with an oxidizing agent to yield elemental sulphur and hydrogen halide gas. For mercury, gas stream condensation with an additional separation or adsorption method is convenient (IFC, 2007; Gallup, 2003).

Lake Karago: Since the water for drilling would be pumped from Lake Karago, it is desirable to record the long and short term hydrological variabilities of Lake Karago and ensure that water requirements for aquatic life are maintained. A calculation of the mass balance of the lake must be carried out before constructing abstraction intake equipment. Water for drilling must be recycled as much as possible to minimize the pumping of water from the lake.

Hydrothermal eruptions: Reservoir pressures must be maintained, steam formation minimized, building on or excavating in active thermal ground avoided, and the risk of hydrothermal eruptions minimized.

Subsidence and landslides: Subsidence and other ground deformations are mostly the result of reservoir response to mass withdrawal during production. When subsidence is linked to a pressure drop in the reservoir, re-injection of the brine after electricity production mitigates the issue (Kristmannsdóttir and Ármannsson, 2003).

The risk of landslides can be minimized by carrying out detailed hazard mapping, groundwater assessment, deformation monitoring, and setting up warning signs amongst other management techniques. Landslides are most likely to take place during production and are not expected during exploration drilling.

Landscape: For management and the reduction of visual impacts, detailed site planning, facility design, material selection, a re-vegetation program and adjustment to transmission line routing are required. Other visual impacts such as construction equipment, drilling rigs and materials, vehicles and other heavy equipment are only temporary.

For minimizing the number of drill sites, directional drilling for production wells is recommended during which 4 to 8 boreholes can be grouped to one platform and wellheads placed in semi hidden buildings (Geirsson and Hrólfsson, 2010).

Tourism: The drilling activity will change the visual aesthetic value of the project area but will not affect the National Volcanoes Park as all 3 boreholes will be outside it but in the vicinity of the park. But in the future, the habitat of mountain gorillas will be destroyed if the drilling is carried out within the park. Geothermal power plants have been constructed in national parks in many countries, for example Olkaria I (45 MWe), Olkaria II (105 MWe), Orpower Olkaria III (48 MWe), and the commissioned Olkaria IV (140 MWe) is expected in 2013; all are located in Hell's Gate National Park in the Rift Valley of Kenya. Despite the reduction in the total number of tourists in Kenya, the geothermal power plants in the Hell's Gate Park have contributed to an increased number of visitors who come to watch wild animals in the park, the geothermal facilities and surface manifestations (KenGen and GIBB, 2010).

6.3 Environmental monitoring plan

Environmental monitoring is important for the purpose of stopping or moving forward a project. The monitoring must be incorporated from the drilling phases because the discharge of any drilling fluid and geothermal fluid into surface water or into the atmosphere may have serious environmental and social effects in the area. The following measures should be considered:

- Installation of an H_2S monitoring network with the number and location of monitoring stations determined through air dispersion modelling, taking into account the locations of emission sources and the area of community use and the habitation of mountain gorillas;
- Monitoring temperature differential of effluent and receiving water bodies and compliance with Rwanda regulations with respect to thermal discharge;
- Assessing hydrological records for short and long term variability;
- Monitoring the response of mountain gorillas to geothermal well discharge and noise;
- Monitoring of rainfall for chemical pollutants from the commencement of drilling activity to well testing completion;
- The monitoring team made up of Rwanda Development Board (RDB), the Ministry of Infrastructure, the Energy Water and Sanitation Agency (the developer), the Rwanda Utility Regulatory Agency (RURA), Rwanda Bureau of Standards (RBS), the Ministry of Natural

Resources, Rwandan Natural Resources Authority (RNRA), Rwanda Environmental Management Authority (REMA), and Karisoke Research Centre should monitor the flora and fauna in the National Volcanoes Parks;
- If the resource is proven, the feasibility study will be carried out before the design of a wellhead generation unit. The parameters to monitor must include but are not limited to geological formations (seismicity), landslides, subsidence, land use, drinking water and aquatic life protection, air quality standards, noise standards, solid waste disposal and reuse, and waste heat.

7. CONCLUSIONS AND RECOMMENDATIONS

Environmental impacts of geothermal power generation and direct use are generally controllable and relatively small. Exploration drilling must comply with the environmental legislation in Rwanda. The monitoring programme must be integrated into all steps of project implementation. Rwanda as a signatory of the treaty on biodiversity and conservation of its habitat has to avoid drilling activity in the park. The Virunga Volcanic Range (VVR) holds a large variety of threatened species of mammals, reptiles, birds, amphibians and plants among which 24 species are listed by the International union for Conservation of Nature (IUCN). The park is also of great importance to the economy of Rwanda by attracting researchers and tourists worldwide who come to track mountain gorillas and bring a lot of money. National and international educational institutions are also undertaking several studies on the flora and the fauna of the National Virunga Park (NVP).

Even though geothermal energy causes smaller emissions of CO_2, SOx and NO_x than fossil fuel energy but comparable to hydroelectricity and nuclear energy, it cannot be confirmed that the drilling activity will not affect the wellbeing of unhabituated mountain gorillas, unused to human disturbances. The most significant impacts of exploration drilling on mountain gorillas are: the unpleasant smell of H_2S and noise during well testing. The effects of these on the gorillas are unknown and, since infant gorillas are very small, their health could be in danger. Geothermal fluids may contain other gas pollutants like mercury and boron (toxic for some plants). Possible environmental problems like the disturbance of vegetation and loss of wildlife habitat are expected to be minor; however, an environmental impact assessment report must be filed before any permits can be granted for geothermal exploration drilling in Karisimbi.

Geothermal solid waste made up of drill cuttings are not of great concern as they are disposed of in sumps or into landfills. Liquid waste enriched in dissolved chemicals shall be recycled, separated in settling or flocculation ponds.

Exploration drilling has small socio-economic effects on the local community, such as land acquisition and the resettlement of evacuated people. The immediate benefits to local people will include land compensation, job creation and improvement of the transport infrastructure.

The Karisoke Research Centre should carry out particular monitoring of two social groups of mountain gorillas, Susa and Karisimbi, inhabiting the nearest area to the prospect. In case the mountain gorillas are disturbed by drilling noise, they could be displaced to areas further away.

If a geothermal resource is proven, drilling will continue and a power plant will be built in the area. Hence, the price of electricity will be reduced, and job creation, knowledge transfer and capacity building for Rwandans in geothermal energy will be improved.

Exploration drilling has short term impacts on the environment which will finish after only six months. Long term effects like subsidence and microseismic activity may take place during reinjection and production. Unpredictable impacts like hydrothermal eruptions and landslides depend on the geological structure of a prospect.

Until now, no background information on the air quality in the Karisimbi geothermal prospect has been available for comparison after drilling; therefore, the installation of an air monitoring station is proposed. MININFRA and EWSA should discuss the shortening of the well testing period with the contractor since it is the noisiest phase of exploration drilling.

Three vertical exploration wells can be drilled in the Karisimbi prospect of the Nyabihu and Rubavu districts. However, the drilling contractor has to minimize the size for the drill pad and construct noise protection barriers to reduce the effects on local people, mountain gorillas and other endemic species of wildlife inside the NVP.

MNINFRA and EWSA initially have to involve local authorities and present to them a plan of detailed project activities. The MININFRA and EWSA have to organize meetings, prepare brochures and educate residents and local leaders regarding the benefits and impacts of the project. They also need to explain to all stakeholders the immediate and long term impacts and benefits of the project.

The drilling contractor will be required to minimize the amount of drilling fluids and use recycling as much as possible, and is restricted in discharging geothermal or drilling fluids into waterways. In difficult situations, a flocculation pond should be constructed near the drill site.

The following recommendations are put forward:

(i) To establish a joint monitoring team made up of representatives from the Rwanda Environment Management Authority (REMA), Rwanda Development Board (RDB), animal behaviour specialists from the Karisoke Research Centre and the developer prior to the start of drilling. The team will assess the response of mountain gorillas and other endangered animals to the drilling operation. This team will also monitor other wildlife movements, soil erosion, vegetation destruction, accident cases, water use and quality, and waste disposal.

(ii) After exploration drilling, in the future, directional drilling will be used for all wells which will be sited in the park or its vicinity. This will reduce the number of drill pads and environmental deterioration.

(iii) MININFRA and EWSA, in collaboration with the local authorities of the districts and sectors in which the project will be executed, may start to expropriate and compensate land owners before starting the mobilization of drilling equipment and services.

(iv) Involvement of the local population is important for project acceptance; the Ministry of Infrastructure should present the project's activities to local authorities and to the population and respond to all their concerns.

(v) The contractor should be requested to hire local employees for casual jobs.

(vi) Noise monitoring and air quality assessment equipment should be installed in the Karisimbi area and the developer be asked to comply with national standards. If they do not exist, international standards should apply.

(vii) After well completion, the contractor is obliged to restore the site and plant fast growing trees.

(viii) The drilling contractor is requested to minimize drilling fluid by recycling.

(ix) The Institute of Earth Science and Engineering of the University of Auckland (UNISERVICES), after carrying out a full EIA in October 2011, must organize consultation meetings with local people, the Karisoke Research Center, REMA and the Department of Conservation of RDB.

(x) The GoR should register the project in the future for carbon credits as it reduces gas emissions.

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